Rice Farming Systems

NEW DIRECTIONS

International Rice Research Institute

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INTERNATIONAL RICE RESEARCH INSTITUTE
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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 the 13 nonprofit international research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 50 donor countries, international and regional organizations, and private foundations.

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

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Foreword

The global family of rice research institutes and scientists dedicated to improving the productivity, profitability, stability, and sustainability of rice farming systems is strengthening and growing. A major indicator of that increasing capability is the establishment of new rice research facilities in many countries.

The dedication of the Sakha Rice Research Center in Kafr El-Sheikh, Egypt, is an outstanding indicator of expanded national capabilities. IRRI has long-standing collaboration in rice research and training with Egypt. We are proud to have cosponsored the International Symposium on *Rice Farming Systems: New Directions* that marked the inauguration of the Sakha Center. The symposium opened new opportunities for collaboration with Egypt, not only by international institutes, but also by other national programs in the region.

The symposium was jointly sponsored and organized by the Ministry of Agriculture and Land Reclamation, Egypt, and IRRI. Its objectives were

- To review current research on all aspects of the productivity, profitability, stability, and sustainability of rice farming systems in Egypt.
- To suggest research to increase and stabilize rice yields and increase incomes of Egyptian farmers.
- To review the current status of postharvest technology, including milling and processing, and suggest improvements.
- To suggest ways through which the new Sakha Rice Research Complex might assist in human resource development and technology sharing in countries with agroecologies similar to those of Egypt.

Participants' recommendations for meeting those objectives are included in this book.

Members of the program organizing committee were the Hon. Dr. Youssef A. Wally, Deputy Prime Minister and Minister for Agriculture and Land Reclamation, Arab Republic of Egypt, chair; Dr. M. S. Swaminathan, IRRI Director General 1982-87, vice chair; Dr. Norman E. Borlaug, International Center for the Improvement of Maize and Wheat (CIMMYT); Dr. John Mellor, International Food Price Research Institute (IFPRI); Dr. Joseph Hulse, International Development Research Center (IDRC), Canada; Dr. A. Kesseba, International Fund for Agricultural Development (IFAD); Dr. N. C. Brady, Science and Technology

Division, USAID; and Dr. Ahmed Momtaz, Director General, Rice Research and Training Project and Deputy Director, Agricultural Research Center, Egypt.

The local arrangements committee included A. Momtaz, W. Janssen, T. Hardt, Hassan Khedr, Jack Swagerty, E. A. Siddiq, A. M. Nassib, Rashad Abu El Enin, M. A. Bishr, F. N. Mahrous, and M. S. Balal. The proceedings were edited by **ecs** Editorial Consultant Services, New Delhi, India. IRRI's Communication and Publications Department handled the book's production.

Klaus Lampe
Director General

Welcome

AHMED MOMTAZ
Chairman, National Organizing Committee

Today, 31 January 1987, coinciding with the First Gomad Second 1407, is an important day in the 70-year history of rice research in Egypt. Our dream of establishing a center of excellence for rice research, to serve Egypt and other countries of this part of the world, has come true—through the joint efforts of the Egyptian Ministry of Agriculture and Land Reclamation and the United States Agency for International Development (USAID). To commemorate this happy occasion, we are sponsoring—together with the International Rice Research Institute—this historic symposium on *Rice Farming Systems: New Directions.*

I am reminded of the National Rice Conferences we used to hold each February, from 1981 to 1985, under the USAID-funded Rice Research and Training Project, to present annual progress reports and plan the technical program for the next year. This week's symposium—unique, and of great significance to us—has a different theme and aims. Our research thrust until today has been largely directed to increasing production—which, no doubt, is very important to keep pace with our fast-growing population. Realizing, however, that increased farm income—and hence, the improved economic well-being of our farming community—is as important as production to achieving real progress and prosperity, now we are seriously considering reorienting our research strategies. Keeping in view the limitations of our land and water resources, we are looking for innovative approaches to supplement conventional ones to attain the projected production targets. This week's symposium covers almost every aspect of rice and rice-based farming systems, with one aim; planning research and management strategies for the future.

It is a great privilege and pleasure for me to cordially welcome the distinguished scientists who have come to make this symposium productive and valuable for Egypt and countries of similar ecology. They are scientists and policymakers of great distinction, from prestigious research institutions. We have invited as many Egyptian scientists as possible from all research institutions, with the hope of providing an opportunity—especially for the younger generation—to interact with the eminent scientists from frontier fields of the agricultural sciences.

To all my colleagues who have stood with me in organizing this symposium, I say one word from deep in my heart: "Thanks."

Once again, I extend to each one of you a warm welcome.

Dedication

YOUSSEF A. WALLY
Deputy Prime Minister and Minister of Agriculture and Land Reclamation,
Arab Republic of Egypt

It is a happy coincidence that we are dedicating the Sakha Rice Research and Training Center to the rice farming community of our great country on the 70th anniversary of rice research in Egypt. Everyone in the field of agriculture must be happy and proud, as I am, that the rice research that started in a small way in 1917 has grown today into a prestigious center for rice research and training. There can be no better and more fitting manner to commemorate this historic occasion than to hold an international symposium on a theme so urgent and relevant to our present situation.

At the outset, I take this opportunity to thank, on behalf of the Government of Egypt and on my own behalf, the United States Agency for International Development (USAID) for its generous assistance in building this unique facility for rice research in Egypt. The International Rice Research Institute (IRRI), with which Egypt has enjoyed over the past two decades a close research relationship, has been of great help in making this day a memorable one. I thank Dr. M. S. Swaminathan, Director General of IRRI, for his role in sponsoring and organizing this symposium.

The theme, appropriate to the present context; the choice of Kafr El-Sheikh, the heart of the rice-growing area, as the venue; and the gathering of a rare blend of top scientists and policymakers from prestigious research centers of the world make the present symposium especially significant to us. On behalf of the scientific community of Egypt, the International and National Organizing Committees, and on my own behalf, I have great pleasure in extending a warm welcome to you all, especially those who have come from abroad, traveling long distances, to be with us here.

About rice in Egypt

As you all must know, the Arabs brought their language and religion to Egypt. But probably few of you are aware that they also brought rice to Egypt. Since then, rice has enjoyed a place of paramount importance in the economy of Egypt—as the most important staple after wheat, as the second major foreign exchange-earning agricultural commodity, and as the most effective and profitable means of reclaiming hundreds of thousands of feddans of salt-affected lands.

Egypt is among the countries with the highest rice yields in the world. Ideal weather, rich soil, abundant water, a relatively pest-free environment, and, above all, our hard-working farming community make this possible. However, the country that had remained agriculturally prosperous since the time of the earliest Pharaohs, with abundant food to feed its people as well as a sizable surplus to share with the needy, became—just a decade ago—a food-importing country.

The level of food imports may look alarming when considered on a commodity basis, but not when viewed in terms of the relative economic advantage of importing low-cash crops like wheat to export high-cash crops. The fact remains, however, that the domestic food demand is outpacing the production of staple food. To cite the example of rice, as against 600,000 to 700,000 t of rice exported around 1970, the level has come down to less than 30,000 t by 1985, with no marked change in the per capita consumption level of 35 kg of milled rice, thus showing a shift from the state of surplus to a state of self-sufficiency in rice.

Immediate strategies to narrow the food deficit

Population control

One of the major problems we face today is the steadily increasing population growth rate. Over a period of 50 yr, the growth rate has gone up from 1.8 to 2.7%. At the present rate, we add every year about 1.35 million people to an already oversized population. This trend is making all our developmental efforts to raise the living standard of our people a futile exercise, as our President underscored in his address to the People's Assembly way back in 1982. I quote,

> "We cannot overlook the present rate of population growth. It obstructs development effort. It stands in the way of realizing our hope to improve the living conditions for all Egyptians. It makes our ambition confined to preventing further deterioration of the present conditions. This we cannot accept."

In response to his call, an all-out effort is under way to motivate our people to adopt appropriate family planning measures.

Improving agricultural growth

Several factors impede the progress of planned production growth, and I shall deal briefly with the major ones and the remedial measures under way to counter them.

Area and quality of arable land

The agricultural prosperity of this country has been entirely dependent on about 2.5 million hectares of arable land, all confined to the valley and delta of the River Nile. The growing population—and proportionately increased needs for housing, roads, and other amenities as a result—has proved a serious threat to this limited land wealth. According to one estimate, about 21,000 ha of fertile land have been used every year for such purposes. If this trend continues unchecked, 50% of the fertile land would be lost in just 50 yr; this underscores how watchful and concerned we have to be to conserve this precious land.

While explaining the trend of land utilization for unproductive purposes, I am reminded of the attitude of the Pharaonic rulers of ancient Egypt, not to allow even road construction in the Delta, as they feared that it would swallow sizable areas of productive land. The canals were the means of both irrigation and transport. The rulers chose to build houses for themselves and their dead in far-off hillocks and deserts. The moral to be deduced from this is that we should think several times before converting even one square foot of productive land to nonproductive purposes.

Housing leads not only to loss of land area but also to the deterioration of its quality, as fertile topsoil from adjoining fields is indiscriminately used for making red bricks. Realizing the potential danger of such practices, through presidental decree, a law enacted in 1983, banning housing, brick factories, and elevation of soil in the cultivated areas, has come into force from August 1985.

Completion of the Aswan High Dam in 1970 had, amidst its innumerable advantages, a few adverse effects too. For instance, the rising water table and increasing salinity downgraded more than half of the best lands in the Delta and Valley, within 5 to 6 yr. Our efforts to improve drainage through installation of a tiled drainage system have helped, so far, to restore 50% of the 2.5 million hectares. The drainage facility is to be extended to another 0.6 million hectares in the coming years, through assistance from the World Bank and other sources. Constant monitoring of soil and water is one of our strategies to improve and sustain the productivity of these lands.

Yield and productivity maximization

As I mentioned earlier, Egypt has one of the highest per unit crop yields and cropping intensities in the world. Yet, for a country like ours, with serious limitation of arable land area and water resources, the major avenue to step up production is to harness the unexploited genetic yield reservoir of crop plants, on the one hand, and to look for innovative technology to further intensify cropping, on the other. Yield gap analysis reveals that yields of cereals and vegetables could be raised by 50-75 and 150-200%, respectively, over the present levels. In respect of rice, it has been demonstrated that adoption of improved crop management technology alone would help the farmers to harvest as much as 9 t/ha, as against the national average of 6 t/ha.

In parts of the USA, with agroclimatic conditions similar to ours, the productivity is said to be 70% higher than in Egypt. For instance, improved varieties of tomato and strawberry introduced from California yield respectively three to eight times higher than the local varieties. Similarly, through introduction or development of least land-intensive varieties, productivity and profitability of the existing cropping patterns could be enhanced. In the widely practiced rice - clover rotation, introduction of relatively shorter duration rice varieties, with no marked yield loss, could give 25% higher yield of clover in the first cutting. Two crops of rice or rice plus soybean or sunflower during summer still remains a theoretical topic. I appeal to our scientists to objectively develop varietal management technologies to bring into practice such possibilities, rather than try to fit in those already tailored for some other purpose and situation.

Exploring the prospects of horizontal growth

Arable land area and adequate irrigation potential to cultivate it economically are the components of horizontal growth. Immediately after the revolutionary command council came into power, a search for potential cultivable land and water resources was initiated and intensified. This led to the discovery of three major depressions in the Western Desert, what is now called New Valley. Underground aquifers with an estimated 50,000 km^3 of good water and economically cultivable land area of over 52,000 ha hold great promise for a major horizontal expansion in New Valley. Also Quettara in the north and about 42,000 ha with underground water potential at 40 m depth, found along the Sudanese border recently through satellite photography, brighten further our hope for bringing a sizable area under cultivation in the Western Desert. An extensive survey by expert teams from abroad and Egypt suggests that over 25,000 ha could be economically cultivated in the foreshore land of Aswan High Dam Lake Area using the lake water. Areas between Khor Tomas and Abu Simbel on the Western shore and areas around Khor Allaqi appear promising. Besides the deserts, over 67,000 ha in the Nile Valley and Delta could be economically cultivated, as per our estimates.

As for irrigation water, the main source is our share of 55.5 billion m^3 from the Nile water. Efforts are under way to raise the available quantum of water to 73.9 billion m^3 by 2000 AD, through reuse of drainage water, exploiting groundwater in the Delta and Valley, and saving water by improved irrigation. Of this, after 64.6 billion m^3 is used for the estimated area of cultivation in 2000 AD, the surplus 9.3 billion m^3 is to be utilized for an additional area of 0.71 million ha. Utilizing the groundwater potential in New Valley, we propose to extend the cultivation from the present level of 19,000 ha to about 52,500 ha.

We often hear the complaint that whatever land area has been gained through reclamation so far has been nullified by the rapid rate of urbanization. Also, it is said that a very large proportion of the reclaimed area remains either noncultivated or least productive and that thereclaimed area, constituting 13% of the total cultivated area, contributes less than 2% on an average to the national production. This is not wholly true. Also, this does not mean that we should give up or tone down our efforts to reclaim and cultivate potential areas. One set of scientists uncovered, after great effort, the potential land and water wealth. But now it is for another set of scientists to develop appropriate technology to profitably use them. Low productivity in New Valley, for instance, is not due to low quantum or quality of water or poor land. Rather, it is because of lack of appropriate production technology and profitable farming systems, as amply evident from the wide gap between experimental and farmer's yield levels.

Similarly, Aswan High Dam Lake Area has several khors, or inlets, with flat land, all along the 500 km long lake shore, on either side. But its utilization possibilities have not gone beyond the discussion phase. When man is striving for alternative sources of energy, artificial rain, gene transplanting, placing man on alien planets, and so on, it is ironic that the level of technology needed to utilize available but not easily exploitable resources in such situations as Aswan High Dam Lake has not as yet been developed.

Adoption of innovative techniques

No matter where it has been developed, if a technology suits our situation and would help to increase production, we have open minds to adopt it. Several instances substantiate this attitude of ours.

Agricultural mechanization, as a substitute for draft animal and human labor, was introduced primarily to overcome the acute shortage of labor and increasingly inhibitive wage structure, which prevent farmers from adopting timely and optimum practices. The yield gap in rice, for example, is not due to farmers' lack of knowledge of improved practices. It is because farmers are unable, due to physical limitations, to practice timely planting and harvesting, maintain optimum plant density, etc. It is here that machines were introduced to maximize production and minimize postharvest losses, through timely operations.

Our scientists can facilitate this technology by developing appropriate varieties. I am very happy that our rice scientists at the Agricultural Research Center (ARC) have come out with two new high-yielding, nonlodging, dwarf varieties—Giza 175 and Giza 182. Combining a high level of resistance to blast disease with highly acceptable grain quality, they are also highly amenable to mechanical planting and harvest.

Plastic culture (greenhouse of plastic with drip irrigation) is yet another innovative technology with which we are experimenting. The objective is to produce the vegetables required for the country in an area several times smaller than that devoted to vegetable cultivation today. According to our experts and the experience of others, a greenhouse of 50 m^2 area is capable of producing yields equivalent to those of 1 feddan (0.42 ha) of land. Introduction of this technology in newly reclaimed areas would help to realize a sizable area of good land for other crops and save a considerable volume of irrigation water, if this is perfected for our situation.

I understand that the People's Republic of China has succeeded in developing hybrid rice commercially and in extending its cultivation to over 8 million hectares. Egypt, by virtue of its high yields and risk-free environment, should be an ideal place for exploitation of hybrid vigor. There are many other areas, including postharvest technology, by-product utilization, biotechnology, etc., where advances are being made continuously in one part or another of the world. I believe that science and farming are international languages. There is no sensitivity in this area about obtaining any information from any nation. As I mentioned earlier, we have open minds, to evaluate and adopt any new technology found suitable, regardless of whether it has come from the east or west. Also I am one of those who believe that only a dynamic research program can sustain a dynamic production program.

Collaborative research with international research institutes

On several occasions in the past, I have expressed our interest in the international agricultural research centers such as the International Rice Research Institute (IRRI), International Wheat and Maize Improvement Center (CIMMYT), International Center for Agricultural Research in the Dry Areas (ICARDA), International Food Policy Research Institute (IFPRI), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and others. They would be welcome to organize either jointly or independently strong collaborative research programs in Egypt. We are happy that IRRI will collaborate with us, from 1 March 1987, through a U.S.-funded new program to develop the second phase of our rice research. It is our strong desire and wish that this joint venture lead to the development of the Rice Research and Training Center into a major center for regional research and training activities for the benefit of Sudan, countries in the Sahel with irrigated rice, and others with similar ecologies. We are keen to involve similarly other international research institutions in our mission to evolve the most productive and profitable agriculture in this part of the world.

All research for the well-being of rural millions

Research and technology can be from home or abroad. But its ultimate purpose and goal should be to alleviate hunger and poverty, to increase farm income, and to generate employment in the rural world. I am particularly happy that all the international agricultural research centers under the Consultative Group on International Agricultural Research (CGIAR) are striving to direct their research efforts toward the noble goal of improving the economic well-being of millions of small farmers in the ecologically and economically underprivileged regions. Healthy agriculture is the most powerful weapon a country can think of to free itself from economic and political pressures. It would be apt here to quote our President, who expressed this feeling in a clear and loud voice in his address at the Rome Meeting of the International Fund for Agricultural Development in 1982: “Whoever does not command the means to feed himself can feel neither freedom nor dignity.”

I am delighted to see before me a gathering of eminent scientists from far and near—but all associated in one way or another with rice, the most important cereal crop in the world. You have a heavy program ahead of you to discuss topics ranging from farming systems to biotechnology. I am confident that your deliberations will bring out concrete recommendations for achieving increased productivity, stability, and profitability in rice-based cropping systems for this part of the world. I hope it is a precursor of many more symposia on rice and rice-based farming systems here.

It is now my privilege and pleasure to formally dedicate the Sakha Rice Research and Training Center to the farming community of our great country and inaugurate this historic International Symposium on Rice Farming Systems: New Directions.

A vision of Egyptian agriculture

Frank G. Wisner
Ambassador of the United States of America to Egypt

These are important times for Egypt and for Egyptian agriculture. Your conference is particularly meaningful because the leaders gathered here represent the commitment that the Arab Republic of Egypt has made to agriculture. As this century draws to a close, Egypt is expanding her technology rapidly. In the field of agriculture, as in other fields, she is strengthening her position of leadership in scientific and technological research in the region.

I bring to you today a message of confidence from my government and my people. Egypt's economy can grow—indeed, grow rapidly—and the results of growth can be shared with all of Egypt's people.

The Government of Egypt knows what is required for this economy to grow and has taken bold steps to stimulate growth. The United States of America wants a prosperous and productive Egypt and seeks to work in partnership with your government and people. Nowhere is this truer than in the field of agriculture. For in this field, which has great potential for immediate growth—perhaps more potential than any other sector of your economy—I have a vision of your agriculture and its great promise to the future of Egypt.

Because your government has been willing to make difficult decisions, I see six million farmers who, armed with greater incentives to grow what they wish and buy what they need, have the possibility to play an even greater role and compete in a free market. All of us should welcome the new prices the government has set for the produce of farmers, Each of us should welcome the end of crop procurement quotas and crop area controls. All of us welcome the opening of a freer trade in produce, equipment, and fertilizer.

I see these same farmers having access to technology and research facilities which they need and which the Government of Egypt and its friends have invested heavily in to provide. I see production of crops for which Egypt has a comparative advantage, like rice, doubling in the years ahead. Where Egypt can now produce 6 metric tons of rice per hectare, your scientists and their American friends know that it is possible to grow 12 tons.

I also see farmers having access to more credit so they can continue to be, as others, productive members of Egyptian society. I am especially proud of the fact that my government is associated with Egypt in expanding rapidly the availability of credit to farmers so that they can purchase the equipment, seeds, and fertilizer they require. Finally, as controls are replaced by incentives, I see Egypt's farmers once again assuming their place in a dynamic export market and returning Egypt to her competitive position in the export of food and fibers.

As Egypt proceeds and indeed enters a new age of technology, this growth—which all of us welcome—is yet another demonstration of the commitment your government has made to sound economic policies. I applaud this. In agriculture, particularly, there lies the chance for long-term growth—growth that will not only supply the food needs of the population but be the keystone of many of your industries.

The United States is proud to be part of the efforts to stimulate growth in the Egyptian economy. Given our history, our agricultural history, and our pride in that history, we have been particularly proud to make a contribution in Egypt and to have put at the disposal of your government over the last several years some $400 million in American-financed credit projects, improved irrigation systems, commodities, and high-technology research centers like this one. These are all examples of how we support your desire to improve the life of Egypt's people.

But the challenge does not end with the dedication here today or with this conference. Researchers must continue to work on disease and insect resistance, gene splicing, and postharvest techniques. Extension agents and other specialists must continue to take research results from the laboratories to the farmers' fields, and politicians and administrators must continue to improve the policy and procedural environment which will give adequate incentives to the Egyptian farmer.

As I look before me today and see so many trained scientists, talented researchers, distinguished professionals, and a dedicated leadership, I am proud of the American-Egyptian partnership in agriculture. I am particularly proud, at this place where we are gathered today and with my countrymen, to be able to share with you what we treasure most: our science, our technology, but above all our friendship.

No time to relax

M. S. Swaminathan
Director General of the International Rice Research Institute

Global grain stocks currently exceed 400 million tons. At the same time, more than 400 million children, women, and men go to bed hungry each night. Rice is the staple food for nearly 45% of the world's population. It is mostly produced and consumed by small farmers. During the last 20 yr, we have made substantial progress in increasing per capita food availability, in spite of the large rise in human population. Suitable combinations of technologies, services, and government policies have made such progress possible. Many developing countries have achieved self-sufficiency at current levels of purchasing power among their people. Since the terms self-sufficiency and food security are often used to convey different meanings, I would like to deal with the evolutionary steps in the battle against hunger.

Battle against hunger: evolutionary steps

Step 1: Food self-sufficiency

Food self-sufficiency has become a statistical concept for measuring the quantitative adequacy of food availability within a country. The quantitative adequacy can come from homegrown food and/ or food imported on commercial or concessional terms. When a nation describes itself as self-sufficient in food, it implies only that food is readily available in the market. Those countries that have achieved quantitative self-sufficiency in domestic food supply entirely because of homegrown food, or that have the economic ability to purchase food on commercial terms in the international market can be described as having achieved *self-reliance* in achieving food *self-sufficiency.* India, for example, is self-sufficient in food today at the present low levels of purchasing power and consumption capacity among the rural and urban poor. Therefore, food self-sufficiency under this concept does not imply the elimination of hunger, which can coexist on a fairly large scale with food grain surpluses. Nevertheless, it is important that all countries try to achieve self-reliance in the quantitative availability of food grains for their population as a first step in their strategy for achieving freedom from hunger.

Step 2: Food security

According to the Food and Agriculture Organization of the United Nations (FAO), food security implies physical and economic access to food by all people at all times.

Thus it involves concurrent steps in production and distribution. Countries that have achieved self-sufficiency should vigorously work toward attaining food security. This will involve efforts to generate adequate purchasing power among all sections of the population.

Step 3: Nutrition security
The concept of nutrition security integrates genetic concerns with the FAO's food security goal. It involves the quantitative and qualitative adequacy of food intake, coupled with the availability of clean drinking water and environmental sanitation (Swaminathan 1986). Only when a country achieves nutrition security for all its people will it have provided an opportunity for every child and adult to express his or her innate genetic potential for physical and mental development. It is the duty of every nation to achieve nutrition security for its population. This will call for development efforts and investment decisions, which can, on the one hand, enhance the purchasing power of the poor and, on the other, lead to improved sanitation and drinking water supply. Ultimately, the full flowering of a human personality depends on balanced nutrition and on the educational and sociocultural environment. Unfortunately, this goal seems to be a distant dream.

We thus face many challenges. We must produce more food from less land. We must add the dimensions of income and employment to that of production in our agricultural research strategies. Above all, we must ensure the economic and ecological sustainability of the production techniques. The International Rice Research Institute (IRRI) has therefore decided to pay intensive attention during the coming years to research and technology sharing aimed at:

- defending the gains already achieved in increased rice production and productivity;
- reducing the costs of production without lowering yields;
- extending the frontiers of high-yield technology to ecologically disadvantaged areas;
- evaluating the ecological and economic sustainability of new technologies; and
- designing rice farming systems that can give higher incomes, generate more jobs, and ensure the livelihood security of the rural poor.

As IRRI works more in the unfavorable rice-growing environments, much of the research will have to be done in collaboration with appropriate national research systems. At the same time, we must work to benefit from the expertise of advanced research institutions to harness their *upstream* research capabilities to solve complex *downstream* problems such as breeding varieties with resistance to soil stresses, stable resistance to pests and diseases, and higher yield ceilings under favorable and unfavorable conditions.

Approaches and priorities

In examining current and future activities and priorities, these considerations establish the basic ground rules:

1. IRRI must continue to focus on those areas where IRRI can play both catalytic and complementary roles that will benefit the rice world.
2. The Institute's research portfolio must remain dynamic, continuously moving toward areas where IRRI can perform valuable services or where national programs have specific needs. Change should reflect evolving strengths and needs of national rice systems.
3. IRRI's research portfolio should be controlled by internal assessment and monitoring mechanisms that allow the identification of new research opportunities, the realignment of priorities, and the redeployment of resources. Existing research should be organized to facilitate identification of areas where cutbacks might enable reallocation of resources.

IRRI's strategy for optimal planning of research and training for the next 5-10 yr will be influenced by:

1. the rate of development of national rice research programs,
2. the way national increases in supply and demand for rice are met,
3. the changing social and economic goals of national programs and the Consultative Group on International Agricultural Research (CGIAR), and
4. the breakthroughs in science and technology, particularly in biotechnology.

IRRI's concern for developing strong collaborative programs with the most disadvantaged rice-producing countries helps to increase the rice production and research capacities of the nations that have the least resources and it enhances the livelihood security of the poorest ricedependent populations. This implies a greater need for research leading to technological advances in nonirrigated environments, because countries with the lowest national rice yields also tend to be those with the smallest proportion of irrigated ricelands, the lowest adoption of modern varieties, and the lowest use of fertilizer.

IRRI recognizes that each partnership with a national research system must be tailored to that country's requirements. This strategy was described at the time of IRRI's 25th Anniversary (IRRI 1985). To illustrate the need for a multiple-choice approach to research and development strategies, rice-producing countries were broadly grouped into four categories on the basis of current average national rice yields (Table 1). Large countries, such as India, may have areas (such as in the northwest) where Group I or II conditions prevail, but other regions (such as in eastern India) may fall into Group III or IV.

In Group I countries, where there are fewer constraints, the greatest shared interest, given current knowledge, may be research designed to raise yield ceilings. IRRI's major cooperation with countries in this group may be upstream research, with the additional opportunity of adapting and transferring scientific innovations to solve rice production problems in the developing world.

Group II countries need concurrent efforts to increase and sustain yields and to increase production efficiency by using available technologies to raise yields to levels demonstrated as feasible in Group I countries.

Group III countries may require more research on increasing yields under unfavorable ecological, economic, and policy environments. Large areas of most of these countries are rainfed and may have deficiency and toxicity soil constraints and

Table 1. Classification of ricegrowing countries according to the gap between 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

Source: IRRI 1985.

serious pest and disease problems. Inadequacies in research infrastructure, input delivery systems, and capital available to modernize agriculture could also play important roles.

The Group IV countries have rather low national average yields and—with the exception of Brazil—have the most unfavorable resource endowments for rice production. Here again the reasons for low yields vary. The entire rice area in some countries is rainfed upland. Identifying research areas that need attention should be based upon careful study of the potential impact points.

IRRI's research must be based on achieving a proper balance of the individual country's development goals, research strategies, and research capabilities. In irrigated and favorable rainfed areas, more attention should be given to raising the yield ceiling through techniques such as the commercial use of modern innovations in biotechnology. At the same time, an integrated breeding approach will have to be used to develop multiple resistances to pests, or tolerance for adverse soil factors. The complementary development of appropriate management practices may best be achieved by a multidisciplinary approach.

Matching supply and demand

The World Bank predicts that the real price of rice and other major cereals, typified by wheat, will stagnate, at least in the short to medium term. Due to the success of modern rice technology, rice production has increased more rapidly than has population, particularly in Asia. Contributing to falling international prices is a world market for rice. Less than 3% of production is traded internationally. A number of major Asian countries that have traditionally imported rice have reached self-sufficiency or near self-sufficiency (Indonesia, India, Bangladesh) and a number of new and expanding markets have contracted (particularly in African nations with scarce foreign exchange) (Siamwalla and Haykin 1983). The current low international rice price has been exacerbated by excess production and export subsidies in a number of industrial nations.

Low prices, should they continue as the World Bank predicts, have several important implications for IRRI's research priorities.

First, we must seek other opportunities to increase rice farm incomes and alternative employment for farm labor in ricedependent regions. Diversifying to other crops compatible with rice-based farming systems and to livestock and fish, and identifying economic uses of rice by-products are increasingly important in rice research processes.

Second, rice farmers are increasingly facing a cost-price squeeze. While rice prices are falling, the prices of commodities that a farming family must purchase have not fallen; they may even have risen. Research must strive to increase the cost-effectiveness of rice technology in favored environments while maintaining current yield levels, and to increase the productivity of rice grown in adverse environments.

Third, possibly of critical importance in the medium to longer term, low rice prices can act as a disincentive to the investment in the rice sector (research, irrigation, fertilizer) that is necessary to boost and sustain rice productivity in the long run.

Fourth, low rice prices will discourage farmers from producing more, which in turn may force rice prices up.

A rigorous analysis of the implications—from IRRI's point of view—of alternative scenarios of international market conditions, investments in research and rice infrastructure, national supply and demand projections, and rice policies is planned in cooperation with the International Food Policy Research Institute (IFPRI) and the Rockefeller Foundation. The FAO and the Trilateral Commission project that rice supplies in Asia must increase by more than 3.5% a year to at least the end of the century if increase in real price and, consequently, of poverty-induced malnutrition are to be prevented.

However, it is unlikely that rice production will increase at more than 3% a year—the rate achieved in the 20 yr since the introduction of modern rice technology—unless innovations to increase rice yields emerge as infrastructure is developed (Barker et al 1985). Indeed, although Africa is in the news today and is the primary focus of the CGIAR, major problems of hunger and unemployment may occur in Asia by the turn of the century because of the pressure of population on land (Mellor and Johnston 1984) and because low rice prices are dampening the public and private investments necessary to sustain increases in rice supply. Even today, there are more undernourished people in Asia than in Africa.

Asia must continue to increase rice production, and in less favorable economic circumstances than in the past, until populations are stabilized. IRRI will continue to work with national agricultural research systems (NARS) to meet this challenge.

Focusing on poor producers

An important shift in the goals of the CGIAR and of IRRI is increased focus on improving the "nutritional level and general economic well-being of low income (rice-dependent) people." There is as much concern for equity issues related to increasing livelihood security of the poor as for efficiency issues related to increasing total output per se.

One implication of this shift in concern is that IRRI should allocate more of its resources to those environments where most of the rice-dependent rural communities and poorer rice producers are located. In general, these are adverse rice-growing environments, where farmers have derived little benefit from the technological changes that swept more favorable environments.

Another implication is that rice alone is unlikely to sustain farm incomes. Rice-based farming systems that include upland crops as well as livestock and fish, and management systems that will preserve, if not enhance, land productivity and income-generating capacity must be developed.

A third implication is that IRRI has a responsibility to assist NARS in developing technologies that can increase the income of rural women, thereby contributing to increased household income. The poorer the household, the greater the need for women to have independent access to income.

This shift in focus implies a shift in resource allocation from the favorable to the less favorable rice environments, where production and social conditions indicate that the need for improvement is most acute. Such a shift is already occurring at IRRI. At the same time, the importance of maintenance and upstream research to elevate and stabilize rice yields in favorable environments cannot be overemphasized.

IRRI's major programs

IRRI has five major program areas. The latest tools of science and technology, such as biotechnology, computer science, satellite imagery, and micro-electronics, are being utilized in all five, using collaborative research with advanced institutions—such as the "Research Bottlenecks" project supported by the United States Agency for International Development (USAID) and the Genetic Engineering Network, supported by the Rockefeller Foundation—as major pathways for accomplishing the research tasks.

Germplasm improvement. Germplasm improvement covers all aspects of germ-plasm collection, conservation, evaluation, and utilization. It includes plant breeding for different environments and for resistance to pests and diseases, testing under the International Rice Testing Program (IRTP) network, and utilizing tissue culture, genetic engineering, and other innovative techniques.

Crop and resource management. Crop and resource management complements genetic improvement by undertaking research on the management of rice and rice-based cropping systems. It consists of six major, integrated program directions:

1. soil and nutrient management,
2. water management,
3. crop management,
4. pest management,

5. farm machinery and postharvest systems, and
6. rice farming systems.

Two major networks, the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) and the Asian Rice Farming Systems Network (ARFSN), help test and refine research results in collaboration with NARS.

Socioeconomic environmental impact. The Socioeconomic and Environmental Impact Program promotes integrated studies of factors governing the ecological, social and economic impact and sustainability of rice and rice-based farming technologies. A major concern of this program area will be to provide information to scientists and policymakers who have the responsibility for maximizing the desirable impacts of new technology while minimizing their undesirable impacts.

Education and communication. Education and communication stresses on-campus and cooperative activities in knowledge and skill sharing. The opportunities that computer technology offers for enhancing instruction and communication will be fully utilized.

National research system cooperation. A wide range of approaches to NARS cooperation is being adopted. Approaches include the effective use of networks, cooperative research and training programs, and country projects supported by special project funding. The goal is to improve the impact of existing research networks, and to promote upstream-downstream research networks that can help adapt advanced technology to solve complex field problems.

Targeting research by rice culture type

Classifying rice research by water regime is useful because it is the principal determinant of rice varietal requirements and crop production practices. Five water regimes are usually distinguished: irrigated, rainfed shallow, deep water, upland, and tidal wetland, following the classification of IRRI (1984). The major categories are divided into several subcategories on the basis of climatic and soil determinants of rice production (Table 2).

Well-defined research programs are being established within each culture type in all program areas. A scientist's research within a rice environment and problem area is defined by identifiable research projects with achievable objectives, clear timetables, and quantifiable and recognizable outputs. The rice culture type focus within a research program area may be identified in the designation of a research project. For example, research project XY ZZ would identify Program area X, rice culture type Y, and research problem ZZ; thus each cell in the matrix of problem areas by rice culture types is identifiable. Such a system will facilitate monitoring progress in the development of technologies for less favorable environments.

While this separation of research by rice culture types appears precise and subject to clear accountability, in practice there can be a spillover between rice cultures. Some research is not environment-specific. Many research areas cut across rice cultural boundaries. For example, in the control of rice tungro virus and blast, some rice varieties such as IR36 may be widely adapted to more than one environment. The principles developed in soil chemistry and physics transcend the boundaries of wetland rice cultures. Nonetheless, while we recognize its short-

Table 2. Rice environment classifications based on general surface hydrology.

Irrigated
Favorable temperature
Low temperature, tropical zone
Low temperature, temperate zone
Rainfed lowland (0-50 cm)
Rainfed shallow, favorable (0-25 cm)
Rainfed shallow, drought prone (0-25 cm)
Rainfed shallow, drought and submergence prone (0-25 cm)
Rainfed shallow, submergence prone (0-25 cm)
Rainfed medium deep, waterlogged (25-50 cm)
Deep water
Deep water (50-100 cm)
Very deep water (> 100 cm)
Upland
Favorable upland with long growing season
Favorable upland with short growing season
Unfavorable upland with long growing season
Unfavorable upland with short growing season
Tidal wetlands
Tidal wetlands with perennially fresh water
Tidal wetlands with seasonally or perennially fresh water
Tidal wetlands with acid sulfate soils
Tidal wetlands with peat soils

Source: IRRI 1984.

comings, the merits of focusing research by rice culture type are deemed sufficient to warrant adoption of this system.

Progress has been slow in increasing rice production in less favorable areas, where the vast majority of the world's poor rice-dependent farmers, landless laborers, and rural communities live. The generation of improved varieties and crop management techniques for these environments is necessary to increasing both productivity and stability, and thereby incomes in these ecologically underprivileged areas.

Rice ecologies

Irrigated rice. More than 55% of the world's riceland is irrigated; China, which contributed 36% of the world's rice production from nearly 25% of the world's rice area, accounts for a large proportion of the irrigated rice culture type. In the tropics, less than 40% of the rice grown is irrigated. Another 5-10% is favorable rainfed lowland, where varieties and technology developed for irrigated conditions are often directly applicable. Numerous improved varieties developed by IRRI and national programs over the last 25 yr, coupled with improved management, were the basis of recent productivity gains in rice. More than 80% of the world's rice is now produced from modern rice varieties grown in these favorable environments. In general, the rice farmers in irrigated areas are economically better off than rice farmers in other ecologies.

Rainfed lowland. Within the four unfavorable categories, the scope for increasing production and productivity is greatest in the rainfed lowland environment. The area planted to rainfed lowland rice is perhaps as large as the three other unfavorable categories together. Many modem varieties developed by national rice programs and by IRRI are well adapted and widely grown under shallow rainfed conditions. Some (IR36 and 1R42) were selected from irrigated breeding programs, demon-strating the transferability of research between rice culture types. In less favorable shallow rainfed areas, such as drought-prone areas, several lines have consistently outyielded check varieties in recent IRTP nurseries and national variety trials. The performance of these cultivars demonstrated that IRRI's research in drought-prone rainfed lowland environments should yield results soon.

About 30 million hectares of the world's wetlands grown to rice are flooded to less than 30 cm depth each year. In addition, more than 10 million hectares of wetlands in Africa and an almost equal area in Latin America are not being utilized. These rainfed areas may be subject to drought and to occasional serious floods likely to damage a rice crop; therefore, yields in such areas are normally lower than in areas where irrigation is assured. The lower productivity and higher risks involved in rice production mean that farmers and credit agencies usually invest less in inputs for rice production in this culture than they do in irrigated rice. Nevertheless, experience at Iloilo in the Philippines and elsewhere has shown that there are opportunities for major advances in the production of rice and other food crops in these areas, even where it is not possible to develop irrigation systems.

Upland rice. About 20 million hectares (15% of the world's rice area) are planted to upland rice: 11.5 million in tropical Asia alone; 6 million in Latin America, mostly in Brazil; and another 2 million in West Africa. Yields are low and prospects of major increases are lower than in irrigated and rainfed lowland rice environments. Nonetheless, IRRI's increased commitment to upland rice research is starting to pay off: trials in recent years have shown that considerable progress has been made in producing better upland varieties for specific locations.

Equity also deserves attention in upland rice. Many of the poorest subsistence farmers depend on this rice environment for their sustenance. In a recent 41-country survey, upland rice breeders identified drought, weeds, blast and brown spot, acid soil, and phosphorus management as the most critical, but researchable, constraints to increased upland rice productivity. Other factors that must be considered are in land management: land degradation and the low sustainability of upland rice systems, soil erosion and consequent deposit of silt from upland to lowland rice areas, and dams and canals to supply water to upland farmers. Water harvesting and crop life-saving irrigation also need attention.

Deepwater rice. Globally, deepwater rice is grown on about 12 million hectares. Some 10 million hectares of the deepwater ricelands are in South and Southeast Asia in four major river deltas: the Mekong in Vietnam and Kampuchea, the Chao Phraya in Thailand, the Irrawaddy in Burma, and the Ganges-Brahmaputra in Bangladesh and eastern India. Few management practices can be modified for deepwater rice, but to ensure that we realize the full advantage of new varieties with greater yield potential, we must maintain some activities in crop management. An integrated pest management-cum-aquaculture project has been initiated in India, Bangladesh, Burma, Thailand, and Vietnam, with the coordinating center at Chinsurah, West Bengal, India.

Adverse soils and tidal wetlands. Tidal wetlands and adverse soils such as peatlands, mangrove swamps, and acid sulfate soils are a vast and largely unexploited land resource for rice production. About 5 million hectares of tidal wetland rice are now grown. Vast areas of tidal wetland and problem soils (estimated at more than 50 million ha in Asia) not now used for rice production have the potential for rice cultivation if tolerant varieties and appropriate management practices are developed.

Given current land development costs and rice prices, it may not be economical to develop these lands. However, expansion into the currently idle wetlands may occur as pressure on land increases and as improved understanding of soil-related problems and land management makes rice cultivation on these lands feasible. This makes it important to characterize the extent and nature of the problems in tidal wetlands and adverse soil areas and to support varietal development and crop and land management to increase the productivity of rice grown in these difficult areas. Saline coastal and irrigated areas pose special management problems of particular concern to the International Irrigation Management Institute (IIMI). IRRI may complement the search for solutions to these problems through research on varietal improvement, problem soils, and associated crop and land management.

Benefits by rice culture type

Three criteria may be considered in evaluating IRRI's research objectives; the weight given each will determine the distribution and nature, of the Institute's impact. First, efficiency considerations help to identify priorities in the distribution of research funds across rice culture types. Second, equity considerations counterbalance the first objective; IRRI is interested in developing rice technology and rice-based cropping systems adapted to those regions where modern varieties have had the least impact. Third, IRRI is interested in orienting its research toward its comparative advantage in solving problems that national research programs are unable to address adequately.

IRRI earlier studied anticipated yield gains under different environments (IRRI 1982). This analysis has been adjusted and updated. Small adjustments were made in rice area by culture type to bring that in line with IRRI's current terminology (IRRI 1984). A second adjustment allows for a modest increase in rice cultivation on currently idle wetlands (5 million ha) by the year 2000. A third adjustment allows for the expansion of upland rice by 1.2 million hectares by the end of the century, reflecting the opportunities for substantial upland area expansion in Sumatra and Kalimantan, Indonesia; northeastern Thailand; and eastern India. A fourth adjustment decreases estimated yields of upland crops grown in rice-based systems, but increases income projections in that most of them will be high-value grain legumes. Table 3 summarizes the underlying assumptions and estimated benefits, assuming that the model represents the Asian rice scenario.

In irrigated areas, it was estimated that yield increases averaging 1.2 t/ ha and intensity increases averaging 0.4 crop per year were possible by the year 2000. Three

Table 3. Underlying assumptions and projected benefits from rice research for rice production environments in South and Southeast Asia.

	Irrigated		Rainfed			
	One rice crop	Two rice crops	Shallow wetland	Deep-water	Floating	Dry-land
Area in each type of rice production (% of total)						
1980	21	19	30	12	5	12
2000	26	25	23	9	5	11
Yield (t/ha)						
1980 estimated means	3.0	3.0	1.8	1.4	1.0	1.0
Potential increase by 2000	1.2	0.9	0.8	0.8	0.5	0.5
Average number of crops/ha per year						
Rice, 1980	0.9	1.8	0.7	0.7	0.9	0.8
Dryland crops 1980	0.3	0.2	0.4	0.3	0.3	0.5
Increase in no. of rice crops per annum by 2000	0.4	0.5	0.3	0.2	0.1	0
Increase in no. of dryland crops per annum by 2000	0.2	0.2	0.1	0	0.1	0.3
Total benefits from increased production						
Million US$	9,300	5,300	4,600	1,400	370	840
% of total	43	24	21	6	24	4

Source: IRRI 1982.

estimates, coupled with a net growth rate in irrigated area of 1.5% and other area adjustments, as specified, resulted in a projected growth rate in rice supplies of just over 3.4%—slightly lower than that predicted by the Trilateral Commission as necessary to sustain per capita rice supplies. Modest as these production gains may be, when valued in terms of the conservative prices (even in comparison with today's low international prices), the gross value of increased output is large. Continued real investment in IRRI of about $25-30 million per year, plus investment in national rice programs, may generate an added value of rice in excess of $15 billion a year in South and Southeast Asia alone by 2000. These increases reflect yield and cropping intensity growth, given present proportions of irrigated land with the same inputs, policies, and institutions that now exist.

Of particular interest is the distribution among rice culture types of gains attributable to research investment (and irrigation development). The important point is that increases in irrigated rice (57%) are predicted to dominate rice supply increases in South and Southeast Asia, based on the assumption that the area under irrigated rice will continue to grow 15% as it has over the past 20 yr. But this growth rate may not be sustained, because of low rice prices. When the model was rerun with the assumptions of 1%, 0.5%, and 0% net annual growth rates, irrigated rice contributed less to supply increases. Nonetheless, the gains from irrigated rice research continued to be about equal to or greater than gains from all other environments combined.

It must be stressed that the estimates of rice yield and expected benefits of the different cultural types are speculative. Even so, the preceding analysis demonstrates that the returns from rice research in South and Southeast Asia appear to be extremely large. From an efficiency viewpoint, investment in irrigated rice should get continued priority. Indeed, there may be substantial underinvestment in rice research in Asia, given the potential gains and the size of the Asian population whose staple food is and will be rice.

Obviously, these benefits will not result from IRRI research alone. They will be the product of the entire rice research system, of national programs and IRRI combined. I conclude this presentation with a brief discussion of methods for strengthening cooperation with NARS.

National research system cooperation

IRRI's work during the past 26 years is an outstanding example of the power of purposeful cooperation. The various pathways through which IRRI, national research systems, and universities in developing and developed countries have forged symbiotic links are shown in Table 4. The progress in the development of strong national research systems in most rice-growing countries is striking. Agriculture is largely a site-specific vocation; the precise agricultural technologies recommended to farmers have to be tailored to suit local agroecological,

Table 4. 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

Source: IRRI 1985.

socioeconomic, and cultural factors. A strong national research system is mandatory for stimulating and sustaining a dynamic rice production program. That is why, almost from its inception, lRRI has given high priority to collaborative work with rice scientists in all countries where rice is grown and consumed. Also, IRRI has trained nearly 5,000 scientists from national rice research institutions since 1964.

Some methods of collaboration, such as international networks, are beneficial to all countries. Other methods have to be fine-tuned to suit specific needs. IRRI has developed mechanisms through which its partnership with non-IRRI scientists can be continuously adjusted to changing needs. Annual collaborative research planning meetings, jointly organized by the NARS of major rice-growing countries and IRRI, provide opportunities for maximizing benefits from the complementary strengths of the concerned NARS and IRRI.

In addition to directing partnerships with NARS, IRRI is a conduit, channeling forward edge technologies to NARS. An excellent example of recent efforts is the Rockefeller Foundation's support for a network bringing the expertise of the world's leading molecular biologists and genetic engineers to bear on solving practical field problems of rice production. Another example is cooperative research among scientists in Australia, the USA, and at IRRI to develop technologies for improving fertilizer efficiency in rice.

IRRI also works to enable strong NARS to assume regional and international responsibilities. The Hunan Hybrid Rice Research Center in China and IRRI collaborate in organizing training programs on different aspects of hybrid rice research and development for scientists from rice-growing countries. Similarly, IRRI collaborates with the National Azolla Research Center of the Fujian Academy of Agricultural Sciences, Fuzhou, China, in organizing training programs on biofertilizers, particularly *Azolla.*

As IRRI evolves priorities oriented toward more unfavorable rice-growing environments, much of the work will have to be done with NARS. Two examples illustrate this new pattern of collaborative research.

Rainfed upland rice. IRRI believes that a coordinated research program, including the establishment of three major regional centers in Indonesia in Asia, Ivory Coast in West Africa, and Brazil in Latin America, would help to accelerate progress in increasing and stabilizing upland rice yields.

Problem soils. A coordinated grid of research centers—Indonesia for organic peat soils, Vietnam for acid sulfate soils, and India and Pakistan for saline/ sodic soils—will help immensely in developing improved varieties and management practices for problem soil areas.

Collaboration on upland rice research exemplifies the joint efforts between IRRI and research organizations in Africa and Latin America as well as in Asia. IRRI collaborates with the CGIAR institutions in other regions of the world and, through them, with various NARS. In addition, IRRI scientists work directly with the rice research scientists of Madagascar and Egypt—the two major rice producers of Africa. To strengthen rice research and varietal testing in East, Southern, and Central Africa and in the Caribbean, IRRI liaison scientists are now based in Tanzania and the Dominican Republic, in addition to those located at the

International lnstitute of Tropical Agriculture (IITA) and the International Center for Tropical Agriculture (CIAT). IRRI recognizes the potential for greatly increased rice production in Africa and stands ready to assist in every way possible to help realize that potential for food production and income generation.

Conclusion

Egypt has shown that high yields can be obtained in difficult environments. The Rice Research and Training Center at Sakha can help not only Egyptian farmers to increase the productivity and profitability of rice farming systems in Egypt, but farmers in other countries with similar rice-growing conditions. IRRI scientists are looking forward to the privilege of strengthening our partnership in rice research and training to better serve the rice world.

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Progress in agricultural research

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Unprecedented technological developments have changed agriculture throughout the world. The developing countries especially have benefited from the Green Revolution. While the international agricultural research centers have contributed significantly to the advances of the last two decades, they cannot solve all the problems that persist. The interests of developing countries are best served when they have their own strong national research systems that can focus on location-specific constraints and critically analyze questions of energy conservation, environmental quality, genetic resources, and the impact on society of technological change. Such research should be linked not to individuals but to institutions, both national and international, so that scientists can work in cooperation, without duplicating effort. Rather than wait for spinoffs from industrialized nation research, national systems should use emerging technologies, such as biotechnology or computer simulation models, combining them with traditional methods to develop agriculture in directions best suited to their national situations. Underpinning such research should also be a strong governmental commitment, enlightened policies, and clearly defined priorities for development. Egypt has made notable strides in thisdirection and could well lead agricultural research in the entire region.

This auspicious occasion of dedicating the Sakha Rice Research and Training Center affords a good opportunity for us to reflect on the agricultural research that has brought agricultural productivity to the level realized worldwide today. It also provides a moment to consider future challenges and opportunities for further achievements.

As we look back on past agricultural research on rice and other crops, it seems timely today to congratulate those scientists and technical workers who have planned and conducted agricultural research in Egypt, and particularly those who have labored long and hard with the staple crop of rice. They have shown leadership in research in arid/irrigated land rice culture. Their research efforts have yielded superior rice varieties and management systems that, in the hands of the dedicated farmers of this country, have produced remarkably well. Egypt continues to have one of the highest levels' of national rice production in the world.

During the 8 yr I served as the Director General of the International Rice Research Institute (IRRI), I recall working with the agricultural investigators and their leaders in the Ministry of Agriculture and Food Security. I was pleased to be able to watch the progress and improved rice productivity their programs generated. While I hesitate to single out any individuals for special comment, I must say my personal contacts with two of them bring back pleasant memories. For years, Dr. M. S. Balal represented his country at the annual conferences held at IRRI headquarters. He was one of the leaders who helped create the International Rice Testing Program (IRTP) and implement those components that were applicable to drier areas.

Dr. M. M. El-Gabaly also contributed significantly to the success of IRRI and to the international networks of which IRRI was a part. As a member of the IRRI Board of Trustees, he helped guide IRRI's long-term plans. He has also been influential in the adoption of some IRRI varieties here in Egypt and in trying out multiple-cropping systems.

In my work in the U.S. Agency for International Development (USAID) during the past 5 1/2 yr, I have witnessed the commitment of other Egyptian leaders to quality agricultural research programs, particularly, the strong commitment of the Honorable Dr. Youssef A. Wally, Deputy Prime Minister and Minister of Agriculture and Land Reclamation. He has consistently placed high priority on agricultural research, including that for rice. He has not only provided leadership for expanded research efforts in his Ministry but also sought the advice of international panels to do even better. This new research and training center and the associated programs are a credit to his dedication.

In offering congratulations on this fine new facility devoted to rice research, I would like to say how glad my USAID colleagues and I are that our agency could contribute to the development and construction of the Sakha Rice Research and Training Center. We are pleased that USAID has been able to share in the costs of this facility and the expanded rice research program that has been under way for years here in Egypt. A few American scientists have had the privilege of working in Egypt and they have kept me informed of the significant progress that has been achieved.

This facility can well serve as the nucleus around which Egyptian agricultural researchers can further expand and improve a cadre of rice scientists and develop a critical mass of information on rice culture in the Mid-East and other rice-growing arid areas. The Egyptian program can serve as an example and encourage research in other countries in this region of the world.

As this building is dedicated, we must remember its relevance to the broader worldwide issue of food production. Hunger and malnutrition comprise a dual challenge to the developing nations around the world, and it is the poorer people in these countries who suffer the most. Probably the greatest challenge facing the world today is to produce sufficient food to feed the human family now and another 80 million new members each year. And the challenge does not stop here. We must also ensure that the poorest members of this world family have more food and a better diet than their parents and grandparents had.

We must also keep in mind that, worldwide, rice is the primary food staple for more low-income people than any other crop. It grows under perhaps the widest range of soil and water environments of any major crop. And it provides most of the human nutritional needs, since in some areas rice furnishes some 80% and more of the diet.

Inasmuch as this symposium is concerned with food production on a broad basis and because most of this food is going to be produced in developing countries, I would like to address the general subject of agricultural research in the Third World. Some of the problems and opportunities will go beyond those faced in Egypt, but many will be pertinent to this country.

Agricultural research progress and agricultural production

During the last three decades, unprecedented technology changes have impacted on agriculture throughout the world. Developing countries, in varying degrees, have benefited from these advances; i.e., from the Green Revolution with its high-yielding cereals such as wheat, rice, and maize. On the average, Third World agricultural output increased at the historically high rate of just under 3% annually during the 1960s and 1970s and is still increasing at a commendable rate. But because these gains were largely offset by increases in population, per capita agricultural and food output has increased only about 0.35% annually. However, since two-thirds of less developed country populations derive their main incomes from agriculture, these changes have had a widespread beneficial impact.

Although many subsistence farmers in developing nations still do not have adequate diets, without the products of agricultural research of the last 30 yr, hunger and malnutrition would be much more widespread. Improved crop varieties that are higher yielding, more tolerant of negative environmental factors such as high-salinity soils, more resistant to diseases and pests, and yet are consumer-acceptable, serve as one example of beneficial products from integrated agricultural research. Likewise, research on the management, protection, and utilization of major crops requires an integration of the efforts of various disciplines, such as agronomy, plant breeding, food chemistry, agricultural economics, entomology, and plant pathology.

While agricultural research has achieved some major scientific breakthroughs, serious constraints to crop production exist over wide areas of the world: lack of sufficient soil moisture to support crop production (particularly critical in Africa and Latin America); control and management of plant diseases and pests, where agricultural researchers are just beginning to get a foothold; and others such as soil erosion, particularly where the slash-and-bum system of agriculture is practiced, to name just a few.

Strong agricultural research systems

The Green Revolution was sparked by products of research of the international agricultural research centers (IARCs), particularly IRRI and CIMMYT (Centro Internacional de Mejoramiento de Maiz y Trigo). As a consequence, some have assumed that these IARCs offer the solution to problems even more formidable than those faced in the 1960s and 1970s. It must be pointed out, however, that the successes of the past 25 yr have been due in no small measure to quality national agricultural research programs and to their linkage to the international centers. Certainly rice production in Egypt has been underpinned by a continually improving national research system.

The success of intercountry research programs and networks depends largely on the excellence of the national research programs and the scientists involved in the regional efforts. This is certainly the case for the International Rice Testing Program to which Egypt so effectively contributes. Likewise, success of attempts by scientists in industrialized countries to focus on developing country problems is determined to a marked degree by their interaction with competent counterparts in developing countries. There is no substitute for strong and viable national research programs to meet many of the needs of the developing countries.

Strong indigenous research systems can ensure focus on location-specific constraints. While research in the industrialized countries can indeed be helpful to the indigenous agricultural research systems, research of local scientists is more apt to be focused on the problems of the developing countries. Incidental benefits of industrial-nation research to the developing countries are frequently delayed and, in some cases, may not be obvious at all.

A second important reason for strong indigenous agricultural research systems relates to the self-interest of the developing countries in such questions as energy conservation and utilization, environmental quality, and conservation of genetic resources. The developing countries must have capability of their own to critically analyze these questions, which may be only incidentally related to their core food production problems.

Thirdly, national research systems must be strong enough to take advantage of emerging research methodologies, such as those we see in modern biotechnology. Developing country scientists must be performing alongside their counterparts in industrialized countries. I don’t subscribe to the notion that acountry such as Egypt should not be involved in biotechnology research because it is too sophisticated. Some say that the developing countries simply should wait until the industrialized nations produce improved cultivars and animal strains through the use of modem biotechnology and then try to apply these products to meet their own national needs. In my judgment, it would be to the disadvantage of Egypt and other developing countries to do so. I think they should work in collaboration with the industrialized nations, and should focus these newly developed methods on the crops and animals of most concern to themselves. The urgency of this involvement is made even more critical by changes in patent policies in relation to new varietal development.

Major criteria for success

To make the most effective use of agricultural research, a country must meet three major criteria. First, and foremost, there must be commitment on the part of national leaders and at all levels of government and of private industry to the long-range use of research to help solve agricultural development problems. Strong national commitments are essential for at least the next three or four decades if agricultural research systems are to meet their goals.

National commitments to agriculture and to agricultural research must be demonstrated in several ways. For example, problems and opportunities in agricultural research must receive attention at the highest levels in government. Funds must be made available, not only to build and staff new research facilities, such as this Sakha Rice Research and Training Center, but to operate them over a period of years.

Strong national commitments also involve educating and training qualified scientists and strong support for these scientists once they are trained. Furthermore, these scientists must have personal commitments that are as strong as their leaders'. Support for research should be given not merely to satisfy the disciplinary whims of these scientists, but to solve human problems. But once the research has been done and technologies are available for the agricultural system, the scientists should be recognized and honored for their accomplishments.

It is obvious that Egyptian commitments to improve agricultural research have been made at the highest level of government. Deputy Prime Minister Wally and other Egyptian leaders are demonstrating this commitment by supporting agricultural research and by organizing this symposium.

A second criterion for success is the setting of clear national agricultural development goals and, concomitantly, the establishment of agricultural research priorities to help achieve these goals. Too often attempts to identify such priorities result in the mere listing of all the agricultural research that might be done. Some hard decisions must be made to determine which research areas are the most important, which processes the most limiting, and which research methodologies show the greatest promise of accomplishment. Likewise, priority setting must consider who is the most likely to benefit from the research once it is performed.

It is obvious that Egypt has moved toward firming up its agricultural research priorities. Your leaders should be congratulated for initiating a process of priority setting and for choosing rice as a priority research focus.

A third criterion for success is that agricultural research efforts must be effectively organized and firm decisions made as to who does the research. Insofar as possible, collaboration rather than competition should prevail among institutions. Too often national agricultural research is fractionated among the various performing organizations. No real system is evident. The research is scattered among institutes and universities in the responsible ministries and each guards jealously its assumed prerogatives. There is a minimum of collaboration and, in most cases, competition for funds and credit as well.

Every effort should be made to establish some kind of a coordinating mechanism, and a funding authority that rewards collaboration. I know that Egypt has struggled with this problem and is making some progress toward its solution.

National research plans commonly assure that three types of research be performed by appropriate institutions. a) Problem-oriented basic research to take advantage of the best methodologies modem science can offer; universities and ministries of science usually play a lead role in this type of research. b) Applied research ranging from centralized laboratory and greenhouse studies to location-specific field studies; "sector" ministries such as the Ministry of Agriculture usually take the lead in this type of research. c) Interactive "consequences" research to ascertain the possible effects of changing technologies on such national concerns as the quality of the environment, and the societal costs and benefits of the new technologies; universities and other ministries of government may be involved in this type of research.

Egypt has many advantages over most other rice-growing countries. It already has a cadre of well-trained scientists concerned with rice. It has a core rice research program that can attract the best scientists in the Ministry of Agriculture and in universities. Furthermore, it already has one of the highest levels of rice production in the world.

Some say Egypt has already reached an acceptable level of performance in rice production. But those who understand the constraints on rice production in Egypt recognize that the full potential of this country to produce rice has not yet been realized. Yields have tended to level off in the past 10 to 15 yr. Severe attacks of the blast disease have shown that the genetic base for this crop must be broadened. Salinity buildup in some land areas reminds us of the possible vulnerability of production levels to this problem. Lastly, we know that a production level of 6 t/ha is about one-third of the biological potential for the rice crop. Egyptian rice scientists should be challenged to provide technologies that will take their country above the rice production plateau of the past decade.

International collaboration

At no time in the history of agricultural science has there been a greater need for collaboration among researchers from different countries. Lessons learned as the Green Revolution progressed tell us how important it is, and scientific progress since the 1970s has made such collaboration even more critically necessary. Several of these lessons could be referred to.

First, research must be linked into existing institutions and not just to individuals. The success of the Consultative Group on International Agricultural Research system rests, to a major extent, on a blending of an international research focus with a corresponding commitment to expanding capacity at the national level. As national institutions strengthen their own research, training, and problem-solving capabilities, they are better able to benefit from and contribute to the scientific work conducted concomitantly at the international level. The end result has been the creation of a synergistic system based on true symbiosis and partnership between scientists at the international centers and their colleagues within widely dispersed national research programs. Egypt has played a major role in these efforts.

Second is the need to go beyond what I call "show-and-tell." Let me give you an example of what I mean. At one time in a program sponsored by IRRI, scientific researchers from different countries devoted considerable time and effort to testing each other's seeds in the International Rice Testing Program. Each year they came together to report on progress. The problem here was that each individual country report was not always relevant to any of the other reports. Furthermore, little information was shared among the cooperators. It was simply a "show-and-tell" performance. Then the procedures were changed. A set of common ground rules, along with a common scoring system to measure success and failure, was developed by the researchers working as a group. The result—in one year, 85% of the data collected was exchanged among the cooperators. Data could then be compared and results discussed in a truly scientific manner.

Third, regional and national research institutions should not try to set priorities independent of those they serve—the farmers. Decisions on how best to use the scarce resources available must be made through a careful evaluation of the actual needs and problems confronting the farmers. This sounds obvious, but there are countless examples of great amounts of time and money being used to address a particular concern of the scientist—not a real need of the farmer.

Finally, great care must be taken to avoid duplication of effort. The challenges we face are too great, the human and financial treasure too limited to be wasted on repeating each other's work. One nation can ill afford to pursue alone a research agenda without reference to other countries. They cannot function in a vacuum; they must cooperate. Each country, each institution must focus on the subjects it is best equipped to handle.

Research methodologies

Others in this symposium will be addressing the substance of the specific research on which national researchers could well focus. However, I would like to mention two general methodologies that, I hope, will receive attention in the future. Each of them offers considerable potential for solving problems of developing countries.

Biotechnology

The traditional methods of research that have served us well in the past will continue to help us find solutions to the ever-present problems of plant pests and diseases, adverse soil conditions, unfavorable climatic conditions such as low rainfall, flooding, and others. But, in addition, agricultural research programs must explore and apply the vast potential of biotechnology and other recent technologies to solve developing country agricultural problems.

The new scientific methods, collectively called "biotechnology," offer a new arsenal of skills that have arisen from combining molecular biology, genetics, immunology, and cell biology. Through biotechnology, the potential exists to develop growth hormones that increase total crop production rates or redirect specific plant processes to enhance the production and quality of marketable products. Enhancing the efficiency of biological nitrogen fixation could help move the world's agriculture away from dependency on petroleum-based fertilizers, by which it is now constrained.

Such accomplishments can have great significance for developing nations where population pressures are most extreme, where crop production levels are lowest, and where even the more traditional research techniques have been notably underutilized. As we well know, natural constraints of soil and biological environment continue to dominate the efforts of farmers in these areas. They cannot afford the lime, fertilizer, and other agrochemicals needed to overcome these environmental limitations. Thus, yields and incomes remain low, and some developing nations become increasingly dependent on food imports. Even in Egypt, where yields are high, environmental constraints limit production of rice and other crops.

Genetic engineering offers the possibility of dramatically improving this situation. Rather than modifying the environment to improve plant production, biological scientists focus on modifying the genetic makeup of crops to overcome stress. Transferring that capability to cereals and other nonlegumes could help remove the constraints of these less favorable environments. While traditional plant breeding methods have done much to move agriculture in this direction, the gene splicing techniques of modern genetic engineering show promise of both accelerating the process and providing the potential for far greater change than can be expected through traditional methods. Research has shown that the transfer of genetic material into plant cells is possible. This increases the likelihood that genes can be introduced into plant cells to enhance agricultural production and crop quality.

Modern biotechnology also offers the potential to control the common plant and animal diseases, pests, and parasites. For example, researchers discovered that a chemical produced by animal cells in response to viral attack inhibits virus infection in plants; tobacco mosaic virus and alfalfa mosaic viruses were inhibited by the compound. And the chemical can be produced synthetically and inexpensively enough for commercial production. Such findings open up a new approach to the control of plant viruses.

Biotechnology research on herbicide-resistant strains of crop plants also has considerable potential. The search in the past for species-specific weed killers has led to difficulties where crops are rotated. For example, some legumes may do poorly in a field treated the previous year with herbicides to control weeds in maize. It is likely that resistance to specific herbicides can be incorporated into the genetic makeup of the legumes and other crops.

Such biological tools as these can lead to research breakthroughs that can help the agricultural community in developing nations improve crop production, which has tended to level off following the dramatic surges of the 1960s and 1970s. There is no question in my mind that genetic engineering, for example, offers great potential to provide new cultivars resistant to major insect pests and diseases, and tolerant of drought, temperature extremes, salinity, and other adverse soil conditions.

As I pointed out earlier, biotechnology techniques are not too sophisticated for scientists in developing countries. While it is true that scientists in industrialized countries may have greater resources to carry out some of the most basic research on gene splicing, the literature is uncovering innovative techniques that are within the resources of scientists from the Third World. Developing country scientists should focus these techniques on the agricultural problems of their farmers.

In time, I would expect biotechnology techniques to offer much to Egyptian rice researchers. If there are expectations to move up the nationwide yield barrier to

7-8 t/ha or even higher levels, significant breakthroughs will be needed. Varieties that will yield well even under conditions of high salinity must be sought. Likewise, high-yielding varieties with shorter growing periods will be needed to permit the full utilization of the growing seasons in Egypt. Broad-based resistance to the blast disease could be one of the products of biotechnology-based research.

Soil-crop-climate modeling

While biotechnology is the most prominent of the new technologies being used in development assistance research programs, another recent technology is worthy of mention today as we survey future needs and opportunities for crop production increases. The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) uses systems analysis and computer simulation systems to develop methods to help decisionmakers, including farmers, to make better choices among alternatives.

Using agricultural simulation models, researchers can quickly and inexpensively predict the problems and potentials of crop productivity with particular combinations of soil type, environmental constraints, and management resources. By using this technology, countries can reduce the amount of site-specific research and avoid disastrous crop choices. IBSNAT is an international effort that employs the latest technical knowledge and information technology to help agriculturists "fit" their crops to the conditions in which they farm.

Thus, by combining the applications of traditional methods of agricultural research that have proven successful over the years with newer research techniques such as biotechnology and other technologies, we can strive to produce better paths to successful agriculture, particularly for the small farmers of the developing world.

Conclusion

I would like to present two challenges to the agricultural researchers of Egypt. First, focus your efforts on raising the production ceiling for rice in Egypt. Egyptian scientists have the capability of providing higher yielding varieties and improved technologies and cropping systems that can help raise this ceiling. To do so, however, will take improved coordination among scientists at universities, discipline-oriented centers in the Ministry of Agriculture, and scientists located at facilities such as the Sakha Rice Research and Training Center that we are dedicating today.

Second, strive to realize your potential to become the true leaders of the agricultural community of the Mid-East; utilize the talented human resources of the Egyptian agricultural sector to generate the agricultural research processes that can improve crop production in rice and all major cereals and other economically crucial crops in this region. This new building, equipped with the latest research equipment and materials, can help achieve this goal.

Egyptian agricultural scientists can help neighboring nations and other countries to meet regional and national needs, using a network approach to agricultural research. This cooperative research focus must include interaction with scientists in developed countries and the IARCs around the world.

The future success of agriculture and agricultural research rests on a multitude of factors: hard work, dedication, human resources, and continuous coordination, cooperation, and collaboration combined with enlightened national policies that foster these efforts and programs. I am pleased to see the extent to which national leaders and scientists from government, universities, and the private sector support the efforts to improve the agricultural productivity and quality in Egypt.

This new building for the Rice Research and Training Center is concrete evidence of the cooperation between Egypt and the USA to strive toward improved output of Egypt's agricultural research. I wish you well in this endeavor.

Notes

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The role of early-maturing rice varieties in the cropping systems of Egypt

M. M. EL-GABALY

The traditional pattern of agriculture in Egypt—one winter crop per year—has been governed since ancient times by the water available from the Nile. With the construction of major dams and with irrigation water freely available, both cropped area and cropping intensity have substantially increased; with early-maturing varieties of rice, such as IR28, three crops a year are possible, and total cropped area could be extended from the present 4.4 million to 6.5 million ha. Experiments in the three major rice-growing governorates have shown that growing early varieties could both increase total production and be highly profitable to the farmer, giving net profits per hectare per day more than three times those obtained from the traditional single-cropped Giza 172 variety. This potential should be tapped to reduce the heavy cost of present food imports and subsidies, releasing funds for other needed development in the country.

The pattern of agriculture in Egypt is influenced by the availability of water from the River Nile, as to both quantity and time. From the early historical period up to the early nineteenth century, one winter crop was grown under the prevailing "basin" system of irrigation.

With the construction of the Delta Barrage and the old Aswan Dam, summer crops—cotton, sugarcane, and rice—were introduced into Egyptian agriculture, increasing the cropping intensity to nearly 150%, with about 50% of the land left fallow during the summer months.

With the continuous increase in population and shortage in food commodities, both vertical and horizontal expansion in agriculture became an urgent necessity. As a result, the idea of the High Dam seemed a logical solution to conserve the 34 billion m^3 of water lost annually to the Mediterranean. With the completion of the Aswan High Dam in 1970, it became possible to cultivate all the land during the summer to raise the area of rice to about 0.5 million ha and the cropping intensity to almost 200%, or about 2 crops/yr.

However, even this increase in cropping intensity and the vertical and horizontal expansion have not been able to meet the increasing food demands of a population that has grown from 19 million in 1950 to 50 million in 1986.

The food problem

As a result of the increased demand and the failure of the existing land resources to cope with it, the food gap has increased from about 1.5 million tons in 1970, to almost 10 million tons in 1986. This is because the yield of most crops grown in Egypt is high, compared with international yields. Therefore, the annual rate of growth in agriculture did not exceed 2.5%, whereas the annual population increase was 2.6-2.8% and the increase in food demand 5-6%.

Egypt now imports about 60% of the food it consumes, with a total food import of almost U.S. $3 billion/ yr. In addition, the government food subsidies exceed U.S. $2 billion/yr. These costs put a heavy burden on Egypt's balance of payments and greatly affect the investments available for its National Development Plan.

Changing conditions after the building of Aswan High Dam

Traditionally, late-maturing varieties of crops (i.e., cotton, rice, wheat, maize) have been grown in Egypt, making it almost impossible to raise the cropping intensity beyond 200%. In addition, the interval between the harvest of one crop and the planting of the following ones may exceed 80 d/yr, which can be considered as wasted days.

The Aswan High Dam, completed in 1970, has created a water bank from which Egypt can withdraw water at will to meet its agricultural requirements. Before the High Dam, the amount of water available at Aswan was unpredictable; but now, Egyptian agriculture enjoys a water stability that is rarely matched anywhere in the world.

Besides water for irrigation, Egypt is also endowed with favorable growing conditions throughout the year. Temperatures vary between 35 °C average in summer and 20 °C in winter. These favorable conditions make it possible to introduce early-maturing crop varieties-developed in the 1960s and 1970s—in place of traditional late-maturing ones. If this is fully achieved, the cropping intensity can be increased to 3 crops and the cropped area from the present 4.4 million to about 6.5 million ha, i.e., an additional 2.1 million ha. In this newly created cropped area, a second crop of rice, maize, soybean, cowpea, etc., can be grown during the Nili season (mid-August to end of November). This will solve the problem of Egypt's shortage of maize, oil, and animal feed. The production of rice can be increased by about 2 million tons to be exported, so that badly needed wheat may be imported. Egypt can make use of each growing day of the year to produce crops and utilize its limited land and water resources to the maximum to solve its present acute food shortage.

Introducing early-maturing varieties

The introduction of early-maturing varieties of rice, cotton, maize, and wheat into Egyptian agriculture started in 1980, with rice varieties IR28, IR50, and IR9752, which were introduced and tested for double-cropping in small plots. The limited results indicated a good first crop but a low-yield second crop, which was due mainly to the high percentage of sterile seeds. This question was thoroughly discussed with specialists—S. Yoshida, G. S. Khush, and T. T. Chang—at the International Rice Research Institute (IRRI). It was thought to be due to low night temperatures during the flowering stage of the second crop. To minimize this effect, it was considered advisable to shift the planting date of the first crop to April and the second crop to July, so that the second crop could escape the very low night temperatures during October.

In 1980, the first relatively large-scale field experiments were carried out by a team from the Egyptian Academy of Scientific Research and Technology at the University of Alexandria, the University of Tanta (Kafr El-Sheikh), and Shawa (Dakahlia) where two crops of rice were grown (Table 1).

The second-crop yield was low because the crop was transplanted a month late, during the first week of September; it should have been transplanted no later than the first week of August, to escape the low night temperatures during October and November.

Since these were the first experiments in Egypt with double-cropping of rice, we repeated them in three of the main rice-growing governorates and, as much as possible, maintained proper sowing dates for each crop, as this was found to be the dominant factor in determining the yield of each crop. The area covered by the first crop in the governorate was about 92.4 ha and that by the second crop was about 35.7 ha (Table 2). A late rice crop of IR28 was grown after a crop of soybean, on an area about 48.3 ha. Table 3 shows the rice yield obtained in the experiment.

Economic evaluation

An economic analysis and evaluation were carried out to compare the advantages of double-cropping early-maturing varieties of rice (IR28) and single-cropping traditional varieties (Giza 172).

The analysis included:

1. Yield per unit of land area.
2. Labor, water, and agrochemical requirements of each crop, and other costs of production.

Table 1. Yield of 2 crops of IR28 compared with that of Giza 172.

Crop	Yield (t/ha) University of Alexandria	Yield (t/ha) University of Kafr El-Sheikh	Yield (t/ha) Shawa	Yield (t/ha) Ras El Khalig
1st	3.0	2.9	2.8	beans
2d	0.8	1.2	1.2	2.1
Total 2 crops (IR28)	3.8	4.1	4.0	
Giza 172	2.0	1.8	2.2	1.6

Table 2. Yields of 2 crops of rice in 3 governorates in Egypt.

Governorate	Location	Variety	Previous crop	Yield (t/ha) 1st	Yield (t/ha) 2d	Total yield (t/ha)
	Khazan	IR9712	Berseem	7.1	–	14.0
		IR28	Rice	–	6.9	–
Beheira	Misida	IR28	Berseem	9.5	5.2	14.7
	Edfina	IR28	Beans, barley, berseem	8.4	4.7	13.1
Kafr El-Sheikh	Daklat	IR28	Wheat	8.1	5.6	13.6
Dakahlia	Orman	IR28	Berseem	8.6	5.5	14.1
	Demira	IR28	Berseem	7.8	6.1	13.9

Table 3. Yield of late IR28 rice crop following soybean in Egypt.

Governorate	Location	Yield (t/ha)
Beheira	Gabaris	5.9
	Edfina	7.1
Dakahlia	Ras El Khalig	5.7
	Sabria	3.6
	Abou Galal	6.0

Table 4. Yield, gross income, cost of production, and net income of double-cropped early-maturing IR28 versus traditional Giza 172, Egypt.[a]

Item	1st crop IR28	2nd crop IR28	IR28 after soybean	Giza 172
Yield (t/ha)	8.6	5.0	6.0	6.2
Gross income (£E/ha)	1166.2	719.0	743.8	827.1
Production cost (ƒE/ha)	478.1	451.7	451.7	486.7
Cost (LE/t)	55.8	90.4	75.9	78.6
Net profit (LE/ha)	688.1	268.2	387.2	340.3
Water requirements (m^3/ha)	7973	7497	7497	15470
Net profit/1000 m^3 water (LE)	86.2	35.7	51.5	23.8
Net profit/ha per d (LE)	8.6	3.6	4.8	2.4

[a] US$1 = LE1.07.

3. Net return to the farmer (using farm gate prices).
4. Net return per 1,000 m^3 of water.
5. Comparison of alternative cropping patterns, including early-maturing varieties (IR28) and local varieties (Giza 172).

The results (Table 4, 5), showed that the early-maturing varieties, double-cropped, gave substantially larger net profits per hectare and per 1,000 m^3 water than the traditional rice variety.

Table 5. Net profit per hectare of cropping patterns (farm gate prices in LE). [a]

Cropping pattern	Net profit (LE/ha)	Net profit/1000 m^3 of water (LE)
	Patterns with IR28	
Wheat - rice	1057.90 [b]	50.80 [b]
Beans - rice	1344.70 [c]	63.60 [c]
Berseem - rice	1287.60 [d]	41.70 [e]
Berseem/soybean - rice	972.70 [e]	51.30 [d]
	Patterns with Giza 172	
Wheat - rice	441.90 [b]	22.50 [b]
Beans - rice	728.70 [d]	36.50 [c]
Berseem - rice	835.80 [c]	28.20 [d]

[a] US$1 = LE1.07. [b] Central Bank of Egypt, 1982. [c] Egyptian Academy of Scientific Research and Technology, Agricultural Research Council, 1981. [d] Egyptian Academy of Scientific Research and Technology, Agricultural Research Council, 1982. [e] Khidr 1979.

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Rice in Egyptian and global agriculture

R. W. Herdt

An appropriate way to think about rice in Egyptian and global agriculture 15 yr hence is to look at the role of rice in world agriculture over the recent past. Although wheat and maize dominate grain production in the developed world, rice is most important in the developing world. It makes up about 35% of the total of crop output (food calories) in the developing world, animal products as a group contribute another 10% (Table 1).

Rice contributes roughly the equivalent of one-third of all food energy largely because of its dominant position in Asia, which has two-thirds of all developing country population.

Wheat is clearly the most important cereal in North Africa and the Middle East. Noncereals are more important in sub-Saharan Africa than in any other region, with roots and tubers contributing 27% of the food energy. In Latin America, livestock products are more than twice as important as in other developing regions; within the cereals, maize is the most important. The relative importance of the major components of output changes slowly; thus, although the data in Table 1 are not the most recent, they provide a useful indicator of the relative importance of different crops.

Developing country rice production amounted to about 460 million tons (unhusked) in the 1983-85 period—a 105% increase over the 1960-62 period, which amounts to an average annual compound growth rate of 3.2%. All developing countries together produced 95% of the world's rice, developing Asia dominating with 89% of total production (Table 2).

The international trade picture is somewhat different: developing countries exported 76% and imported 85% of the rice that moved internationally. Stated another way, developed countries produced 5%, exported 25%, and imported 15% of the world's rice. Thus, the impact of the developed countries in world trade in rice is disproportionately large; considering their production and consumption. The developed countries are relatively much more important producers, traders, and consumers of wheat and maize, the two other cereals that dominate world production.

Table 1. Contribution of major foods to production by region in developing countries.[a]

	1976-80		Share of production (%)			
	million t	%	Asia	North Africa and Middle East	Sub-Saharan Africa	Latin America
Cereals	670.0	74	78	84	51	64
Wheat	145.6	16	15	47	2	12
Rice (husked)	282.4	32	42	5	7	9
Maize	136.7	15	12	8	19	31
Millet and sorghum	68.9	8	6	6	21	9
Others [b]	36.6	4	3	17	3	3
Noncereals [c]	140.4	16	13	6	42	17
Roots and tubers	88.3	10	8	2	27	10
Pulses	95.0	11	2	3	6	3
Groundnuts	16.2	2	2	2	5	1
Bananas and plantains	11.0	1	1	–	5	3
Livestock products	89.0	10	9	9	7	19

[a]Based on data from Paulino (1986). estimate made by author for livestock products based on FAO consumption data. [b]Data on "cereals" for China include pulses. [c]Data for noncereals are converted to wheat equivalents based on calories.

Table 2. Production, stocks, and international trade of rice (million tons), by major world region, 1965-68 and 1983-85 (USDA 1986).

	Production		Stocks		Total imports		Total exports	
	1965-68	1983-85	1965-68	1983-85	1965-68	1983-85	1965-68	1983-85
World	264.8	461.5	11.5	18.8	7.0	11.6	7.6	11.9
Africa (less Egypt)	4.2	6.5	0.1	0.4	0.7	2.9	0.1	0.0
East Asia (less Japan)	102.9	187.7	0.5	2.5	0.5	0.5	1.8	1.5
South Asia	70.5	122.5	6.4	6.5	1.5	0.7	0.4	1.2
Southeast Asia	51.2	99.1	1.7	4.6	1.8	2.0	2.4	5.0
Middle East (inc. Egypt)	3.4	4.2	0.1	0.3	0.3	2.3	0.5	0.1
Latin America [a]	9.7	16.3	0.8	1.4	0.4	1.0	0.4	0.6
Developed countries [b]	22.7	25.2	1.9	3.1	1.8	2.2	2.1	3.5

[a]Central America, Caribbean, and South America. [b]World less other named regions: mainly Europe, Japan, USA, and Oceania.

Rice in Egypt

Rice is an important crop in Egyptian agriculture. It occupies about 20% of the area planted to summer crops, roughly 9% of total harvested area (Alderman and von Braun 1984). In 1986 about 400,000 ha were planted, somewhat less than were planted in the early 1970s (Table 3). This is roughly similar to the area planted to cotton; two-thirds the area planted to wheat; and about half the area planted to

Table 3. Area, production, and yield of rice in Egypt, 1966-86 (USDA 1986).

	1966-68	1976-78	1967-77 growth rate	1984-86	197785 growth rate
Area (thousand ha)	387	444	3.0	407	–
Production (rough rice, thousand t)	1916	2332	1.4	2361	0.2
Yield (t/ha)	4.9	5.3	0.8	5.8	1.1

maize. Thus, because of Egypt's diversified cropping patterns, rice is an important crop, although it does not dominate Egyptian agriculture the way rice dominates in many Asian countries.

Rice yields are high and increasing in Egypt. The current level of nearly 5.8 t/ha of rough rice makes Egyptian yields nearly the highest in the world, just slightly below Japan (6.1) and ahead of the USA (5.6) and China (5.3) (USDA 1986). Between the mid-1960s and the mid-1970s, yields increased by 400 kg/ha and between then and the mid-1980s increased another 500 kg/ ha. The rate of increase appears to have accelerated between the two periods.

Yield increases have served to offset area reductions that occurred between the 1970s and the 1980s, so that production remained at about 2.3 million tons, which was adequate to meet Egypt's needs. In contrast to wheat, rice is not imported by Egypt in any significant quantity.

Food consumption patterns in Egypt are so influenced by subsidies that it is impossible to think of the future of Egyptian agriculture without explicit assumptions about subsidies. The apparent self-sufficiency in rice is very much a result of large imports of wheat on the one hand and the configuration of relative food prices on the other.

Researchers at the International Food Policy Research Institute (IFPRI) have conducted detailed studies of Egypt's food policies (Alderman et al 1982), including their impact on trade (Scobie 1981, 1983), their effect on the agricultural system as a whole (von Braun and de Haen 1983), and their impact on income distribution and consumption (Alderman and von Braun 1984). This literature is far too rich to review here, but does provide a basis for judging what may happen to Egyptian rice consumption as incomes increase or as rice prices change relative to other prices. The relevant data are summarized in Table 4.

They indicate that consumers are moderately responsive to price and income changes in their consumption of rice. They are substantially more responsive in their consumption of fresh meat and pasta, but consumption of balady bread is virtually not affected by income or price.

One can speculate that as long as subsidies remain at current levels, rice production and consumption can be kept in close balance, but if the capacity to import and subsidize other cereals weakens, the demand for rice is likely to increase. As Alderman and von Braun (1984) put it: "A substantial cut in wheat subsidies would certainly induce a rapid increase in rice consumption, even if rice were not

Table 4. Selected food consumption parameters, Egypt, 1981-82 (Alderman and von Braun 1984).

Parameter	Income quartile	Location	Food: Rice	Pasta	Balady bread	Fresh meat
Expenditure elasticity	Lowest	Rural	0.56	1.05	0.04	1.13
		Urban	0.36	0.51	–0.02	1.58
	Others	Rural	0.26	0.48	0.01	0.37
		Urban	0.13	0.24	–0.05	0.67
Own price elasticity	Lowest	Rural	0	–1.41	n.a.	–2.16
		Urban	–0.14	–0.61	n.a.	–2.88
	Others	Rural	0.36	–0.22	n.a.	–0.61
		Urban	–0.13	–0.30	n.a.	–0.82
Cross price elasticity with noodles	Lowest	Rural	0.34			
		Urban	0.24			
	Others	Rural	0.15			
		Urban	0.15			

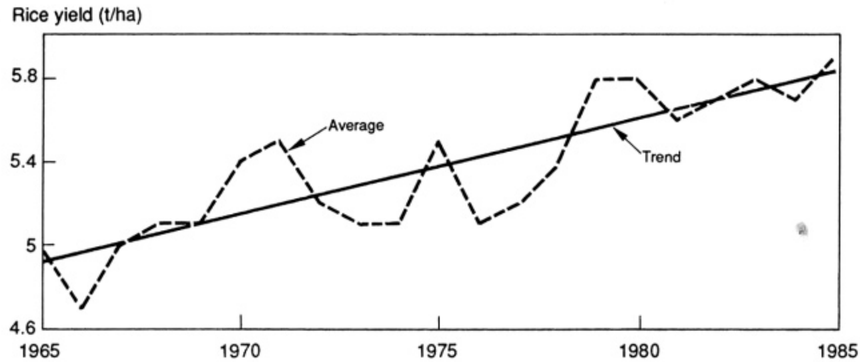
subsidized. In one scenario, rice would be a major import crop with about half a million tons imported annually. That prospect raises two questions: 1) how great is Egypt's capacity to increase rice production? 2) what is the capacity of the rest of the world to supply rice to Egypt?

Potential production increases

Possible sources of added rice production are from land shifted out of some other crops into rice or from new land. The former results in no net gain; the latter is virtually impossible. So yield improvement is the obvious route. I will confine my comments on Egyptian rice production to one aspect: the degree to which unexploited technical potential for raising yields per hectare currently exists. Does profitable technology exist that, for some reason, farmers are not using? Three sets of information provide some indications about the issue: the level of trend of yields, Egypt's yields relative to those in other countries with similar agroclimatic conditions, and experiments that compare farmers' actual yields with attainable yields.

Figure 1 shows national rice yields in Egypt since 1965, which increased at an average rate of 1.0% per year. There were some fluctuations over the period, with a suggestion of slowing in the 1969-72 to 1974-77 period, but the increase is clear. Comparison of discrete groups of years, as in Table 3, suggests some acceleration of yield increases after the mid-1970s, but that is less certain. And even at the beginning of the period, yields were high compared with most Asian countries.

The sources of these yield increases are not obvious. Rice production in Egypt has long been completely irrigated. Fertilizer rates are not available on a crop basis, but overall chemical fertilizer use in Egypt was 232,000 t in 1960-62, 475,000 t in 1974-76, and 853,000 t in 1982-84 (FAO 1986a), a fairly rapid rate of increase. New



1. Annual average yields and yield trends of rice in Egypt, 1965-85 (USDA 1986).

varieties have been introduced, but their yield potential is not dramatically higher. In sum, national average yields of 5 t/ha in the late 1960s were achieved with rather good practices; these were improved somewhat to give the observed gains, but no dramatic changes in technology have occurred.

Yields in Egypt are among the highest in the world. Eleven countries with over 10,000 ha of rice recorded yields in excess of 5 t/ha in 1985 (FAO 1986b). Only Australia, North Korea, South Korea, Japan, and the USA ranked ahead of Egypt, and even the highest national yields were only about 20% greater than Egypt's. This does not indicate that there is an obvious opportunity to exploit technology from other places.

Research conducted to determine the unexploited yield potential or "yield gap" that may exist on farmers' fields in Egypt shows useful results in this regard. The yields on demonstration farms (the "Mabrouk-4" program) using the package of recommended technology averaged 8.9 t/ha from 1981 through 1984, roughly 0.5 t/ha above the levels that research workers were able to obtain over the same period (Sharaf et a1 1986). The yields on demonstration farms exceeded the national average by about 3.5 t/ha; however, this number probably overstates the unexploited yield potential. A comparison of the yields of Mabrouk-4 participating farmers with those of nonparticipating farmers in the same villages and nonparticipants in other villages indicates a yield difference of slightly over 1 t/ha (Table 5).

Analysis of the survey data reporting costs of inputs indicated significant differences in the costs of production of the participating and nonparticipating farmers. In 1982 costs per feddan (0.42 ha) were LE 200 for traditional compared with only LE 154 for Mabrouk-4 participant farmers. In 1983, costs were LE 260 for traditional compared with LE 248 for participants (Sharaf et al 1986). The Mabrouk-4 participants were using lower levels of labor and animal power and higher machinery inputs and presumably more skillful timing of operations to obtain higher yields with lower input costs.

Table 5. Rice yields obtained by Mabrouk-4 demonstration program participants and nonparticipants and national average yields in Egypt, 1982-84.

Year	Rice yield (t/ha)		
	Demonstration villages		Other villages, nonparticipants
	Participant farmers	Nonparticipant farmers	
1982 (n = 468)	6.6	5.7	5.7
1983 (n = 945)	7.9	6.4	6.2
1984 (n = 100)	8.6	7.4	7.4

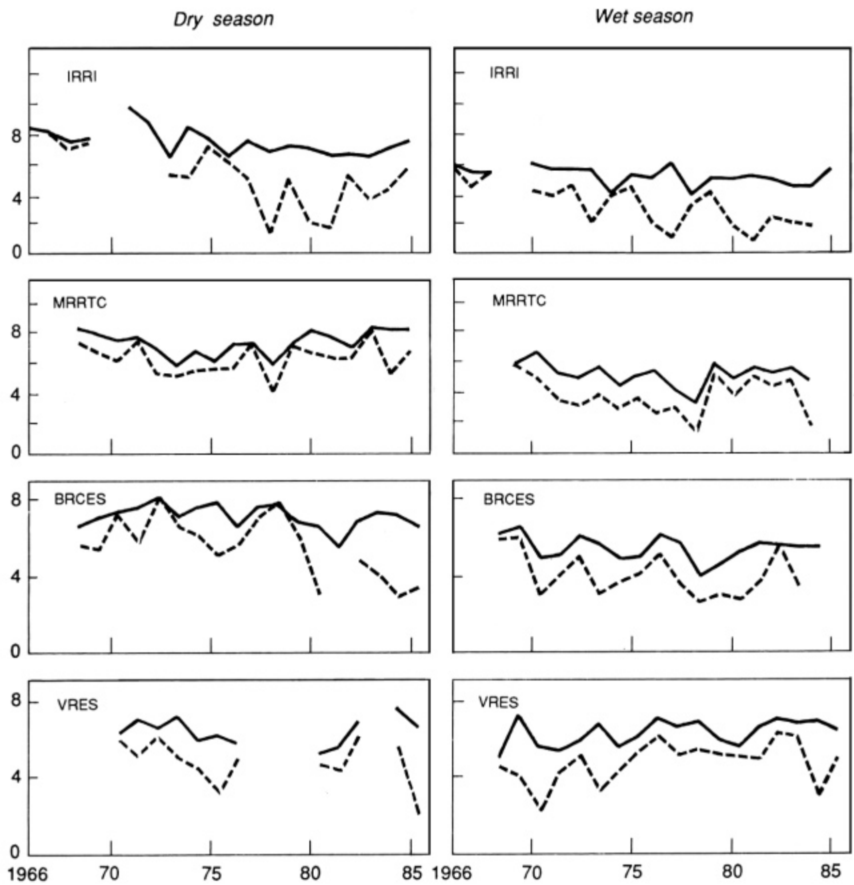
Asian experience and situation

Thus, while there appears to be a small exploitable yield gap in Egypt, it cannot be closed simply by applying more inputs, but will require more skill, care, and knowledge. That, of course, is the challenge for research, and it is a formidable challenge, as experience in other parts of the world shows. In Burma, rice yields increased by 93% over the 1967-85 period; in Indonesia, by 95%; in the Philippines, by 92% over the same period. These increases are typical of the experience in much of Asia: all exceed the 18% increase achieved in Egypt over the same period. However, because yield levels were much higher in Egypt to begin with, the increase was about 1 t/ha in Egypt and the other countries.

Asian rice yields

The rapid increases in Asian rice yields were based on new varieties, fertilizer, and irrigation. New varieties were introduced in the late 1960s, and spread to about 50% of the rice area by the 1980s (Barker and Herdt 1985). Fertilizer use on rice increased from about 10 kg/ ha of nutrients to over 50 kg/ha (Barker and Herdt 1985). Data recording the growth in irrigated area are much less precise; however, it is estimated that by the late 1970s, irrigated riceland was 35% of the total area in India, 90% in China and Korea, and about 50% in the rest of Asia (aside from the deepwater areas of Bangladesh, Burma, and Thailand). The rate of growth in irrigation was much more modest than in variety adoption or fertilizer use, however, because of the extremely high capital requirements. In sum, new technology and capital investments made rapid increases in Asian rice yields possible, and led the region to gain self-sufficiency by the late 1970s.

Casual familiarity with these facts has led many observers to assume that research in developing Asia has continued to generate ever-improved technology since the mid-1960s. However, an examination of the available data does not support that supposition. Figure 2 shows yields recorded in a set of long-term experiments conducted at the International Rice Research Institute (IRRI) and at three other experiment stations in the Philippines. These data are from fertilizer



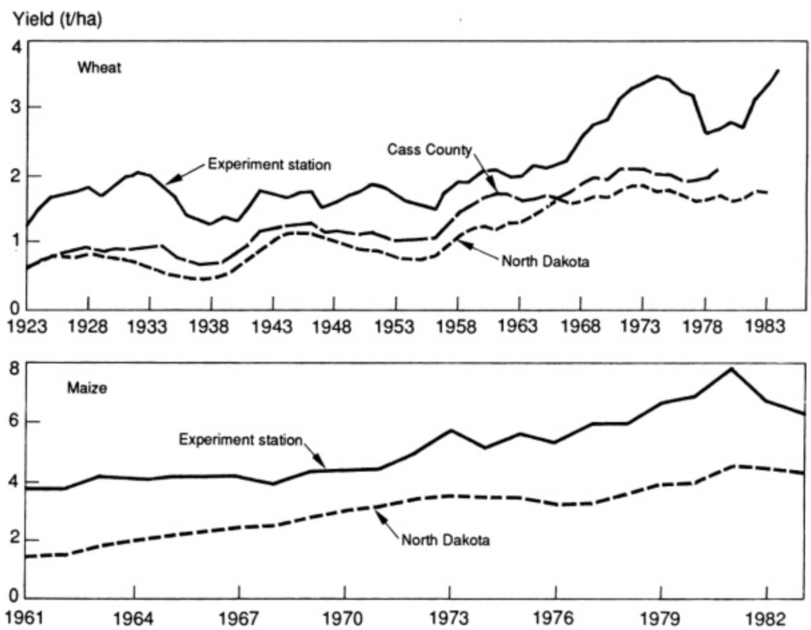
2. Experimental field rice yields 1965-85. IR8 (—) and highest yielding entry (—) at 4 research stations in the Philippines (source: IRRI Annual reports). IRRI = International Rice Research Institute, MRRTC = Maligaya Rice Research and Training Center, VRES = Visayas Rice Experiment Station, BRCES = Bicol Regional Center Experiment Station.

response trials in which the most promising new varieties or experimental lines and established varieties are grown. The figures show measured yields of IR8 and the highest yielding entry at 60 kg N/ ha in the wet season and 90 kg/ ha in the dry season, the fertilizer levels at which maximum yields are most frequently observed. The eight graphs show slightly different patterns—yields are consistently higher in the dry season, the highest yieldingentry (HYE) almost always outperforms IR8, and yields of IR8 are usually lower at IRRI than at other locations. However, the major conclusion of importance for this discussion is that these maximum experiment station yields (under ideal conditions) have not increased over the 20-yr period. In fact, in most cases they appear to have decreased.

This is not to say that there have not been improvements in Asian rice technology over time. As compared with IR8, growth duration has been significantly reduced, permitting more harvests per year, and resistance to insects and diseases has been improved, reducing the need for purchased pesticides—two important advantages for Asian farmers. And, as indicated earlier, average national rice yields in Asia have increased sharply with the widespread adoption of the new technology. The data in Figure 2 support the contention that there has been little advance in the maximum rice yield achievable under ideal (experiment station) field conditions in tropical Asia since the mid-1960s. As a result, the gap between experiment station maximum yields and average farmers' yields in that region has been narrowing. I believe this indicates that there is inadequate investment being made in tropical rice research and that, as currently available technology is increasingly exploited by Asian farmers, it will become difficult to continue to increase average yields.

This situation contrasts with that in the USA (and, I believe, other parts of the developed world), where agricultural research continues to keep maximum yields well above average farmers' yields. An illustration is provided in Figure 3 for wheat and maize in North Dakota; somewhat similar data for soybeans across a large number of locations in the USA show the same picture (Ruttan and Schoenek 1982), as do maize data for Illinois (Swanson et al 1977).

Experimental evidence comparing rice farmers' production practices with maximum yields in on-farm experiments in Asia suggests rather modest differences, as did the trials in Egypt that are summarized in Table 5. In over 450 experiments (carried out in 9 provinces of 6 Asian countries over a period of 3 yr), the difference



3. Experimental field and average farm yields, 5-yr moving averages. North Dakota wheat and maize (Fargo Agricultural Experiment Station) 1986, North Dakota Crop and Livestock Reporting Board, USDA Agricultural Statistics).

between farmers' average yields and average yield with the high-input package was 33%, or about 900 kg/ha, in the wet season. Of this, 22%, or about 200 kg/ha, resulted from farmers failing to apply the optimum level of inputs. The other 700 kg/ ha yield difference resulted from researchers applying uneconomically high input levels. The economically recoverable yield gap was much smaller than the average yield gap of 900 kg/ha observed in the experiments.

My conclusion from that large body of data and analysis stands: What is technically possible is more modest than what most observers admit; the economics of substantially higher yields are not attractive; the costs associated with the credit and tenure arrangements that often prevail in developing countries make higher input use totally unattractive to some farmers. Thus, the available technology is being used to its potential. If further growth is to be realized, continued development of technology must be combined with institutional reforms that make current technology attractive to users (Herdt 1979).

The following implications of these data are clear to me:

- Available rice technology is being exploited by Asian rice farmers faster than it is being created and therefore the unexploited potential is being reduced.
- The research that is being directed at increasing tropical rice yield potential has been too little or the wrong kind to produce the necessary results.
- It is normal and desirable to observe a significant gap between experiment station and average farm yields.

Meeting future rice needs

What is the capacity of the world to produce enough additional rice to meet future needs? This kind of question, so dear to the hearts of research policymakers, is impossible to answer without many assumptions about demand factors as well as about production. Economists familiar with the world rice scene generally would agree on the following: 1) the capacity to meet future world rice demand depends very much on the performance of the rice sector in Asian countries, 2) small shortages or surpluses can have very great effects on world rice prices, 3) most countries in which rice is a major staple will, if possible, intervene in their domestic markets to prevent sharp price fluctuations. One implication is that if in any large Asian country (China, India, Bangladesh, Indonesia) production fails to keep pace with demand for more than 1 or 2 yr, it would have a signficant impact on world prices. Shortages in smaller countries can be somewhat more easily absorbed, especially if they are offset by increases in other countries.

To determine the extent to which rice production could be increased by further intensifying fertilizer use and irrigation with existing varieties, a set of models was developed based on production relationships specific to variety type, water control, and land quality. A complete discussion of the models and results of their application is beyond the scope of this paper, but a few highlights are useful (Barker and Herdt 1985).

The models distinguish five different technologies of rice production by irrigation and variety type. The use of fertilizer is closely associated with the use of modern varieties, which, in turn, is closely associated with the availability of irrigation. Some rainfed areas are planted to semidwarfs, but those varieties are mainly grown with irrigation and are expected to spread only slowly to rainfed areas. Individual models were developed for the eight countries shown in Table 6, which produce 85% of Asia's rice. Analysis shows that if, between 1980 and 2000, the irrigated area grows at the historical rate, modern rice varieties continue to spread at a rate similar to this historic pattern, and fertilizer availability grows at 5%/yr, the use of modern technology will reach the levels indicated in Table 6, with total output of 409 million tons.

The adequacy of this level of production can be judged only by comparing it with the projected level of demand. Demand was projected using the income and population growth rates and the income elasticities shown in Table 7. Most projection exercises assume that any shortfall between future demand and production will be covered by imported rice, but our model incorporates the price elasticities of demand shown in the table, so that price implications of alternative import policies can be determined.

Table 6 shows that with the base run supply projection, only Thailand will export rice in the year 2000, when net imports required to hold prices constant for the 8 countries are projected to reach 35.4 million tons. If self-sufficiency (zero imports) is imposed, rice prices are projected to nearly double their 1980 levels by 2000, and per capita consumption to fall from 135 kg to 126 kg.

Under this projection, most countries will reach what are, with present technology, rather high levels of fertilizer application, and modern varieties will have spread about as widely as one could expect, given each country's irrigation capacity.

The data may appear to indicate considerable scope for extending irrigation, especially in Thailand, Burma, and Bangladesh, and in many other countries where only half to two-thirds of the rice area is projected to be irrigated in 2000 AD. However, much of the land in the delta areas of these countries is too low-lying to permit effective water control. In other places, irrigation is expensive, and in most countries its construction is also constrained by the capacity to mobilize the necessary human and physical capital resources. To determine the potential effect of greater investments in irrigation, a rapid growth scenario was developed in which it was assumed that irrigated rice area grew at twice the rate of the historical period.

That scenario shows a significant difference in the percentage of area irrigated in 2000 in countries where irrigation increased rapidly since 1960, but shows little difference where irrigation either spread slowly or where a very large proportion of the rice area was irrigated in 1980 (e.g., China). Average irrigated area for the eight countries would reach 62% compared with 54% in the base run, and modern varieties would reach 72% of the total rice area. Under this scenario, rice production would reach 466 million tons, net imports would reach only 13.6 million tons, and besides Thailand, Burma and Sri Lanka would export, if rice prices held at their 1980 level. If imports were constrained to zero, rice prices would increase by only 30%, and per capita consumption would rise to 144 kg.

Obviously, output growth dependent on irrigation investment comes at a cost to the economies involved. However, food imports are also costly and require

Table 6. Base run projections of production, consumption, and prices of rice for selected Asian countries for the year 2000 (Barker and Herdt 1985).

Country	Production[a] (million tons)	Fertilizer (kg/ha)	Percent of area		With zero imports		With imports to hold price at 1980 level	
			Modern varieties	Irrigation	Rice price index (1980 = 100)	Consumption (kg/capita)	Consumption (kg/capita)	Imports (million tons)[b]
China	196.1	14%	65[c]	94	113	109	116	6.0
India	99.4	67	68	51	210	69	89	13.0
Indonesia	34.1	89	74	84	380	112	204	8.5
Bangladesh	28.7	32	63	24	171	144	188	5.4
Thailand	23.8	25	18	41	100[d]	201[d]	201	–0.3
Burma	14.7	71	56[e]	21	127	178	195	0.6
Philippines	9.6	61	89	52	225	82	114	1.7
Sri Lanka	3.1	102	73	66	207	99	141	0.5
Total or average	408.8	75	64	54	192	126	156	35.4

[a]Rough rice. [b]Milled rice; negative sign indicates exports. [c]Hybrid rice. [d]Exporting nation, assumed to continue exports [e]Includes modern and "improved" varieties; the balance are traditional varieties.

Table 7. Annual growth rates of population and income in 8 Asian countries, and elasticities of demand with respect to income and prices used in the IFPRI rice projections model (Barker and Herdt 1985).

Country	Projected growth rate of		Income elasticity	Price elasticity
	Population[a]	Income per capita		
China	1.2	2.0	0.45	–0.50
India	1.8	2.0	0.45	–0.50
Indonesia	1.5	5.0	0.50	–0.60
Bangladesh	2.5	2.0	0.45	–0.50
Thailand	2.3	5.0	0.05	–0.30
Burma	2.4	2.0	0.30	–0.40
Philippines	2.7	3.5	0.25	–0.40
Sri Lanka	2.3	2.0	0.40	–0.60

[a] Values for 1980-85. Because of the rapid growth of per capita income, the Income elasticity was assumed to decline by 0.1 every subsequent 5-yr period.

recurring annual foreign exchange costs. The fast rate of output growth requires substantially higher irrigation investments than the base run, but because of the extra output produced, food import costs are lower in subsequent years. This effect is illustrated in Table 8. It was estimated that in 1985 annual expenditures of US $5 billion would be required to hold real rice prices constant, following the base run scenario. The fast output growth scenario, which produces net exports in 1985, has a lower annual net cost, although its irrigation investment cost is twice that of the base run. By the year 2000, annual expenditures of $16 billion are required even in the fast growth scenario, with about one-third required for imports. The base run scenario requires annual expenditures of $20 billion, with most of that going for rice imports.

The "basic" and "fast growth" analyses both assumed constant productivity of technology, suggesting that increases in the productivity of fertilizer and irrigation are necessary if developing countries are to meet their needs for rice through 2000. An indicative projection assuming such increases in productivity was made to determine how great a productivity gain would be adequate. To illustrate the type of assumption: the production function for irrigated semidwarf varieties in the base model for the Philippines reaches a maximum of 2.9 t/ha at 105 kg of fertilizer nutrients. In the indicative projection it reached a maximum of 4.4 t/ha at 128 kg of fertilizer nutrients in 2000. This productivity is within the potential of genetic material now available but is not being reached on the average across all rice farms in the Philippines. In order to raise the average productivity to that level, I believe it will be necessary either to produce better varieties or to teach farmers how to better exploit the existing ones—and both require continued investment. Such an increase in productivity would enable the Philippines to keep up with demand through 2000; comparable increases in productivity would enable other countries to do likewise.

This analysis convinces me that there is little significant "unused potential" in current rice technology and that continued improvements in technology as well as increased fertilizer use and irrigation investments will be needed to produce enough

Table 8. Annual costs (US$ million) associated with 2 alternative projections of the future rice situation in 8 Asian countries.[a]

	Base run case				Fast output growth case			
Year	Irrigation	Fertilizer	Net imports	Total	Irrigation	Fertilizer	Net imports	Total
1985	1,741	1,410	1,903	5,054	3,224	1,500	–270	4.454
1990	1,815	1,720	6,195	9,730	3,458	1,906	1,755	7,119
1995	1,917	2,030	10,955	14,902	5,954	2,272	4,515	12,741
2000	2,051	2,407	15,972	20,430	7,199	2,818	6,000	16,017

[a] Irrigation costs are the annual investment costs; fertilizer costs are the value of fertilizer used in rice production at a price of US$225/t of urea; costs of Imports are for the amounts shown in Table 1 at a price of US$300/t of milled rice.

rice to adequately feed Asia over the coming several decades. It also suggests that there is relatively little prospect that Asia will have the capacity to respond to large increases in the demand for rice from other regions of the world. However, this type of trend analysis does not reflect how countries make adjustments to year-to-year shocks. Those adjustments may well lead to different outcomes than those summarized in this paper, and it is almost certain that the movement from the present situation to the future one will not be the smooth trend that such models project.

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Notes

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Research and management strategies for increased rice production in Egypt

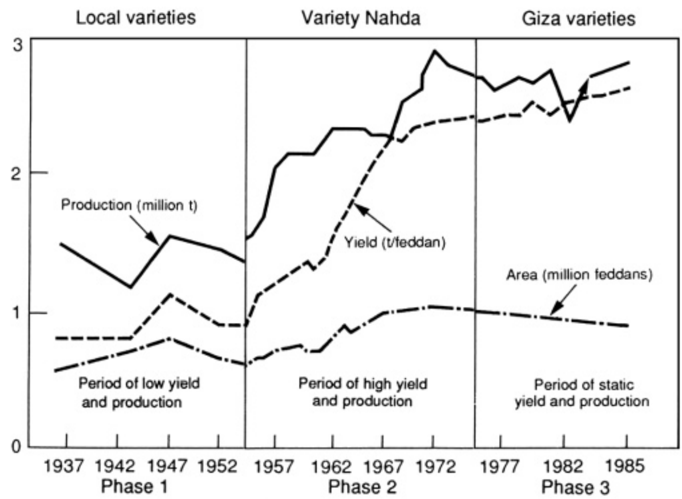
A. MOMTAZ

With population growing rapidly and outstripping agricultural production growth in Egypt, a need has arisen to study in depth the current food production and consumption in the country and to plan appropriate strategies to meet the projected food needs of the future. Rice is the second major food staple of Egypt, and this paper spells out various research and management approaches to meet the projected rice needs in the next 13 yr. Points particularly emphasized are a) the research prospects for exploiting still untapped production potential, b) the need to involve and utilize the scattered talents of the country through coordinated programs, c) the relevance of having collaborative research ties with international agricultural centers, and d) the importance of creating an efficient system of research administration.

Since its introduction into Egypt by the Arabs, around AD 600, rice has gradually assumed a unique place in Egyptian agriculture as a crop of great economic significance. Systematic breeding research was initiated as early as 1917, with the limited objective of developing a suitable variety for the Nili (mid-August to end of November) crop, During the past seven decades, this has grown into a massive program with several major objectives. The growth and development of rice research and the resulting increase in production and productivity have been extensively reviewed in the past. However, at this juncture, when we are ambitiously establishing a national center for rice research, what we need is to examine a) our rice production/productivity trends, b) our rice requirement for domestic consumption in the next 10-15 yr, c) our present level of research effort and its adequacy to meet such production demands, and d) broadly, the research and training approaches, the level of international cooperation, and the type of research and administrative infrastructure needed. Such an inquiry would help us plan more scientifically our future research strategies and restructure our organizational components to accelerate rice production and productivity. With this theme in mind, I, as a plant breeder and administrator, have tried to project my ideas through this paper.

A glance at the past

Rice production in Egypt falls roughly into three phases (Fig. 1): 1937-52—the period of low production and yield, 1953-74—the period of major production and yield advances, and 1975-85—the period of static production and yield.



1. Five-year moving averages of rice production, area. and yield in Egypt, 1937-85. 1 feddan = 0.42 ha.

In the first phase, although the low production was mainly due to the small area under rice, low yields were a result of low-yielding varieties, dependence on floodwaters of the River Nile for irrigation, and poor management. Before the initiation of systematic breeding research, Egypt was cultivating large long-grain indica varieties, such as Java, Kef-El-Bind, Ain El-bind, Ambari, Reshti, and Americana. Subsequently, because of their higher yield potential, short-grain japonica varieties, such as Yabani, Sebeeni, Agami, and Nabatat Abiad, began to be cultivated.

Through breeding achievements between 1935 and 1953, eight new varieties were released. All except Giza 14 were bred through pureline selection. Among them, mention may be made of Yabani 15, Yabani Montakhab 5, Yabani M7, Yabani M47, Yabani Pearl, and Agami M1.

Rice research gained momentum in Egypt during the second phase. The high production and high yield that characterized this phase were the result of two major factors—area under rice doubled following the completion of Aswan High Dam, and the most productive variety, Nahda, a pureline selection released in 1954, was widely cultivated. Breeders increasingly resorted to cross-breeding, and important varieties like Giza 159 for saline areas, and Giza 171 and Giza 172 for normal soils, were identified for extensive cultivation.

Static production and yield characterized the third phase (1975-85), probably because Giza 171 and Giza 172 offered no marked genetic yield advantage over Nahda and no major change was made in the package of practices, except after 1984.

Our rice requirement in AD 2000

Egypt had always been a rice surplus country in the past, with its export quantum reaching as high as 718,000 t in 1969. Since 1972, with an increasing per capita consumption rate and no scope for further production increase, exports had declined rapidly, to as little as 35,000 t in 1985. In other words, from the surplus state, Egypt has been pushed down to the state of self-sufficiency in rice production. At the present level of per capita consumption of 35 kg of milled rice and a population growth rate of 2.7%, the domestic rice requirement is estimated to rise in the next 14 yr from the present level of 2.5 to 3.5 million tons of rough rice (Table 1). To realize the estimated quantity, the national average yield has to rise from the present level of 5.7 to 10.7 t/ha.

Prospects of achieving the production goal

Although Egypt is gifted with growing conditions that favor the highest rice yields, such as assured irrigation, high solar radiation, ideal day and night temperature ranges, and a relatively insect- and disease-free situation, its achieving the estimated production targets is not an easy task.

Stabilizing yields. Of various approaches, yield stabilization is the foremost vertical means of reaching the production target. Yields can be stabilized by insulating varieties with resistance to or tolerance for all yield-limiting biophysical stresses, on the one hand, and by adhering widely to an improved package of practices, on the other. Yield gap analysis, which tells us to what extent per hectare yield could be increased through improved management, reveals as wide a gap as 2.8 to 3.7 t/ha between potential (national demonstration average) and actual yields in farmers' fields (national average) (Table 2). By bridging this gap alone, a production increase of over 20% can be achieved at the presently available level of varietal technology.

From the breeders' end, yield stabilization must be accomplished by continuously evolving varieties with adequate levels of tolerance for various

Table 1. Domestic requirement of rice in Egypt, 1983-AD 2000.

Year	Population (million)	Rough rice in million t		Required yield increase (t/ha)
		Domestic requirement	Deficit	
1983	–	2.5	–	–
1986	49.60	2.7	0.2	0.75
1990	55.24	3.0	0.3	1.3
1995	63.11	3.4	0.4	1.5
2000	72.10	3.5	0.5	1.5

Table 2. Yield gap between potential and actual rice yields in Egypt, 1982-84.

Year	National average yield (t/ha)	Extension demonstration average yield (t/ha)	Yield gap (t/ha)
1982	5.7	8.5	2.9
1983	5.7	9.4	3.7
1984	5.7	8.6	2.8

biophysical stresses. In Egypt, blast disease and salinity are the two major yield destabilizers. While it is relatively easy to breed stable salinity-tolerant varieties, breeding for blast resistance is complicated by highly unstable host-pathogen relationships. Although weather conditions favored the development and spread of blast disease, it never posed a serious threat to the rice crop until 1984, when it appeared in severe epiphytotic proportions, knocking down all popular varieties and hundreds of advanced breeding lines, with the exception of varieties from the International Rice Research Institute (IRRI).

Various explanations have been advanced to account for the epidemic. But a logical one seems the appearance of a new virulent race of the pathogen that was either introduced from outside or already existed at very low frequency but built up suddenly because of the abrupt increase in area planted to a susceptible variety, Reiho. This is evident from the marked change observed in the race spectrum of the pathogen since 1984, compared with what was observed in the previous years.

The costly experience of 1984 underscored the need for a continuous and intensive research effort to develop appropriate varieties that could cope with the fast-changing racial spectrum of the pathogen. Gene rotation—the sequential release of varieties, each with a matching resistance gene; gene deployment—simultaneously cultivating several varieties, each carrying a different resistance gene; and gene pyramiding—release of varieties with multiple resistance and tailoring of varieties combining vertical and horizontal (durable) resistance—are some of the short- and long-term breeding strategies under way to combat blast disease in the coming years.

Maximizing productivity. Maximizing productivity is another approach to stepping up production. This concept is becoming increasingly popular following the development of very short-duration varieties in several crop plants, which are conveniently fitted into varied multiple cropping sequences. For instance, following the successful development of photoperiod-insensitive short-duration varieties of rice, it has become possible to grow two crops a year in place of a single crop and three crops in double-cropped areas. Where the rice-after-rice pattern is not physically or economically feasible, nonrice components like legumes, soybean, sunflower. etc., are fitted.

In Egypt, where a relatively short growing season is one of the major physical constraints, replacement of land-intensive (long-duration) varieties with relatively early-maturing varieties would make the widely popular clover - rice and wheat - rice rotations more profitable and easy to practice. This possibility has come true with the introduction and increased cultivation of varieties like IR28. Also, the commercial viability of growing three crops a year such as clover - sunflower/ soybean - rice or clover - rice - rice has been explored. The results of 5 yr, however, were not encouraging, largely because of poor growth and hence low yields of the second crop of rice. Yet if very short-duration varieties of high yield potential suitable as a direct seeded first crop, and cold-tolerant varieties suitable as a transplanted second crop could be developed, three-crop patterns would help increase production levels by 20%.

Exploitation of hybrid vigor may be regarded as the second major research breakthrough, closely following the development and exploitation of the plant type concept in rice breeding. Cultivated over 8 million ha in China today, hybrid rice has been found to yield about 20% more than the highest yielding variety of a region. Enhanced physiological efficiency—as evident from increased biomass production, higher harvest index, increased sink capacity, and better root system—has been found to be the basis of the high yield potential of hybrids. This finding strengthens the view that yield ceilings could be further raised only through physiological manipulation of the rice plant. Research to develop all requisite lines suited to different growing conditions is under way at IRRI. Preliminary studies on the prospects for growing hybrid rice in Egypt reveal that some of the hybrids involving Chinese male-sterile lines and indica-japonica varieties like Milyang 54 yield 15-20% higher than some of our best varieties. Our breeders are planning to intensify hybrid breeding in the coming years, as Egypt would be an ideal place for such innovative approaches, being a very high-yield, risk-free region for growing rice.

Besides the research and management aspects, we must pay attention also to the use of pure seed, improvement of village mills, and improvement of storage conditions to help further increase production.

Second phase of research

To identify the choice of approach in research and development strategies for different countries, IRRI has grouped major rice-growing countries into four categories, based on the gap between current average national rice yield and potential average yield of 6 t/ha (Table 3). Egypt, along with countries like Australia, Japan, Korea, Italy, and the USA, figures in Group I, which represents a zero gap. This implies that the existing varieties have reached the "genetic saturation point" for yield potential and the yield expression is free from the influence of any biophysical constraint. Thus, the research strategy in this group of countries must be to raise the genetic yield ceiling itself.

Table 3. Classification of rice-growing countries according to the gap between their average and potential (6 t/ha) rice yields (source: Khush and Garrity 1984).

	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

The yield history of rice in Egypt, say, from the release of variety Nahda in 1954, shows hardly any stage characterized by a marked jump in the genetic yield potential. The claims of 10-15% yield advantage of new varieties over the preceding ones—Giza 171 and Giza 172 over Nahda, Reiho over Giza 171 and Giza 172, and newly identified strains over Reiho—are largely attributable to improved resistance to blast combined in the successively developed varieties. The spectacular yield gains expected fron nonlodging dwarf varieties introduced in the early 1970s also failed to come true. The yields of local tall varieties such as Giza 171 and Giza 172 and the improved varieties remained comparable at 90-100 kg N/ha, thus suggesting no distinct advantage of the nonlodging habit in terms of fertilizer response under Egyptian conditions. In other words, it implies that the genetic ability of the plant type to make use of nutrients is limited to about 100 kg N/ ha. Unless and until this physiological block is removed through genetic manipulation, nonlodging nature would be of no special advantage for attaining major productivity increases. While such innovations are possible through increase of biomass, harvest index, etc., the immediate solution to achieving the production targets of the next 5-10 yr lies in tapping the still unexploited yield potential of the currently available genotypes, as discussed in the previous section.

Recent accomplishments in varietal improvement

When variety Nahda became increasingly susceptible to blast, it was replaced in 1974 by highly resistant and equally productive varieties Giza 171 and Giza 172, which continue to occupy over 80% of the rice area in Egypt. The impact of these varieties on production, however, has been marginal, as evident from the national average yield (Table 4), which has scarcely changed.

Although these varieties have satisfactory yields and disease resistance, the breeders began around 1978 to emphasize development of varieties combining nonlodging dwarf habit, to make them suitable for mechanized harvest, and early maturity, to fit them into remunerative cropping patterns.

In indica rice, Dee-Geo-Wu-Gen (DGWG), a spontaneous dwarf mutant, was utilized to breed most productive nonlodging dwarf varieties. Japonica rice, however, has been handicapped by lack of such a physiologically efficient plant type gene for similar exploitation. This genetic gap was gradually bridged to a great

Table 4. Growth of area, production, and yield of rice in Egypt, 1951-85.

Year	Area		Production		Yield	
	thousand ha	Index	thousand t	Index	t/ha	Index
1951-55	210	100	830	100	3.9	100
1956-60	298	142	1434	173	5.0	131
1961-65	347	165	1937	233	5.3	137
1966-70	455	217	2344	282	5.1	132
1971-75	428	204	2504	302	5.5	143
1976-80	433	206	2363	285	5.5	142
1981-85	412	196	2333	281	5.7	147

extent by using japonica dwarfs of induced or spontaneous origin. For instance, in Japan, two sources, Reimi, an induced dwarf mutant, and Jikokku, a spontaneous dwarf, played a major role in development of a series of varieties with improved plant type. Similarly in the USA, using Calrose 76, an induced dwarf mutant from the variety Calrose, paved the way to developing a series of high-yielding dwarf varieties such as M-7, M-101, S-201, M-301, and M-302. In Korea, another japonica rice-growing country, the indica dwarfing gene DGWG was used to develop several high-yielding dwarf indica-japonica varieties such as the Tongil, Milyang, and Suweon series.

In Egypt, efforts are under way to make use of japonica mutant gene sources from Japan and the USA as well as the indica gene DGWG, and to induce short-statured mutants in Giza 171, Giza 172, and Giza 159. Meanwhile, Reiho, a Japanese variety introduced as a genetic stock in 1973, was found to meet our immediate requirement for nonlodging, short-statured habit and relatively early maturity. Because of its impressive stand and yield potential, it was taken to large-scale on-farm demonstrations during 1983, and cultivation over an area of 126,000 ha in 1984; however, in the same year, this variety was severely affected by blast, and several other indigenously developed breeding lines also proved highly susceptible. During this season, our breeders, in close association with pathologists, carefully screened the whole breeding nursery, isolating 10 cultures combining an apparently good level of resistance to the disease and high yield potential. These lines were intensively evaluated and, along with other disease-free lines isolated in the following year, were intensively screened during 1985 for stability of their resistance to the virulent race(s) and for yield performance. Four highly promising lines (Table 5) were identified.

To watch their yield stability and reaction to the pathogen when grown over large areas in farmers' fields, we expanded the area under IR1626 and other promising strains, depending on seed availability, by including them in on-farm and demonstration trials and large seed multiplication programs on state farms. This exercise helped us assess their disease reaction as well as agronomic performance more precisely, under farmers' field conditions. On the basis of their performance, we propose to diversify the varietal composition by adding to the presently cultivated spectrum strains of indica, japonica, and japonica-indica origin, carrying diverse resistance genes. This would be one of our key strategies to keep blast disease under control.

Coordinating the research effort

Coordinated program for rapid testing of material and management practices. Precise evaluation of promising breeding lines is as important as generation of breeding material in varietal improvement programs. Rather than evaluate elite lines at one or two locations over many years to assess their performance, we now use multilocation evaluation, which facilitates rapid accumulation of station years of data. Information obtained on the stability of performance of a test entry through multilocation testing would be as reliable as that obtained over several years at a single location. This concept is particularly relevant and useful to countries like Egypt, which grow one rice crop a year.

Table 5. Performance of promising cultures for yield and blast resistance during 1985 in Egypt.

Culture or variety	Parentage	Yield average, 1983-85 yield trials (t/ha)	Duration seed-to-seed (d)	Plant type	Grain type	Blast reaction[a]		
						1983-85 Blast nursery score	Greenhouse	Spore trap
			Normal soil					
IR1626-203	Indica/indica	11.29	141	Dwarf	Long	R	R	MR-R
GZ1394-10-1	Indica/japonica	10.26	142	Dwarf	Short	R	R	MR-R
GZ2175-5-6	Indica/japonica	10.94	147	Dwarf	Short	R	R	R
			Saline soil					
GZ1368-5-4	Indica/indica	9.13	145	Dwarf	Medium	R	R	R
			Checks					
Giza 171		9.34	159	Tall	Short	S	S	R-S
Giza 172	Japonica/japonica	9.19	150	Tall	Short	S	HS	R-S
IR28	Indica/indica	9.71	134	Dwarf	Long	R	R	R

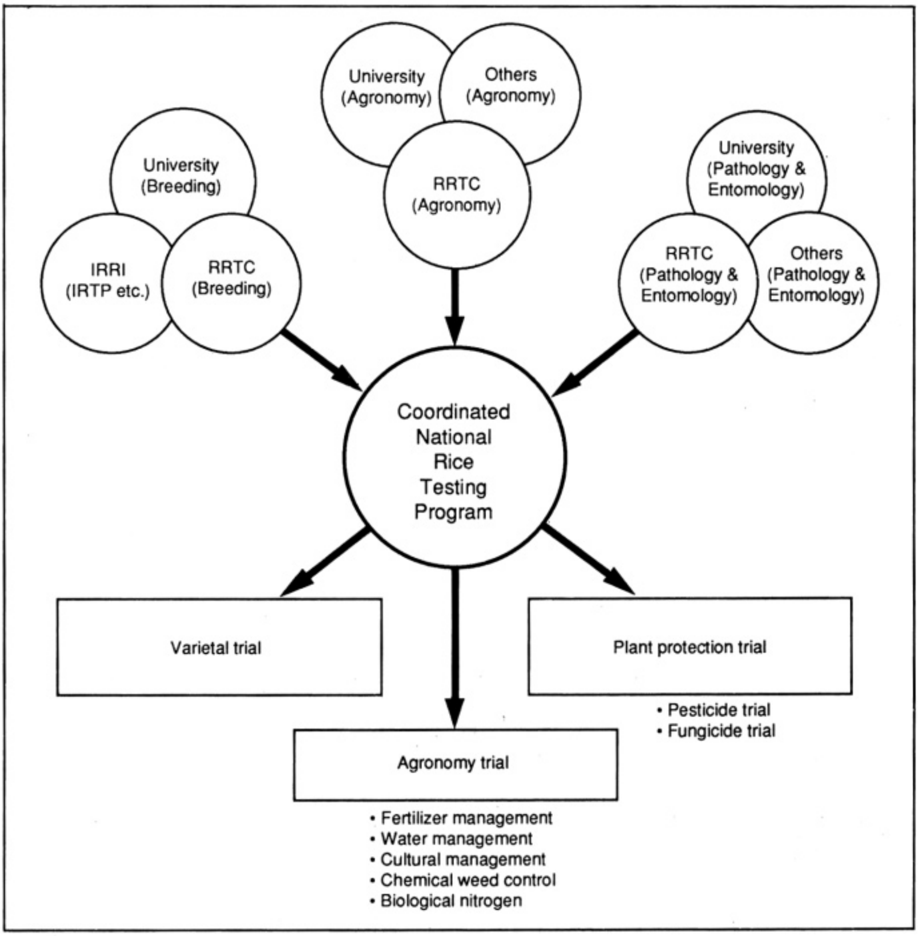
[a]R = resistant (score = 1-3), MR = moderately resistant (score = 4), S = susceptible (score = 5-9) on a scale of 1-9.

The Egypt Rice Research and Training Center (ERRTC) now uses three-tier yield-testing, based on the same principle. Yet, there is scope to develop such testing further, to make it more broad-based and effective. Today, breeding materials developed at ERRTC alone are subjected to multilocation testing. Research material emerging from other national agricultural research centers, such as universities and the Egyptian Academy of Scientific Research and Technology, on the other hand, either remain unnoticed or are unduly publicized without being adequately field-tested over locations and years. These lapses—which are due to paucity of funds, field facilities, and manpower to undertake extensive testing—can be overcome by creating a common testing program for the whole country that would pool all the scattered findings on merit and put them to the common test.

A Coordinated National Rice Testing Program (CNRTP) was therefore conceived, which would involve active participation of ERRTC, various universities, and national research centers engaged in rice research; its organizational structure is schematically presented in Figure 2. Under the CNRTP, the participating centers, or cooperators, would nominate their best material or management practice for inclusion in the appropriate trials, conducting one set of trials at their centers and attending the annual workshop meetings. There will be separate testing programs for varietal testing, management practices, etc.

During annual workshop sessions, various trials would be constituted by the respective groups. The layout plans, material, and directions for conducting the trials would be despatched from the coordinating center to various cooperators. The trial data received from cooperators, as for example in the varietal testing program, would be assembled and statistically analyzed, and reports prepared for discussion in the workshop. Convinced that this type of coordinated endeavor would help immensely to identify and recommend jointly the most suitable variety and package of practices to the Egyptian farmer, we implemented the scheme in 1986. To start with, variety, fertilizer, and herbicide trials were laid out at six locations, three of which were on university farms. The data jointly assembled and statistically analyzed are expected to be of great help in resolving some of the disputed problems, such as fertilizer response of dwarf varieties and relative advantage of certain varieties over others.

Task force for monitoring the rice crop. A national task force was formed by the Director, Agricultural Research Center (ARC), with the main objective of scientifically supervising the national rice improvement program during the 1985 rice season. The task force was a nine-member Supreme Committee, with the Director of ARC as Chairman and seven Scientific Supervising Groups, each assigned to one rice-growing governorate. The Supreme Committee's role was to supervise and coordinate all activities relating to the rice improvement program and to follow up the progress of the work plan. Scientific Supervision Groups, each consisting of five to nine scientists, drawn from ARC, universities, and the ERRTC, periodically visited farmers' fields in their respective governorates and collected first-hand information on the varietal diversification and crop condition, with special reference to incidence of blast, brown spot, stem borer, soil problems, and management level. Remedial measures were suggested, depending on the crop condition. The constant watch on crop health all over the delta and joint field



2. Coordinated National Rice Testing Program for Egypt, 1986.

evaluation on the performance of varieties helped the scientists' body to arrive at definite recommendations in their regular review meetings.

In a way, it was the blast epidemic in 1984 that brought together the scientists of ARC and those of the universities in 1985 to jointly undertake the crop monitoring task. Commendable cooperation in this national venture was extended by the scientists of the Egyptian Academy of Scientific Research and Technology. How great an impact it would make on rice research and production if such scattered talents were pooled and integrated with ERRTC on a permanent basis!

International assistance for national rice research

Two decades of research partnership with IRRI

Research links between Egypt and IRRI are nearly two decades old. Egypt was one of the earliest among japonica rice-growing countries to become interested in using the new indica dwarf plant type for advancing its production goals. On the one hand, Egypt's unique agroclimatic advantage that allows us to grow equally well both indica and japonica rices, and, on the other hand, the fact that long-grain rices get a higher premium in the world grain market, encouraged us to take advantage of material and knowledge generated by IRRI. The material support in the initial years was through a continuous supply of large volumes of advanced breeding lines, segregating early-generation material, and genetic stocks. Over 2000 IRRI lines, evaluated during 1970-75 at Sakha for yield performance and tolerance for various stress situations, led to the identification of three long-grain strains—IR579-48, IR28, and IR1626-203. IR579-48, the first high-yielding dwarf variety to be cultivated in Egypt, was released in 1974 as Giza 180. IR28 impressed us as far back as the early 1970s, among the early-maturing lines. Although attempts to make use of it in the crop intensification programs failed, as a variety combining blast resistance, early maturity, and high yield, it has been getting popular since 1984. IR1626-203, yet another identification made as early as 1971, by virtue of its higher yield potential, blast resistance, and good milling and cooking qualities, has been recommended for general cultivation from 1987.

Increased research interaction with IRRI started with Egypt's active participation in the International Rice Testing Program (IRTP) from 1976. Under this program, more than 1,000 lines are received every year, and 3 major yield nurseries and 3 observational nurseries are being grown. This program is of mutual benefit to Egypt and to IRRI: the endless flow of material received through this channel enables us to widen the genetic base of our breeding material immensely for all major economic traits, especially for plant type, resistance to blast and stem borer, and tolerance for salinity; the data we provide on the performance of entries in various nurseries help IRRI to assess the relative stability of yield and tolerance for stresses and to disseminate the findings to rice workers all over the world.

In addition to material support, IRRI has contributed considerably to accelerating our rice research, by training several of our young scientists, inviting the participation of our senior scientists in annual rice workshop meetings and symposia/ seminars, and keeping us abreast of all new developments in rice research through reading material. Between 1981 and 1985, IRRI directly participated in our research and extension programs through the University of California at Davis (UCD) Rice Research and Training Project, funded by the United States Agency for International Development (USAID). Since 1985, we have had a direct collaborative project with IRRI, restricted to breeding and seed production. We hope that the two decades of research partnership with IRRI will continue to grow with added strength for our mutual advantage.

Expanded research activity under the Rice Research and Training Project

Establishment of the USAID-funded Rice Project in 1980 marked the beginning of expanded research and extension activities. With UCD as the principal contractor and the University of Arkansas (USA) and IRRI (Philippines) as subcontractors, the project has helped Egypt during 1981-85 by a) strengthening rice research in all major fields, b) organizing an elaborate extension program to disseminate the research findings among farmers, c) streamlining the seed production program,

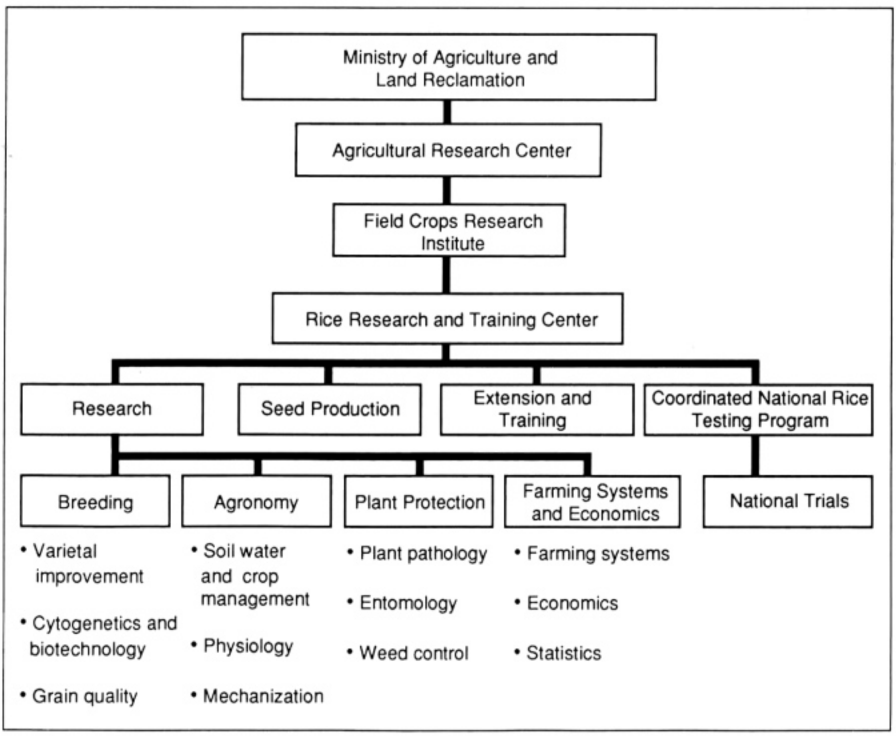
d) training abroad our rice scientists in priority areas of research, and e) providing the Rice Research Center with sophisticated laboratory equipment and farm machinery. USAID continues to assist us to build a strong national rice research program through the Egypt-IRRI cooperative research program.

The Egypt Rice Research and Training Center

The Egypt Rice Research and Training Center (ERRTC) is another step forward in building a strong research base for rice. It has been established, with the mandate of

1. Conducting research on all aspects of the rice crop and rice-based cropping/farming systems.
2. Imparting training in rice production techniques to research and extension workers.
3. Disseminating all relevant research findings to the farmers.
4. Organizing a scientific seed production program.

To fulfill this mandate, ERRTC will be organized with four major functional units: Research, Extension and Training, Seed Production. and Coordinated Rice Testing Program, as schematically represented in Figure 3. Their major objectives and role in accelerated rice research and production are outlined here.



3. Organizational structure of the Egypt Rice Research and Training Center.

Research

The research component envisages:

- Developing high-yielding dwarf varieties combining ideal maturity range, tolerance for biophysical stresses, and acceptable milling-cooking qualities.
- Developing appropriate and economically viable agronomic practices for realizing the highest yields under normal and saline soil conditions.
- Studying all species of rice disease and insect pests, blast and stem borer in particular, with the ultimate goal of developing efficient and economic control measures.
- Developing appropriate varietal and management technologies for extending rice cultivation to New Valley and Aswan High Dam Lake area.

Accordingly, five major research disciplines—Breeding, Agronomy, Pathology, Entomology, and Farming Systems and Economics—are included under this component.

Extension and training

Extension being the vital link between researchers and farmers, its main role will be to

1. evaluate new technology on farmer's fields,
2. develop plans and materials for transfer of new technological packages for adoption by farmers, and
3. identify production constraints experienced by farmers and search for solutions to these.

The extension wing of the Rice Research and Training Center will work in close association with the Agricultural Extension Directorate.

Seed production

The major aim of the seed production component is to organize production of various categories of seed on a scientific basis and establish appropriate relationships with the Egyptian industry.

Coordinated testing program

The purpose of the coordinated testing program is to rapidly evaluate suitable varieties and management techniques for adoption by farmers. (Details of the program are outlined in an earlier section of this paper.)

Research management

More production at lower cost and increased farm income are the ultimate goals of all agricultural development projects. Achieving these goals requires an interdisciplinary team approach to develop appropriate varietal and management technologies as well as means to rapidly disseminate the same to farmers. This would imply active involvement of plant breeders, agronomists, pathologists, entomologists, microbiologists, extension specialists, and agricultural economists. It is not an easy task to make scientists from diverse fields and backgrounds work harmoniously and with the sense of achieving the common objective of the project. The task is even more difficult in cooperative/ collaborative projects sponsored by international agencies, because, unlike national programs, the ones with foreign collaboration involve basically three parties—the Ministry of Agriculture of the host country, the donor country, and the implementing organization. The Rice Research and Training Project of 1980-85, for example, involved the Ministry of Agriculture of Egypt, the host country; USAID, the donor agency; and the University of California, Davis, the implementing organization. The Egyptian Major Cereals Improvement Program (EMCIP) and the National Agricultural Research Project (NARP) are also projects involving similar collaboration.

In such setups, the major problem is that the three parties seldom understand the basic purpose of the technical assistance alike. Conflicts and compromises in the basic goals, agreed upon by the contracting parties, are not made known to the implementing agency. Similarly, in the preparation of the technical program, the implementing organization has no opportunity to involve scientists, who are recruited much later to execute the same. This being inevitable in the majority of such collaborative projects, achievement of the project goals, as conceived and agreed upon by the contracting parties, would depend entirely on how dynamic the research administrators of the project are and how efficient the research management system practiced is.

In our experience with several national and international projects, efficient research administration is the backbone of success. An ideal administrative system is one where information can flow freely from administrators to program staff and vice versa, without the side games of deception, power struggle, credit grabbing, and personal likes and dislikes. Also, the ideal system is flexible enough to allow scientific freedom, but within the scope of the project goals, encourages a team approach, while discouraging indiscipline among scientific staff. To achieve this level of perfection in the functioning of a research project, the major prerequisite is a healthy professional relationship at every level.

Communication is basic to ensuring such a relationship among the staff and of the staff with administrators.

Improper communications, even coming from the same source, could make the staff understand instructions differently and fix a different order of priorities and resort to different methods of problem solution. The following are some of the means to improve communication and hence strengthen the professional relationship at different levels.

1. *Communication between leaders of the host country and the implementing agency.* Understanding each other's points of view and developing mutual confidence in each other's professional competence, personal methods of handling problems, etc., are vital and basic to the success of a project. The following steps would help to bring the leaders of the two parties closer.
   - Routine meeting between them every day for a short period to exchange views on the day-to-day problems and activities of the project.
   - Regular correspondence in writing, rather than orally, on all aspects concerning the project.
   - Private sessions to resolve matters of disagreement.

2. *Communication between the leaders and the program staff.* To implement approved technical programs to introduce any new aspect or to modify the approved program, proper communication between the program staff and the administrators is important. Procedures of the following kind would help to achieve this end.
   - For approved research activities, routine action memos from the program team seeking directions would do.
   - If any change in the research thrust or method of approach is desired, the concerned program team should send a proposal, unanimously agreed on, in the form of a memo to both the leaders for comments.

   If the leaders feel that the proposal was within the scope of the project goals, that there was no overlapping with other ongoing programs in the project, and that budget would not be a limitation, they should jointly approve it, after discussion. Any further discussion needed should be at a separate seminar, arranged to present the proposal before the entire project staff. This might help to improve the proposal further.

   If the conflict is still not resolved, the proposal should be referred to higher authorities for approval. The proposal becomes legitimate only after approval by both leaders.

   The administration should use the same system to communicate with the project staff. All instructions and messages to the staff should be sent through regular written memos, signed by both leaders. Signing by both is necessary to express the unanimity of their decision.
3. *Communication between staff of different programs of the project.* Communication between different programs in the project should be encouraged through seminars where the staff could interact and learn about one another's programs, and through symposia and annual meetings.
4. *Encouraging the staff:* The greatest satisfaction to a scientist is the recognition of his research accomplishments by his administrators and the government and fellow scientists. Administrators of agricultural projects must bear this in mind, to give full credit to those who made outstanding contributions that had directly or indirectly led to increased production and rural prosperity.

Thus, an efficient system of research management is vital to accomplishing the research goals.

Notes

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Address: A. Momtaz, Deputy Director General, Agricultural Research Center, Ministry of Agriculture and Land Reclamation, Egypt.

Innovative approaches to rice improvement

G. S. KHUSH

Major advances have been made in rice improvement through conventional breeding methods. However, at the International Rice Research Institute, these methods are now being supplemented with innovative breeding approaches. Improved evaluation and selection procedures are being followed. Shuttle breeding permits the exposure of early generation materials to appropriate stresses that do not occur at Los Baños, Philippines. Heterosis breeding has opened new avenues to raising the yield potential of rice. Recurrent selection and biparental and disruptive mating are being employed to accumulate genes governing quantitative traits and to break undesirable linkages. We have expanded our program on wide hybridization to transfer useful genes from wild species to cultivated rice. Limited gene transfer may be accomplished through pollen irradiation. Haploid breeding permits rapid attainment of homozygosity. Somatic cell cultures are proving useful in obtaining somaclonal variants to supplement existing variability. Techniques for genetic transformation are being developed through the Rockefeller Foundation-supported research network on genetic engineering in rice.

Major increases in rice production have occurred in most of the rice-growing countries during the last two decades. As an example, rice production in the Philippines increased from 4 million tons in 1965 to 9.1 million tons in 1985. From the beginning of rice cultivation in Indonesia, about 2000 yr ago, to 1965, rice production increased to 12.9 million tons; however, in the 20 yr between 1965 and 1985, it increased to 39 million tons—an increase of 300%. These phenomenal increases in many countries (see Table 1) have come largely from improved rice varieties and the resulting adoption of improved cultural practices and increased cropping intensity. As a result of these production increases, most of the countries in Asia, where 92% of the world's rice is grown and consumed, have become self-sufficient in rice. However, these achievements should not be cause for complacency. By the year 2000, the global population is expected to grow to 6.2 billion, from 4.8 billion in 1985. Rice production will have to be doubled in the next 25-30 yr to meet the demands of increasing population. Most of this requirement will have to be met from increased productivity per unit area, as the availability of new lands for rice cultivation is limited.

Table 1. Increases in rice production in selected Asian countries, 1965-85.

Country	Rice production (million t)		% increase in 1985 over 1965
	1965	1985	
Bangladesh	15.7	22.5	143.3
Burma	8.0	14.5	181.2
China	92.0	171.3	186.1
India	45.9	91.5	199.3
Indonesia	12.9	39.0	302.3
Korea (South)	4.8	7.8	162.2
Malaysia	1.2	1.8	150.0
Pakistan	1.9	5.0	263.1
Philippines	4.0	9.1	227.5
Sri Lanka	0.8	2.3	287.5
Thailand	11.1	19.5	175.6
Vietnam	9.8	15.8	161.1

Rice is grown under favorable (irrigated with good water control) or unfavorable (rainfed lowland, upland, deep water, and tidal wetlands) environments (Khush 1984). Out of 146 million ha of land planted to rice annually, about 79 million (or 55%) is irrigated; the rest is rainfed. Improvements in rice production have largely occurred in the irrigated areas where 80% of the world's rice is produced. Hundreds of improved rice varieties with higher yield and yield stability have been produced for these favorable environments. However, increases in the productivity of rainfed rice have been marginal. Very few improved varieties with better yielding ability have been released for the unfavorable environments. Therefore, for further increases in rice production, future challenges are twofold:

1. For the favorable environments—to develop rice varieties with higher yield potential and yield stability, superior milling and cooking quality, and shorter growth duration.
2. For the unfavorable environments—to develop improved varieties with higher productivity and yield stability, with tolerance for environmental stresses.

The key to the genetic improvement of rice so far has been the exploitation of dwarfing genes and the incorporation of genes for disease and insect resistance and short growth duration. This progress has been achieved by the use of conventional breeding methods such as pedigree, bulk, backcross, and mutation breeding. These time-tested methods will continue to be used but will be supplemented with innovative breeding approaches. Some of the innovative approaches now being used at the International Rice Research Institute (IRRI) or having the promise for use in rice improvement are:

1. Improved evaluation and selection procedures.
2. Shuttle breeding.
3. Heterosis breeding.
4. Recurrent selection.
5. Biparental and disruptive mating.

6. Single-seed descent.
7. Wide hybridization.
8. Limited gene transfer via pollen irradiation.
9. Haploid breeding.
10. Tissue culture.
11. Somatic hybridization.
12. Gene transfer through transformation techniques.

Improved evaluation and selection procedures

Plant breeders are often faced with the low efficiency of selection for yield in early segregating generations. Heterogeneous soil fertility conditions, intergenotypic competition due to closer spacing, seasonal variations, and micro- and macro-environmental effects are some of the factors responsible for low selection efficiency. These factors, singly or jointly, mask the full expression of genetic potential of segregants in the F_2 and F_3 generations, which makes it difficult to discriminate between high- and low-yielding individuals. Since yield potential of genotypes involves strong genotype × nitrogen (N) interaction, it is important to select for N response in the early segregating generations. With currently used methods, such selection is deferred until the F_5 to F_7 generations. Therefore, there is always a possibility of losing genotypes showing ideal N response, i.e., fair yield potential with low N and high yield potential with high N.

Several studies (Fasoulas 1973, Frey 1964, Thakare and Qualset 1978) indicate that optimal selection environments, such as high fertilizer rates, good water management, and wider spacing, should be the ones that favor the maximum expression of yielding ability of individual genotypes in early generations. Fasoulas (1973) has argued that selection in segregating generations involves heterozygous and heterogeneous populations, whereas a commercial crop involves a homozygous and homogeneous population. He has suggested planting plans and selection procedures for optimal expression of attributes of individuals in F_1 populations. We are experimenting with suggested techniques to see if selection efficiency for yield in early generations can be increased.

Shuttle breeding

Under unfavorable environments, the rice crop is subjected to various stresses such as drought, soil problems, and excess water. For rapid progress in developing improved varieties for these situations, early generation materials must be exposed to actual stresses, which may not exist at the breeding station. For example, at the IRRI experimental farm at Los Baños, Philippines, we cannot select for tolerance for drought, excess water, submergence, or various adverse soils, or for stem elongation ability. To overcome this problem, we have designed collaborative shuttle breeding projects with several national programs to develop improved varieties for adverse soil and climatic conditions. Parents, usually an improved variety or a breeding line from IRRI and a locally adapted variety from a collaborating country, are selected jointly by IRRI and national program scientists.

Crosses are made, and F_1 progenies are grown at IRRI. The F_2 populations are grown under target environments, where they are exposed to appropriate stresses. Adapted plants are selected and seeds are sent back to IRRl for growing F_3 progeny rows. They are concurrently evaluated for grain quality and for resistance to diseases and insects. Selected F_4 progenies are again evaluated under target environments. F_5 progeny rows are planted at IRRI and evaluated for disease and insect resistance and grain quality. This shuttling between locations by growing alternate generations facilitates selection for appropriate stress tolerance as well as for grain quality and disease and insect resistance. We have shuttle breeding projects with several national rice improvement programs for developing improved breeding materials for low-temperature tolerance and for rainfed lowland, upland, deep water, and tidal wetland conditions (IRRI 1985).

Heterosis breeding

Heterosis breeding has been successfully adopted in China to increase rice productivity beyond the levels established by semidwarf varieties (Lin and Yuan 1980, Yuan 1977). Results at IRRI (Virmani and Edwards 1983; Virmani et al l981, 1982) and elsewhere also indicate that significant heterosis exists in rice, which can be exploited to develop high-yielding hybrids using cytoplasmic male-sterility and fertility-restoration systems. Their high yield potential is attributable to simultaneous increase in dry matter production and harvest index. Besides, rice hybrids also possess a stronger and more active root system and are more efficient physiologically. This breeding approach enables us to retain desirable combinations and overcome the effects of undesirable (repulsion phase) linkages found in parents; therefore, we are using this as a supplementary approach, to increase the yield potential of lines developed through conventional breeding.

The recent discovery of a wide-compatibility gene in rice (Ikehashi and Araki 1986) has opened up the possibilities for exploiting the high level of heterosis observed in indica/japonica crosses. Generally, the F_1 hybrids between indica and japonica varieties are sterile. However, if one of the parents has the wide-compatibility gene, the F_1s will be fertile.

The major problems of heterosis breeding are the necessity of changing seed every season, the high cost of hybrid seed, and the continuous dependence on ex-farm sources for the supply of seed. Furthermore, employment of this approach is contingent upon the ability of the country to organize a systematic seed production, processing, certification, and distribution program.

Recurrent selection

Recurrent selection is used primarily to promote recombination and to increase the frequencies of favorable genes for quantitatively inherited traits. It is cyclic, with each cycle encompassing the two phases of plant breeding: a) selection of a group of genotypes that possess favorable genes and b) mating among the selected genotypes to obtain genetic recombination (Frey 1982). Although this breeding approach has been extensively used in cross-pollinated species, its principles are equally valid for autogamous species (Hallauer 1981). Its use in self-pollinated species has been limited by technical problems of intermating and inadequate seed production. However, some recent advances, such as the use of genetic male sterility to facilitate crossing, have led to increased application of recurrent selection in the breeding programs for autogamous species. Since a monogenic male-sterile mutant was developed in rice variety lR36 at IRRI (Singh and lkehashi 1981), interest in using the recurrent selection approach in selected composite populations of rice has increased. A significant amount of intermating is possible in these populations, since male-sterile rice plants have been observed to have outcrossing rates of up to 52% (IRRI 1980).

Composite populations are constituted from the F_2 seed of the crosses involving a genetic male-sterile line and a number of parents selected for the breeding objectives. Recurrent selection can be practiced in these populations following the procedures outlined by Gilmore (1964), Jensen (1970, 1978), and Brim and Stuber (1973).

Biparental and disruptive mating

Biparental mating involves intermating of selected plants in the F_2 generation, so as to accumulate favorable genes and to break linkages, thereby releasing a greater reservoir of genetic variability for selection (Joshi 1979). This breeding approach has been investigated at IRRI (Ventura 1984) and has been found to give more desirable segregation (among and within biparental families) than F_3s for traits such as days to 50% flowering, 1,000-grain weight, and grain yield. Association between characters tended to shift toward favorable or unfavorable values, presumably due to new complex genic combinations in biparental progenies. Path analysis also confirmed that intermating tended to shift the direct effects and indirect effects positively or negatively. It is therefore essential to combine the biparental breeding approach with an effective selection procedure to select only the desirable genotypes.

Disruptive mating involves the intermating of unlike plants in segregating generations. It leads to greater opportunity for crossing over, which releases latent variation by breaking up the predominantly repulsion phase linkages (Thoday 1960). Frey (1982) proposed the use of this breeding approach when germplasm from exotic, and especially wild or weedy species, is used and when there is the problem of linkage drag, whereby an undesirable allele is brought into a breeding population because it is linked to a favorable gene. We are using disruptive mating at IRRI in crosses between wild and cultivated rices intended to increase stigma and anther size in cultivated rice. Resulting lines are expected to have increased outcrossing, a trait useful for hybrid rice breeding. Wide crosses are also being attempted at IRRI to transfer genes for disease and insect resistance from wild to cultivated species. Disruptive mating would be useful in such crosses.

Single-seed descent

Single-seed descent (SSD) is a method of sampling sometimes used in autogamous species to ensure that the range of genotypes in the original population will also be present in the future generations (Brim 1966). This breeding approach aims at 1) maintaining the broadest possible representation of genotypes in the base population until selection is practiced, and 2) increasing genetic variation among F_4 to F_6 advanced generation progenies.

Ikehashi and HilleRisLambers (1977) discussed the details of this method in relation to rice breeding, At IRRI, this method is being used through the Rapid Generation Advance (RGA) technique to breed rices for cold tolerance, submergence tolerance, and photoperiod sensitivity. The use of SSD in breeding for high yield potential is also worth exploring. For such a scheme, about 5,000-10,000 plants in the F_2 population of selected crosses should be grown in the RGA facility and advanced to the F_5 generation. Three seeds should be selected from each plant in each generation from F_3 to F_5, and one-third of the bulk seed should be used to advance the generation. The F_5 bulk population should be grown along with the best-yielding check variety (planted every tenth row) in the field under conditions of high fertility, wide spacing (40 × 30 cm), and good insect control. The plants superior to those in the check variety should be selected. The F_6 progenies should be evaluated under stress (biotic and abiotic) and nonstress conditions and those found superior under both conditions should be selected and evaluated for yield.

Wide hybridization

The increases in yield potential of rice have primarily been achieved through changing the harvest index. The total biomass production in rice and other cereals has remained the same (Austin et al 1980, Jain 1985). Therefore, further improvements in the yield potential are most likely to occur through increases in biomass production (Khush and Virmani 1985). In several other crops, such as oats, sorghum, and pearl millet, improvement in biomass production and yield potential have been achieved through introgression of wild germplasm into cultivated varieties (Frey 1983). We are also trying this approach in rice, where cultivated varieties of *Oryza sativa* have limited variation for total biomass production per unit area and time.

Other possible uses of wide hybridization include the opportunities for transferring genes for disease and insect resistance and tolerance for various abiotic stresses (Table 2). For example, *O. officinalis* and *O. australiensis* are highly resistant to brown planthopper. Until now it was not possible to transfer these genes to *O. sativa* because of the barriers to crossability and lack of recombination. However, Jena and Khush (1985) obtained F_1 hybrids between 3 elite lines of *O. sativa* and 18 accessions of *O. officinalis* through the embryo rescue technique. Although the F_1 hybrids were completely sterile, a few backcross progenies were obtained, which were allotriploids. Further backcrosses of these BC_1 progenies produced BC_2 progenies that were like *O. sativa* but had a few traits, such as resistance to the brown planthopper, from *O. officinalis.* Thus we have successfully transferred a useful gene from *O. officinalis* to *O. sativa* across crossability and recombination barriers. Many innovations have been made for producing distant hybrids in other crop genera (Brar and Khush 1986). These techniques are being used for producing distant hybrids involving rice.

Table 2. Wild species of *Oryza* with traits of economic importance.

Wild species	Useful trait
O. nivara	Resistance to grassy stunt and blast
O. barthii	Resistance to bacterial blight
O. perennis	Floral characters for outcrossing
O. glaberrima	Resistance to green leafhopper
O. officinalis	Resistance to brown planthopper
O. australiensis	Resistance to brown planthopper
O. coarctata	Resistance to salinity

Interspecific hybrids are also being explored for refining tools for hybrid rice breeding. Several wild species have floral characteristics such as long anthers and long and exserted stigmas, which are being transferred to maintainer and restorer lines of rice to increase their outcrossing potential. Development of new cytoplasmic male-sterile lines possessing diverse cytosterility systems is another possibility.

Limited gene transfer via pollen irradiation

Pandey (1975) proposed irradiation of pollen at high doses and use of such pollen in hybridization in order to transfer only certain genes, rather than the complete chromosome complement, of the male parent. The killed pollen is able to discharge its pulverized DNA segments into the embryo sac of the female parent. Preliminary experiments in tobacco (Jinks et al 1981), wheat (Snape et al 1983), and barley (Powell et al 1983) indicate that progenies derived from irradiated pollen increasingly resembled the female parent. The method is simple and inexpensive and does not require sophisticated facilities.

Though the exact mechanism of gene transfer through pollen irradiation is not known, the method is attractive to plant breeders, as it avoids the cumbersome recurrent backcrossing and selection procedures required for re-accumulation of favorable genes from the more productive and/or adapted parent. This method can also be used for transferring genes from distantly related species without going through a “bridge” species.

We have initiated research at IRRI on the pollen irradiation technique to transfer Basmati grain quality traits into high-yielding, disease- and insect-resistant elite lines, because desirable combinations of high-yielding plant type and Basmati grain quality have not been obtained so far through conventional breeding methods. The method may also be used for limited gene transfer for traits such as increased dry matter production, brown planthopper resistance, and bacterial blight resistance from related species of the genus *Oryza* into cultivated varieties.

Haploid breeding

Haploid breeding involves the production of a large number of haploids from an intervarietal cross. Since these haploids come from recombinant gametes, each is genetically different. Chromosome doubling leads to the production of completely homozygous individuals. Progenies of these doubled haploids represent true breeding lines. Thus, the time taken to reach homozygosity and to fix desirable gene combinations is considerably less than with conventional methods. Several varieties of rice, wheat, and tobacco have been developed through this method in China (Hu Han 1985). Similarly, barley variety Mingo, developed through haploid breeding, is widely grown in Canada.

The haploid method is also useful in improving the selection efficiency for yield and other traits of low heritability controlled by many genes. The efficiency of selecting superior genotypes in the early generations (F_2-F_4) is rather low with the conventional breeding procedures. In the doubled haploid lines there is more additive genetic variance than in the conventional F_2 and F_3 generations; besides, the dominance variance is eliminated (Table 3). In the F_3 and F_4, additive and dominance effects contribute to phenotypic differences between individuals, whereas variation in doubled haploid progeny is only due to microenvironmental effects (Snape 1982). Doubled haploid plants are genetically identical from one generation to the next, whereas heterozygosity within conventionally bred lines may cause the genotypic correlation between parents and offspring to be less than unity. This selection efficiency in doubled haploid population is likely to be higher when there is greater dominance variation in the cross.

Two methods are generally used for producing haploids. Anther or pollen culture is the most widely used technique. Haploids have been produced through anther culture in 247 species representing 88 genera and 34 families. Another method, called the chromosome elimination method (Kasha and Reimberg 1981), is routinely used in barley and has now been applied for producing haploids of wheat. It involves pollinating the intervarietal hybrids of barley or wheat with pollen from *Hordeum bulbosum.* Fertilization takes place but the chromosomes of the male parent are progressively eliminated during the early cell divisions of the zygote. However, the zygote continues to develop, resulting in a haploid embryo.

Tissue culture

A number of in vitro techniques are useful tools in plant breeding, utilized both for creating new variability and for increasing selection efficiency. Somaclonal variation has been observed as an important source of variability in a number of crop species, such as sugarcane, wheat, potato, tobacco, and rice (Larkin and Scowcroft 1981).

Table 3. Expectations of phenotypic variances in different generations (Snape 1982).

Generation	Variance[a]
F_2	$V_A+V_D+V_{EI}$
F_3 family means	$V_A + 1/2\ V_D + V_{EP}$
F_1 derived DH means	$2V_A + V_{EP}$

[a]V_A = additive component of variation, V_D = dominance component of variation. V_{EI} = Environmental variance between F_2 individuals, V_{EP} = Environmental variance within F_3/dihaploid progenies.

Somaclonal variation does not seem to be species- or explant-specific, and variation for a wide range of characteristics, such as disease resistance, salinity and aluminum toxicity tolerance, morphological characters including plant height, panicle size, fertility, maturity, etc., has been recorded. The exact mechanisms and causes of somaclonal variation are not well understood.

Somaclonal variation for various characters has been reported in rice (Kucherenko 1980, Oono 1981, Schaeffer et a1 1984, Suenaga et a1 1982, Yoshida and Ogawa 1983, Zong-Xiu et al 1983). Oono (1981) studied 1,121 somaclones derived from 75 calli of a genetically pure line (progeny of a doubled haploid of rice variety Norin 8). In the R_2 generation, variation was observed for seed fertility, plant height, heading date, morphology, and chlorophyll deficiency. Kucherenko (1980) found that 36% of the R_2 lines differed from the parent variety in various traits; some lines had two or even three altered traits. Schaeffer et al (1984) found variation for seed size, protein content, height, and tiller number in anther culture-derived plants of Calrose 76. At IRRI, Suenaga et al (1982) observed that of the 521 R_2 lines, 54% were considered variants for brown leaf spot, chlorophyll deficiency, plant height, flowering date, plant morphology, and seed fertility. Somaclonal variation in rice has been observed for useful traits such as aluminum tolerance (Yoshida and Ogawa 1983), salinity tolerance (Croughan et al l981, Rains et al 1980), resistance to brown spot disease (IRRI 1985), and high lysine and protein content (Zapata 1984).

The selection efficiency is increased because large populations of cells can be exposed to stress conditions in the laboratory to select desirable cell lines, which is more efficient and economical than selection under field conditions. Possible uses of tissue culture in rice improvement are enumerated in Table 4.

Somatic hybridization

Protoplast fusion is a unique technique for producing somatic hybrids between otherwise sexually incompatible species. Several intergeneric somatic hybrids, such as potato + tomato and *Arabidopsis* + *Brassica campestris,* have been produced. The system may be advantageously used in rice for transferring alien genes from sexually incompatible species such as *Oryza coarctata,* which is highly tolerant of salinity.

Protoplast fusion may also be used for transferring male sterility from one line to another without the cumbersome process of backcrossing. This can be done by fusing protoplasts of a commercial variety to be sterilized with the irradiated protoplasts of cytoplasmic male-sterile lines where the nucleus of the latter is killed by radiation.

Protoplast fusions can also be used for producing cybrids and organelle recombinants. Cell organelles, such as mitochondrial and chloroplast genomes, carry genetic information for male sterility, disease resistance, and other desirable traits. The protoplast fusion technique provides a unique opportunity to exploit cytoplasmic variability by producing cybrids and exchange of the organelles not possible through conventional breeding.

Table 4. Possible uses of tissue culture in rice improvement.

Breeding objective	Applicable tissue culture approaches
Salinity tolerance	1. Exploit somaclonal variation for salinity tolerance in well-adapted and high-yielding varieties such as IR36. 2. Exploit somaclonal variation to improve plant type of otherwise salt-tolerant traditional rice varieties such as Nona Bokra and Pokkali. 3. Use a mutagen on cultured cells, followed by selection of tolerant cells grown on media enriched with high concentration of salts, re-generate plants from such resistant cells. 4. Transfer alien genes from highly salt-tolerant wild species such as *Oryza coarctata.* Embryo rescue, in vitro fertilization or protoplast fusion could be used to achieve such wide crosses. 5. Fix desirable gene combinations for salinity tolerance, following anther culture of intervarietal or wide crosses.
Nutritional quality	1. Subject cultured cells — preferably haploid cells — to amino acid analogue such as S-aminoethylcystein (S-AEC), select resistant cells, and regenerate plants showing increased protein and lysine in the seed, 2. Exploit scmaclonal variation to isolate mutants with increased lysine and protein content.
Diseaseresistance	1. Use somaclonal variation to isolate rice germplasm resistant to phytotoxins and other fungal, bacterial, and viral diseases. 2. Use possible combination or mutagenesis of cultured cells followed by selection of cells under toxic concentrations of host-specific toxins. 3. Incorporate genes for resistance to pests such as brown planthopper from related wild species *(O. australiensis).* Follow embryo rescue to obtain the interspecific crosses or derivatives of such crosses. 4. Explore use of wide hybridization involving cultivated rice varieties and wild species resistant to viruses and other diseases for transfer of alien genes fur developing disease resistant varieties.

Table 4 continued

Breeding objective	Applicable tissue culture approaches
Increased biomass production	1. Identify wild species with higher biomass production. Use such species in crosses with cultivated rice varieties to enhance the biomass production and further raise the yield potential. 2. Exploit variability for sink-source in wild species to break the yield barrier of cultivated rice varieties.
Hybrid rice	1. Use somaclonal variation or induced mutations to obtain new male-sterile lines in commercial rice varieties for use in hybrid rice improvement. 2. Explore anther culture of promising hybrid rices for fixing desirable gene combinations to derive true-breeding varieties as high-yielding as the hybrids. 3. Use fusion of x-irradiated protoplasts of cytoplasmic male-sterile lines and un-irradiated protoplasts of commercial rice varieties to transfer male sterility in rice varieties, eliminating the necessity of backcrossing. 4. Produce on a large scale somatic embryos from superior F_1 hybrid combinations and encapsulate them for use as seeds in farmers' fields.
Rapid homozygosity	1. Use anther culture to develop homozygous lines through fixation of desirable gene combination in the immediate generation and also to reduce the breeding time to develop new rice varieties.
Improving selection efficiency	1. Use anther culture to develop dihaploid true-breeding lines. Such lines would not exhibit any dominance gene effects. Selection efficiency for agronomic traits in such lines would be higher than in the conventionally bred lines showing dominance interactions.
Production of somatic hybrids, cybrids, and organelle recombinants	1. Use protoplast fusion, which provides a unique opportunity to produce a) somatic hybrids between sexually incompatible species, b) cybrids, and c) mitochondrial as well as chloroplast recombinants.

Gene transfer through transformation techniques

Crop productivity can be manipulated within the limits of the available gene pool. Breeders generally confine themselves to the primary gene pool of the crop. However, the new techniques of molecular biology and genetic engineering are proving useful in moving genes from unrelated species to crop plants, resulting in broadening of crop gene pools. Three techniques of genetic engineering hold promise for application to rice improvement:

1. Electroporation,
2. Micro-injection of DNA, and
3. Vector-mediated gene transfer.

Genetic engineering techniques have been successfully employed in accomplishing transformation in several crops; for example, Murai et a1 (1983) transferred the phaseolin gene from bean to sunflower through a tumor-inducing plasmid vector. The expression of the transferred gene in cultured tissue of sunflower demonstrates the potential for successful gene transfer from unrelated species and its expression in the recipient's genome. Recently, Horsch et a1 (1984) reported regeneration of normal plants from *Nicotiana plumbaginifolia* cells transformed with an *Agrobacterium* strain carrying a tumor-inducing plasmid with a chimeric gene for kanamycin resistance. Examination of the progeny of the transformed plants showed normal Mendelian inheritance of the engineered gene. The electroporation technique has been used to achieve transformation in maize (Fromme et a1 1986).

Rapid progress is being made in developing protocols for achieving vector-mediated gene transfers in rice under the "Upstream-Downstream'' research network funded by the Rockefeller Foundation. The two components that are receiving major research attention are the development of vectors for monocots and the regeneration of plants from isolated protoplasts. The present status of research on vectors for monocots was summarized by Caplan and Van Montagu (1986). Regeneration of plants from isolated protoplasts of rice was achieved recently (Abdullah et a1 1986). Thus it is anticipated that success in genetic transformation in rice will be achieved soon. This will permit the introduction of novel traits not presently available in the genus *Oryza.* For example, if apomixis can be introduced from *Pennisetum* or other grass generainto restorer parents of the F_1 rice hybrids, it will help fix heterosis, thus eliminating the need to produce the F_1 seeds continually.

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Notes

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New possibilities for rice breeding

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Rapid progress in rice genetics and biotechnology has opened up new possibilities in rice breeding; four such broad possibilities are described. 1) Widening genetic variability by utilizing the huge genetic resources laboriously collected through international cooperative efforts throughout the world. Such resources make it possible to markedly improve genetic characters of rice, such as disease and insect pest resistance, tolerance for adverse soils and temperatures, grain quality, and cooking quality. 2) Utilizing wide-compatibility genes. It may be possible to exchange useful genes between indica and japonica types without any sterility problem and to produce F_1 hybrid varieties with a high level of heterosis. 3) Utilizing tissue culture techniques, including mass production of artificial seeds of F_1 hybrid varieties and selection of somaclonal variation. 4) Introducing techniques of molecular genetics into rice breeding methods. The recombinant DNA method may open up possibilities for introducing foreign genes, such as the *Bacillus thuringiensis* toxin gene, a herbicide tolerance gene, and others, although molecular genetics must progress further before these techniques can be applied to plant breeding.

Cultivated rice, *Oryza sativa* L., is assumed to have originated from the mountainous areas of tropical Asia, and it has differentiated into many ecotypes through its distribution to the surrounding regions (Nakagahra 1984).

The history of rice breeding, especially that with modern genetic techniques, is very short when compared with the span of the evolution of rice cultivars. But breeding progress in the last 1 century may be comparable to that in the previous 20 centuries. The characteristics of rice cultivars, such as yielding ability, resistance to diseases and to insect pests, and tolerance for nonoptimal temperatures and adverse soils have been greatly improved in the past 20 yr by utilizing the genetic resources collected from the rice-cultivating countries in the world through international cooperative efforts.

With the rapid progress of rice genetics and biotechnology, we expect some new possibilities in rice breeding in the near future. The first is widening genetic variability by free utilization of huge genetic resources. The second is utilizing wide-compatibility genes to produce F_1 hybrids between indica and japonica types. The third is utilizing tissue culture techniques. including mass production of artificial seeds of F_1 hybrid plants and selection of somaclonal variations. The fourth possibility is the introduction of techniques of molecular genetics, such as the recombinant DNA method, in rice breeding.

Widening genetic variability

The potential of plant breeding depends on the genetic diversity of the source materials. The use of resistance genes from exotic sources to breed for plant protection is well known. Breakthroughs in plant improvement have also been achieved in many other areas: not only in breeding for high yields but also for improved grain quality, tolerance for nonoptimal temperatures and adverse soils, and others.

A successful example of utilizing the genetic resources available in rice is the breeding work done at the International Rice Research Institute (IRRI) in the Genetic Evaluation and Utilization (GEU) program. IRRI has evaluated a large number of accessions from the collection for many important characteristics. The testing methods for each characteristic were developed at IRRI to screen the best genetic resources useful for breeding objectives (Khush 1984).

One of the most valuable achievements of this program is the rice variety IR36, bred by repeated crossing of 13 parental varieties (from 6 countries) and incorporating useful characteristics from each. IR36 has wide adaptability in tropical rice-cultivating countries, and is now planted on more than 11 million hectares, because of its resistance to a broad spectrum of diseases: blast, bacterial leaf blight, grassy stunt virus, and tungro virus; its resistance to insect pests, such as brown planthopper, green leafhopper, gall midge, and stem borer; its tolerance for adverse soil conditions, such as salinity, alkalinity, zinc and iron deficiency, and iron, boron, and aluminum toxicity (Khush 1984).

For further improvement of major characteristics of rice cultivars, we have to search for better genetic resources from the genetic collections. As the International Rice Germplasm Center (IRGC) for cultivated rice and wild relatives, IRRI has preserved more than 68,000 accessions of Asian cultivars and 1,100 wild taxa. The International Board of Plant Genetic Resources (IBPGR) nominated the IRGC as the base collection of indica rice types (Chang 1985). A duplicate set of IRGC collections is being stored at the U.S. National Seed Storage Laboratories, Fort Collins, CO, USA (Chang 1985). The National Institute of Agrobiological Resources in Japan (NIAR) preserves mainly japonica types, with about 10,000 accessions, and has been designated the base collection of the japonica type of rice by IBPGR (Chang 1985). In addition to these, the International Institute of Tropical Agriculture (IITA) has about 2,500 accessions of *Oryza glaberrima* cultivars, about 7,500 accessions of African *O. sativa* cultivars, and 100 accessions of wild relatives (Ng 1986).

These vast genetic resources preserved in the international and national institutes have been laboriously collected through international cooperative work throughout the world. They are expected to be distributed to rice breeders and researchers in any country, under the international consensus on free exchange of genetic resources.

Some rare characteristics of enormous value have been identified through mass screening, when the size or the diversity of genetic resources was adequate. It is also notable that the success of the screening in many cases goes beyond initial expectations.

One new possibility is to breed varieties highly tolerant of low temperatures, by accumulating different cold-tolerance genes from different regions, such as Hokkaido of northernmost Japan, Russia, the mountainous area of Yunan Province in China, and the highlands of tropical Asia. Another area of our interest is to develop stable blast-resistant varieties. In general, blast fungus adjusts its virulence to changed resistance in rice cultivars; thus blast resistance bred by use of a single true resistance gene breaks down, without exception. Therefore, it is necessary to develop multiline varieties that include a number of different true resistance genes screened from the available genetic resources: these are expected to have stable resistance to blast disease.

Utilization of wide-compatibility genes

Rice improvement through distant crosses is not always easy because of various reproductive barriers. Phylogenetic remoteness, such as hybrid inviability, hybrid sterility, and hybrid breakdown are often suggested. The partial F_1 sterility in hybrids of indica and japonica types due to gamete abortion results in segregation distortions in many characteristics, and the free combination of the genes from both parents is inhibited; the gene frequency of japonica types, especially, is reduced in the offspring of indica, japonica hybrids, resulting in a bias toward the indica parent (Nakagahra 1986). Therefore the backcross method has been employed in Japan to incorporate useful genes from indica rice into japonica cultivars (Toriyama 1972).

Recently, Ikehashi and Araki (1986) reported that some wide-compatibility varieties produce fertile F_1 plants when crossed to indica as well as to japonica varieties. According to their genetic analysis, the F_1 sterility of indica/japonica hybrids is caused by an interallelic effect of S^i (from indica)/ S^j (from japonica), and wide-compatibility varieties carry the different allele S^n, which makes fertile F_1s in the heterozygote with S^i and S^j. Therefore the F_1 plants with genotypes of S^n/S^j and S^n/S^i and all the homozygotes of S alleles show spikelet fertility.

A set of multiple *S* alleles is closely linked with the marker gene *C* (chromogen for pigmentation of apiculus color), and is located between *C* and *wx* (waxy endosperm) loci on the linkage group I (Chromosome 6) (Ikehashi and Araki 1986). The S^n gene can easily be incorporated into indica or japonica cultivars by back-crossing or by any other breeding method. Individual plants showing the apiculus color controlled by the *C* gene can be selected for crossing as carriers of the S^n gene; such plants, because of the close correlation between the *C* and *S* locus, have a high probability of carrying the S^n gene.

Individuals with the S^n gene are expected to break down the reproductive barriers of hybrid sterility between indica and japonica type. When these individuals are crossed with varieties belonging to a different ecotype, F_1 plants are expected to produce offspring with free recombination of genes from both parents, without any inhibition. The wide-compatibility genes were found in Ketan Nangka of the javanica type and in American varieties such as Century Patna 231 and CP-SLO (Ikehashi and Araki 1986).

The wide-compatibility genes are also expected to play an important role in developing F_1 hybrid varieties between indica and japonica varieties. In general, F_1s from distantly related crosses of rice reveal a high level of heterosis in growth habits but a high degree of spikelet sterility. However, F_1 varieties between indica and japonica types with the S^n gene are expected to be fertile and will be high-yielding because of their high level of heterosis.

The S^n gene of Ketan Nangka and of CP-SLO does not show wide compatibility when crossed with the Aus group varieties of the indica type. Another gene of different locus from an Indian variety, Dular, is expected to be employed as a donor of the wide-compatibility gene for crosses between the Aus group and other ecotypes (Araki et al 1985). Different types of the wide-compatibility gene may be found among the genetic resources.

Utilization of tissue culture techniques

There are two possibilities of utilizing tissue culture techniques for rice breeding. One is mass production of artificial seeds or seedlings; the second is a selection of somaclonal variations.

At present, commercial seed of hybrid rice varieties is produced only by the use of the cytoplasmic male sterile (CMS) system, which consists of cytoplasmic male-sterile lines, maintainer lines, and restorer lines. The first CMS line in rice cultivars was developed in Japan in 1966 (Shinjyo and Omura 1966), but the first commercial F_1 hybrid variety was released in China in 1976 (HPRRI 1977). The CMS system can be used only for the limited cross combinations between the CMS lines and their corresponding restorer lines. No highly productive cross combinations are employed at present without the CMS system for developing hybrid varieties. Therefore, a simple seed production method for hybrids, without the CMS system, is highly desirable.

Artificial seed production by tissue culture may be one way to solve this problem. At present, only a species such as carrot, *Daucus carota* L., is known to reveal the synchronous formation of a somatic embryo by tissue culture consistently (Ohyama et al 1986). But information on somatic embryo formation in Gramineae is limited. One example is maize: some special maize inbred lines, which possess a special gene for somatic embryo formation, are known to develop easily into somatic embryos by tissue culture when placed on artificial media at a young embryo stage (Green and Phillips 1975). Therefore, there is a possibility of finding such a special gene in rice also, to accelerate somatic embryo formation.

When the somatic embryo formation method is established in rice, artificial seed or seedling production for hybrid varieties should be considered for practical use. Mass production of artificial seeds or seedlings makes it possible to utilize any kinds of cross combinations of high-yielding ability, without use of the CMS system. However, the cost of producing artificial seed or seedlings is much higher at present than that of growing hybrid seed by the CMS system. Mass production methods need to be refined and costs considerably lowered before artificial seeds or seedlings can be released to farmers.

The other possibility of utilizing tissue culture techniques is a selection of somaclonal variations. There are many reports suggesting the occurrence of somaclonal variations. For example, the frequency of haploid cells in pollen callus reduced to nearly 30% after 55 d of anther inoculation (Oono 1983), and more than 70% of D_2 lines regenerated from diploid seed callus indicated one or more variations of agronomic traits without any special treatment for increasing mutation ratio (Oono 1983).

Other than such spontaneous variations, somaclonal mutation for resistance to tryptophan analog, 5-methyltryptophan (5MT). was selected from the seedderived callus after cultivation on a high level of 5MT concentration media. The 5MT resistance was expressed in the cultured cells and regenerated seedlings, and inherited by their offspring (Wakasa and Widholm 1986).

Other trials for selecting somaclonal variations for tolerance of unfavorable conditions, such as salinity, low temperature, disease toxicity, and so on, are under way.

Introducing techniques of molecular genetics into rice breeding

The recombinant DNA method may explore a great possibility to introduce foreign genes into rice cultivars. At present, the Ti-plasmid is expected to be the best possible vector for applying the recombinant DNA method to plants (Fraley et al 1983), but it cannot be used for rice, because *Agrobacterium tumefaciens,* carrier of the Ti-plasmid, does not have a virulence to monocotyledonous plants. The other transformation methods, such as the polyethylene glycol (PEG) method (Uchimiya et al 1986) and electroporation method (Fromm et al 1986), are being developed. Uchimiya et al (1986) reported that the chimeric gene containing the kanamycin resistance gene of transposon (Tn5) with *nos* promoter was incorporated into the rice protoplast by the PEG method, and transformed rice callus grew on the media containing kanamycin, but no regenerated plants developed.

Some examples of favorable genes for incorporating into rice plants from foreign organisms are the herbicide resistance gene (Comai et al 1985), the *B.t.* toxin gene (Adang et al 1986), and the coat protein gene of virus (Abel et al 1986). Farmers growing rice that has the herbicide resistance gene of microorganisms could save labor in keeping their fields weed-free by applying special herbicides that would kill all the plants except the herbicide-resistant rice varieties. If the *B.t.* toxin gene incorporated into rice plants produces active *B.t.* toxin, rice plants are expected to be resistant to lepidopterous insects, such as stem borer, rice plant skipper, rice leaffolder, and rice green caterpillar; farmers would thus be able to save the money they now spend on insecticides and also be released from the unhealthy work of applying insecticides. The same expectation will be realized when coat protein genes of various virus diseases are effectively used to reduce disease severity; thus we will be able to use the artificial virus tolerance gene to cope with the occurrence of new virus diseases. However, further progress in molecular genetics is needed before we can apply the recombinant DNA method to rice breeding.

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Notes

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Rice varietal improvement in Egypt

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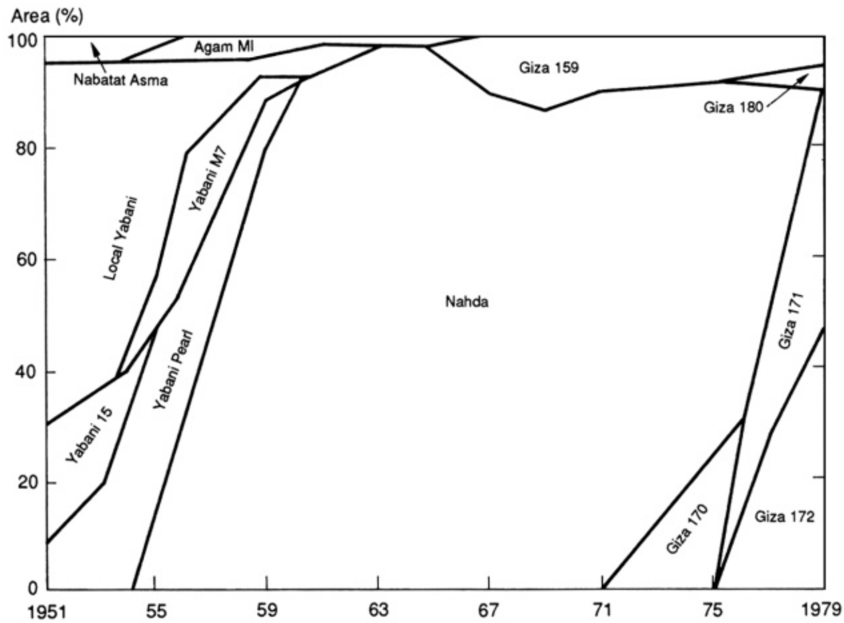
Rice breeding research in Egypt has been accelerated in the recent past, to overcome the disadvantages of the most widely grown varieties, Giza 171 and Giza 172. The objective of the current breeding program is to develop high-yielding semidwarf varieties that combine resistance to blast and stem borers with early maturity, improved grain quality, and tolerance for soil salinity. Recent achievements in varietal improvement, since the blast outbreak in 1984, are: a) identification of diverse donor sources for blast resistance; b) identification of six promising strains: IR1626-203, GZ1 108-4-1, GZ1368-5-4, GZ1394-10-1, GZ2175-5-6, and IR19743-46; c) release of two new varieties for general cultivation from 1987: short-grain Giza 175 (GZ1394-10-1) and long-grain Giza 181 (IR1626-203). Future strategies are discussed, with major emphasis on improving the present breeding approaches and utilizing innovative ones such as tissue culture techniques and heterosis breeding.

Rice breeding research in Egypt, to develop varieties suited to Egyptian farming systems and able to withstand biological and physical stresses, dates back to 1917. Breeding efforts in the early years resulted in the release of several Yabani varieties: Yabani 15, Yabani Pearl, Nabatat Asmer, Yabani M5, Giza 14, and Agami M1.

In 1954, a major breakthrough came with the release of the variety Nahda, a pureline selection with high yield potential, resistance to blast, and excellent milling and cooking qualities. Nahda occupied more than 90% of the rice area for about 20 yr (Fig. 1). With the breakdown of its blast resistance in the early 1970s, Nahda was replaced in 1976 by two relatively more resistant varieties of hybrid origin, Giza 171 (Nahda/Calady 40) and Giza 172 (Nahda/Kinmaze), which continue to occupy over 85% of the rice area (Balal 1978).

Besides Nahda, the long-grain variety, Arabi, was released in 1960, followed by the salt-tolerant variety Giza 159 (Agami M1/Giza 14) in 1965, and the short-statured, long-grain varieties, Giza 180 (IR579-48) and Sakha 2 (IR1561-228) in 1974.

A need for change in our breeding strategy was felt toward the late 1970s, with increasing problems of labor shortage, inhibitive wage structure, and farmers' desire to adopt more remunerative cropping patterns and quality characteristics for

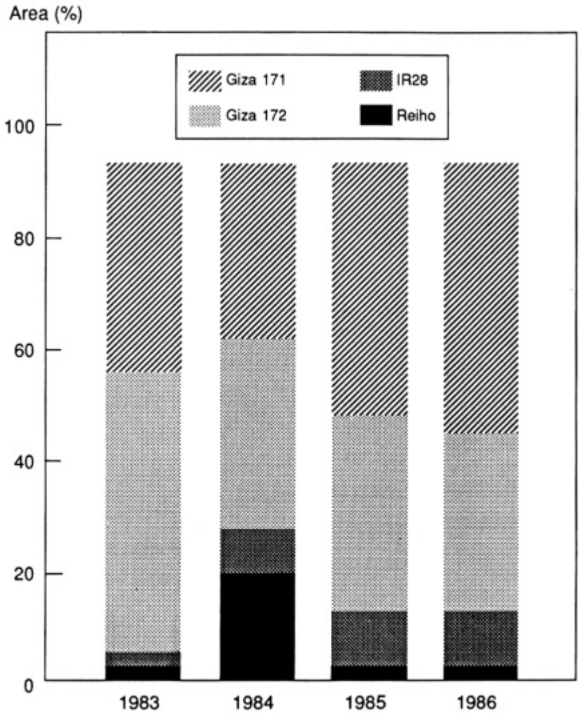


1. Annual area planted to different rice varieties in Egypt, 1951-79.

export. Thus, breeding research since then has been directed to evolving high-yielding varieties, with emphasis on 1) earliness, so that they can be easily fitted into the popular cropping patterns and give higher farm productivity, and 2) nonlodging short stature, to suit mechanized rice farming. Having readily found most of the desired features in Reiho, a Japanese variety introduced in 1972, we intensively evaluated it for yield, disease and insect resistance, and grain quality requirement, and put it through very extensive on-farm testing during 1981-83. Reiho was found to possess a wider spectrum of resistance to blast than the prevailing varieties.

However, Reiho became highly vulnerable to the new race(s) of the pathogen that appeared in 1984. This new race was so virulent that not only Reiho but all prerelease entries (GZ951, GZ882, GZ587, etc.) and practically all breeding material of japonica origin became susceptible. However, materials of indica origin, especially varieties from the International Rice Research Institute (IRRI), such as Giza 180 (IR5791), IR28, and IR1626-203, retained their resistance.

Today, Giza 171 and Giza 172 are the varieties predominantly grown in Egypt, on about 85% of the rice area. In addition, the early-maturing variety IR28 is grown on about 10% of the area (Fig. 2). However, Giza 171 and Giza 172 are late-maturing and more susceptible to blast and lodging, and IR28 is handicapped by less acceptable cooking qualities.



2. Annual area planted to different rice varieties in Egypt, 1983-86.

Current breeding objectives

Considering the drawbacks of the prevailing varieties, the breeding program has been accelerated and reoriented to develop or identify rice varieties for four different purposes and growing conditions:

1. For normal soils: high-yielding dwarf varieties, combining resistance to blast and stem borers.
2. For saline and newly reclaimed areas: high-yielding, dwarf, salt-tolerant varieties, combining resistance to blast and stem borers.
3. For export: high-yielding, dwarf, long-grain varieties, combining blast and stem borer resistance with better milling quality.
4. For intensifying cropping: high-yielding early- and very early-maturing varieties.

Breeding procedures

Hybridization programs emphasize crossing the local varieties and promising strains with introduced ones to incorporate genes for improved plant type, early maturity, blast resistance, salinity tolerance, and superior grain quality into the indigenous commercial varieties.

Crossing patterns

About 300 single and multiple crosses are effected annually (Table 1) and the F_1s are raised at IRRI in Los Baños, Philippines, as a winter nursery. The majority of these are top and multiple crosses involving indica and indica-japonica strains as parents (Fig. 3). The analysis of crossing patterns reflects the order of priority given to breeding for nonlodging plant habit, short duration, blast resistance, and tolerance for soil salinity (Fig. 4).

Over 3,000 pedigree lines (F_3-F_5) are studied annually, one-fourth of these pertaining to saline soils (Table 2). All the lines are screened under appropriate stress conditions for reaction to blast.

IRTP nurseries

In 1976, Egypt started to participate in the IRRI International Rice Testing Program (IRTP) by planting the following nurseries:

1. International Rice Yield Nursery Very Early (IRYN-VE)
2. International Rice Yield Nursery Early (IRYN-E)
3. International Rice Observational Nursery (IRON)
4. International Rice Blast Nursery (IRBN)
5. International Rice Salinity and Alkalinity Observational Nursery (IRSATON)

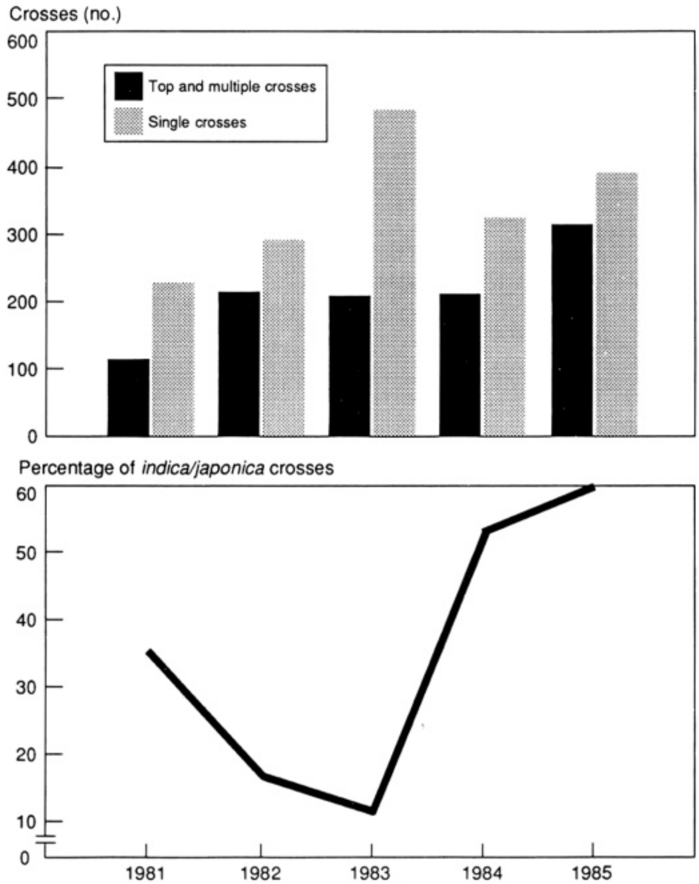
Every year these nurseries provide us with a large volume of breeding material for testing under local conditions and making use of the promising lines (Table 3).

Mutation breeding

Mutation breeding has been used in Egypt since 1963 as a supplement to cross-breeding. Several varieties, such as Agami M1, Arabi, Nahda, Bluebelle, and Giza 159, were treated with physical and chemical mutagens to obtain outstanding mutants with high yield, resistance to blast, and long and slender grain. Recently, Giza 171 and Giza 172 were treated with EMS and gamma rays to obtain early-

Table 1. Numbers of new crosses made and F_1 and F_2 populations of rice grown at Sakha, Egypt, 1983-85.

Material	New crosses (no.)			
	1983	1984	1985	Average
New crosses	231	320	397	316
F_1s	100	100	96	99
F_2s				
Normal soils	344	337	284	322
Saline soils	63	65	18	49



3. Number and types of crosses in rice breeding in Egypt, 1981-85.

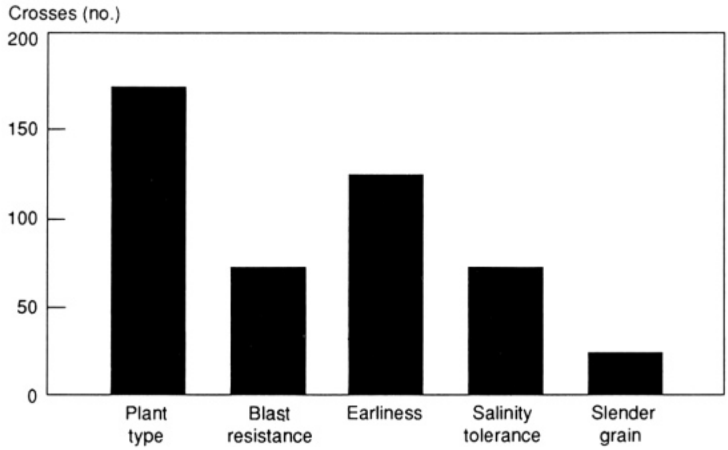
maturing short-statured mutants. Selection in the M_3 - M_5 generations identified 16 promising mutants.

Multilocation yield evaluation

Promising lines selected from advanced generations, IRTP nurseries, and other sources are grouped into medium and early and subjected to three stages of testing: preliminary, regional, and final yield trials. They are tested under both normal and saline soil conditions over locations.

The most promising lines identified in the final yield trials are included for extensive on-farm verification and national yield trials (Table 4).

All entries in the various trials are intensively screened for reaction to blast (under blast nursery and greenhouse conditions), salinity tolerance in lysimeters, and grain quality.



4. Order of priority for crossing rice varieties in Egypt's varietal improvement program, 1981-85.

Table 2. Volume of pedigree nursery (rice) grown at Sakha, Egypt, 1983-85.

Generation	Pedigree lines (no.)			
	1983	1984	1985	Average
F_3				
Normal soils	699	853	1759	1104
Saline soils	761	255	40	342
F_4				
Normal soils	707	261	684	550
Saline soils	112	488	367	322
F_5				
Normal soils	823	520	212	518
Saline soils	62	45	245	117
Total				
Normal soils	2229	1634	2655	2172
Saline soils	935	758	652	782

Recent achievements

Following the severe blast outbreak in 1984, rice breeding research was intensified, placing major emphasis on combining high levels of blast resistance in all future varieties with high yield potential, nonlodging habit, and short duration. The volume of crosses was increased, parental choice diversified, and intensive screening done of the entire breeding material, from the F_3 generation, and all entries in the yield trials, for blast reaction. This led to the identification of several blast-resistant lines combining all desired agronomic and quality features and of diverse donor sources for resistance (Table 5).

Table 3. Nurseries evaluated at Sakha, Egypt, in the International Rice Testing Program (IRTP), 1985.

Nursery [a]	Entries (no.)	Selections (no.)
IRYN-VE	30	4
IRYN-E	30	8
IRON	350	27
IRSATON	100	4
IRBN	400	–
Total	910	43

[a]IRYN = international Rice Yield Nursery, VE = Very Early, E = Early, IRON = International Rice Observational Nursery, IRSATON = International Rice Salinity and Alkalinity Tolerance Nursery, IRBN = international Rice Blast Nursery.

Table 4. Composition of various yield trials of rice in multilocation testing of promising lines, Egypt.

Trial	Entries (no.)	Location
Preliminary medium duration	20·30	Sakha
Preliminary short duration	20-30	Sakha
Preliminary salinity tolerance	20-30	Sakha, Sirw
Regional medium duration	12-16	Sakha, Gemmiza, Zarzora
Regional short duration	12-16	Sakha, Gemmiza, Zarzora
Final medium duration	8-10	Sakha, Gemmiza, Zarzora, Sirw
Final short duration	8-10	Sakha, Gemmiza, Zarzora
Final salinity tolerance	8-10	Sakha, Sirw
On-farm trials	6-8	20 districts
National trials	6-10	3 colleges and 3 research stations

Six promising strains were identified in the multilocation yield trials: IR1626-203, GZ1108-4-1, GZ1368-54, GZ1394-10-1, GZ2175-5-6, and IR19743-46. Resides their high yield potential and high level of resistance to blast, these lines are 1 to 3 wk earlier, are nonlodging, and have acceptable grain quality (Table 6).

Studies of the relative performance of the 6 most promising entries with reference to yield and reaction to blast over a 4-yr period, from 1983 to 1986, reveal IR1626-203 (IR22/IR24) to be consistently the highest yielder (Table 6). Its mean yield in the national yield trials over 4 yr and 4 locations is 9.9 t/ha as compared with those of the check varieties Giza 171 (8.9 t/ha), Giza 172 (8.6 t/ha), and IR28 (8.7 t/ha). Its highly favorable starch characteristics, such as amylose content, medium gelatinization temperature, and relatively soft gel consistency, make cooking and keeping qualities of this strain more acceptable to Egyptian consumers than any other long-grain strain available today. By virtue of its higher yield and markedly earlier maturity, nonlodging habit, and acceptable quality, it has been recommended for general cultivation as a new long-grain variety, Giza 181, from 1987.

GZ1394-10-1 (IR28/IR1541//Giza 180/Giza 14) is another very promising strain with short grain, a high level of blast resistance, truly nonlodging habit, high

Table 5. Some promising donor sources identified in rice germplasm for leaf and neck blast resistance in Egypt.

Leaf blast		Neck blast	
Resistant	Tolerant	Resistant	Tolerant
Japonica			
Toride 1	Mizuho	Toride 1	Bai-Ke-Song
YNA-282		YNA-282	Kaohsuing-141
Yomji No. 1		Mizuho	GZ2171-34-2
Bai-Ke-Song		Ai-Cheng 4	GZ172M94-1-9-3
Ai-Cheng 4		Ai-Keng 23	
Ai-Keng 23		Yomji No. 1	
Kaohsuing-141		Kim Rad F 87	
Kim Rad F 87			
Indica japonica			
GZ1394-10-1	GZ2175-5-6	GZ1394-10-1	GZ2175-5-6
GZ2175-5-3	GZ2175-5-4	GZ2175-5-1	GZ2175-5-4
Suweon 287		GZ2175-5-3	
Suweon 294		Suweon 287	
Milyang 23		Suweon 294	
Milyang 49		Milyang 23	
Milyang 54		Milyang 49	
Iri 346		Milyang 54	
		Iri 346	
Indica			
GZ1368-5-4		GZ1368-5-4	Si-Pi-692033
Co 34		Co 34	
BG35-2		BG35-2	
UPR102–8		UPR103-8	
IRGA409		IRGA409	
Si-Pi-692033		IR1626	
IR1626		IR28	
IR28			

and stable yield potential, and high milling percentage. Recently, pathologists have found this strain to possess a consistently high level of partial resistance to disease. This strain has also been recommended for general cultivation as a new short-grain variety, Giza 175, from 1987.

GZ1368-54 (IR1615-31/BG94-2) is a high-yielding strain with high levels of tolerance for soil salinity, very high levels of resistance for nearly all known isolates and races of blast found in Egypt, and medium grain type. It has been recommended for extensive field-testing in 1987 over large areas in appropriate governorates.

Future strategies

The goals for rice breeding in Egypt are to develop varieties with higher yield potential, resistance to blast and stem borers, short stature, early maturity, salinity tolerance, and acceptable grain quality. These characteristics will be of great value in overcoming some of the constraints and problems in rice production in Egypt today.

Table 6. Yield and ancillary characteristics of the most promising rice strains in Egypt, 1983-86.

Strain	Parentage	Yield (t/ha)	Trials (no.)	Plant height (cm)	Duration (d)	Blast reaction score[a]	Grain shape	Milling (%)
Giza 171	Nahda/Calady 40	8.9	29	138	159	4-7	Short	72.3
Giza 172	Nahda/Kinmaze	8.6	56	130	147	4-7	Short	71.6
IR28	IR833-6/IR1561-149//IR1737	8.7	35	99	134	1-2	Long	70.0
IR1626-203	IR22/IR24	9.9	30	95	142	1-2	Long	69.9
GZ1108-4-1	Co 34/GZ472	9.5	17	109	133	1-2	Medium	69.3
GZ1368-5-4	IR1615-31/BG94-2	8.9	15	107	139	1-2	Medium	69.2
GZ1394-10-1	IR28/IR1541//Giza 180/GZ14	9.0	14	93	136	1-2	Short	70.4
GZ2175-5-6	Calrose 76/Giza 172//G214	9.5	8	109	147	1-2	Short	71.8
IR19743-46-2	IR1929-192/IR10176-79	8.2	11	96	117	1-2	Long	70.1

[a] Blast reaction score = 1-3, resistant, 4-9, susceptible.

The following strategies are recommended to achieve such breeding goals:

1. *Blast resistance.* Following the sudden outbreak of blast in 1984, intensified rice breeding research has identified numerous sources of resistance to blast, some of which have already been utilized in the crossing program. However, several new sources of resistance should be introduced to diversify parental choice. Advanced breeding lines should be evaluated in IRRI-IRBN and at several locations over several seasons to identify those with a broad spectrum of blast resistance.
2. *Short stature.* Varietal improvement has successfully developed high-yielding, short-statured varieties. At present over 90% of the breeding lines are of short stature. The main sources utilized are lines and varieties from IRRI, having the *Sd1* gene from the DGWG variety from China. With the start of the Rice Research and Training Project in 1980, an attempt was made to transfer the *Sd1* gene from Californian short-stature varieties, Calrose 76, M-101, and M9, to Giza 171, Giza 172, and Giza 159. Unfortunately, all lines derived from these crosses (GizCal) became highly susceptible to blast in 1984. Therefore, diversification of short-stature genes through introduction and induced mutation is highly recommended.
3. *Early maturity.* Present commercial varieties in Egypt mature in 150-160 d. Earlier maturing varieties with a growth duration of 130-140 d are being developed. Early maturity is important for a) stabilizing yield, b) economizing on water use, and c) increasing cropping intensity. Several sources of earliness are being used in the hybridization program, such as IR28, IR58, IR9129, IR19743, Fujihikari, and Ai-nan-tsao. It would be desirable to develop or identify early-maturing varieties, of about 120 d duration, without sacrificing the yield potential (IRRI 1982).
4. *Salinity tolerance.* Salinity-tolerant varieties are badly needed for presently cultivated saline soils and newly reclaimed lands. Giza 159 and Giza 172 have a good level of such tolerance. However, varieties with higher levels of salinity tolerance and blast resistance are needed. Numerous improved breeding lines have been developed at IRRI (IR2153-26, IR10198, and IR13168) and locally (GZ587 and GZ1368). Methods to screen for salinity tolerance in the early generations (F_2 - F_4) should be improved.
5. *Grain quality and stem borer resistance.* Evaluation of quality characteristics as well as stem borer resistance in the advanced generations will be continued.
6. *Participation in IRTP.* Participation in IRRI-IRTP nurseries, such as IRYN-VE, IRYN-E, IRON, IRBN, and IRSATON, should be continued (IRRI 1982).
7. *Collaboration with IRRI.* Collaboration with IRRI should be continued, to grow the single-cross F_1s and make topcrosses with selected parents, as well as to enrich the local rice germplasm.
8. *Basic studies.* Basic studies should be conducted on the biochemical, physiological, and genetic aspects of traits important to the Egyptian Rice

Improvement Program, such as blast resistance, salinity tolerance, stem borer resistance, and milling quality.

9. *Heterosis breeding.* In China during the recent past, rice hybrids based on single crosses between cytoplasmic male-sterile lines and fertility restoration systems have spread rapidly and are reported (Efferson 1984) to have a yield advantage of about 20% over pureline varieties. Nevertheless, several problems still exist in heterosis breeding of rice: a) sources of cytoplasmic male-sterility are limited, b) the cost of F_1 seed is high, and c) heterosis is expressed in only a few hybrids (Khush and Jena 1986). In Egypt, preliminary investigations with some of the indica hybrids involving Chinese male-sterile lines revealed hybrids to have no significant yield advantage over our best japonica varieties. Yet a few, like RAX2406 and V20A/ Milyang 54 outyielded our best varieties by 10-15%. Work is under way to study the possibility of transferring the male-sterility factor from Chinese lines and restorer genes from indica-japonica sources to our best varietal backgrounds.

11. *Tissue culture.* Possible application of tissue culture techniques to accelerate the breeding procedures will be studied in collaboration with IRRI (Zapata et al 1986). Anther culture has become handy for rice breeders. Significantly, Chinese scientists have bred a couple of varieties for general cultivation through this technique (Han and Qiquan 1986). With the development of improved facilities in the Rice Research and Training Center (RRTC) at Sakha, the anther culture technique will be utilized in the rice breeding program.

12. *Training.* Several Egyptian rice scientists have been trained during the last 5 yr under the Rice Research and Training Project, However, further training in specific areas such as biotechnology, breeding for disease and insect resistance, and computer and biometrical analysis, is needed.

13. *Expanding the area under rice production.* Since arable land is the most limiting factor in Egyptian agriculture, efforts should be made to take advantage of areas where water is available, such as: New Valley, nondesert saline and newly reclaimed areas, and the foreshore areas of Aswan High Dam Lake.

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Commercial exploitation of hybrid vigor in rice

Yuan Longping

China is the first country in the world to exploit heterosis in rice commercially. Hybrid rice yields about 20% more than the best nonhybrid varieties; in 1986, it was planted in over 9 million hectares, or 27% of the total rice area, yielding an average of 6.5 t/ha. Many different types and combinations of both indica and japonica hybrids have been developed to suit a wide range of agroclimatic conditions in the major rice-growing regions of China. The expression of heterosis in hybrid rice involves four aspects: better morphological traits, higher physiological efficiency, multiple resistance to diseases and insects, and wider adaptability than nonhybrids. Our experience in developing the genetic tools (the A, B, and R lines) has shown that: a) distant hybridization is the effective way to breed A lines, b) screening bytestcross is a convenient way to obtain R lines, and c) R genes as well as male-sterile cytoplasm can be transferred to any desired varieties. Hybrid rice seed is currently produced on 0.15 million hectares, yielding an average 1.7 t/ha. The field area ratio between A line multiplication, F_1 seed production, and commercial production is 1:50: 3000. The key points of seed production techniques are synchronization, isolation, proper row ratio, spraying of GA_3, and supplementary pollination. The correct techniques must be followed and a well-organized system maintained for successful hybrid seed production. Outside China, initial results from trials at the International Rice Research Institute in the Philippines and in some national programs indicate possible yield increases of 1 t/ha. Hybrid seed production techniques developed in China seem adaptable in other countries; nevertheless, some problems must be solved before hybrid rice can go into commercial production.

The phenomenon of heterosis in rice has been reported by many scientists since 1926 (Jones 1926). However, the efforts outside China to make use of this phenomenon in commercial production failed either due to lack of effective genetic tools or difficulties in hybrid seed production, or because there was no significant heterosis in japonica hybrids (Koga 1986). These problems were finally solved in the 1970s by the unremitting efforts of Chinese scientists.

In China, research on hybrid rice was initiated in 1964. The genetic tools (i.e., cytoplasmic male-sterile, maintainer, and restorer lines) essential to developing F_1 hybrids were successfully developed in 1973. Hybrid varieties with remarkable heterosis were identified in 1974, and seed production techniques were fundamentally established in 1975. In 1976, hybrid rice was released to farmers. Since then, the acreage of hybrid rice has increased rapidly each year (Table 1). So far, China is the only country in the world to exploit heterosis in rice commercially.

Distribution, area, and yield potential of hybrid rice in China

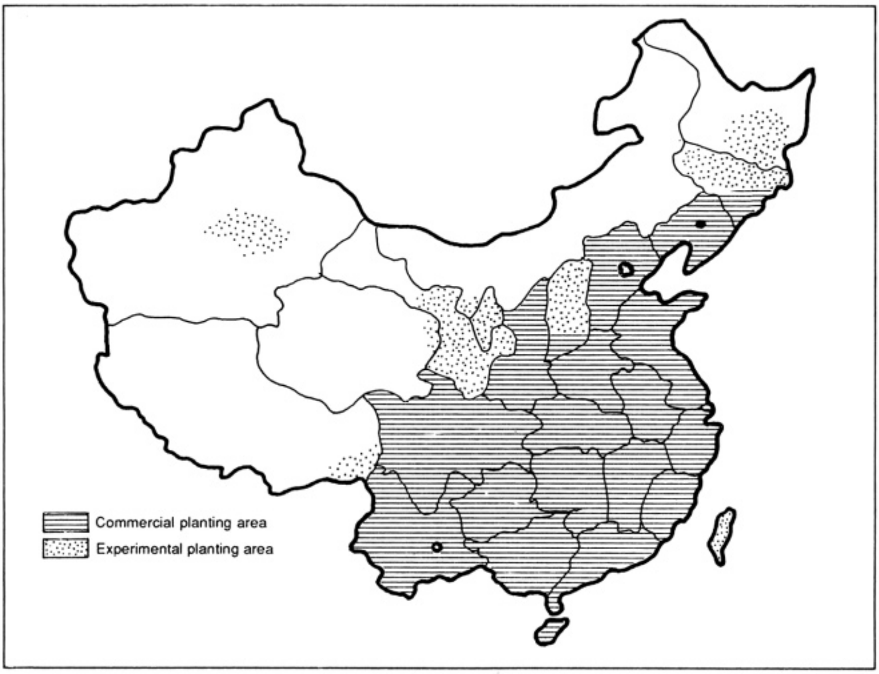
At present, China has about 32 million hectares under rice, of which more than one-fourth is hybrid rice. This is planted under a wide range of agroclimatic conditions all over the major rice-growing areas, from Liaoning Province (cold temperate region, latitude 43°N) to Hainan Island (tropical region, 18°N) and from Shanghai (longitude 125°E) to Yengnan Province (95°E) (Fig. 1). Therefore, there are many different types as well as combinations of hybrid rice suitable for various climates and soil conditions.

1. Photoperiod-sensitive indica hybrids with long growth duration, such as Zhen-Shan 97A/IR30, are used as late-season crops in South China.
2. Medium-maturity indica hybrids, such as Zhen-Shan 97A/IR24 and V20A/IR26, are planted as both early- and late-season crops in the southern part of China. In the midsouth (Yangtze Valley) they are widely cultivated as late-season crop in the double-cropped rice areas, or as medium-season crops in the single-cropped areas.
3. Early-maturing indica combinations, such as V20A/26-Zhe-Zao and V20A/IR9761-19-1-64, are used as the first crop in double-cropping regions south of the Yangtze River.
4. Early-maturing japonica hybrids are distributed north of the Yellow River.
5. Japonica hybrids with medium or long growth duration are grown as the second crop in the Yangtze River basin.

It has been proven that hybrid rice varieties have 20-30% yield advantage over conventional pureline varieties, if proper cultivation techniques are adopted. In 1985, for example, hybrid rice yields averaged about 6.5 t/ha versus only 5.2 t/ha for total rice yields (Table 2).

Table 1. Harvested area of hybrid rice in China, 1976-86.

Year	Area (million ha)
1976	0.15
1977	2.13
1978	4.33
1979	5.07
1980	4.93
1981	5.10
1982	5.60
1983	6.75
1984	8.84
1985	8.43
1986	9.01



1. Distribution of hybrid rice area in China, 1983.

Table 2. Rice area and yield in China, 1985.[a]

Rice type	Area (million ha)	Production (million t)	Yield (t/ha)
Total rice	31.8	166.9	5.2
Hybrid rice	8.4	54.6	6.5
Hybrid rice/total rice	26.4%	32.7%	123.4%
Hybrid rice/conventional rice			134.9%

[a]Statistics from the Ministry of Agriculture, Animal Husbandry, and Fisheries, China, 1985.

In recent years, medium-duration hybrid rice has occupied 1.9 million hectares in Sichuan Province and 0.8 million in Jiangsu Province. Average yield in both provinces was about 7.5 t/ ha. Hunan Province grows about 1.3 million hectares of hybrid rice as a second crop, with an average yield of 6 t/ ha, while the average yield of conventional varieties is 4 t/ha (Table 3). The yield of japonica hybrids in Liaoning Province ranged from 7.5 to 8 t/ha. In addition, there are a number of high-yield records in small areas; for example:

- The medium-duration hybrid Shan-You 2, grown on an army farm south of Beijing from 1983 to 1986, yielded an average of 11.3 t/ha.

Table 3. Second-crop rice area end yield in Hunan Province, China, 1986.[a]

Rice type	Area (million ha)	Production (million t)	Yield (t/ha)
Total rice	2.0	10.7	5.8
Hybrid rice	1.3	7.4	5.9
Hybrid rice/total rice	63.3%	69.3%	109.3%
Hybrid rice/conventional rice			130.4%

[a] Data from the Hunan Agriculture Bureau, Hunan, 1986.

- The maximum yield of japonica hybrids (Li-You 57) in Liaoning Province was 13.7 t/ha.
- The maximum yield of indica hybrids in Jiangsu Province was 14.4 t/ha for a medium-duration crop and 22.6 t/ha for double-cropped hybrid rice in Fujian Province.

The cumulative yield increase from cultivation of hybrid rice from 1976 to 1985 is over 94 million tons. Clearly, the development of hybrid rice is of strategic significance to increasing food production in China.

Research work on hybrid rice

Three essential technical criteria must be fulfilled in order to make hybrid rice a commercial success:

1. Developing suitable cytoplasmic-genetic male-sterile (CMS), maintainer, and restorer lines, or the "three-line'' approach.
2. Breeding F_1 hybrids that possess strong heterosis over the best commercial varieties available.
3. Producing large amounts of hybrid seed by cross pollination.

Three-line breeding

The first set of CMS lines, called the "WA" type, was developed in the early 1970s through wide crosses, using a male-sterile wild rice (*O. sativa* f. *spontanea* L.) as female parent. After that, a number of other types of CMS lines as well as their maintainers and restorers were found. At present, seven types of CMS lines are used in commercial production (Table 4).

Our experience in the development of three-line breeding could be summarized as follows:

1. The effective way to breed a cytogenic system of CMS lines is through distant hybridization, using primitive types as the cytoplasmic source and advanced breeding lines originating from temperate regions as the nuclear source.
2. Screening existing better varieties or lines by making testcrosses with CMS lines is a convenient way to obtain restorer lines for indica rice. This is

Table 4. CMS lines from different cytoplasmic sources being used commercially for hybrid rice seed production.

Type	Cytoplasm source		Representative CMS lines	Area (thousand ha)	Remarks
	Species	Strain or variety			
WA	*O. sativa* f. *spontanea*	Male-sterile wild rice	Zhen Shan 97A, V20A	8,100	
GA	*O. sativa* L.	Gambiaca	Chao Yang 1A	70	
Di	*O. sativa* L.	Dissi	Di Shan A	70	Indica,
DA	*O. sativa* f. *spontanea*	Dwarf wild rice	Xie Qin Zao A	50	sporophytic
HI	*O. sativa* f. *spontanea*	Common wild rice	Qin Si Ai A	30	Indica, gametophytic
BT	*O. sativa* L.	Chinsurah Boro II	Li Ming A	110	Japonica,
TI	*O. sativa* L.	O-Shan-Ta-Bai	Lu Qian Xin A	10	gametophytic
Other				<10	

because the frequency of R lines in indica varieties is rather high—about 20% (Yuan and Virmani 1986).

3. Restorer genes as well as male-sterile cytoplasm can be transferred to any desired varieties by using various crossing methods.

Heterosis in rice

From 1972 to 1974, using CMS lines as the female parents, the Hunan Academy of Agricultural Sciences (HAAS) made 53 cross combinations and studied heterosis in rice. Selection and identification of these materials led to five conclusions:

1. Over 95% of these combinations outyielded the parents by 30-70%.
2. Half of the combinations gave 20-30% increase in grain yield over the standard improved varieties.
3. Long-duration hybrids gave higher yields than short-duration ones, and indica types gave higher yields than japonicas.
4. The yield of cross combinations made with closely related parents was similar to that of each parent.
5. The yield in the F_2 generation was 50% lower than that in the F_1.

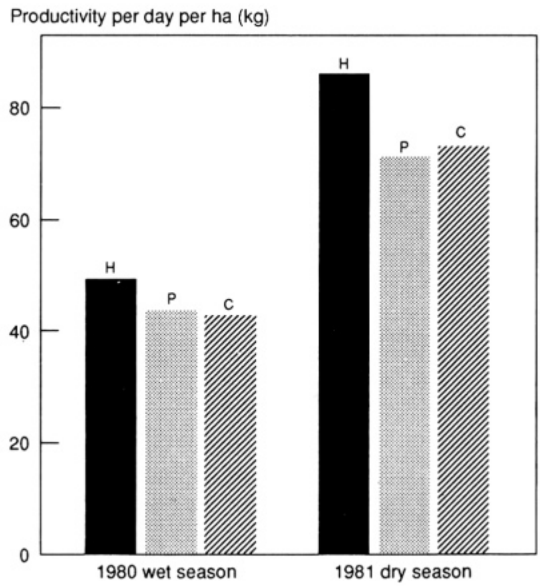
The best of these early hybrids, such as Nan-You 2 and Nan-You 3, were chosen for a hybrid rice yield trial on 7 ha at HAAS in 1975. The trial was a remarkable success: the best conventional variety yielded 6.5 t/ha, but hybrid yields averaged 7.8 t/ha.

According to our studies, the expression of heterosis in hybrid rice involves four main aspects:

1. Better morphological traits, such as a vigorous root system, larger panicles, heavier grains, stiffer culms, and better plant type (Table 5).
2. Higher physiological efficiency, such as photosynthetic function, root activity, rapid growth rate, etc., which results in higher productivity per day per hectare (Fig. 2).

Table 5. Performance of high-yielding hybrid rice variety Shan-You 63 in Suinin County, Hunan Province, China, 1985.

Growth duration (d)	Plant height (cm)	Panicles (no./m^2)	Spikelets (no./panicle)	Seed set (%)	1000-grain weight (g)	Yield (t/ha)
138	110	313	169	85.1	31	12.3



2. Productivity/day per ha of F_1 rice hybrids (H), their parents (P), and check varieties (C). IRRI 1980-81 wet and dry season trials.

3. Multiple resistance to major diseases and insects because of the dominant or partial dominant nature of most resistance genes (Table 6).
4. Wider adaptability, due to broader genetic background, especially in some adverse soil (drought, saline-alkali) conditions, where hybrids perform much better than conventional varieties.

Hybrid seed production

The procedure for hybrid rice seed production differs from that of pureline varieties. It involves two steps:

1. Multiplication of CMS lines.
2. Production of F_1 hybrid seed.

At present, the field area ratio between CMS line multiplication, hybrid seed production, and commercial production is about 1:50:3000.

Table 6. Disease and insect pest resistance identification for hybrid rice Wei You 64 (V20/IR761-19-1). [a]

	Disease susceptibility [b]				
Period	Blast	Leaf blight	Sheath blight	Yellow dwarf	Brown planthopper
1982 late season		S	MR	MR	
1983 late season	MR	MR	LS	R	MR
1984 late season	R	S	LS		

[a]Data from the national regional trial. [b]S = susceptible, LS = less susceptible, MR = moderately resistant, R = resistant.

The key points in the technique for hybrid seed production are:

1. Synchronization of heading stage of male and female parents.
2. Distance or time isolation from foreign pollen sources.
3. Proper row ratio and row orientation.
4. Flag-leaf clipping to remove the main obstacle to cross pollination.
5. Gibberellin sprays to induce emergence of the basal part of panicles of CMS lines from the leaf sheath.
6. Supplementary pollination by rope-pulling or rod-shaking.

In the early years, before 1981, hybrid seed yield averaged only about 0.75 t/ha. However, seed production techniques are being constantly refined, and seed yields have increased significantly. In 1986, for instance, the total land for hybrid rice seed production in China was about 0.15 million hectares and the average yield was 1.7 t/ha. In Hunan Province, the average yield of 20,000 ha is 2.3 t/ha. In Zhong-Jiang County, Sichuan Province, the average yield of 200 ha reached nearly 4.5 t/ha. The seeding rate for commercial hybrid rice is only about 30 kg/ ha compared with 110 kg/ ha for nonhybrid rice varieties.

Seed production has been increased mainly by:

1. Transplanting two seedlings per hill instead of one for CMS lines.
2. Expanding the row ratio between male and female parents from 1:6-2:8 to 1:8-2:12 or higher.
3. Using a higher dosage of GA_3 (75 g/ha) to make the whole panicle grow taller than the flag leaf so that leaf clipping is no longer needed.
4. Using good and special field management to promote vigorous growth in the early and middle stages but to inhibit the growth of flag leaves in the late stage.

Hybrid research outside China

Encouraged by the achievements in China, rice breeders at the International Rice Research Institute (IRRI) in the Philippines and in national programs in other countries are exploring the potential of this technology for increasing rice yields further.

Of more than 400 experimental hybrid combinations tested at IRRI to date, several significantly outyielded the best varieties in the trials. Table 7 shows the mean yields of the best experimental hybrids compared with the mean of the best check varieties in trials; on the whole, the best hybrids outyielded the best check varieties by 20-40%.

Outside IRRI also, some experimental F_1 hybrids showed an average 13-23% yield advantage over the best check varieties in the trials conducted during 1980-85 (Table 8). Some combinations, such as V20A/ Milyang 46, V20A/ IR54, Zhen-Shan 97A/IR2307-247-2-3, and IR48531A/IR54, showed superior performance at more than one location.

Table 7. Yield of the best experimental rice hybrids and extent of their superiority over the best check variety in trials at the International Rice Research Institute, Los Baños, Philippines.

Hybrid	Year	Yield (t/ha)	Percentage of best check
	Wet season		
IR11248-242-3/1R15323-4-2-1-3	1980	5.9	122
Zhen Shan 97A/IR13420-6-3-3-1	1981	6.2	123
Zhen Shan 97A/IR54	1982	4.4	113
IR46828A/IR54	1983	5.3	112
IR46828A/IR54	1984	4.5	140
IR54752A/IR13419-113-1	1985	5.1	107
Mean		5.2	120
	Dry season		
IET3257/IR2797-105-2-2-3	1981	10.4	132
IET3257/IR2797-105-2-2-3	1982	8.9	135
IET3257/IR42	1983	9.6	124
IR29799-17-3-1-1A/IR2797-125-3-2-2	1984	7.2	108
IR46828A/IR13524-21-3-3-3-2-2	1985	5.4	123
IR54754A/IR46R	1986	7.4	119
Mean		8.2	123
Overall mean		6.7	122

Table 8. Yield of the best experimental rice hybrids and extent of their superiority over the best check variety in trials conducted in Indonesia, Korea, and India, 1980-85.

Country	Trials (no.)	Yield of best hybrid (t/ha)		Percentage of best check	
		Range	Mean	Range	Mean
Indonesia	11	4.2- 8.9	6.2	102-170	123
Korea	9	8.1-11.5	9.0	97-142	113
India					
Subtropics	5	6.2- 9.8	8.1	103-130	120
Tropics	14	3.3- 7.3	5.6	91-132	112
Overall	39	3.3-11.5	7.1	91-170	116

Some hybrids commercially grown in China were introduced into the USA in 1981 and evaluated at several locations in five states. The hybrids yielded 38-40% more than the check varieties (Table 9, 10) (Calub 1985).

The hybrid seed production techniques developed in China have been tested in experimental seed production plots at IRRI and in Indonesia and Korea. Seed yields ranged from 0.1 to 1.6 t/ha at IRRI, and from 0.6 to 1.8 t/ha in Indonesia. Korean rice scientists obtained 0.75-1.5 t/ha seed yields during 1985 (Yuan and Virmani 1986). Seed yields depend on the synchronization of flowering of male and female parents, on the season, and on the agronomic and floral traits of parental lines. Generally, seed yields tend to increase as seed producers become more experienced. The results from IRRI, Indonesia, and Korea indicate that the seed production techniques used in China can be adapted for use outside China.

However, the development of hybrid rice outside China presents two major problems:

1. The existing CMS lines as well as combinations used in China are not suited to tropical areas because of their poor resistance to the local diseases and insects. Therefore, it is necessary to develop new CMS lines by transferring the cyto-sterility system of “WA” or other types into lines with multiple

Table 9. Percent yield increase of the rice hybrid RAX2414 over the variety Mars (3-yr average) in southern USA.

Location	Yield (t/ha)		Yield increase (%)
	RAX2414	Mars	
Stoneville, MS	10.4	6.8	53
Crowley (LSU), LA	11.0	7.9	39
Crowley (ASC), LA	9.4	6.6	42
Stuttgart, AR	9.0	7.2	24
Beaumont, TX	9.6	6.4	50
Belle Glade, FL	6.6	4.9	31
Mean	9.3	6.7	40

Table 10. Percent yield increase of the hybrid RAX2405 over the variety Lemont (2-yr average) in southern USA.

Location	Yield (t/ha)		Yield increase (%)
	RAX2405	Lemont	
Stoneville, MS	7.1	4.9	43
Crowley (LSU), LA	10.4	7.3	43
Crowley (ASC), LA	8.6	6.3	38
Stuttgart, AR	9.7	6.7	45
Beaumont, TX	10.9	8.6	27
Belle Glade, FL	6.1	4.4	40
Mean	8.8	6.4	38

Table 11. Grain quality of rice hybrid L 301A/R29.

Grain type	Alkali value	Amylose content (%)	Milling yield (%)		Degree of white belly
			Milled rice	Head rice	
Long	2.0	23	70	57	0-1

resistance. This work is being done extensively at IRRI, and some elite CMS lines that appear to be well adapted to the tropics have been developed.

2. The grain quality of hybrid rice is unacceptable in some countries. However, this problem does not seem too difficult to solve. Our recent studies have shown that with appropriate selection of parents, hybrids possessing desired grain quality as well as high yield can be produced (Table 11).

In brief, prospects for developing hybrid rice outside China look bright. We predict that hybrid rice will be put into commercial production in some countries in the near future.

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Varietal performance in international irrigated rice trials

D. V. Seshu

The International Rice Testing Program (IRTP) coordinated by the International Rice Research Institute has established a global network for exchange of elite rices among rice scientists around the world and evaluation of those rices under diverse environments. The IRTP nurseries have been designed for evaluation under different cultural systems and for screening for varietal resistance to important biological, physical, and chemical stresses. Among those, one set of the nurseries is targeted to irrigated conditions. Worldwide evaluation of the irrigated trials since the inception of IRTP in the mid-1970s identified several promising varieties of different growth durations, some of which have shown a wider adaptability. Varieties have been identified for tolerance for extreme temperatures and adverse soil conditions. Several of the promising lines possess resistance to one or more of the major diseases and insects. The testing program in Africa identified varieties for irrigated conditions specifically suited to the region. Some of the entries in the irrigated nurseries have been released for cultivation in different countries, and several have been used as parents in various national breeding programs.

A network for rice improvement scientists around the world has been systematized with the creation of the International Rice Testing Program (IRTP) in 1975, coordinated by the International Rice Research Institute (IRRI) and funded by the United Nations Development Programme. The main objectives of the IRTP are to exchange elite genetic materials from different countries and from IRRI among rice scientists around the world and to provide a testing mechanism for the breeding material generated by individual rice improvement programs. This multicountry cooperative program also provides an opportunity to identify genetic donors for resistance to various biological, physical, and chemical stresses and to monitor genetic variation in the major pathogens and insects that threaten rice production.

The international nurseries are broadly grouped into two categories, namely, the target environment nurseries and the stress screening nurseries. The target environments for which the nurseries are composed and tested include 1) irrigated and 2) rainfed; the rainfed category in turn includes a) upland, b) lowland (shallow water), c) deep water, d) floating rice, and e) tidal wetlands.

This paper summarizes the salient findings from the IRTP irrigated nurseries evaluated across locations in different rice-growing countries since the inception of the program in 1975. The irrigated trials include both yield and observational nurseries. The yield nurseries are divided into 4 maturity groups—very early (about 100d), early (100-120 d), medium (120-140 d), and late (more than 140 d)—and only the nurseries under the first 3 groups are organized on a regular basis. The observational nursery has different subsets, also based on maturity. Irrigated nurseries are also organized specifically for low-temperature and arid regions. Screening nurseries for diseases and insects of relevance include those for identifying resistance to blast, bacterial blight, tungro virus, stem borer, gall midge, brown planthopper, and whitebacked planthopper. A nursery is composed for screening against salinity and alkalinity. A special nursery, named the International Rice-Weather Yield Nursery (IRWYN), was organized during 1982-84 to study the impact of major climatic factors on the growth and yield of irrigated rice.

Irrigated yield nurseries

Varietal performance

The IRTP yield nurseries are generally conducted in a randomized complete block design with three replications. The cultural practices are based on location- and season-specific requirements. Insecticide application is restricted to a need-based minimum. The entries that performed well across locations and years in different maturity groups are as follows:

- Very early: IR50, IR9729-67-3, UPR103-80-1-2, BG367-4, BG367-7, IR25588-7-3-1, IR25924-51-2-3
- Early: IR36, KAUl727, IR9828-91-2-3, C1321-9, Taichung sen yu 285, IR13429-196-1, IR13240-108-2-2
- Medium: IR42, IR54, BR51-282-8, BG90-2, BG400-1, IR13540-56-3-2-1, IR21820-154-3-2, IR28118-138-2-3
- Late: RP975-109-2, CR149-3244-198, CR1009, IR4625-132-1-2

The relative yield ranks of these entries in different years are summarized in Table 1. The entries that produced the highest average yields across locations in the 1985 yield nurseries were:

- Very early: IR50, IR25924-51-2-3, IR32429-47-3-2, UPR103-80-1-2
- Early: Chianung sen yu 26, KAU1727, C662083, IR13240-108-2-2, Si-pi 692033, IR36
- Medium: BG380-2, BR153-2B-10-1, IR21820-154-3-2, IR28118-138-2-3

The agronomic traits and reactions to diseases and insects of the above entries are furnished in Tables 2 to 4.

Some entries such as IR36 and BG367-4 performed well under both irrigated and rainfed upland conditions. IR36 has consistently been among the top five entries in the IRTP irrigated trials since 1975. It was included in the international upland rice yield trials from 1976 to 1979, and was among the top five entries in three of those years. Likewise, BG367-4 was among the highest yielding entries in the irrigated trials in different years and was the overall highest yielding entry in the 1985 upland yield nursery.

Table 1. Yield ranks of promising entries in international irrigated rice yield trials in different years.

Entry	Yield rank							
	1978	1979	1980	1981	1982	1983	1984	1985
			IRYN[a] (Very Early)					
BG276-5			10	4	4			
BG367-4				1		3	4	
BG367-7			4	4	4			
IR25588-7-3-1						3	4	11
IR25924-51-2-3						1	8	3
IR50				2	1	3	1	1
IR9729-67-3			1	2	2	3		
UPR10380-1-2					4	2	4	5
No. of locations			30	38	41	47	45	38
No. of entries			20	25	28	30	30	24
			IRYN (Early)					
Chianung sen yu 13			5	4	11			
IR13429-196-1			2	4	3			
IR36	2	4	2	2	3	16	8	4
IR9828-91-2-3			1	2	3			
KAU1727						1	2	3
Taichung sen yu 285				1	7	4		
No. of locations	30	43	41	52	38	37	41	34
No. of entries	28	28	28	20	28	29	30	25
			IRYN (Medium)					
BG400-1			5	15	2	1		
BR51-282-8	6	1	1	2	7			
IR13540-56-3-2-1			1	1	1			
IR21820-154-3-2-2-3						1	1	1
IR28118-138-2-3						1	4	4
IR42	1	5	5	4	8	9	14	22
IR54	6	5	1	2	2			
No. of locations	28	37	29	37	32	30	25	25
No. of entries	28	28	28	29	28	30	30	28

[a]IRYN = International Irrigated Rice Yield Nursery.

Yield trends

The highest yields obtained for any entry at any location over different years ranged from 7.7 to 10.4 t/ha for the very early group (1980-85), 8 to 10.8 t/ha for the early group (1975-83, and 7.6 to 12.8 t/ha for the medium group (1975-85). The particulars of the varieties and locations relative to those highest yields are given in Tables 5 to 7.

Both the preflowering and postflowering durations are relatively longer at the higher latitudes where the temperatures during the crop season are lower than in the tropics and favor higher yields. For example, in the 1984 yield trial of early-maturing lines, a set of 7 sites located at the lower latitudes (5-25° N) had a mean yield of 4.7 t/ha and flowering duration of 86 d, whereas a set of the same number of sites at the higher latitudes (27-35° N) recorded a mean yield of 6.8 t/ha and flowering duration

Table 2. Agronomic and stress resistance characteristics of entries in the 1985 IRYN (Very Early) that produced the highest average yields over 46 locations in 19 countries.

Designation	Cross	Days to flowering (no.)	Plant heigh (cm)	Panicles (no./m^2)	Reaction to stress[a]									Amylose content
					BI	NBI	LSc	BB	ShR	GID	WBPH	GLH	RWM	
IR50	IR2153/IR28//1R36	86	82	419	6	4	8	5	6	6	7	3	5	High
Av over local checks	–	87	95	335	6	7	6	4	5	5	7	–	5	–
IR25924-51-2-3	IR10154/IR9129//IR9129	87	86	391	6	6	6	4	5	7	5	3	7	Intermediate
IR32429-47-3-2-2	IR19058/IR9129	86	82	378	3	5	5	4	4	5	5	3	5	High
UPR103-801-2	IR24/Cauvery	83	82	31 3	6	5	5	6	6	6	5	7	5	High

[a]Locations reporting the reactions: BI (leaf blast) – Guangzhou, Los Baños; NBI (neck blast) – Malan, Arce; LSc (leaf scald) – Malan, Arce; BB (bacterial blight) – Los Baños, Omon, Comilla, Titabar, Patna; ShR (sheat rot) – Comilla, Titabar, Malan; GID (glume discoloration) – Malan; WBPH (whitebacked planthopper) – Omon; GLH (green leafhopper) – Los Baños; RWM (rice whorl maggot) – Long Xuyen.

Table 3. Agronomic and stress resistance characteristics of entries in the 1985 IRYN (Early) that produced the highest average yields over 41 location in 15 countries.

Designation	Cross	Days to flowering (no.)	Plant height (cm)	Panicles (no./m^2)	Reaction to stress[a]									Amylose content
					BI	NBL	BB	RTV	SR	ShR	BPH	GLH	CSWM	
Chianung sen yu 26	C632082/Chianung sen 8	100	102	301	5	5	5	8	7	5	8	5	5	Intermediate
KAU 1727	Triveni/IR2061	96	96	305	5	5	5	4	7	5	7	7	3	High
C662083	C632063/Chianung sen yu 7	92	87	299	–	–	–	–	–	–	–	–	–	Low
IR13240-1 08-2-2-3	IR30S/Babawee//IR36	94	86	348	5	7	6	5	5	5	7	7	5	Intermediate
Si-pi 692033	Si-pi 661 044/Si-pi 651 020	95	95	309	3	7	5	8	9	5	7	7	3	Intermediate
IR36	IR1561//4*IR24/ *Oryza nivara* /// CR94-13	92	84	343	5	5	5	8	9	–	4	5	3	High

[a]Locations reporting the reactions: BI (leaf blast) – Bumbwi Sudi; NBI (neck blast) – Nieuw; BB (bacterial blight) – Los Baños, Suphanburi, Cantho, Patna; RTV (rice tungro virus) – Canlaon; SR (stem rot) – Kala Shah Kaku; ShR (sheath rot) – Habiganj; BPH (brown planthopper) – Honiara; GLH (green leafhopper) – Los Baños; CSWM (caseworm) – Omon.

Table 4. Agronomic and stress resistance characteristics of entries in the 1985 IRYN (Medium) that produced the highest average yields over 28 locations in 11 countries.

Designation	Cross	Days to flowering (no.)	Plant height (cm)	Panicles (no.m^2)	Reaction to stress[a]				Amylose content
					Bl	BB	GLH	WBPH	
BG380-2	BG90-2*4/OB677	100	92	252	9	5	5	9	High
BR153-26-10-1-3	IR578-172-2-2/BR1-2-B-19	103	102	281	5	7	9	7	High
IR21820-154-3-2-2-3	IR1529/IR4432//IR7963-30-2	101	94	320	3	5	3	3	Intermediate
IR28118-138-2-3	IR54/IR7963//IR9828	108	96	299	6	4	3	7	High

[a]Locations reporting the reactions: Bl (leaf blast) = Wangdiphodrang; BB (bacterial blight) = Los Baños, Patna; GLH (green leafhopper) = Los Baños; WBPH (whitebacked planthopper) = Dokri.

Table 5, Highest yields obtained in the International Rice Yield Nursery (Very Early), 1980-85.

Year	Highest yielding entry	Yield (t/ha)	Days to flowering (no.)	Location and latitude	Site mean for yield (t/ha)	Mean flowering duration (d)	CV (%) yield
1980	IR19728-9-3-2	7.7	63	Rangsit, Thailand 14 °N	5.2	61	12.1
1981	IR19746-28-2-2	9.6	82	Changsha, China 28 °N	6.8	84	13.8
1982	Reiho (local check)	10.1	106	Sakha, Egypt 31 °N	7.6	101	10.4
1983	IR50	10.4	88	Swat, Pakistan 35 °N	7.9	88	11.3
1984	UPR103-80-1-2	10.2	105	Amol, Iran 36 °N	8.2	106	19.5
1985	Kexuan 93 (local check)	9.7	105	Haukou, China 30 °N	7.6	97	5.9

Table 6. Highest yields obtained in the International Rice Yield Nursery (Early), 1975-85.

Year	Highest yielding entry	Yield (t/ha)	Days to flowering (no.)	Location and latitude	Site mean for yield (g/ha)	Mean flowering duration (d)	CV (%) for yield
1975	IET1444	8.0	73	Pattambi, India 10 °N	6.5	77	12.0
1976	BG34-8	9.0	73	Maha Illupallama, Sri Lanka 8 °N	7.6	78	7.6
1977	Faro 15	8.5	120	Hyderabad, India 17 °N	6.4	91	8.8
1978	RP79-5	10.0	88	Dokri, Pakistan 28 °N	6.7	100	22.7
1979	TNAU8870	10.5	96	Dokri, Pakistan 28 °N	7.4	91	25.7
1980	BAU19-3	9.7	–	Dokri, Pakistan 28 °N	7.2	–	18.7
1981	IR36	8.7	93	Kyaukse, Burma 21 °N	6.8	93	22.8
1982	Giza 172 (local check)	10.1	118	Sakha, Egypt 31 °N	6.4	116	8.1
1983	KAU1727	10.8	108	Sakha, Egypt 31 °N	7.4	117	12.6
1984	IR13240-108-2-2-3	10.7	110	Wangdiphodrang, Bhutan 27 °N	8.6	110	9.8
1985	#910 (local check)	10.5	108	Haukou, China 30 °N	7.8	106	7.4

Table 7. Highest yields obtained in the International Rice Yield Nursery (Medium), 1975-85.

Year	Highest yielding entry	Yield (t/ha)	Days to flowering (no.)	Location and latitude	Site mean for yield (t/ha)	Mean flowering duration (d)	CV (%) for yield
1975	BR51-91-6	7.6	92	Pattambi, India 10 °N	6.3	90	10.8
1976	IR2863-38-1-2	12.8	106	Palmira, Colombia 3 °N	8.0	102	27.1
1977	BR51-46-5	10.9	109	Hyderabad, India 17 °N	8.3	109	10.6
1978	IR4422-98-3-6-1	9.5	117	Palmira, Colombia 3 °N	7.0	114	12.9
1979	IR4422-98-3-6-1	10.7	94	Titabar, India 26 °N	7.8	91	16.0
1980	IR13540-56-3-2-1	9.1	108	Rajendranagar, India 17 °N	7.0	113	12.1
1981	PAU143-8-4-2-PR505	9.3	110	Dokri, Pakistan 28 °N	6.3	118	12.2
1982	IR13540-56-3-2-1	8.9	90	Rangsit, Thailand 14 °N	5.3	95	12.3
1983	ITA212	11.2	108	Gambella, Ethiopia 8 °N	8.9	105	10.6
1984	BR153-28-10-1-3	9.2	109	Mandalay, Burma 21 °N	7.6	108	12.1
1985	BG380-2	11.2	109	Dokri, Pakistan 28 °N	7.7	117	18.9

of 106 d (Table 8). The dry season yields at several tropical sites were higher than in the wet season ones, primarily because of higher solar radiation (Table 9).

Yield-weather relationships

Seshu and Cady (1984) studied the yield-weather relationships in rice, based on the results from the IRTP irrigated yield trials (early maturity) conducted at several locations in different countries from 1976 to 1981. They developed the following model to explain the relationship, using two weather variables measured during the

Table 8. Yield and days to flowering at different latitudes, IRTP early-maturing, irrigated yield nursery, 1984.

Latitude (°N)	Location	Grain yield (t/ha)		Days to flowering (no.)
		Mean[a]	Highest	
	Lower latitudes			
5	Bumbong Lima, Malaysia	4.3	6.3	79
9	Garoua, Cameroon	6.3	7.5	85
12	Mandya, India	5.6	8.0	92
14	Suphanburi, Thailand	5.1	5.8	81
18	Chiang Mai, Thailand	2.1	3.5	80
20	Cuttack, India	4.4	6.7	99
25	Patna, India	3.8	5.7	83
	Mean	4.7	6.2	86
	Higher latitudes			
27	Wangdiphodrang, Bhutan	8.6	10.7	110
29	Neijiang, China	6.8	8.2	112
29	Kaul, India	5.6	6.6	98
31	Dehra Ismail Khan, Pakistan	6.3	9.0	104
31	Sakha, Egypt	8.2	10.3	111
32	Nanjing, China	5.8	7.3	100
35	Milyang, Korea	6.4	8.6	109
	Mean	6.8	8.7	106

[a] Mean over 30 entries.

Table 9. Solar radiation and temperature during ripening phase and grain yields compared between wet and dry seasons at 4 International Rice Weather Yield Nursery (IRWYN) sites.

Location	Latitude (°N)	Solar radiation (mWh/cm^2)		Mean temp (°C) at ripening		Grain yield (t/ha)	
		Wet season	Dry season	Wet	Dry	Wet	Dry
Masapang, Philippines	14	445	672	26.8	27.6	3.4	5.8
Sanpatong, Thailand	18	469	593	27.1	28.1	4.2	5.9
Hyderabad, India	17	385	544	24.5	26.4	3.0	5.3
Joydebpur, Bangladesh	24	363	561	27.4	28.8	2.5	4.9

ripening stage—the average daily solar radiation (RAD) in mWh/cm^2 and the average daily minimum temperature (MINT) in °C:

$$\hat{Y} \text{ predicted yield} = 30.2 + \underset{(.0009)}{0.0041\ RAD} - \underset{(0.18)}{2.10\ MINT} + \underset{(0.004)}{0.038\ (MINT)^2}$$

The values in parentheses are the standard errors of the estimated coefficients.

Oldeman et al (1986) used three preflowering and two postflowering weather variables to relate the yield-weather relationship in the IRWYN trials and postulated the following prediction equation:

$$\hat{Y} \text{ (predicted yield)} = \underset{(0.05)}{4.80} + \underset{(0.07)}{0.57\ DNB} - \underset{(0.03)}{0.15TDB} + \underset{(0.009)}{0.064\ RSB} + \underset{(0.02)}{0.17\ RSC} - \underset{(0.02)}{0.13\ TNC}$$

where

DNB = day-night temperature difference before flowering,
TDB = day temperature before flowering (°C)
RSB = radiation sum × 10^{-3} (mWh/cm^2) before flowering
RSC = radiation sum × 10^{-3} (mWh/cm^2) after flowering
TNC = night temperature after flowering (°C)

The important role of radiation and temperature in the irrigated trials is illustrated by the following comparison of data on the variety IR36 from two IRWYN sites under optimum management (Table 10).

Temperature stress nurseries

Low-temperature stress

An IRTP observational nursery designated as International Rice Cold Tolerance Nursery (IRCTN) is aimed at evaluating and identifying appropriate breeding lines that are suitable for low temperatures as in the temperate and subtropical zones and at higher altitudes and in dry season crops of some areas in the tropics. Low-temperature stress can occur at any one or more of the growth stages, depending

Table 10. Comparison of data on IR36 from 2 sites.

Weather factor	Growth stage	Suweon (Korea)	Joydebpur (Bangladesh)
Radiation sum (mWh/cm^2)	Transplanting to flowering	37,348	30,716
Radiation sum (mWh/cm^2)	Flowering to ripening	17,055	9,973
Minimum temperature (°C)	Flowering to ripening	18.7	24.8
Day-night temperature (°C) difference	Flowering to ripening	8.8	7.2
Mean temperature (°C)	Seedbed	16.3	28.2
	Yield (t/ha)	10.3	2.6

upon the geographical location. This stress can cause stunting, leaf discoloration, delayed flowering, incomplete panicle exsertion, and spikelet sterility, and the type of injury depends upon the time of occurrence of the stress relative to the growth stage of the crop.

Several promising lines have been identified from the multilocation evaluation of IRCTN; they are predominantly japonicas, but include some indicas. Interaction between varietal tolerance and growth stage was observed in several instances. Some lines that showed consistently good performance at most growth stages over different years were as follows:

- Japonicas: Stejaree 45, Eiko, Ching-shi 15, K335, Tatsumi-mochi, Fuji 102, Jodo, Barkat
- Indicas: K39-96-1-1-2, K31-163-3, China 1039

A comparison of the number of days to flowering at selected sites in the tropical, subtropical, and temperate regions shows that K335 has a good degree of stability in duration to flowering (Table 11).

High-temperature stress

High-temperature stress occurs in the regular crops of some countries in tropical Africa and the Middle East and in the dry season crops of some countries in South and Southeast Asia. Depending upon the growth stage of occurrence, heat injury (from temperatures exceeding 35 °C) causes reduced height and tillering, white leaf tips, reduced spikelet number, reduced grain filling, and sterility (Yoshida 1981). The indica varieties are better adapted to high temperatures than the japonicas. IRTP screening trials indicated distinct varietal differences in heat tolerance. Some promising lines include IR2006-P12-12-2-2, UPR9616-1-1-1, CR156-5021-207, Pusa 2-21, and N22.

Evaluation in arid regions

Special IRTP nurseries are evaluated at selected sites in the arid rice-growing regions of South and West Asia and North Africa. Salinity is one of the major problems encountered in these regions. Some lines identified as promising were under those conditions:

- Aridity with moderate to low temperature: IR3941-25-1, IR19746-28-2-2, IR9129-209-2-2, Giza 172, Giza 180, Giza 1077-7-1-3, KAU1727, IR29725-109-1.
- Aridity with high temperature: IR29692-99-3, Si-pi 692033, UPR82-1-7.

Salinity and alkalinity stress nurseries

Saline and sodic soils are widespread in many rice-growing countries in the tropics and subtropics such as Bangladesh, Burma, Cambodia, Egypt, Gambia, Guinea, India, Indonesia, Iran, Iraq, Nigeria, Pakistan, Philippines, Senegal, Sierra Leone, Sri Lanka, Thailand, and Vietnam. Such soils are major obstacles to increasing rice

Table 11. Varietal differences in stability of days to flowering, 1984 IRTP Cold Tolerance Rice Nursery.[a]

Variety	Days to flowering at different sites[a]					
			Subtropical		Tropical	
	Temperate[b]		High altitude	Plains	High altitude	Plains
	1	2	3	4	5	6
Tolerant entries						
Stejaree 45	138	110	95	90	98	75
Ching-shi 5	149	118	94	93	108	71
Barkat	131	96	88	89	96	78
K335	116	88	80	77	84	73
China 1039	138	110	85	88	96	69
Nontolerant entry						
IR19746-26-2-3-3	NF	NF	96	94	105	73

[a] 1 = Szarvas, Hungary (latitude: 4 °N; elevation: 85 m), 2 = Vercelii, Italy (45°N; 132 m), 3 = Wangdiphodrang, Bhutan (37° N; 1500 m), 4 = Changsha, China (37° N; 30 m), 5 = Banaue, Philippines (17° N; 1200 m), 6 = Joydebpur, Bangladesh (23° N; 8 m). [b] NF = did not flower.

yields in the arid and coastal areas. The International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON) is designed to identify lines genetically tolerant of these soil problems. The IRSATON entries that showed consistently good performance over different locations and years were:

- Salinity
  - Traditional: Pokkali, Nona Bokra, Nona Sail (sel.), Patnai 23
  - Improved: Pokkali derivatives: IR4595-4-1-13, IR4630-22-2-5-1-3
  - Nona Bokra derivatives: IR8236-B-B-336-3-2, IR9884-54-3, IR10198-66-2
  - Others: CSRl, IR2307-247-2-2-3, IR9764-45-2-2
- Alkalinity
  - Traditional: Pokkali, Getu
  - Improved: IR4595-4-1-13, IR10206-29-2, IRl1248-23-3-2, IR9884-54-3, IR11418-15-2, IR4227-109-1-3-3, IR9764-45-2-2, IR46, CSRI

The salt-tolerant improved rices conferred a comparative yield advantage of 2 t/ha (Ponnamperuma 1984).

Disease nurseries

Screening nurseries for major rice diseases are organized as a part of IRTP. The diseases include blast *Pyricularia oryzae,* bacterial blight *Xanthomonas campestris* pv. *oryzae,* and tungro virus disease transmitted by the green leafhopper *Nephotettix virescens.*

Blast

Blast is a widely prevalent disease, occurring in both irrigated and rainfed rice. Uniform blast nurseries were in progress even before the IRTP was initiated. Most of the screening tests of the International Rice Blast Nursery (IRBN) were confined to seedling blast. Differential reactions in several IRBN entries across locations were evident, confirming the prevalence of different races of the pathogen (Seshu et al 1986). Some IRBN entries that showed resistance to seedling blast at most locations over different years were as follows:

- Traditional: Tetep, Tadukan, Carreon, Ta-poo-cho-z
- Improved: Suweon 300, IRAT104, CIAT-ICA5, IR5533-PP850-1, IR1905-PP11-29-4, IR27325-27-3-3, IR1416-128-5-8, IR45474-1-2, IR3259-5-160-3, IR19660-00948-1

Among the japonicas, the varieties Fukunishiki and Toride-1 revealed a broad spectrum of resistance.

Several improved derivatives of Tetep showed resistance across locations but in differing patterns, and from the nature of their reactions, it appears that Tetep resistance is governed by several major genes.

Bacterial blight

Bacterial blight has become a major disease of rice in Asia during the past two decades, causing severe damage to the crop. No effective chemical control method has been found against the disease. Increasing the rates of nitrogen fertilizer application to obtain optimum yields also increases the incidence and seventy of disease. Through the International Rice Bacterial Blight Nursery (IRBBN), several promising resistant lines have been identified, some of which are:

- Traditional: DV85, BJ1
- Improved: BR51-282-8, Cisadane, IR13423-17-1-2, IR4442-46-3-3, IR26717-1-1-2, RP633-76-1, IR54, IR64

IRBBN results show evidence of various strains of the pathogen, and the strains in South Asia appear to be more virulent than those in East and Southeast Asia.

Tungro disease

Tungro, one of the most destructive rice diseases prevalent in South and Southeast Asia, is a virus transmitted by green leafhoppers. Both the virus and the vector damage the crop, and resistance to each is known to be independently controlled. Some of the entries in the International Rice Tungro Nursery (IRTN) found promising for resistance over different years and locations were as follows:

- Traditional: ARCl1554, Utri Merah, Utri Rajapan, Gam Pai 30-12-15, Naria Bachi
- Improved: IR9729-67-3, IR9828-91-2-3, RP825-45-1-3, R51-315-4

Insect nurseries

IRTP nurseries targeted to major insect pests include those designed to identify resistance to stem borer—primarily yellow stem borer *Scirpophaga incertulas* and striped stem borer *Chilo suppressalis*—gall midge *Orseolia oryzae,* brown planthopper *Nilaparvata lugens,* and whitebacked planthopper *Sogatella furcifera.*

Stem borer

Stem borer occurs in almost all rice-growing countries, although the species may differ from region to region. The insect causes damage at both vegetative and heading stages, causing deadhearts and whiteheads. Screening for resistance is done primarily in the field, and where facilities exist, it is done in the screenhouse. The International Rice Stem Borer Nursery (IRSBN) identified the following entries as having moderate to good resistance across different locations to yellow and striped borers:

- Yellow borer
  - Traditional: TKM6, CO 18, W1263, MTU15,
  - Improved: IR1820-52-2-4, IET2845, IR9828-23-1, IR3941-9-2, IR15723-45-3, IR13639-34
- Striped borer
  - Traditional: TKM6, Taitung 16, W 1263
  - Improved: IET2845, IET5540, CR157-392-4, IR1514A-E666, IR2798-143-3, IR20, IR36

Gall midge

The gall midge is a serious rice pest in South and Southeast Asia and parts of West Africa. The damage results in plant stunting and the affected tillers produce no panicles. The presence of the larva causes the leaf sheath to develop into a gall, called a silvershoot. The results of evaluation of the International Rice Gall Midge Nursery (IRGMN) reveal distinct biotypic differences in the insect between different countries and within large countries like India (IRRI 1981). Some of the varieties identified as resistant through the multilocation evaluation of the IRGMN were:

- Traditional: W1263, PTB18, PTB19, PTB21, Leuang 152, Eswarakora
- Improved: RPW6-17 (Phalguna), Kakatiya, CR157-392-4, BG380-2, IR36

Brown planthopper

The brown planthopper is a serious pest of rice throughout Asia. It causes the feeding damage called hopperburn. In addition, it transmits the virus disease known as grassy stunt. Because of the economic importance of this insect, rearing and varietal resistance screening programs are well established in many countries. Thus. most of the screening tests of the International Rice Brown Planthopper Nursery (IRBPHN) in different countries are conducted in the greenhouse. The IRBPHN results reveal distinct differential reactions at different sites for most test entries, suggesting the occurrence of selection for biotypes within the hopper populations (Seshu and Kauffman 1980). The biotypes of the insect in the South Asian countries proved to be more virulent than those in East and Southeast Asia. Some entries rated resistant at most locations were:

- Traditional: PTB33, Rathu Heenati, Babawee, Balamawee, Suduru Samba

- Improved: Rathu Heenati derivatives—IR13540-56-3, IR17494-32-1, IR21912-131-2,
  PTB33 derivatives—IR19660-45-1, IR19661-23-3, IR56, BG367-2, RP1756-121

Whitebacked planthopper

The whitebacked planthopper is prevalent in most countries in Asia, and the nature of damage by this insect is similar to damage caused by the brown planthopper. The rearing and screening methodologies employed are also similar. The results of multilocation evaluation of the International Rice Whitebacked Planthopper Nursery (IRWBPHN) also provided evidence of biotype differences in the insect. Some of the promising IRWBPHN entries are as follows:

- Traditional: ASD8, ADR52, PTB19, PTB33, Rathu Heenati, Vellathil Cheera, WC1240
- Improved: IR13458-117-2-3, IR15529-253-3-2, IR17492-18-6-1, IR17307-11-2-3, IR2035-117-3

Irrigated rice trials in Africa

Some of the entries in IRTP irrigated trials that performed well across locations in West Africa are as follows:

- Savannah region: IR2823-339-5-6, IR3273-P339-2-5, IR42, IR54
- Humid region: IR4422-98-3-6, IR2041-178-1, IR2373-P335-2-5, ITA212, BG90-2, BW298-1, BR51-46-2, BR51-118-2, IR46, UPR103-80-1-2
- Low-temperature areas: IR7167-33-2-3, IR3273-P339-2-5, B2983-Sr-57-1-2, B2982g-Sr-2-9, B2161c-Mr-57-1-3

IRTP entries that produced good yields in the irrigated on-farm trials in some sub-Saharan countries during 1983-84 are shown in Table 12.

Utilization of IRTP entries in national programs

To date, 108 entries originating from 15 countries and from IRRI have been released as varieties in 46 countries in Asia, Africa, and Latin America. Further, several hundred entries have been utilized as parents in various breeding programs in different countries.

Table 12. Outstanding entries from IRTP nurseries in on-farm trials in sub-Saharan Africa, 1983-84.

Entry	Yield range (t/ha)	Country
IR3273P339-3-5	3.6-6.2	Nigeria, Ghana, Togo, Sierra Leone
IR2042-178-1	3.6-6.0	Benin, Nigeria, Togo
IR4422-98-56-1	4.5-8.5	Ghana, Liberia, Nigeria, Senegal, Sierra Leone
BG90-2	4.2-7.8	Ghana, Niger, Nigeria, Gambia, Senegal, Tanzania
IET2885	3.8-7.1	Ghana, Mali
IR42	4.0-7.9	Ghana, Mali, Niger, Senegal, Tanzania
IR46	4.0-6.8	Cameroon
IR54	4.0-6.8	Kenya, Nigeria
IET1444	4.0-6.5	Tanzania
ITA212	4.0-7.0	Tanzania
IR13429-299-2-1-3	4.0-7.0	Tanzania
IR21015-80-3-3-1-2	4.0-7.0	Tanzania
IR36	4.0-6.0	Tanzania

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Fertilizer use efficiency in rice

M. R. Hamissa and F. N. Mahrous

The main target of the soil and water program under the Rice Research and Training Project in Egypt is to improve rice production and quality through efficient fertilizer use and water management. Experiments across 6 yr showed that 1) grain yields of both transplanted and direct seeded rice increased with increasing applied nitrogen up to 144 kg/ha, if the previous crop was a nonlegume, although there was no significant increase beyond 96 kg/ha; 2) time and method of application determined the percent recovery from fertilizer N; 3) the relative effectiveness of five phosphorus sources tried was about equal; 4) applying zinc sulfate to the nursery gave better yield response than dipping seedlings in 2% zinc oxide solution; and 5) prolonging irrigation intervals from 4 d to 8 and 12 d decreased yields, except in drought-resistant variety IET1444, which was not significantly affected, and Giza 172, which gave high yields even under drought.

In Egypt, fertility studies started as early as 1912, when pioneer research workers of the Agricultural Society conducted their first fertility trial on rice. At that time, Egyptian farmers did not use any fertilizer on ricefields, as they believed that it would be leached out with flooding and the plant would not be able to utilize it.

Since then, considerable data have been accumulated on nutrient needs, rate, source, and time and method of fertilizer application. Nevertheless, the development of new improved varieties of rice with high yield potential and tolerance for lodging, the continuous change in the fertility status of rice soils, and the new technology of the fertilizer industry necessitate continuous research in this field.

This paper describes and discusses the results of some of the fertility studies carried out under the Rice Research and Training Project (RRTP) and new directions for future work.

The ultimate goal of these studies is to economically increase the production and improve the quality of rice through efficient use of fertilizer and good water management.

We hope that the results obtained will have practical value under local conditions, where fertilizers represent a major expense for the farmer.

Fertility studies under the Rice Project

Several topics have been investigated since we started the RRTP; the most important are described in this paper.

Analysis of rice soils

Composite soil samples were collected from various experimental sites for chemical analysis and soil definition to help interpret the results of our experiments.

Rice soils in Egypt are of recent alluvial origin, formed by annual deposition of sediments carried by the River Nile at its former flood stages. Existing soils are anthropic variants of Gleysols and Fluvisols formed under dry climatic conditions.

The textural class of the soil varies from clay loam to heavy clayey. Chemical analysis of these soils (Table 1) indicates a wide range of chemical constituents of various soils; however, pH values fall in the range of moderate alkalinity. The soils are rich in calcium carbonate but poor in organic matter. Total soluble salts are low and below the level of toxicity. Cation exchange capacity is rather high. The concentration of total and soluble nitrogen (N) is fairly low. Available phosphorus (P), determined by Olsen's method, shows moderate values. Soluble and exchangeable potassium (K), extracted by the ammonium acetate method, are fairly high, reflecting the general characteristics of most Egyptian soils. The concentration of zinc (Zn) ranges from low to adequate, while iron (Fe) and manganese (Mn) seem quite sufficient.

Fertilizer requirements for rice

The main purpose of the study on fertilizer requirements for rice is to determine the response of transplanted and direct seeded rice to N, P, and Zn, as affected by the cropping system. Twelve field trials were conducted at experimental farms as well as in farmers' fields in different rice-growing governorates of Egypt. Data obtained from these trials (Table 2) indicated that:

1. When transplanted rice followed a nonlegume crop, grain yield of rice increased as N level increased up to 96 kg N/ha; this level gave a 61% yield increase over the control. Application of 16 kg P/ha (36 kg P_2O_5) increased yield by 14%; and application of 5 kg Zn/ha (24 kg $ZnSO_4$) increased yield

Table 1. Analysis of soil samples from rice-growing areas of Egypt.

Determination	Range of results	Mean
Textural class	Clay loam heavy clayey	
pH (2.5:1)	7.3 - 8.3	7.9
$CaCO_3$ (%)	2.1 - 8.3	3.9
Total soluble salts (%)	0.09 - 0.33	0.17
Organic matter (%)	1.22 - 2.24	1.7
Total N	0.07 - 0.11	0.09
Total soluble N (ppm)	13.0 - 58.0	37.0
Nitrate N (ppm)	12.0 - 15.0	
Available P (Olsen) (ppm)	1.0 - 29.0	12.0
Available K (am. acetate) (ppm)	228.0 - 633.0	464.0
CEC (meq/100 g soil)	31.0 - 61.0	46.0
Exchangeable Ca (meq/100 g soil)	10.0 - 34.0	22.0
Available Zn (DTPA) (ppm)	0.5 - 4.0	
Available Fe (DTPA) (ppm)	6.0 - 8.0	
Available Mn (ppm)	7.0 - 14.0	

Table 2. Response of transplanted and direct seeded rice to applied nitrogen, phosphorus, and zinc, as affected by cropping system.

Fertilizer treatment (kg/ha)			Rice grain yield (t/ha)	
N	P[a]	Zn[b]	After nonlegumes	After legumes
			Transplanted rice	
0	0	0	6.0	7.2
0	16	5	6.6	7.7
48	16	5	7.8	9.3
96	16	5	10.7	9.7
144	16	5	10.6	9.8
192	16	5	10.5	9.7
96	0	5	9.4	10.0
96	16	0	9.6	9.8
LSD (1%)			1.6	ns
(5%)			1.2	
			Direct seeded rice	
0	0	0	6.3	7.5
0	16	5	6.6	7.5
48	16	5	7.5	8.2
96	16	5	8.1	8.0
144	16	5	8.5	6.9
192	16	5	7.4	6.0
96	0	5	7.6	7.0
96	16	0	7.6	6.9

[a]Appiled as 36 kg/ha P_2O_5.[b] Applied as 24 kg/ha $ZnSO_4$.[c] After nonlegumes, average of three experiments; after legumes, one experiment.

by 11%. When rice followed a legume crop, rice yield increased up to 25% at the same rates of N, but no response was obtained from either P or Zn.

2. Grain yield of direct seeded rice increased gradually up to 144 kg N/ha. However, when berseem (clover) preceded rice, the maximum rice yield was obtained at 48 kg N/ha. P and Zn, at the same rates as for transplanted rice, also increased yield.

Nitrogen requirements for traditional and improved rice varieties

The objective of this trial was to study the response of traditional and improved rice varieties to different rates of N and to determine the most suitable time and method of fertilizer application. Twelve fertility treatments with different rates of N and various times and methods of application were used on three rice varieties: Giza 172, a traditional tall variety, and IR28 and IR1626, both improved, short-statured ones.

Average yields of all 3 varieties increased with increasing N, up to 144 kg/ ha, when fertilizer N was applied as a single dry application. However, the difference between 96 kg and 144 kg N/ha was not significant (Table 3). The short-statured varieties also responded better to N than the traditional variety did.

In regard to the effect of time and method of fertilizer application, for variety IR28, 96 kg N/ha in a split application (2/3 incorporated in dry soil + 1/3 at panicle initiation [PI]) was more productive than 144 kg N as a single basal dry application (Table 3).

Table 3. Nitrogen requirements for traditional and improved rice varieties as affected by timing and method of application.

Rate (kg N/ha)	Time and method of application[a]	Grain yield (t/ha)			Fertilizer treatment mean (t/ha)
		Giza 172 (traditional)	IR1626 (improved)	IR28 (improved)	
Control	–	6.1	6.3	6.5	6.3
48	Incorporated in dry soil	8.3	7.0	7.3	7.5
96	Incorporated in dry soil	8.2	7.8	7.9	8.0
144	Incorporated in dry soil	7.6	8.1	8.3	8.0
96	Topdressed at midtillering	7.6	7.1	8.2	7.6
96	2/3 incorporated in dry soil + 1/3 at PI	8.1	7.5	8.6	8.1
96	2/3 topdressed at midtillering + 1/3 at PI	8.4	8.1	7.6	8.1
96	2/3 topdressed at rapid tillering + 1/3 at PI	8.4	7.6	8.4	8.1
96	1/3 incorporated in dry soil + 1/3 topdressed at midtillering + 1/3 topdressed at PI	7.9	8.6	7.8	8.1
96	1/3 incorporated in dry soil + 1/3 topdressed at rapid tillering + 1/3 topdressed at PI	8.3	8.0	8.1	8.1
96	Topdressed at rapid tillering	8.6	7.5	7.8	7.9
96	Topdressed at PI	7.9	7.7	7.4	7.7
	Variety mean	7.9	7.6	7.8	
LSD 5%			0.2		0.6
1%			0.3		0.9
LSD (Fer. treat. × variety) 5%				0.8	
1%				1.1	

[a]PI = panicle initiation.

Variety × spacing × fertilizer interaction

To develop effective recommendations for the best N level and plant spacing for medium-tall and tall rice varieties, we studied two varieties—Giza 172 (traditional tall) and Reiho (medium-tall)—using three spacings and three levels of N. The closest plant spacing, 20 × 20 cm, was superior to the other spacings (20 × 30 and 20 × 40 cm) when no other variables were considered.

Considering the interaction of all factors, we concluded that Reiho and Giza 172 gave the highest—and almost equal—yields at the closest spacing (20 × 20 cm) when fertilized with 96 kg N/ha.

Relative effectiveness of nitrogen source and time and method of placement

A coordinated experiment was run with the International Rice Research Institute (IRRI) under the International Network for Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) project, to compare the effectiveness of various N sources and methods of placement. As Table 4 indicates, no significant differences were detected among various N sources at comparable levels of fertilizer. However, yields obtained

Table 4. Relative effectiveness of various sources of nitrogen applied to rice crops in Egypt.

Treatment no.	N level (kg/ha)	N Source	Time and method of application[a]	Grain yield (t/ha)
1 (control)	0	None		7.0
2	58	Urea	2/3 broadcast at 15 DT + 1/3 at PI	8.3
3	58	SCU	Incorporated in dry soil	9.5
4	58	SGU	Point placement 10 DT	9.8
5	29 + 29	SGU + urea	Point placement 10 DT and at PI	8.6
6	87	Urea	As treatment (2)	9.6
7	87	SCU	As treatment (3)	9.5
8	87	SGU	As treatment (4)	10.1
9	58 + 29	SGU + urea	As treatment (5)	10.1
10	116	Urea	As treatment (2)	9.5
11	116	SCU	As treatment (3)	11.0
12	116	SGU	As treatment (4)	10.1
13	87 + 29	SGU + urea	As treatment (5)	9.9
14	174	Urea	As treatment (2)	9.7
15	174	SCU	As treatment (3)	9.6
16	174	SGU	As treatment (4)	10.7
17	145 + 29	SGU + urea	As treatment (5)	10.4
18	87	Ammonium sulfate	As treatment (2)	9.2
LSD 5%				1.6

[a]DT = days after transplanting, PI = panicle initiation. SCU = sulfur-coated urea, SGU = urea supergranule.

Mean for N level

N (kg/ha)	Yield (t/ha)
0 =	7.0
58 =	9.1
87 =	9.8
116 =	10.1
174 =	10.1

Mean for N source	Yield (t/ha)
Urea	9.3
scu	9.9
SGU	10.2
SGU + urea	9.7

with sulfur-coated urea (SCU) and supergranule urea (SGU) were slightly higher than those with ordinary urea, probably because the slow release of N from the first two sources sustained the crop over its entire growth period. Also, the deep placement of SCU and SGU would minimize N losses from volatilization and denitrification, whereas urea broadcast on the soil surface would suffer significant N loss, which in turn would reduce its efficiency.

The N unit in both urea and ammonium sulfate had about equal value. However, the price of the N units and the value of the crop produced must be considered before a definite conclusion is reached as to the most profitable source of N to be used.

The fertilizing value of phosphorus sources for rice

Different sources of P were evaluated in a coordinated experiment with IRRI under the INSFFER project. The P sources tested were phospal (a highly reactive rock phosphate), guano (a low reactive rock phosphate), Egyptian rock phosphate, and triple superphospate. The standard fertilizer was single superphosphate.

Although local rock phosphate at 40 kg/ha (18 kg P/ha) gave the highest yield (8.7 t/ha), no significant difference was found among the various sources. This might be because the soil contained adequate available P at the experiment site (14.3 ppm, by Olsen's method).

Therefore, to obtain conclusive results on this topic, a test site deficient in soil P should be selected and the carryover effects of these P sources should also be evaluated.

Effect of zinc in different forms on rice production

Recent work has revealed that rice sometimes shows a definite response to Zn application in wetland soils, where transformation processes release more P but less soluble Zn than in dryland soil. A field trial was therefore conducted to study the response of rice to Zn in different forms, applied either to the nursery or to the main field. We found that Zn applied to the nursery at the rate of 48 kg $ZnSO_4$/ha (= 11 kg Zn) was more effective than dipping the seedlings in 2% ZnO solution (Table 5). When seedlings received Zn in the nursery, no further application was needed; however, if no Zn was applied to the nursery, applying $ZnSO_4$ to the main field, before transplanting, increased crop yield.

Foliar spray and soil application of nutrients for rice

A comparative study was made of the fertilizer value of some foliar spray compounds that contain macro and micronutrients; soil application of some of the micronutrients was also included in the experiments. No significant difference was detected among various fertilizer treatments in this study. However, $ZnSO_4$ applied to the soil gave the highest yield (9.6 t/ha), followed by Sicostreen, a chelated Zn used as foliar spray, which gave 8.8 t/ha.

Table 5. Effect of Zn application on grain and straw yield of lowland rice in Egypt.

Zn applied to		Other fertilizers[a]		Yield (t/ha)	
Nursery	Field	N	P	Grain	Straw
0	0	0	0	5.5	4.8
0	0	+	+	7.6	6.4
0	5 kg/ha[b]	+	+	8.0	
0	0	0	0	6.1	5.1
11 kg/ha[c]	0	+	+	8.4	7.2
0	5 kg/ha[b]	+	+	8.3	7.4
0	0	0	0	5.4	4.4
Seedlings dipped in 2% ZnO solution	0	+	+	8.1	6.6
0	5.5 kg/ha[b]	+	+	8.2	6.6
LSD 5%				0.6	0.7

[a]+ = fertilizer applied; N constant at 96 kg/ha; P constant at 16 kg/ha, applied as 36 kg P_2O_5. [b]Zn applied as 24 kg $ZnSO_4$. [c]Zn applied as 48 kg $ZnSO_4$.

Efficient use of fertilizer nitrogen in lowland rice

A trial was conducted to study the response of rice to different levels of N and the efficiency of fertilizer N as affected by rate, timing, and method of application. A tracer technique using ammonium sulfate enriched at 5% atom excess level with N-15 was used in the study.

As Table 6 shows, grain and straw yields as well as total N uptake by the crop increased as the rate of N increased, up to 108 kg/ha. As regards timing and method of N application, the four treatments (see Table 6) gave roughly comparable values. However, point placement was slightly superior to the rest. N broadcast in water before leveling and the traditional method of applying it (2/3 topdressed at 15 d after transplanting (DT) + 1/3 at PI) gave lower values than other treatments.

The percent N derived from fertilizer increased as the rate of N increased up to 108 kg/ha, but the difference between 72 and 108 kg N/ha was nonsignificant. Comparing time and method of N application, we found point placement clearly the most efficient treatment; N broadcast in water before leveling, the least efficient.

Fertilizer N uptake showed a similar trend. Recovery from fertilizer N ranged from 9.6 to 39.4%. Again, point placement recorded the highest value; the traditional treatment and that where N was broadcast on the water, the lowest values.

Time and method of fertilizer application for rice grown on salt-affected soil

A trial was conducted to determine the best timing and placement of N fertilizer applied to rice grown on saline soils. On a soil with 7 dS/m, planted to a promising salt-tolerant rice variety, split application of N (2/3 either incorporated in dry soil

Table 6. Efficiency of fertilizer N use as affected by rate, timing, and method of application to lowland rim, determined by a tracer technique.

Time and method of application[a]	Rate of N applied (kg/ha)	Yield (t/ha)		Total N uptake (kg/ha)	% N derived from fertilizer	Fertilizer N uptake (kg/ha)	% recovery
		Grain	Straw				
–	0	4.7	4.8	68.7	–	–	–
Banded in dry soil	36	6.3	6.8	87.5	7.2	6.3	17.4
	72	7.5	9.4	120.7	16.0	19.3	26.9
	108	8.7	9.1	128.5	18.2	23.4	21.6
Broadcast in water before leveling	72	6.3	7.9	89.8	7.7	6.9	9.6
Point placement	72	7.6	9.5	115.2	24.6	28.3	39.4
2/3 banded in dry soil + 1/3 at PI[a]	72	6.6	8.2	105.3	14.2	14.9	20.7
2/3 topdressed at 15 DT[a] + 1/3 at PI	72	6.0	6.2	87.2	14.8	12.9	17.9
2/3 topdressed at 35 DT + 1/3 at PI	72	7.3	7.7	105.7	20.5	21.7	30.1
LSD (5%)		0.9	2.4	21.5		5.6	

[a]DT = days after transplanting, PI = panicle initiation.

before planting or topdressed at 35 DT + 1/3 at PI) was not statistically different from a single application incorporated in dry soil before water leveling and transplanting (Table 7).

Physiological studies on the relationship of salinity, fertility, and rice varieties

Physiological studies were conducted to determine the response of rice varieties Giza 172 (salt-tolerant) and Reiho to different methods of N application under 4 salinity levels: the natural 2.04 dS/m, and 5, 10, and 15 dS/ m. Fertilizer application methods were incorporation in dry soil, broadcasting at 15 DT, and split application (1/2 at 15 DT + 1/2 at PI).

No harmful effect was observed from salinity levels up to 5 dS/ m (Table 8). On saline soils, split application of fertilizer N was superior to a single dose applied either before planting or at 15 DT. Incorporating fertilizer N in soil with salinity level of 15 dS/ m resulted in desiccation of the transplanted seedlings and complete loss of yield.

Effect of nitrifying inhibitor on nitrogen-use efficiency

The main aim of this study was to evaluate the efficiency of fertilizer N by minimizing N losses with a nitrifying inhibitor, dicyanodiamide (DCD). Adding 5% DCD to urea did not provide any beneficial effect, whether the fertilizer N was applied in a single dose incorporated in the soil before transplanting or in a split dose.

Response of rice varieties to nitrogen levels under different water regimes

To develop optimum management practices for maximum rice yields, we studied four rice varieties under different water regimes and N levels. The 36 treatments included various combinations of: 1) 3 water regimes; i.e., irrigation every 4, 8, and 12 d after transplanting, the irrigation depth being constant at 7.5 cm; 2) 3 N levels—48, 96, and 144 kg/ ha; and 3) 4 rice varieties—Giza 172, Reiho, IR28, and IET1444.

Table 7. Effect of time[a] and method of fertilizer N application (72 kg N/ha) to rice grown on saline[b] soils in Egypt.

N treatment	Yield (t/ha)	
	Grain	Straw
Control	5.2	5.9
Incorporated in dry soil before irrigation	5.9	7.5
2/3 incorporated in dry soil + 1/3 at PI	6.2	7.4
Surface-applied at transplanting	5.7	6.5
2/3 topdressed at 15 DT + 1/3 at PI	5.3	6.4
2/3 topdressed at 35 DT + 1/3 at PI	6.1	7.2

[a]DT = days after transplanting, PI = panicle initiation. [b]Soil salinity level: EC = 7 dS/m.

Table 8. Rice grain yield as influenced by variety, salinity level, and method of N[a] application.

		Grain yield (g/pot)			
Rice variety	Salinity level (dS/m)	N incorporated in dry soil	N broadcast at 15 DT[b]	N applied 1/2 at 15 DT + 1/2 at PI[b]	Mean
Giza 172	Natural level (2.04)	21	24	28	24
	5	24	32	28	28
	10	24	21	19	22
	15	–	17	18	12
Mean		17	24	23	21
Reiho	Natural level (2.04)	18	15	19	17
	5	23	26	28	26
	10	14	18	21	18
	15	–	13	19	11
Mean		14	18	22	18
Average for method of application		16	21	22	

[a]N applied constant, at a rate equivalent to 72 kg/ha. [b] DT = days after transplanting, PI = panicle initiation.

LSD at 5%		g/pot
Method of application	=	1.1
Method of application × variable	=	1.5
Salinity level × variable	=	1.8
Variety × salinity level × method of application	=	3.0

Prolonging irrigation intervals from 4 d decreased rice grain yield: 12% for 8-d intervals and 19.6% for 12-d intervals. Reiho yielded lowest when irrigated at 12-d intervals; IET1444, a drought-resistant variety, was not significantly affected. This variety outyielded the 3 other varieties when irrigated every 4 d and fertilized at the rate of 144 kg N/ha. Giza 172 also gave high yields under drought.

Physiological response of rice to growth regulators and micronutrients

Yield and physiological characters of two varieties of rice, Giza 171 (a traditional tall variety) and IR1626 (a modern short-statured variety), were studied to determine the effect of growth regulators Cycocel and gibberellic acid and micronutrients Zn and Fe.

Two experiments were conducted, one in the field, the other in greenhouse pots; treatments in both were the same. Under field conditions, no significant effect was detected of either growth regulators or micronutrients. However, under greenhouse pot culture, yield increased with applied Zn and Fe, alone or in combination.

New directions for future research

In continuation of our studies, we propose eight research areas.

National program for testing soil and plant tissue to estimate fertilizer requirements for rice

From the inception of the Rice Research and Training Project and the National Rice Institute, one of the strategies to increase rice yields has been to advance a reliable system of soil and plant testing. Using soil and plant tests is an economical and efficient way to determine the amounts of fertilizer a farmer needs, thus saving on unnecessary use of expensive fertilizers.

A national program is therefore proposed, to provide basic information on soil and plant test values, so that reliable recommendations can be made on the nutrient requirements in farmers' fields.

Nutritional requirements for broadcast and drill-seeded rice

Extension and other Ministry of Agriculture personnel estimate that about 20 to 25% of rice acreage in Egypt is currently being direct seeded. This illustrates the farmer's determination to overcome the high labor cost of hand-transplanting.

Preliminary data from extension demonstrations and farmers' fields suggest that high yields can be obtained by direct seeding rice. It is essential, therefore, to evaluate the best fertilizer management for the new short, early-maturing varieties when they are sown either broadcast or drill-seeded. Otherwise, farmers will continue to use present management practices, which suit the traditional tall varieties but which may be inefficient and unprofitable for the modern varieties. The purpose of a proposed study is to determine and compare the nutritional requirements of direct seeded and transplanted rice, to form an information base for extension recommendations to farmers.

Nitrogen balance sheet for rice in Egypt

Of all the fertilizer elements applied to rice, N is the most expensive. It is also the most elusive, the easiest lost, and the most difficult to account for. We need a better understanding of leaching, movement, and transport of fertilizer N, and the extent of volatilization and nitrification-denitrification occurring in Egypt's rice soils. With this base information, procedures and cultural practices can be developed at the farm level to utilize N fertilizers more effectively.

The purpose of a study on N balance would be to determine how soil characteristics, fertilizer management, and cultural practices affect N losses so that measures can be taken to minimize these losses and, in turn, increase fertilizer efficiency.

Fertility studies on rice planted on saline soils

Soil salinity is a serious constraint to rice production in parts of the northern Egyptian Delta. Applying soluble fertilizers to the crop, particularly at high rates, may aggravate soil salinity and further contribute to crop losses. (For example, previous studies have shown that incorporating fertilizer N in soil with a 15 dS/m salinity level desiccated transplanted seedlings and resulted in total yield loss.) Experiments will be established to determine the response of promising salt-tolerant rice varieties to N, P, and Zn, and the most suitable timing and placement for fertilizers. Understanding the effect of salinity and soil flooding on nutrient availability helps solve the nutritional problems of rice in salt-affected soils.

Direct and carryover effects of organic manures in rice-based cropping systems
Most Egyptian soils contain less than 2% organic matter. However, although it is well known that organic matter improves the physical, chemical, and biological characteristics of the soil, thus increasing its productivity, the use of organic matter in ricefields in Egypt has been little studied.

Some studies should be made to evaluate organic manures as supplemental sources of nutrients required for rice. The carryover effect of these organic manures should also be investigated under rice-based cropping systems.

Fertilizer management for new rice varieties
New varieties with high yield potential are being developed by the Rice Research and Training Project. Before their widespread introduction to the farmer, high priority should be given to developing fertilizer management practices to ensure that these new varieties can be established at the appropriate recommended levels of fertilizer under different cropping systems.

Nutritive value and cooking quality of rice as affected by fertilizer application
Studies on the effect of fertilizer management on the quality of rice are rare. The main objective of a proposed study is to relate fertilizer use to nutritive value and cooking quality of rice so that both can be improved through efficient fertilizer management.

***Azolla-Anabaena* association as a biological source of nitrogen for rice**
Azolla is a floating aquatic fern that thrives in both tropical and temperate regions of the world. It has a symbiotic association with the cyanobacterium *Anabaena azollae,* which fixes atmospheric N. The use of azolla in rice culture has been reported in several countries such as China, the Philippines, the USA, and Vietnam. However, azolla is not native to Egypt and few studies have been undertaken locally (and these mostly in the laboratory and the greenhouse) on the propagation of azolla under Egyptian conditions.

The main target of this topic, therefore, is to assess the fertilizing value of some adapted strains of azolla as a biological source of N for rice under Egyptian field conditions. Also, we would like to evaluate residual soil fertility from the use of the *Azolla-Anabaena* association in rice culture.

Notes
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Integrated nutrient management in relation to soil fertility in lowland rice-based cropping systems

S. K. DE DATTA

An understanding of the fate of applied nutrients and their effect on crop production is required in developing practices to improve nutrient efficiency in rice. It is critical that integrated nutrient management is studied tosustain and improve soil fertility in lowland rice-based cropping systems in Asia. Literature on N budget in lowland rice soils is very extensive. Soil N and its management are now emphasized because substantial yield gains can result from resources already on land. By using ^{15}N balance and micrometeorological techniques, progress has been made in quantifying ammonia (NH_3) volatilization and estimating denitrification losses. Interacting factors which control floodwater properties in lowland rice soils are now better understood. Floodwater propertiesand atmospheric parameters such as windspeed largely determine the gaseous loss processes from the lowland rice ecosystem. But because of more developed methodology, greater progress has been made in quantifying NH_3 volatilization than denitrification losses. In integrated N management, including use of biofertilizers and growing a green manure crop in cereal rotation often give more sustainable high crop yields. Considerable scope exists in managing phosphorus (P) and potassium (K) nutrients using a systems approach. For example, P fertilizer application should be based on upland crops, especially on leguminous crops, rather than on cereals such as rice and wheat. Leguminous green manure crops supply P and K, besides N. A wide knowledge gap on nutrient imbalances in the soil exists, particularlyon the interrelationship among K, Ca, and Mg concentrations in different rice plant parts. Sulfur deficiency will become progressively important under intensive cereal croppings. In integrated nutrient management research, more advantages can be derived from a systems research with refined research focus and improved interdisciplinary communication and participation.

Great opportunities exist for increased rice production through increased application rate and improved management of mineral fertilizers and through an integrated nutrient management using mineral and organic fertilizers. Similar, if not greater, opportunities exist for studying soil nutrient dynamics and developing cultural practices that will fully exploit soil nutrients.

In some areas of the world, rice yield increases have been substantial with new production technology. Increased cropping intensity demands more nutrients to sustain this high productivity. For example, a single lowland rice crop producing 9.8 t grain/ha and 8.2 t straw/ha in about 115 d took up 218 kg of N, 31 kg of P, 258 kg of K, and 9 kg of S (De Datta 1985). These and other nutrients removed by the crop must be replenished to sustain high rice production. India and China successfully used green manure in cropping systems of major cereals. In India, a legume crop such as green gram (mungbean) or cowpea is incorporated into rice - rice or rice - wheat croppings to improve physiological energy output (Pillai 1983). China has been using the cropping systems concept to sustain intensive cropping with high outputs using legume in rotation with cereals. Organic and inorganic nutrient sources and their management are also being integrated in rice-based cropping systems (Guo 1986).

Results from recent studies on integrated nutrient management to sustain and improve soil fertility in rice-based cropping systems in Asia are summarized here.

Nitrogen

Asia is now the largest and fastest growing N market in the world. Annual consumption rates of China, India, Pakistan, and Indonesia, among the Asian countries, take up more than 14% of the already large consumption base (Stangel and De Datta 1985). This rapid production and consumption of N fertilizer are important developments in the region. But unless high N losses and low fertilizer efficiency are prevented, most of the potential benefits from increased N fertilizer use may not be realized.

The following information discloses relevant research results on the N fertility of rice soils and fertilizer management for efficient N use in lowland rice. Nitrogen transformation processes and management in lowland rice have been adequately summarized in recent review papers (Savant and De Datta 1982, De Datta and Patrick 1986).

Soil nitrogen

Many chemical and biological processes influence N availability in lowland rice soils. Mineralization of organic N in flooded soils largely depends on the chemical environment and soil microbiological population. Nitrogen supplied by the soil has been repeatedly shown to be sufficient in achieving substantial yields.

Under some conditions, up to 3 t/ha grain yields have been consistently obtained without N fertilizer, while the 3 t/ha grain yield increase was obtained with 100 kg N/ha application using best split urea N (Bouldin 1986). The same author contends that with increased research on soil N and its management, substantial yield gains are possible with resources already on land.

Results of Schön et al (1985) and Mengel et al (1986) support the view that soil solution NH_4^+ tends to equilibrate with the exchangeable soil NH_4^+. The initial exchangeable soil NH_4^+ behaved like N fertilizer, as shown in the linear relationship between initial exchangeable NH_4^+ + N fertilizer and N uptake by the rice crop.

Studies of Keerthisinghe et al (1984, 1985) concluded that the exchangeable NH_4^+ and, in some soils, the nonexchangeable NH_4^+ are the most important soil N fractions easily available to lowland rice at early to mid-tillering stages. Moreover, organic soil N may contribute substantially to N supply at the spikelet-filling stage. In soils rich in vermiculite, the nonexchangeable NH_4^+ should also be considered for fertilizer N recommendation in lowland rice (Mengel et al 1986). Measuring the dynamic changes of mineralization-immobilization processes was made possible using the ^{15}N technique. The amount of N mineralized in soil during the crop's growing season varies with the soil and environmental condition and with the measurement technique used. It ranges from 5 to 1,166 ppm. According to Ito and Watanabe (1981), mineralization can be 5 times greater for biologically fixed N (23.4% mineralized) than for the native soil N (4.6% mineralization).

Nitrification and denitrification

Nitrification or the biological oxidation of NH_4^+ to NO_3^- in lowland soils is common but undesirable because it leads to N loss. It is a mechanism of N loss via nitrification-denitrification in lowland soils. Nitrate has been established as an inefficient N source in lowland rice culture.

The occurrence of nitrification in the rhizosphere of a rice plant, which Savant and De Datta (1982) referred to as site II, was recently studied by Reddy and Patrick (1986). Nitrogen losses were measured in the rhizosphere (soil core with rice plants) and nonrhizosphere (soil core without rice plants) soil systems. Their results suggest that about 18% of the applied N was lost due to the rhizosphere effect.

Special soil and environmental conditions in a flooded ricefield support the redox N processes, i.e., nitrification(oxidation of NH_4^+ to NO_3^-) and denitrification (reduction of NO_3^- to N_2). Potentially, these reactions occur in continuously flooded lowland and upland ricefields, the latter being subjected to alternate flooding and draining cycles. Loss of applied N by denitrification may vary from 0 to 70%. The estimated average N fertilizer deficit ranges from 25 to 35%, but field data are lacking to accurately characterize these losses.

Denitrification is widely recognized as a major cause of N loss in lowland rice culture; however, absolute quantities of loss have not been documented. Low N fertilizer recovery in rice is largely due to nitrification and subsequent denitrification. Losses unaccounted for in plant absorption and soil retention are attributed to apparent denitrification loss.

The gaseous products of denitrification, which include the elemental nitrogen (N_2), nitrous oxide (N_2O), and possibly nitric oxide (NO), must directly be measured to distinguish denitrification loss from other losses. Elemental nitrogen gas is difficult to measure against a background of 78% N in the atmosphere. However, N_2O is normally only 300 parts/billion in the atmosphere and, therefore, losses as such can easily be measured. Craswell and De Datta (1980) were the first to measure N_2O in the tropics to prove that denitrification occurs in lowland ricefields. Nitrous oxide seems to be only a minor product of nitrification-denitrcation.

Freney et al (1981) and Smith et al (1982) attempted to measure N_2O emission under field conditions to provide direct proof of nitrification and denitrification.

Nitrous oxide emissions amounted to less than 0.1% of the applied ammonium sulfate or urea. Using a newly developed methodology (Craswell et al 1985), Fillery and Byrnes (1984) reported only about 1% of the applied urea N lost through denitrification.

A recent study conducted by the International Rice Research Institute (IRRI) and the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia (De Datta et al 1986a) in Mabitac, Laguna, Philippines, showed that total losses with 53 and 80 kg N/ha application rates were highest at about 60% when urea was surface broadcast (Table 1). Estimated denitrification losses were between 28 and 33%. These results imply that, irrespective of total N loss (from 33 to 60%) and measured NH_3 loss (from 6 to 31%), the estimated denitrification losses were remarkably constant (24-31%). Clearly, denitrification losses are hard to control even if NH_3 volatilization losses are checked.

Ammonia volatilization

Nitrogen loss through NH_3 volatilization from flooded soils has been reported by various researchers (Fillery et al 1984, Fillery and De Datta 1986) and reviewed by Mikkelsen and De Datta (1979), Vlek and Craswell (1981), and Fillery and Vlek (1986).

Among the techniques used to measure NH_3 volatilization loss, the micrometeorological technique is perhaps the most reliable and least destructive because it does not disturb the environmental or surface processes influencing gas exchange. It permits continuous monitoring, thus, facilitating determination of the environmental effects. It also provides a measure of the average flux density over a large area.

With either ammonium sulfate or urea applied as N source, NH_3 volatilization losses varied between 5 and 47%, measured using the micrometeorological technique (Table 2).

Table 1. Relationship between, total N loss and NH_3 volatilization. Mabitac, Laguna, Philippines, 1985 late dry season.

Application method	Rate (kg/ha)	Water depth (cm)	Total N loss (%)	NH_3 loss (%)	Estimated nitrification-denitrification loss (%)[a]
Researchers' split[b]	53	0	33	6	27
Researchers' split[b]	53	5	54	22	32
Farmers' split[c]	53	5	60	27	33
Researchers' split[b]	80	0	32	7	25
Researchers' split[b]	80	5	58	27	31
Farmers' split[c]	80	5	59	31	28
LSD 0.05	—	—	13	8	—
Farmers' split in circle[cd]	80	5	55	31	24

[a]By difference. [b]2/3 basal + 1/3 at 5-7 d before panicle initiation [c]2/3 broadcast into water at 10 d after transplanting + 1/3 et booting. [d]Unreplicated treatment.

Table 2. Field experiment measuring loss of N fertilizer via NH_3 volatilization from lowland ricefields, using the micrometeorological technique.

Reference	Estimated ammonia loss of N applied (%)	Fertilizer material[a]	Fertilizer rate (kg N/ha)	Method of measurement	Site
Freney et al 1981	5	$(NH_4)_2SO_4$ broadcast and incorporated	80	Micrometeorological	IRRI farm, Philippines, wet season
	11	$(NH_4)_2SO_4$ topdressed at panicle initiation	40	Micrometeorological	IRRI farm, Philippines, wetseason
Fillery et al 1984	47	Urea topdressed into floodwater, 14 DT	80	Micrometeorological	Maligaya (Muñoz), Philippines, dryseason
	27	Urea topdressed into floodwater, 21 DT	60	Micrometeorological	IRRI farm, Philippines dryseason
Simpson et al 1984	11	Urea broadcast evenly into floodwater	80	Micrometeorological	Griffith, N. S. W. Australia
Fillery and De Datta 1986	41-43	Urea or $(NH_4)_2SO_4$ topdressed into floodwater, 10 DT	58	Micrometeorological	Maligaya (Muñoz), Philippines, dryseason
De Datta et al 1986	27	Urea broadcast into floodwater, 12 DT	53	Simple micrometeoro-logical	Calauan, Philippines, dry season
	31	Urea broadcast into floodwater, 12 DT	80	Simple micrometeoro-logical	Calauan, Philippines, dry season

[a]DT = days after transplanting.

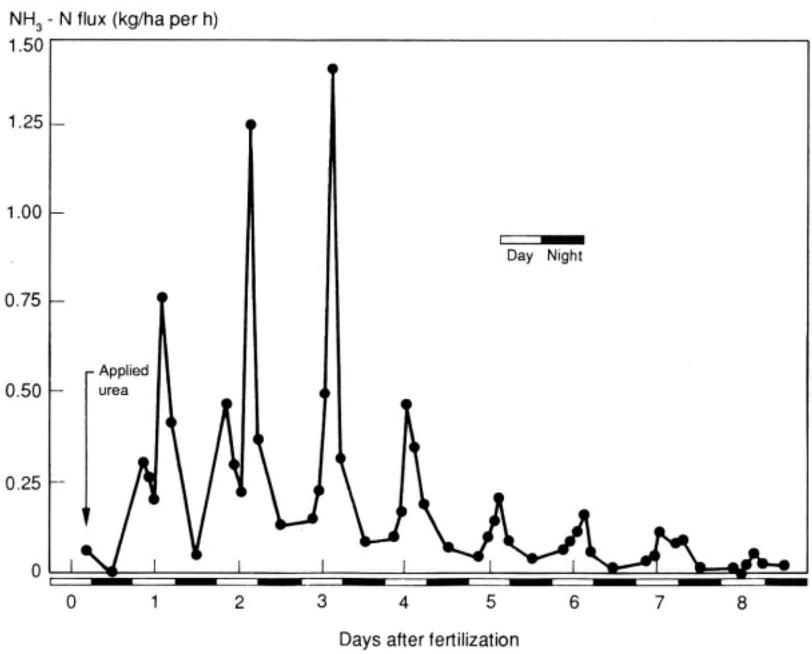
Using a simplified technique discussed by Freney et al (1985), high NH_3 volatilization rates were recorded in a farmer's field in the Philippines between 1400 and 1600 h in the 3 d following urea surface application into floodwater (Fig. 1).

If directly measuring NH_3 volatilization is difficult. then indirect techniques can be employed. In a recent study (De Datta et al 1987), the equilibrium vapor pressure of NH_3 (ρNH_3) in floodwater was used as an indicator of volatilized NH_3. Results suggest that floodwater ρNH_3 was lower when fertilizer was incorporated without standing water than when incorporated with 5 cm water. The ρNH_3 was high 1-4 d after urea was broadcast and incorporated into 5 cm water, suggesting that greater volatilization occurred during this period.

Cultural practices for minimizing nitrogen loss

In recent years, a deeper understanding of the mechanisms causing poor N utilization helped develop cultural practices to improve N fertilizer use efficiency in lowland rice. Basic research results (De Datta et al 1987) suggest that applying N into the floodwater between transplanting and early tillering. as commonly practiced by farmers in Southeast Asia, is wasteful.

Appropriate N application timing and proper water management minimize N loss and maximize N use efficiency in lowland rice. In the 1986 dry season trials in 3 farmers' fields in the Philippines, researchers' timing at 2 N levels gave between 0.4



1. Ammonia fluxes from the circle measured by simplified aerodynamic technique, Mabitac, Laguna, Philippines, 1985 dry season (IRRI-CSIRO collaborative project).

and 0.6 t/ha more grain yield than did farmers' timing (Table 3). Various urea and modified urea products are now available for extensive testing in lowland rice. These include urea of various granule sizes, slow-release, and controlled-release fertilizers.

The potentials of urease inhibitor in reducing NH_3 loss and of nitrification inhibitors in reducing denitrification loss were also extensively tested. Results suggest that the urease inhibitor phenyl phosphorodiamidate (PPD) can somehow control NH_3 loss, but grain yield increases were inconsistent.

Deep placement either by hand or machine also showed promising possibilities. However, tests on machine deep placement have not given consistent results.

Integrated nitrogen management

In countries where fertilizer subsidy was withdrawn, and hence, N fertilizer prices rose, integrating various N sources and their management became highly attractive. Compost, straw, azolla, and green manures are used primarily to supplement inorganic nutrients. China and Vietnam are some of the countries successfully using azolla and green manure.

In South Asia, particularly India, green manure has been used wherever labor and water supply are adequate. Recently, Rekhi (1986) reported from India that research is carried out to maintain long-term soil productivity in the cropping systems. Organic manures, green manures, leguminous crop residues, and inorganic fertilizers are all used to obtain high crop yields with moderate fertilizer application levels.

Biological N fixation is higher when N fertilizer is deep-placed than when it is surface-applied at early rice growth stages. Furthermore, N fertilizer deep placement greatly reduces the population of harmful green algae (Roger and Watanabe 1986). Long-term field experiments have been initiated to monitor fertility changes under a rice - rice system using the integrated nutrient management concept.

Table 3. Effect of N source and application method on grain yield of transplanted rice in farmers' fields. Nueva Ecija, Philippines, 1986 dry season.

Treatment[a]	N fertilizer applied (kg N/ha)	Grain yield[b] (t/ha)
No fertilizer N	0	4.3 e
Farmers' split, PU[c]	58	5.6 c
Researchers' split, PU[d]	58	6.0 b
Point-placement, USG	58	6.1 b
Press wedge, USG	58	5.3 d
Plunger auger, PU	58	5.7 c
Farmers' split, PU	87	5.7 c
Researchers' split, PU	87	6.3 a

[a]PU = prilled urea, USG = urea supergranules. [b] Av of 3 farms. Values followed by the same letters are not significantly different from each other by DMRT at the 5% level. [c] 1/2 topdressed at 15 d after transplanting + 1/2 topdressed at past panicle initiation (PI). [d] 2/3 basal broadcast and incorporated without standing + 1/3 topdressed 5-7 d before PI.

Table 4. Effect of green manuring on the N economy of a rice - wheat rotation (adapted from Tiwari et al 1980).

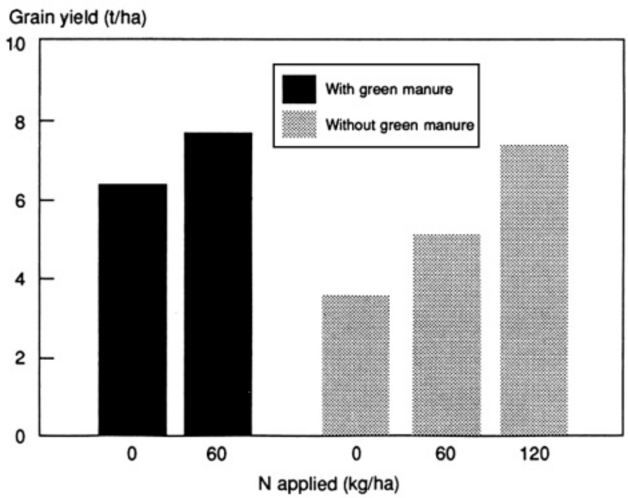
N applied (kg/ha)	Rice yield (t/ha)		Wheat yield (t/ha)	
	Fallow	With green manure	Fallow	With green manure to preceding rice
0	2.4	3.8	1.7	2.4
40	4.0	4.9	1.7	2.8
80	4.6	5.3	1.9	3.2
120	5.0	5.4	2.3	3.4

Nitrogen management in rice-based cropping systems

From India, Tiwari et al (1980) reported that on a partially reclaimed saline-sodic soil, green manuring—besides having a direct effect on rice—had a residual effect on the following wheat yield (Table 4).

Rekhi and Meelu (1983) suggested that in the rice - wheat rotation, an early-maturing mungbean *(Vigna radiata)* can be grown for grain, and the straw used as green manure for rice. The mungbean produced 0.9 t grain legume/ha; mungbean straw incorporation substituted for 60 kg N/ha as inorganic fertilizer (Fig. 2).

China has extensively used organic manures and green manures in rice-based cropping systems, with 4.28 to 12.02 million tons of nutrients used as organic manure from 1949 to 1983. During the same period, the use of chemical fertilizers as nutrients increased from 60,000 to 16.6 million tons (Lin and Liu 1986). Although chemical fertilizer production in China has increased substantially, organic manure,



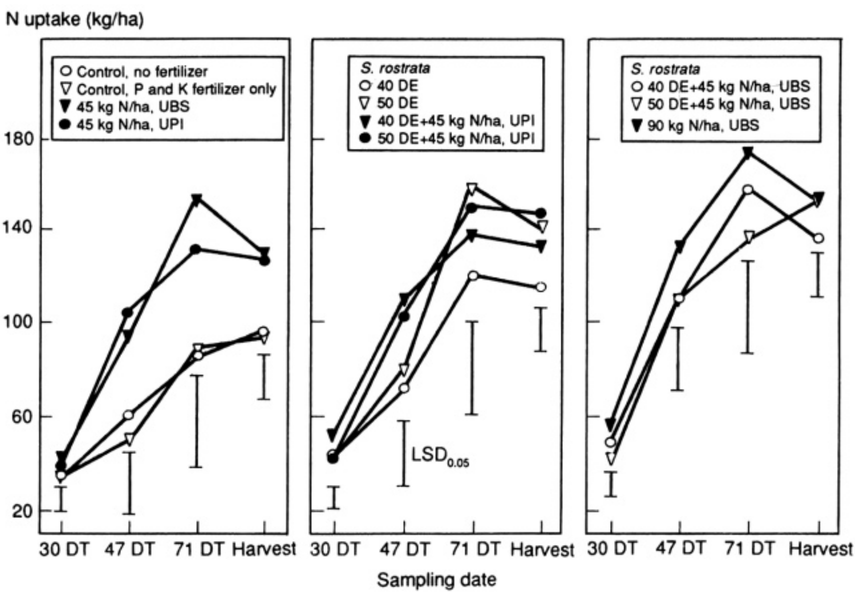
2. Effect of applying summer mungbean straw as green manure on rice yield, 1980-82 (Rekhi and Meelu 1983).

particularly barnyard manure, has remained an integral part of the nutrient source in rice-based cropping systems.

But because of low economic returns, the use of green manure has been steadily decreasing. The area under green manure in economically developed regions along the east and south coasts in China was estimated to have dropped from 1.16 million ha in 1976 to 23,000 ha in 1984 (Guo 1986). Recently, Mamaril et al (1986) reported, based on a field trial at IRRI, that *Sesbania rostrata* incorporated into the soil can accumulate as much as 40-140 kg N/ha. It increased rice grain yield by 1.0 t/ha. The combination of *S. rostrata* (incorporated at 50 d after emergence) and 45 kg N/ha as urea, either split-applied or all topdressed at panicle initiation, gave slightly higher grain yield than did either urea or *S. rostrata* alone. Figure 3 shows the N uptake pattern of rice from combined sources.

Azolla as a green manure has also been extensively evaluated in tropical Asia besides being actually used in China and Vietnam. In a long-term trial at IRRI (8th crop), basal incorporation of fresh azolla and sesbania gave grain yield similar to that with split-applied prilled urea (PU) (Table 5). However, with equal N dose (116 kg N/ha), the highest grain yield was obtained with point-placed urea supergranules (USG) (Table 5).

Bunoan et al (1986) obtained similar results in farmers' fields. They reported that deep-placed USG, alone or in combination with azolla or rice straw as N source,



3. Effect of inorganic N fertilizer and green manure on nitrogen uptake by IR64 rice at different growth stages, IRRI, 1986 dry season. Bars represent LSD at each growth stage. DT = days after transplanting, UBS = urea best split (2/3 N basal + 11/3 N 5-7 d before panicle initiation [PI]). UPI = all area at PI, DE = days after emergence (Mamaril et al 1986).

Table 5. Grain yield of IR64 rice as affected by organic and inorganic N sources at 116 kg N/ha. IRRI, 1986 dry season (8th crop).

Treatment[a]	Grain yield[b] (t/ha)
No fertilizer N	3.5 d
Prilled urea, split application	5.5 b
Urea supergranule, point placement	6.3 a
Fresh *Sesbania rostrata,* soil incorporated	5.4 b
Fresh azolla, soil incorporated	5.0 bc
Fresh rice straw, soil incorporated	4.7 c
Rice straw compost, soil incorporated	5.1 bc

[a]Split application 2/3 urea N, broadcast and incorporated into puddled field without standing water + 1/3 topdressed at 5-7 d before panicle initiation. [b]Means followed by a common letter are not significantly different at the 5% level.

increased grain yield response by 15% over the split-applied PU and in combination with an organic N source.

Reddy et al (1986) suggest that including legume crops such as berseem (*Trifolium alexandrinum*) in the rotation following rice improved soil fertility as compared with other rotations that included only cereals. For example, wheat yielded higher in systems where legume was included than in a rice - wheat system. Rice receiving green manure of mungbean straw (after pods were picked) plus 60 kg N/ ha gave yields similar to those of rice receiving 120 kg N/ha of inorganic fertilizer; this represents a saving of 60 kg N/ha of inorganic fertilizer.

Phosphorus

Rice, like any other cereal, requires a considerable amount of phosphorus (P) for vigorous growth and high grain yield. Many lowland rice soils require added P fertilizers so crops in rice-based cropping systems can produce maximum or most profitable yields. To produce food economically, the crop should efficiently utilize applied fertilizer by absorbing most of it. Barber (1983) contends that it is important to develop practices and to use varieties that are efficient P users.

The available P in the soil increases after soil submergence. Phosphorus transformation processes in flooded soils greatly differ from those in nonflooded soils; they also differ under different water regimes. Understanding the P transformation processes is important for P fertilization of rice, which grows in water regimes ranging from continuous flooding to alternate flooding and drying (De Datta 1981, 1983).

It has been pointed out that a crop yielding 9.8 t grains/ha and 8.2 t straw/ha removed about 31 kg P/ha (De Datta 1985). This amount should be replenished with P fertilizers such as superphosphate in any soil, or rock phosphate, basic slag, and fused Ca-Mg phosphate in acid soils. New P products are being evaluated by the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER). In lowland rice, P application time and method are not as critical as in upland rice.

Management practices to alleviate P deficiency depend largely on soil characteristics such as soil reactions, degree of weathering and kind of clay minerals, on water regime, cropping intensity, and cropping pattern.

Phosphorus application in rice-based cropping systems
In the nontraditional rice-growing areas of Punjab, Haryana, and Western Uttar Pradesh in India, P application should be increased in the rice - wheat rotation areas during the wet season. Drilling P closer to the crop root zone generally improves P use efficiency. In acidic soils and soils of neutral pH, Mussouri rock phosphate gave good results in rice - rice, rice -wheat, and rice - legume cropping systems (Reddy et al 1986).

Research in China on soil and crop management practices on lowland rice - upland crop rotation in acid lowland soils showed that P application to upland crops is more effective than to lowland rice (Jiang et al 1982). Yield increased by 41% when P was applied on early soybean as against only 23% on early rice. In upland crop - lowland rice systems, where P fertilizer was applied to the upland crop, the residual effect of P was sufficient for the succeeding lowland rice crop. Therefore, lowland rice crops did not benefit from an additional P application. On the other hand, in rice - upland crop rotations where P fertilizer was applied to rice, the yield increased by 25% in late soybean in the second season with further application of superphosphate (Table 6).

Based on a number of studies in the tropical and subtropical regions of China, where rice is planted as the main crop in the rice - upland crop system, P fertilizer application should be based on upland crops especially on winter green manure or leguminous green manure crops.

From these and other studies, Jiang et al (1982) surmised that P application efficiency can be greatly improved with proper choice of crop sequence and crop to receive P. Cultural practices such as banding and placement and timing of P fertilizer can be further improved to increase nutrient use efficiency in rice-based cropping systems. Although the importance of residual response to P application is widely recognized, it should be critically evaluated using a systems approach to nutrient management.

Potassium

Intensive cropping and higher potassium (K) removal from the soil necessitate increased use of K-containing fertilizers.

Table 6. Effect of P fertilizer on different cropping systems of the upland rice crop in China (adapted from Jiang et al 1982).

	First season				Second season			
	Early soybean		Early rice		Late rice		Late soybean	
Treatment	NK	NPK	NK	NPK	NK	NPK	NK	NPK
Yield (t/ha)	0.8	1.1	3.2	3.9	4.3	4.3	1.1	1.4
Relative value (%)	100	141	100	123	100	100	100	125

The amount of exchangeable K in soil directly available to plants is related to clay content and to the intensity of mineral decomposition of soils rich in illite and montmorillonite. A portion of the nonexchangeable K may also be available to plants. Illite type of clay minerals are, however, not common in soils of the humid tropics.

Potassium uptake and absorption patterns

The pattern of K^+ uptake follows most closely that of vegetative growth. Seventy-five percent of the total K requirement is taken up even before booting stage, and most of the remaining K^+ even before grain formation begins. Potassium content is highest in leaves and culms, with relatively little K accumulated in the milled grain. There is little K translocation among plant parts (De Datta 1981).

Lowland rice response to potassium

Available K in the soil varies widely. It may range from a few kilograms per hectare of furrow depth to 25 mg/kg or more in soils formed from fine-textured sedimentary materials. Because many lowland rice soils occur in river basins or alluvial valleys and are relatively youthful soils, their K content is frequently high. Where traditional agriculture has shifted to maximum-yield concepts, a significant transition to the use of NP, NK, and NPK fertilization of rice, with good economic returns, has occurred. Detailed research results are summarized by De Datta and Mikkelsen (1985).

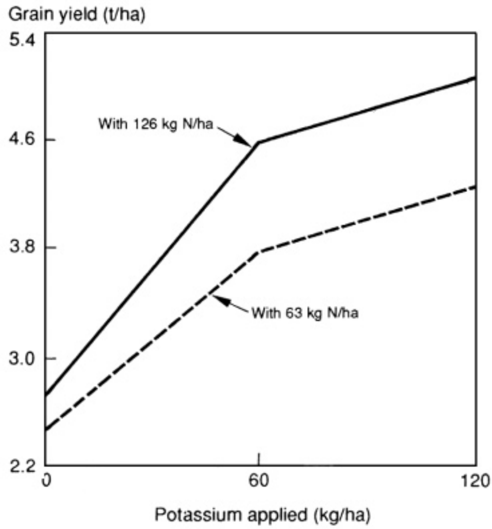
Nutrient balance

In Korea, Japan, and China where rice yields are high (4.5-6.8 t/ha), balanced fertilizer use (NPK and sometimes Si) is emphasized. In other countries in South and Southeast Asia where national yields average from 2 to 3 t/ha, only N fertilizers are generally recommended. Phosphorus or K is applied only to deficient soils.

Results from China demonstrate that K response is markedly increased with increased N level (Fig. 4). A balanced supply of plant nutrients to include K will be increasingly important as modern rice varieties are grown intensively with other upland crops (De Datta and Morris 1984).

Integrated nutrient management

The K requirement of rice is somehow supplied by plant residues (such as stubble), straw incorporation, and K in irrigation water. In countries such as China and India where organic manures are extensively used, response to K from chemical fertilizer correspondingly decreases. Singh (1975) estimated the 1980 total production of K from organic wastes to be 35 million tons in the developing world. The use of organic wastes for K and other nutrients in rice depends largely on the farmers' socioeconomic conditions. Green manuring will be valuable for P and K nutrition, besides N nutrition of rice, where inorganic fertilizer costs are higher, land with marginal use is abundant, and labor for harvesting, transporting, and spreading and incorporating green manure material is cheap (De Datta and Morris 1984).



4. Effect of K fertilizer combined with N (Xie et al 1981).

Potassium and zinc interactions

In a given crop, an optimum concentration of each essential element is needed to produce maximum yield. Maintaining high yields requires fairly close adherence to the optimum balance in nutrient concentration. There are contradictory reports on K and Zn interactions. Potassium and Zn interactions in lowland rice were earlier reported (De Datta 1985). Based on our initial studies, field research was continued in Pangasinan, Philippines, to evaluate IR36 rice response to K and Zn. Table 7 lists the soil properties. Zinc application at all rates in Bugallon soil significantly increased yield in the dry season (Fig. 5). Where Zn was applied with K, grain yields were significantly higher than without K. The highest yield was obtained with 200 kg K/ha in combination with 40 kg Zn/ ha. In the wet season, Zn gave responses of 1 t/ha without K, but K alone at 100 kg/ ha increased yield by 2.1 t/ha. Higher K rates or added Zn gave no further significant yield increase.

At Mangatarem, yield response to Zn was observed only with 100 kg K/ha (Fig. 5). In the wet season, at the same K levels, yields did not significantly differ among Zn application rates. Only in Bugallon soil were yield differences among Zn levels recorded, although this soil had a higher level of available Zn than the Mangatarem soil.

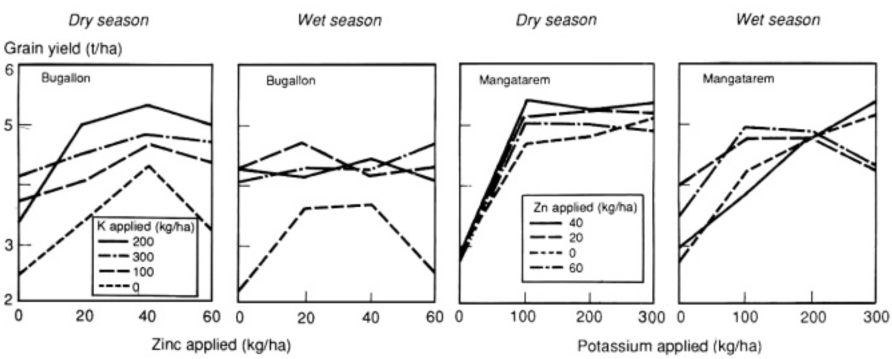
In both seasons, grain yield responded to application of K alone. The same trend was observed in Bugallon during the wet season, but Zn application was needed with K in the dry season to obtain highest yield. Response to Zn was due to very low (<1.0 ppm) exchangeable Zn in the soil. More Zn is needed if Mg level (Ca, Mg <2.0) or if Ca + Mg/ K is high.

Results varied between sites because of nutrient imbalances in the soil. This further confirms a definite interrelationship existing among K, Ca, and Mg concentrations in the different plant parts; hence, interaction responses of the nutrients deficient in the soil.

Table 7. Properties of soils for trials on K-Zn interaction. Bugallon and Mangatarem, Pangasinan, Philippines, 1985.

Soil property	Bugallon[a]		Mangatarem[b]	
	Topsoil	Subsoil	Topsoil	Subsoil
pH (1:1)	5.8	5.8	7.1	7.2
Organic matter (%)	3.4	2.4	2.2	1.9
Total N (%)	0.17	0.10	0.11	0.08
Available Olsen P (ppm)	0.65	0.46	1.6	1.3
Exchangeable cations (meq/100 g)				
Na	0.18	0.14	0.27	0.29
K	0.02	0.01	0.06	0.08
Mg	10	11	24	27
Ca	10.9	10.9	15.2	16.9
Ca/K	545	1090	253	211
Mg/K	520	1070	400	335
Ca/Mg	1.05	1.02	0.63	0.63
Ca + Mg/K	1065	21 60	653	546
CEC (meq/100 g)	24	24	40	43
Fe (ppm, perchloric acid)	3.8	3.8	6.2	6.2
Available Zn (ppm, Katyal and Ponnamperuma)	0.13	0.12	0.02	0.02
Particle size (%)				
Sand	27	28	9	8
Silt	46	43	48	44
Clay	27	29	43	48
Texture	Loam	Loam	Silty clay	Silty clay

[a]Fine loamy, mixed, isohyperthermic Typic Haplustoll. [b]Fine, mixed, isohyper. thermic Aquic Haplustoll.



5. Effect of K and Zn fertilizer on grain yield of IR36, Bugallon and Mangatarem, Pangasinan, Philippines, 1985 dry and wet seasons.

Sulfur

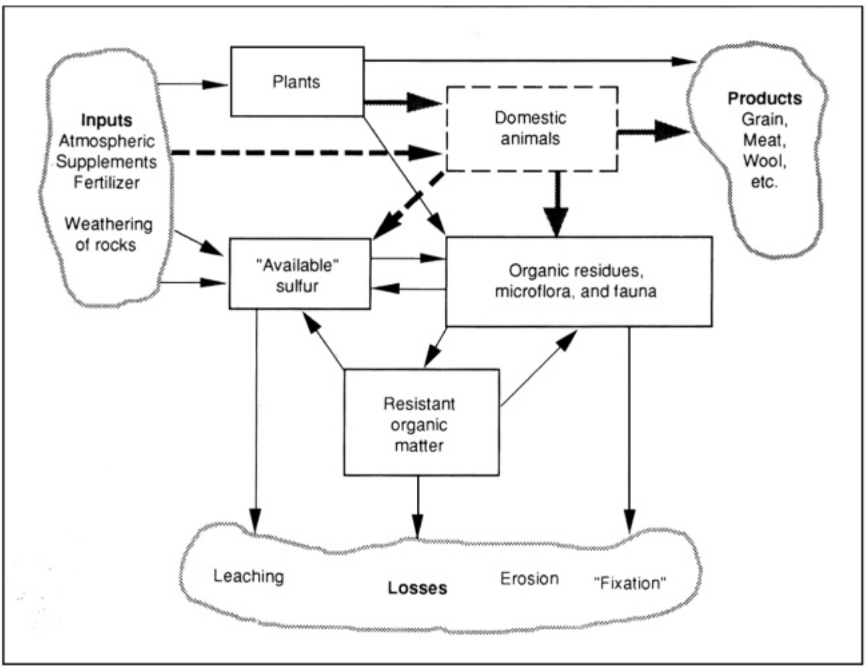
The amounts of sulfur (S) in the profile explored by plant roots are frequently lower in tropical soils than those in temperate regions (Neptune et al 1975). Further, high analysis fertilizers containing essentially no S are increasingly being used. Both of these factors limit S supply to plants in tropical soils.

Sources of S, however, distinctly differ. Sulfur supplied by fertilizer is usually derived outside the production system, while that from the soil results from the interaction of different S-containing materials within the system and their management. Kamprath and Till (1983) proposed a simplified S cycle wherein the S pool is controlled by many competing processes (Fig. 6).

Available sulfur

The available S pool consists of the solution sulfate plus the major portion of the adsorbed sulfate in the profile effectively explored by the plant roots. Factors controlling the adsorption and desorption of sulfate have been extensively studied, as it is the pool from which plants draw their S.

The availability of sulfate adsorbed in the subsoil depends on its accessibility to the roots. Moreover, S uptake by plants is related to the sulfate concentration in the



6. Sulfur utilization in crop and animal production. Irregular shapes show sulfur inputs to and outputs from the production systems. Rectangular boxes represent pools of S-containing materials, grouped for simplicity. All materials in these pools can take part in S recycling. Arrows show flows of S between components. System in broken lines shows the complexity added whendomestic animals are considered as part of the production scheme (Kamprath and Till 1983).

soil solution. Many highly weathered soils retain sulfate strongly somewhere in their profiles. Sorption characteristics have been studied, but the mechanisms by which soils retain S have not been definitely established. Considerable uncertainty exists about the nature and plant availability of adsorbed sulfate. Although plants utilize adsorbed sulfate, S deficiency still occurs in crops growing in tropical soils which contain several thousand kilograms per hectare of SO_4-S within the root zone (Fox 1980).

Rice response to sulfur

Rice response to S has been reported from many countries. Continued use of modern varieties with intensive cropping can remove 10-13 kg S/ha per crop and result in increased S response in many lowland rice soils (De Datta 1985).

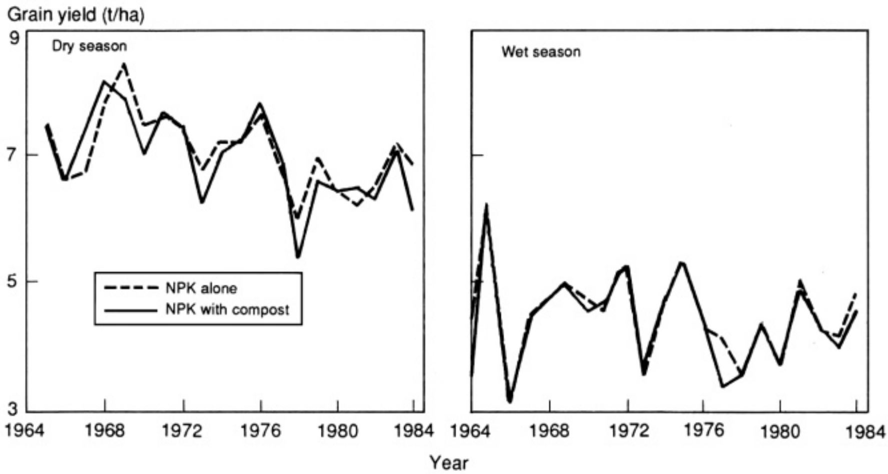
Sulfur deficiency and response to S are widespread in Bangladesh. In Punjab, India, where rice - wheat rotation has resulted in increased cereal production, S deficiency has become widespread. Rice response to S has also been reported in parts of Java and Sulawesi in Indonesia. Field studies classifying S-deficient areas in Philippine rice soils are limited. Islam and Ponnamperuma (1982) reported a significant response to S in 11 out of 30 Philippine rice soils studied in the greenhouse. Several field studies are under way to ascertain the magnitude of S response of rice in the Philippines.

Long-term effects of organic matter application

Nutrient balance is a critical factor in maximizing grain yield of a single crop and in crop intensification. Under intensive rice - rice cropping systems, the demand for P and K increases over time but often only after two or three croppings (De Datta and Gomez 1975, 1982).

A long-term fertility experiment was conducted for 20 yr (1964-84) on Maahas clay soil (Andaqueptic Haplaquolls). Incomplete factorial combinations of N, P, and K were tested. Treatment with NPK supplied partly by straw compost was also tested. Organic + inorganic fertilizer did not increase grain yield more than did NPK from inorganic fertilizers alone (Fig. 7). On soil with intensive rice - rice croppings (1964-84), pH value was lower with either fertilizer applied alone or in combination with compost (Table 8). However, differences in soil characteristics were similar among all inorganic N and inorganic + organic N sources (Table 8). From China, Wang (1986) evaluated the effect of organic manure application on soil chemical properties in experiments conducted in 1979-81 on rice grown in the suburbs of Shanghai. Applying organic manure increased the organic matter content of soil by 8.3% over the initial analysis. Conversely, organic matter content decreased in plots that received no fertilizer or organic manure. Total N was increased by 2.8% over the same period (Table 9).

It is difficult to compare the results on soil fertility changes at IRRI farm, where 20-yr data are available, with those from the suburbs of Shanghai, China, where the experiment was conducted for only 3 yr. Data, however, indicate that the effect of organic manure or compost application on soil parameters depends largely on soil type, cropping period, and cropping sequences.



7. Long-term effect of organic and inorganic fertilizers on rice yields at IRRI. Long-term fertility trial, 1964-84.

Table 8. Changes in soil characteristics in the long-term fertility trial. IRRI Block N_{15}, 1968-84 (data source: De Datta, S. K. IRRI-Agronomy Department).

Soil character	1968	1984		
		No fertilizer	All inorganic N source[a]	Inorganic N source + 24 kg N/ha from compost
pH	6.0	6.0	5.6	5.8
Organic matter (%)	2.0	3.7	4.1	4.2
Total N (%)	0.14	0.19	0.21	0.22
CEC (meq/100 g soil)	45	39	38	39
Available P (Bray 2) (ppm)	12	16	26	24
Exchangeable K (meq/100 g soil)	0.8	1.8	1.6	1.8

[a]Both fertilizer treatments received 13 kg P end 25 kg K/ha with the same N application rate.

Table 9. Effect on soil characteristics of organic manure applied to rice in the suburbs of Shanghai, China, 1979-81 (Wang 1986).

Treatment	Organic matter (%)	Total N (%)
Initial soil analysis	3.5	0.217
Without fertilizer or compost	3.1	0.211
Organic manure (22.5 t/ha)	3.4	0.223

Soil fertility management issues

IRRI long-term experiments evaluated soil fertility changes under intensive cropping, with one dry season and one wet season rice crop each year for 17-20 yr.

Yield increases due to N declined with time more drastically in the first 3 croppings, particularly in the dry season, at all Vertisol and Inceptisol sites. Three out of four sites showed responses to P, but trends and magnitude varied between sites. In dry season croppings, yield increases in response to K (NPK-NP) increased with time in an Inceptisol and decreased with time in a Vertisol.

Systems approach to nutrient management

Increased systems comprehension, refined research focus, and improved inter-disciplinary communication are the advantages of a systems research approach. Optimal management strategies must be developed to supply the nutrients needed by crops grown in a rice-based cropping system.

The peculiar nature of rice soil management and its effect on physical properties and nutrient-supplying capacity of the soil are important considerations influencing nutrient management strategies. Thus, soil management of puddled lowland rice-based cropping systems research is relevant because of

- the effect of puddling on nutrient transformations,
- the residual physical properties of the soil, and
- the soil profile that commonly develops following a few years of lowland rice production.

In systems research, results should provide a basis for judging under which the following adaptability classes, cropping patterns, or component technology should fall:

1. technology that is within the management and resource limitations of small farmers and can be adopted without or with only limited government programs;
2. technology with specific resource constraints, weak markets, or managerial deficiencies that limit adoption; and
3. technology that encounters problems that cannot be solved or cannot be overcome by a program of resource augmentation, market support, or extension activities (De Datta and Moms 1984).

The systems approach to research on nutrient use management should have a goal-seeking orientation and, thus, lead to solving problems, resulting in improved fertilizer management practices for rice and rice-based cropping systems.

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Notes

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Integrated weed control in rice

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Weeds can cause 30-80% yield loss in rice in Egypt. No single weed control method suffices, and integrated weed management—combining indirect (preventive) control methods and direct control—is required. Land preparation, clean seed, planting method, variety, plant spacing and plant density, fertilizer application, water management, and crop rotation are indirect methods of weed control. Hand weeding, mechanical weeding, and chemical weed control are direct methods of weed control. Integrated weed control combines all of these components.

Weeds are a serious constraint to rice production in Egypt, as this crop is very sensitive to weed competition. The most prevalent weeds are *Echinochloa crus-galli* (barnyard grass), *E. colona* (jungle rice), *Cyperus difformis* (small-flowered umbrella plant), *Ammannia* sp. (red stem), and *Eclipta alba* (tago weed). Nearly all commercial rice production in Egypt is accomplished by manual transplanting, and grain yield losses due to weeds were estimated at 30-80% (Ismail et al 1983). For example, 16 plants/m^2 of *E. crus-galli,* competing with 320 plants/m^2 of rice, reduced yield by 37%; 80 plants/m^2 of the weed reduced rice yields 100% (Hassan 1981).

Indirect methods of weed control

Land preparation

The rice seedbed should be tilled 15 to 20 cm deep as soon as it is dry enough to allow field tillage without excessive soil compaction. Large clods not broken or worked down in tillage operations provide a favorable environment for rapid weed seedling growth and establishment (Bayer et al 1985). Clods so large that they are exposed above the water surface provide excellent conditions for growth and survival of grassy weeds, even with the use of currently available herbicides. Puddling, which is the major method of land preparation in rice, markedly reduces competition from weeds (Moody 1977). With pregerminated rice seeds, leveling of the field is more important, because developing rice seedlings can be killed or greatly retarded in their growth when ponding of water occurs (De Datta 1981). To improve seedbed preparation, a laser beam has been used to guide grading equipment as it cuts and fills the soil, while a land plane or a leveler is used for the finishing touches on a level, smooth surface (Huey 1977).

Preventive weed control

Preventing weed growth requires the use of clean crop seed, the proper composting of manure, the use of clean equipment, and the control of water and soil runoff, which spreads weeds. In the USA, cleaning rice seed before planting is essential to prevent infestation by red rice (Smith and Shaw 1966). Keeping seedbeds free of weeds and ensuring that weeds are not transplanted with the rice seedlings are also important. Yield losses of about 60% have been reported when *E. crus-galli* plants were transplanted with rice seedlings and not controlled. Keeping livestock out of fields as much as possible and preventing weeds in the area from going to seed will also help to keep weeds down (Moody 1977).

Crop Competition

Crop competition is one of the cheapest and most useful methods of weed control available to the farmer. Planting methods, plant spacing and density, and the rice cultivars planted all influence weed control.

Method of planting. Transplanted seedlings have a competitive advantage over weeds that grow after transplanting; yield losses are therefore lower in transplanted than in direct seeded rice. Furthermore, transplanted seedlings are less sensitive to herbicide injury (Moody 1977). In direct seeded rice culture, the rice plants compete with weeds from the time they emerge. Direct seeding and mechanical transplanting require less labor than hand transplanting, but they also require improved weeding practices.

In Japan, yield losses due to uncontrolled weed growth ranged from 27 to 59% for rice that was 23.4 cm tall when it was hand-transplanted (Matsunaka 1976). With mechanical transplanting, where shorter, younger seedlings are used (14 cm tall), yield losses to weeds ranged from 80 to 89%. A much wider range and intensity of weed problems can be expected in dry seeded rice. Smith (1970) noted that a dense infestation of *Echinochloa* sp. was difficult to control by cultural or mechanical methods in dry seeded rice.

Rice cultivar. The new short-statured cultivars with upright leaves allow more sunlight to penetrate the crop canopy, and they respond better to nitrogen (N) than taller, leafier cultivars (Smith et al 1977). However, higher light penetration through the canopy combined with high levels of N stimulates weed growth. The short-statured cultivars do not compete well with barnyard grass and other weeds. If new short-straw, short-duration, high-yielding cultivars are to be grown efficiently, weeds must be controlled because these cultivars do not compete with weeds as well as do the traditional varieties that are taller and leafier, or have a longer growing season (De Datta 1969). When weed competition against various rice cultivars was studied, a highly significant negative correlation was observed between plant height and yield reduction caused by weeds: the taller the rice plant, the less the yield reduction (Moody 1977).

Plant spacing and plant density. The closer the rice plants are sown, the more competition they are against weeds and the fewer the weeds that grow in association with them. For good weed control, the primary concern in seeding is the use of good quality, weed-free rice seed. Seeding rates that result in rice stands of 160-220 healthy plants/m^2 are optimum for both yield and competition against weeds (Eastin 1981).

Rice stands as low as 110 plants/m^2, which is satisfactory, will result in good yields if weeds are controlled; however, stands of this density do not compete with weeds as well as the more dense stands. In the Philippines, yield losses from weeds averaged 52% for rice transplanted with a 25- × 25-cm spacing and 29% for rice with a 20- × 20-cm spacing (Estorninos and Moody 1976).

Fertilizer application

Weeds have a large requirement for nutrients; therefore, fertilizers should be applied when they will be most beneficial to the crop and not when they will increase weed competition. Preplant or very early phosphate application stimulates weed growth. To reduce this, phosphate should be applied to the crop preceding rice in the rotation, just before flooding or in the first irrigation, because flooding inhibits weed growth. When N is applied to the rice crop, its effect on the rice will be maximized if weeds are absent. N applied before seeding rice or after emergence of weeds stimulated growth of barnyard grass and aquatic weeds (Smith et al 1977). In direct seeded rice, high levels of N applied to rice after barnyard grass headed reduced weed competition, but N applied when the grass was at the vegetative stage enhanced competition (Smith and Shaw 1966).

Water management

Many weeds cannot germinate under flooded conditions, and water has been recognized as an effective means of weed control in rice. Weed populations decrease as water depth increases. It is essential to keep the field continuously flooded, not only to reduce the number of weeds present, but also to improve the performance of weed control techniques used in association with water management. Herbicides that give excellent weed control when applied to water 6 d after planting perform poorly in the absence of standing water (Moody 1977). A continuous water depth of 5-10 cm is important to improving the effectiveness of herbicides currently used in rice and for reducing the severity of weed competition (Bayer et al 1985). Lowering the flooding level or completely draining the field favors barnyard grass, broadleaf weeds, and sedge, intensifying weed competition with rice, even when currently available herbicides are used.

In Japan, it is well known that water management before or after transplanting of rice markedly governs the effectiveness of soil-applied herbicides such as butachlor and nitrofen (Nada 1977). Continuous flooding also controls red rice (Sonnier 1978).

Cropping system

Crop rotation can be used to minimize crop damage from weeds. Each crop has its own characteristic weeds, and when the same crop is grown on the same piece of land year after year, these weeds tend to build up. Rotation of crops reduces buildup of a certain weed species or group of weeds. The rotation should be planned so that no group of weeds has a chance to develop undisturbed.

The effect of these indirect methods of weed control on specific weeds in the USA is indicated in Table 1 (Moody 1977).

Table 1. Efficacy of cultural practices in controlling weeds in ricefields.

Weed	Efficacy[a]						
	Hand weeding	Seedbed preparation	Dry seeding	Timely flooding[b]	Timely draining[b]	Rice stand[c]	Crop rotation
Algae	Poor	Good	Good	Poor	Good	Good	Good
Cyperus difformis	Poor	Fair	Fair	Poor	Good	Good	Good
Echinochloa crus-galli	Poor	Good	Poor	Fair	Poor	Fair	Fair
Eclipta alba	Poor	Poor	Poor	Fair	Poor	Good	Fair
Oryza sativa (red rice)	Good	Good	Poor	Poor	Poor	Fair	Good

[a]Poor = Practice cannot be used economically in commercial rice or fails to control the weed, Good = gives economic control in commercial rice, Fair = controls weeds somewhat. [b]After Crop emergence. [c]A rice stand of 130 to 215 Plants/m^2 reduces many weed problems.

Direct weed control methods

Manual weeding

Hand weeding is the most common weed control method used in transplanted rice in Egypt. Unfortunately, it is extremely time-consuming and laborious (Ibrahim and Hassan 1986). Also, with rising wages and labor scarcity, hand weeding is becoming increasingly more difficult.

Mechanical weeding

For all mechanical weed control methods, straight-row planting is essential. Rotary weeders are pushed by hand to remove weeds within or close to rice hills; it is also possible to use push-type rotary weeders in direct seeded rice if the seeding is into mud in straight rows (De Datta 1981). Care should be taken to avoid the rice plants during the weeding operation; otherwise appreciable yield reduction can result (Moody 1977).

Chemical weed control

Herbicides are chemicals used for killing or inhibiting the growth of certain plants. Herbicides should not be considered as replacements for other weed control practices, but should be used in conjunction with them in man's never-ending battle against weeds. Continued use of the same herbicide(s) on the same piece of land leads to an inevitable increase in tolerant weeds, particularly perennials, which are difficult to control. Rotating crops and herbicides will reduce the buildup of tolerant weeds, but the only guaranteed method is to remove these tolerant weeds by manual or mechanical means whenever possible. This problem can be researched in Egypt before it occurs at the farmer's level.

Herbicide usage in Egyptian ricefields increased from 28,200 ha in 1980 to 142,200 ha in 1984. The herbicide thiobencarb (Saturn 50%) was used on more than 60% of the treated area; oxadiazon (Ronstar 12% or 25%) and butachlor (Machete 60%) were the two other most extensively used herbicides. For rice, Saturn has been used effectively in nurseries and in direct seeded and hand-transplanted rice. This herbicide has been mixed with pulverized soil or gypsum and spread over the field by hand as an alternative to spray application. Recommended herbicides for rice in Egypt are listed in Table 2.

It is expected that, over time, hand-transplanting of rice in Egypt will be increasingly replaced by broadcast seeding, drilling, or mechanical transplanting. Excellent weed control was obtained in drilling and mechanical transplanting by using herbicide spray combinations and/ or sequentially applied herbicides. A mixture of propanil (Stam F_{34}) with either thiobencarb or butachlor, applied 15 d after seeding or mechanical transplanting, gave 96 to 98% weed control. Basagran 50% (bentazon) is effective as a sequential postemergence spray where *Cyperus* or broadleaf weeds are a problem.

Future plan of work for improving weed control in rice

Research under the work plan of weed science activities in the rice project will include:

1. Surveys throughout the rice area to evaluate the effects of major weeds on yield of rice and shifts in weed population due to changing crop rotations, cultural practices, and herbicide use. Attention will be given to the role of various weed species in losses due to other pests such as diseases, insects, and rats.
2. Study of the biology and control of specific weeds.
3. Collection of weed seed for use in screening trials during the growing season.
4. Herbicide screening for weed control and rice injury, and the interactions between herbicides and other pesticides. The number of compounds tested as well as the range of rates applied will be expanded.
5. Herbicide evaluations in replicated yield tests at Sakha to determine the most suitable materials and the time and method of application for specific weed species in both transplanted and direct seeded rice.
6. Integration of cultural and chemical control procedures into optimum weed management systems for specific weed situations in both direct seeded and transplanted rice, and an economic evaluation of these. Selected systems can be demonstrated in replicated field plots of about 2 ha at Sakha State Farms.

Table 2. Common and chemical names of herbicides recommended for rice in Egypt.

Common name	Other designation		Chemical name
Bentazon	Basagran	50%	3-isopropyl-1, H-2, 1, 3-benothiadzin-(3H)-one-2-dioxide
Butachlor	Machete	60%	*N*-(Butoxyrnethyl)-a-chloro-2,6-dimethylacteanilide
Molinate	Ordram	72%	5-Ethyl hexahydro-1 H-azepine-1-carbothioate
Oxadiazon	Ronstar 12%	25%	2-tert-Butyl-4-dichloro-5-isoproxyphenyl)-1,3,4-oxadiazon-5-one
Perfluidone	Destun	50%	1,1,1-trifluoro-*N*-(2-methylor-4(phenylsulfonyl) phenyl) methane sulfonamide
Propanil	Stam F 34	34%	3,4-Dichloropropionanilide
Thiobencarb	Saturn	50%	5-4-(chlorophenyl)methyl diethyl carbamothioate

7. Studies of the influence of various crop rotation plans on weed populations, including kinds of weeds in various rice-growing areas. Herbicides and herbicide rotation schemes will also be investigated for their effects.
8. An economic evaluation of the losses caused by weeds and the value of various kinds and degrees of weed control.
9. Gathering of preliminary information on interspecific competition between red rice and an improved rice variety in a transplant system, as reflected by yield and lodging.
10. Herbicide evaluations for red rice control.
11. Studies to evaluate the herbicide protectants and antidotes when being used in rice to allow increased herbicide doses without injury to the rice crop.

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Mechanization of rice production in Egypt

A. F. El-Sahrigi and S. Ishihara

Agricultural mechanization became a necessity in Egypt for several reasons: 1) low labor productivity and high costs; 2) escalating opportunity costs of animals; and 3) low output growth of major crops. In addressing these problems, the Egyptian Government has realized the benefits of agricultural mechanization, which include high yields, cropping calendar optimization, recovery of losses of animal products, and enhancement of farm labor productivity. The Agricultural Mechanization Research Institute has prepared a mechanization development plan for 1982-87, which has identified the problems, the possible solutions, and the budget needed to put these into practice. The plan emphasizes the need to mechanize special field crops, including rice. This paper examines the Institute's achievements in the area of mechanized rice farming, the problems faced in introducing it, and action taken to overcome them.

Need for agricultural mechanization

Three critical factors related to the agricultural production environment in Egypt have made farm mechanization not only desirable, but mandatory: 1) low labor productivity and high cost; 2) escalating opportunity costs of animal power; and 3) low output growth of major crops.

Labor productivity and cost

During the past decade, there has been a steady outflow of labor, particularly of adult males, from the rural sector. This migratory trend has been induced, in part, by rapid escalation of the consumer price index for rural areas relative to that in the urban centers. Another factor influencing the emigration rate has been the growth of higher paying employment opportunities in the nonagricultural sectors, and in the neighboring oil-exporting Arab countries.

Labor emigration has created labor shortages and upward pressure on wages during critical periods of the agricultural season, which occur in May, September, October, and November.

Seasonal labor shortage and high input costs have reduced farm income through: 1) increased costs of production in a labor-intensive farming system and 2) increased field losses from inadequate labor input levels.

Escalating opportunity costs of animal power

High population growth rates and relatively static domestic production of animal products have accelerated inflationary price trends for meat and milk in the domestic market. The result of the change in supply/demand and in prices of animal outputs is that opportunity costs of animal power, represented by forfeited production of meat and milk, have made animal draft, the traditional power source on Egyptian farms, unprofitable.

Low output growth of major crops

During the 1970s, output of major cereal and fiber crops was relatively stagnant. Low rates of output growth were attributed to a number of internal and external factors related to biological factors as well as to on-farm cultivation practices. Packages of biological inputs have been developed through various research efforts. Proven mechanical inputs are urgently needed to enhance the delivery efficiency of these yield-increasing biological packages and to improve on-farm management efficiency of farming operations.

Benefits of mechanization

The benefits of mechanization occur chiefly in the following categories:

1. Agronomic practices. Yield is increased through improved tillage and cultural practices, including optimal plowing and seedbed preparation; mechanized planting, cultivation, and harvesting; and soil improvement.
2. Cropping calendar optimization. Research conducted in Egypt and elsewhere has indicated significant increase in crop yields through timely planting and harvesting. Planting at the correct time permits plant growth stages to proceed in concert with favorable climatic conditions. Harvesting at the correct time reduces field losses through crop recovery at optimal moisture content, which reduces shattering. Mechanization of labor-intensive operations can reduce the time required for both harvesting and seedbed preparation for the subsequent crop, permitting the farmer to take advantage of seasonal periods that are most conducive to plant flowering, growth, and improved yields. Shortening the farming operation will also help increase the number of crops grown in an agricultural cycle.
3. Recovery of animal product losses. It has been demonstrated through farm management surveys that draft animals consume more feed and produce less milk and meat than livestock not used for draft purposes. Increased mechanization will remove animals from plows and irrigation devices, thereby generating increased milk and meat output for home consumption and the domestic market.
4. Enhancement of farm labor productivity. Enhanced productivity from mechanization will increase output per work-hour, reduce on-farm labor costs, and help recover production losses caused by labor shortages during peak periods.

Current status of agricultural mechanization in Egypt

During the past 10 yr, Egyptian farmers have come to appreciate some of the benefits of mechanization, showing their willingness to adopt appropriate technologies introduced and provided through extension efforts and private-sector services. Therefore the Egyptian Ministry of Agriculture has prepared a Five Year Agricultural Mechanization Development Plan 1982/83-1986/87. The plan provides an official assessment of mechanization extension requirements and addresses all anticipated needs for capital investment, support facilities, credit funds, maintenance and repair infrastructure, personnel, operating costs, and training installations. As such, the plan is an integrated package of requirements designed to initiate comprehensive mechanization of farming operations throughout the cultivated land area of Egypt.

The 5-year mechanization plan aims at:

1. Mechanization of seedbed preparation at a rate of 100% after clearing the land from the previous crops. Mechanical harvesting of wheat, rice, and faba beans at a rate of 40% by introducing combine operations in allowable holdings; in the remaining areas, a system of two machines is recommended—one for harvesting, the other for threshing and winnowing.
2. Mechanization of sugarcane and horticulture crops at the rate of 40%.
3. Mechanization of planting and harvesting of the remaining crops at a rate of 40%.

The plan will be implemented using the following procedures:

1. Establishing of 100 to 150 pilot governmental custom-hired stations, each serving an area of about 2100 ha, equipped with appropriate agricultural machinery suitable for the crops in that area. Table 1 shows the planned target level of agricultural equipment for each unit of 420 ha (1000 feddan). Training and extension are also incorporated into the center's activities.
2. Facilitating the provision of loans for farmers and tractor owners to encourage them to own and operate tractor-powered agricultural machinery.
3. Encouraging the establishment of both cooperative and private custom-hired stations to provide expensive machinery to those farmers who cannot afford to own it.
4. Providing adequate financial support and high-powered tractors, subsoilers, and land-levelers to each pilot station, which is considered as an economic unit by itself.
5. Providing all cultivated areas in the country with village workshops and maintenance and repair centers, which is one of the national plan objectives.
6. Providing support for training, extension, field irrigation development, and local manufacture of farm machinery in order to achieve the comprehensive plan objectives.

Also, the plan calls for the mechanization of some specialized crops, including rice, stating that a complete and integrated mechanization of rice cultivation from sowing to harvest is required (p. 53), as it could save 14 to 65% of the costs of transplanting and harvesting operations.

Table 1. Targeted level of agricultural equipment in the Five-Year Mechanization Plan for Egypt, 1982-87. [a]

Machinery or equipment	Targeted number per 420 ha [b]
Wheeled tractor	7
Plow	4
Disc plow	1
Disc harrow	2
Final leveling machine	1
Mechanical "Kassabiya"	1
Ditcher	1.5
Ridge plow (3-blade)	2
Pesticide spraying machine	4
Harvesting and bundling machine	2
Fixed hay compressor	1
Threshing and winnowing machine	2
Crop cutting and burying machine	0.5
Loader	0.5
Trailer	4
Subsoil plow	1
Mechanical irrigation power	250 HP
Clover mowing/cutting machine	1

[a]Source: Ministry of of Agriculture, Egypt, Five-Year Agricultural Mechanization Plan, 1982-87. [b]The land area unit used in Egypt is the feddan. lf = 0.42 ha. Plan targets are stated in units of 1000 feddan = 420 ha.

The Egyptian Ministry of Agriculture, represented by the Agricultural Mechanization Research Institute (AMRI), has recognized the benefits of mechanizing rice production, and projects, research programs, and experiments have been set up to demonstrate these benefits. One of the most important of these is the Rice Mechanization Project (RMP), jointly sponsored by AMRI and the Japanese Government, represented by the Japan International Cooperation Agency (JICA) in Meet El-Dyba, Kafr El-Sheikh governorate.

The RMP has developed a methodology for a standardized system of mechanizing rice cultivation to increase land and labor productivity, through research trials and experiments and economic assessment of the outcome of these trials.

The RMP research and trials have concentrated on five main areas: 1) fertilizer application, 2) nursery management, 3) transplanting, 4) water management, and 5) harvesting and grain drying.

The mechanized system suggested by the RMP for rice cultivation is summarized in Table 2, which also compares the suggested mechanization system and the traditional rice cultivation system commonly adopted by Egyptian farmers.

Table 3 gives a comparative cost/benefit analysis of the key factors of the mechanized system suggested by the RMP and the traditional system. The biggest increase in revenue came from mechanized transplanting, followed by rational fertilizer application practices, then by mechanized harvesting. The least benefit came from mechanized seedling nursery management. However, all four practices had a positive effect on net revenue.

Table 2. Comparison of rim cultivation techniques used in mechanical and traditional systems.

Technique	Mechanized system	Traditional system
Fertilizer application	Rational fertilizer application (50% as basal, 20% at the rooting stage, 20% and 10% in the late growth period)	No basal fertilizer application, topdressing in the middle growth period
Seedling nursery management	Box nursery (young seedlings, av 2.5-3.0 leaves) Intensive management	Lowland rice nursery (fully grown seedlings averaging 6.0 leaves) Extensive management
Transplanting	Transplanter (8-row, riding type) Dense planting: 24 hills/m^2 (4 seedlings/hill)	Manual (random and not orderly) Sparse planting: 15 hills/m^2 (20 seedlings/hill)
Water management	Water management according to different growth stages, with mid summer drainage (in the middle growth period)	Successive irrigations
Harvesting and drying	Combine harvester (head-feeding type) Solar grain dryer	Manual reaping Drying in the field and threshing by tractor

Table 3. Cost-effectiveness of mechanizing major cultural practices for rice and changes in yields and net revenue[a] (data collected in experiments done 1981-85).

Cultivation practice	Change in costs (LE/ha)	Increase in yield (t/ha)	Change in gross revenue[b] (LE/ha)	Increase in net revenue[c] (LE/ha)
Rational fertilizer application	+23.32	1.33	166.60	143.28
Seedling nursery management	+11.54	0.31	38.68	27.13
Mechanized transplanting	–37.72	1.5	187.43	225.15
Mechanized harvesting	+34.77	1.26	157.68	122.90
Total	+31.91	4.40	550.39	518.46

[a]LE1 = US$1.07. [b]Change in gross revenue = change in yield/ha × price/t. Change in net revenue = change in gross revenue – change In costs.

The AMRI is conducting research in several areas to overcome many of the problems facing Egyptian farmers in growing rice. For example:

1. Direct seeding of rice: several trials have been successfully conducted.
   - Manual broadcasting of rice 3 d after puddling yielded an average of 9.3 t/ha compared with 5.7 t/ha obtained with the traditional method.

- Coating seed with calcium peroxide and using a seed drill to plant rice 3 d after puddling yielded 8.3 t/ha.
- Direct seeding in dry soil at different depths indicated that the best rate of germination occurred at 1 and 2 cm depth.

All other field operations (fertilizer application, cultivation and weed control, etc.) were kept the same as in the mechanized transplanting system.

2. Methods of sowing and harvesting: an experiment conducted in the 1985 season at Gemaiza farm, in Gharbiya governorate, aimed at comparing different methods of planting (seed drill, manual transplanting, mechanical transplanting) and of harvesting (manual harvesting, mower binder, Yanmar combine, Deutz combine) rice. Preliminary results show that the best combination of planting and harvesting for the best yield, is planting by using a seed drill and harvesting by the Deutz combine. However, the results of this experiment need further investigation, because they are not consistent with the results obtained by the RMP.
3. Lodging problems before harvesting: a solar grain dryer, suitable for Egyptian conditions, has been developed by the RMP to permit harvesting rice at a moisture content of 20-25%.

Several related activities of the AMRI also promote mechanized rice farming, such as:

1. Training activities at RMP Center in collaboration with JICA and at the Maamoura Training Center, with the collaboration of the Government of the Federal Republic of Germany.
2. Vocational training programs carried out with the Engineering and Industrial Design Development Center, Ministry of Industry, in collaboration with the United Nations Development Programme and the U.S. Agency for International Development.
3. Local manufacturing efforts, in collaboration with the Ministry of Military Production, especially in manufacturing an all-crop seed drill of Egyptian design, as well as a Chinese-type transplanter.
4. Land-leveling using laser beam technology, which has been shown to increase yields, since it reduces the amount of irrigation water required, and thus reduces soil salinity.

The key factors hampering mechanization in Egyptian agriculture include:

1. Land fragmentation: small, bunded, and uneven fields.
2. Poor accessibility to fields and inadequate farm-to-market roads.
3. Reluctance of small farmers to participate in cooperative harvesting.
4. Income competition between joint products, e.g., wheat straw and grain, cotton stalks and cotton. Egyptian farmers often give priority to by-products at the expense of the main product.
5. Current tractor management practices, which give low productive time and add unnecessary costs.
6. Inadequate applied research database for the development of appropriately designed machinery.

Applied research, extension and demonstration efforts, and training programs are some of the AMRI's normal activities, undertaken to deal with these difficulties.

Thus the AMRI has established a dynamic process to develop a mechanization system suited to Egypt's needs, based on continuous research and trials to adapt the system as needed to reach well-defined goals.

Notes

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Rice blast disease management

M. A. Marcheti and J. M. Bonman

Effective disease management is best achieved by employing all available technologies, be they chemical, cultural, or genetic. The effectiveness of one disease control measure is enhanced when used with others. Chemical control, though a valuable measure, is discussed only briefly. The adjustment of certain cultural practices—such as time of planting, fertilization, and water management—influences the onset and development of rice blast. The effectiveness of these disease management practices is enhanced greatly when applied to disease-resistant rice varieties. Because the rice blast pathogen *Pyricularia oryzae* comprises many pathogenic races, breeding for simply inherited complete resistance has proven unsatisfactory in many rice-growing areas, particularly in upland culture. But there is strong evidence that durable race-nonspecific partial resistance can be developed and improved in rice varieties through judicious choice of parents, to accumulate in the breeding population many genes that contribute to partial resistance.

Rice blast, caused by the fungus *Pyricularia oryzae* Cav., is among the world's most widespread, serious, and studied diseases of rice. The pathogen can infect susceptible rice plants at any growth stage, but the disease is most frequently observed and most damaging before midtillering and at flowering, when it causes neck blast or so-called "rotten neck." When the requirements of the "disease tetrahedron" are met—virulent pathogen, susceptible host, favorable environment, and sufficient time—the disease can reach epidemic proportions rapidly over large areas as it did in 1978 in Korea in the Tongil varieties and in Egypt in 1984 in the variety Reiho. In 1986, a blast epidemic of lesser proportions occurred in Arkansas, USA, in the popular new variety Newbonnet, grown on 70% of Arkansas' rice area. An estimated 1 t/ha was lost to blast on about 25,000 ha of the 289,000 ha of Newbonnet. Blast was found in other varieties, such as Lemont, Tebonnet, and Lebonnet, but damage was far less in these.

Management of any plant disease is done most successfully by employing tools from all of the technologies available rather than by relying entirely on one or two measures, a strategy encompassed by the concept of integrated pest management. For our purposes here, we can categorize management technologies as chemical, cultural, and genetic. We will discuss the first two briefly and emphasize blast management through genetics by breeding and selecting for durable blast resistance.

Chemical control

Fungicides for the control of rice blast have been under development for over 40 yr. Phenylmercuric compounds were among the most effective, but also were among the first to be banned from use because of the danger to health and environment. The development of highly effective systemic fungicides against blast has opened new possibilities for controlling the disease in more blast-conducive environments. Compounds such as tricyclazole (Froyd et al 1976) and pyroquilon (Bandong et al 1978) are so highly active that even seed treatment can be effective against leaf blast. Farmers in developing countries use fungicides rarely, possibly because fungicides are purchased inputs and because relatively little research on chemical disease control in rice has been done in the tropics. If the small quantities needed for seed treatment were effective, then fungicide use might be economical where blast is a significant constraint to production. In any case, fungicides are most effective when used in conjunction with other strategies that reduce the crop's susceptibility to blast, such as efficient use of nitrogenous (N) fertilizer and planting resistant varieties.

Cultural practices

Manipulations of certain cultural practices are known to reduce exposure to blast or suppress disease development. Among them are time of planting, fertilization (especially with N), and water management.

Time of planting

Planting time can have a marked effect on the development of blast within a rice crop. In the tropics, this seems especially true for crops sown after the dry season. In tropical upland rice, crops sown early during the rainy season generally have a higher probability of escaping blast infection than late-sown crops, which are often blasted severely. In upland areas of Brazil, farmers are advised to sow early to escape inoculum produced on neighboring farms (Prabhu and Morais 1986). In date-of-seeding trials in Florida, spanning February through July, the earlier plantings escaped blast, but blast became more severe with increased lateness of seedings (D. Jones, Univ. of Florida, Belle Glade, FL, USA, 1985, pers. comm.). Planting of early-maturing varieties may accomplish the same end when early planting is not feasible.

Date of sowing may influence the coincidence of weather favorable to rapid disease development and to the more blast-vulnerable growth stages of the rice crop, the seedling/early tillering and flowering/milk stages. Mild night temperature (20 °C) increases the susceptibility of rice plants to blast (Sadasivan et al 1965). Blast is most severe in Bangladesh during periods with ''low'' night temperatures and long dew periods (Miah et al 1980). Periods when these conditions are most common may be avoided by adjusting planting date.

Fertilization

The direct relationship between N fertilization and susceptibility to blast is common knowledge among rice producers. The mechanisms by which excessive N increases susceptibility to blast are not certain; reduced silicon uptake, accumulation of amino acids, and reduction of hemicellulose and lignin are among the possibilities summarized by Ou (1985).

Regardless of the mechanism, N management is perhaps one of the keys to controlling blast in many environments, even though it is not used widely for this purpose. Farmers in North Korea reportedly manage blast by splitting N applications (M. S. Swaminathan, IRRI, 1986, pers. comm.). A limit of 15 kg N/ha is recommended for upland rice in Brazil, specifically to reduce vulnerability to blast (Prabhu and Morais 1986). Farmers in the southern USA frequently split N applications to improve N efficiency and reduce lodging rather than to control blast. Interdisciplinary field research in this area should help to identify principles that could be applied to integrated blast management.

Water management

The availability of water affects the susceptibility of the host plant to *P. oryzae.* Rice grown under upland conditions is more susceptible than rice grown in flooded soil (Kahn and Lilly 1958); under upland conditions, susceptibility is increased further with increasing drought stress (IRRI 1985). It has been suggested that the increased disease observed after water-deficient periods is due to longer dew periods resulting from rapid loss of radiant energy on clear nights during drought. In fact, experiments at IRRI demonstrated that environmental conditions in drought-stressed plots actually were less favorable for infection during the stress period than those in fully watered plots (Bonman et al 1988). After the period of drought stress, greater disease development occurred in the previously stressed plants, probably because of increased susceptibility induced by water deficit (Gill and Bonman 1988).

Similar results were obtained using upland versus flooded conditions (Kim 1986). The dew periods were as long, or longer, in flooded plots, but disease was much greater in upland plots. The difference in color of the plants grown under flooded and upland conditions, the upland plants being a deeper green, indicates that plant nutrition was altered by flooding in such a way as to change the susceptibility of the rice to blast. This change in susceptibility varied with rice variety, the less susceptible variety Brazos (Marchetti 1983) being less severely damaged under upland conditions and being protected even more by flooding than the more susceptible California variety M-101 (Kim 1986).

Water management practices that promote the maintenance of flood in lowland rice and the reduction of drought stress in upland rice could be a valuable component of integrated blast management and probably would increase production in the absence of disease.

Genetics

Breeding of disease-resistant varieties probably is the most cost-effective and reliable method of disease management. In some instances, resistant varieties have provided effective and durable disease control. But in the case of rice blast and many other important field crop diseases, success is short-lived or not easily achieved. Pathogens, like their hosts, are subject to the laws of nature and are capable of evolving under the selection pressures brought to bear by changes in their hosts.

Pathogenic variability

With the demonstration of pathogenic specialization in *P. oryzae* came expanded research into the genetics of blast resistance and its application in rice breeding, and also considerable controversy regarding pathogenic stability within populations of *P. oryzae.* Representative of the opposed views were Ou, who reported isolating several pathogenic races from single-spore cultures (Ou and Ayad 1968), and Latterell, who found most isolates to be stable in their pathogenicity (Latterell 1975). More recent works (Latterell and Rossi 1986, Bonman et al l987) generally support the view that P. oryzae comprises hundreds of pathogenic races, but that, with a few exceptions (Wu and Latterell 1986), virulence of isolates does not change or proliferate constantly with each reproductive cycle.

Resistance breeding

Disease management through resistant varieties is the ideal technology for resource-poor farmers, and efforts to breed resistant varieties continue, even though they have not been entirely successful.

Complete resistance (also known as vertical resistance, specific resistance, true resistance), in which the pathogen fails to produce sporulating lesions, can be manipulated easily by breeders. But it also has been known to break down, sometimes with serious economic consequences. In Korea, the resistance of the Tongil varieties was effective for 5 yr before a virulent race appeared in 1976 (Lee et al 1976). In Japan, the longevity of complete resistance seems to be about 3 yr. The variety Reiho had complete resistance to Japanese races upon its release in Japan in 1969. Its area of cultivation increased until 1973, when it was damaged severely by blast (Matsumoto 1974). Similarly, Reiho was later released in Egypt as a blast-resistant variety in 1984, when it occupied about 25% of the rice crop area. Resistance was overcome that first year, resulting in a blast epidemic of some consequence (Bonman and Rush 1985). In Colombia, a series of resistant varieties was released from 1969 to 1986, but their resistance lasted only a year or two before being overcome by previously unidentified virulent races (Ahn and Mukelar 1986).

In every instance in which it has been investigated, complete resistance was race-specific and monogenic (Kiyosawa 1981, Marchetti et al 1987). Assuming the gene-for-gene relationship described by Flor (1956) and given the variability of the pathogen, it is not difficult to understand why the effectiveness of complete blast resistance is short-lived.

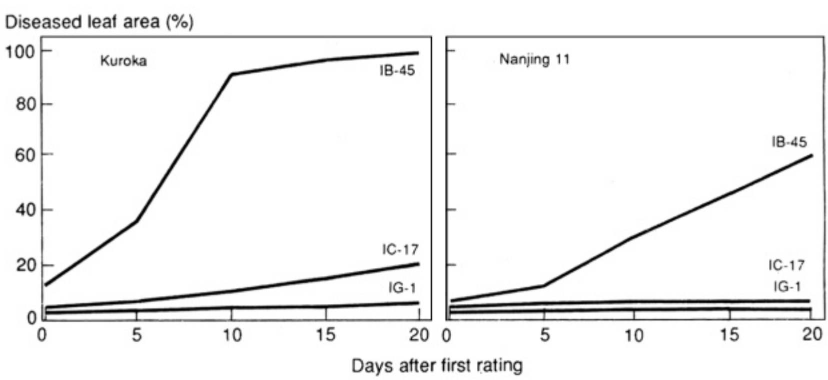
But when complete resistance is overcome, usually some level of residual resistance remains. This residual resistance has been referred to variously as horizontal resistance, general resistance, field resistance, slow-blasting, and partial resistance, among others. There are many examples of partial resistance that appear to be effective and durable under field conditions. For example, the varieties IR36 and IR50 are susceptible to the same races of *P. oryzae* (Bonman et al 1986), but when inoculated with the same isolates, IR36 produces fewer and smaller lesions than does IR50 (Yeh and Bonman). These differences in partial resistance were evident both in blast nursery miniplot tests and under field conditions in the Philippines and in other Asian countries.

In the USA, a number of southern rice varieties that lack complete resistance have sustained only minor losses from blast. Starbonnet and Labelle each occupied over 30% of the total southern acreage during the 1970s and early 1980s in the presence of two or more known virulent races, with only a few, localized outbreaks of blast. At the same time, varieties developed in California, where there is no blast, usually are severely damaged by blast when grown in the southern USA (Marchetti 1983).

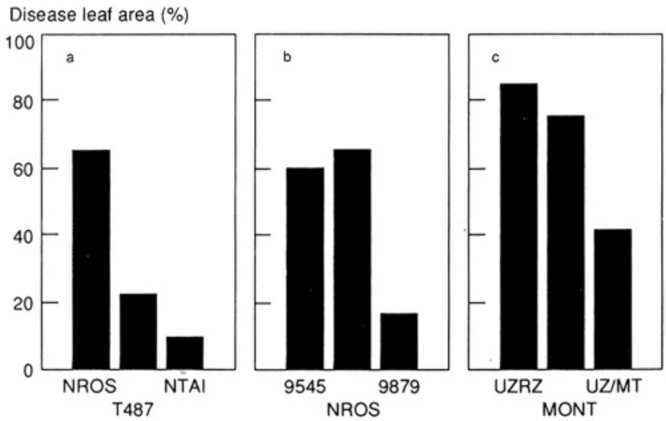
Partial resistance has been observed in upland varieties developed in West Africa (Notteghem 1985) and Brazil (Prabhu and Morais 1986). In Japan, traditional upland varieties have shown long-lasting partial resistance in upland culture, where blast generally is severe (Toriyama 1975). Although durable in Japan, their resistance was not effective under conditions in Latin America (K. Toriyama, Chugoku National Agricultural Experiment Station, Japan, pers. comm.).

Partial resistance may be either oligogenic or polygenic. However, partial resistance in two Japanese varieties, St1 and Chugoku 31, is not only monogenic (*Pi-f* gene), but also race-specific, as evidenced by the loss of partial resistance shortly after their release (Toriyama 1975). Partial resistance of the Japanese variety Kuroka and of the Chinese variety Nanjing 11 was found to be race-specific in miniplot tests in Texas (Fig. 1). However, there is evidence enough that durable race-nonspecific resistance is attainable (Ezuka 1979, Marchetti 1983, Notteghem 1985, Yeh and Bonman 1986).

Miniplot experiments in the USA have produced evidence of transgressive segregation for improved partial resistance (Fig. 2). Both Nortai (Northrose/ Tainan-iku No. 487) and C.I. 9879 (C.I. 9545/Northrose) showed significantly lower levels of disease than did either of their respective parents. A Yugoslav line from the cross Uzroz/ Monticelli also had higher partial resistance than its parents.



1. Two blast-resistant rice varieties with race-specfic partial resistance, indicated by the differences between disease progress curves of rice infected with race IB-45 and rice infected with races IC-17 or IC-1 of *Pyricularia oryzae.* Kuroka is an upland variety from Japan, Nanjing 11 is a very high-yielding semidwarf variety from China. Tests conducted in an outdoor blast nursery in Beaumont, Texas, one race tested a year, 1981-84. Intervals from seedling emergence to initial disease rating varied by year from 13 to 19 d. Reactions of race-nonspecific partially resistant and susceptible varieties were consistent across the 3 tests.



2. Transgressive segregation for improved partial resistance to rice blast. Diseased leaf areas (DLAs) recorded in an outdoor blast nursery (Marchetti 1983) when susceptible check M101 showed 100% DLA. (a) NTAI is a selection from Northrose/Tainan-iku 487. (b) C.I. 9879 is from C.I. 9545/Northrose, (c) Uz/ Mt is from Uzroz/Monticelli. All three are grown in Yugoslavia. NTAI= Nortai, NROS = Northrose. UZRZ= Uzroz, MONT= Monticelli, UZ/ MT = Uzroz/ Monticelli.

Relationship of leaf blast to neck blast

Most screening for blast resistance is done at the seedling stage, when great numbers of lines can be compared simultaneously in a relatively small space. There is less potential for confounding by differences in growth habit and heading dates. Most of the time, when the races present in tests were known, varieties completely resistant to a particular race at the seedling stage were also resistant at the flowering stage, and vice-versa (Ou and Nuque 1963). Examples have been observed, however, in which varieties resistant at the seedling stage sustained some neck blast from the same race of *P. oryzae* (Latterell 1975). Torres (1986) found differential susceptibility in two partially resistant varieties, Kinandang Patong and Brown Gora SN84. Brown Gora had 1/15 the number of lesions/100 cm^2 of leaf area found on Kinandang Patong (11 vs 166), but 14 times as much panicle blast (41% vs 3%). In many cases, including those mentioned by Latterell (1975), susceptibility at the panicle stage was associated with resistance that was less than complete, i.e., high levels of partial resistance.

In general, the panicles of varieties with partial resistance are less susceptible than those of highly susceptible varieties. Partial resistance to leaf blast should result in epidemiologically significant suppression of inoculum for panicle infections (Marchetti 1983). Nonetheless, it would be prudent to evaluate prospective new varieties and parental lines for resistance to neck blast.

A strategy for breeding for durable blast resistance

There is ample evidence that improved and durable partial blast resistance is an attainable goal in rice varietal improvement, in spite of certain potential pitfalls. Most important among the pitfalls are the undetected development of race-specific partial resistance, and the use of exotic sources of partial resistance without verification of their effectiveness in the rice-growing areas for which they are intended. The first of these can be checked through progeny-testing of crosses with highly susceptible varieties. If the partial resistance or a major component of it appears to be simply inherited, one should suspect that it is race-specific. If the resistance is environmentally sensitive, then the ineffectiveness of the resistance should become apparent in a short time under blast nursery conditions in the presence of virulent races of the pathogen.

Frequently, the main strategy of breeder and pathologist, given the choice, is to save only the most resistant-appearing lines in a screening nursery, and usually these are lines with complete resistance to the races present in the nursery. Because complete resistance masks partial resistance, there is no way to evaluate such lines without either challenging them with isolates of *P. oryzae* that are virulent (i.e., the complete resistance is overcome), or by progeny-testing of a cross with a highly susceptible variety. If the progeny segregate into completely resistant and clearly susceptible groups, then most probably the completely resistant line is lacking in partial resistance. On the other hand, if most of the not completely resistant progeny are also not highly susceptible, then probably the completely resistant parent also has a valuable background of partial resistance genes.

Rather than saving only the most resistant lines, it should be more in keeping with the goal of improving partial resistance to eliminate the most susceptible lines, i.e., those that have little or no partial resistance. Using the IRRI blast rating scale (IRRI 1975), lines with ratings of 3-6 probably represent those with usable levels of partial resistance that are not masked by complete resistance. By introducing such lines into a breeding program and avoiding lines with little partial resistance, a strong pool of genes that contribute to race-nonspecific partial resistance could be gradually accumulated in the breeding population.

Conclusion

We have by no means exhausted the list of approaches to blast management. Such breeding strategies as pyramiding of genes conferring complete resistance, gene rotation, and multiline varieties are available also. Sanitation measures, fertilizer practices, and other aspects of rice culture as they relate to the onset and development of blast need further research. Finally, the knowledge gained through research must be communicated and demonstrated to the farmer so that he can use it. The new Sakha Rice Research Center has a vital role to fulfill in this dynamic process.

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Notes

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Management of rice blast disease in Egypt

S. E. M. Kamel and T. A. El-Sharkawy

Blast disease is a serious constraint to rice production in Egypt, though yield losses vary with location and weather conditions. The epidemiology of blast is described and strategies suggested to keep blast incidence below economic damage levels. As the 1984 epidemic showed, the pathogen is extremely variable; its management requires a range of short- and long-term measures: exclusion through strict quarantines, cultural practices such as early planting, elimination of alternative hosts, chemotherapy, and, especially, breeding varieties with stable resistance. A strong predictive system, based on close monitoring of the weather is required. Cost-benefit analysis is also needed, as management must not only control the disease but bring tangible profits to the farmer.

Rice blast disease, caused by *Pyricularia oryzae,* is one of the most serious constraints to rice production, not only in Egypt but in many rice-growing countries. Severe leaf infection totally destroys the foliage, while neck infection results in half-filled or totally untilled panicles, depending on the time of infection.

Estimations of yield losses have been made by many researchers (for instance, Kamel et al 1985, Goto 1965, Padmanabhan 1965, Katsuba and Koshimizu 1970). However, such estimates are valid only for specific regions, because of the differences in time of infection and varietal response (Kamel et al 1985). The percent loss in shortduration varieties was somewhat less than that in long-duration ones when both were inoculated at the same time. Under Egyptian field conditions, percent yield loss associated with 1% panicle infection varies from one season to another, depending on the time of infection—which is governed by the climatic conditions—and the availability of inoculum in the micro-ecosystem of the rice canopy. Over the last 15 yr, yield loss with 1% panicle infection has ranged from 0.9% to 2.5%. However, it generally follows the equation $Y = 0.27–2.8\,X$ where Y is the yield loss and X is the intensity of panicle infection (Table 1).

Figure 1 shows the distribution and extent of panicle blast infection in the rice-growing areas of Egypt during the major epidemic in 1984.

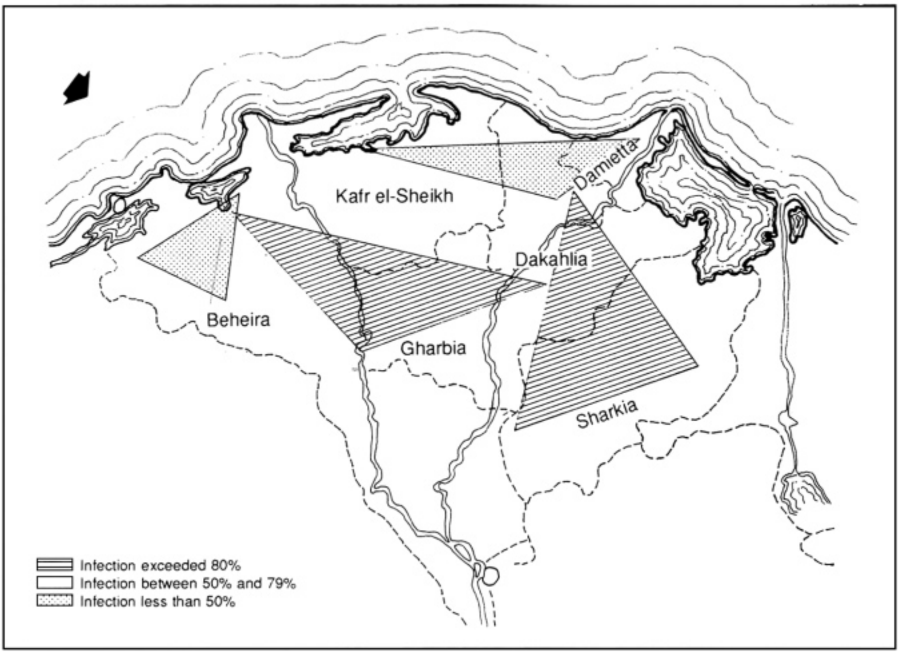
Epidemiology of rice blast

In 1984, the cultivar Reiho from Japan was introduced into Egypt as a commercial variety. Because it was agronomically successful, it became popular and occupied

Table 1. Estimation of losses caused by rice blast disease in Egypt, 1966-84.

Year	Variety	Severity of panicle infection (%)		Grain yield[a] (kg/feddan)		Difference in the severity of infection (%)	Yield (kg)	Losses associated with 1% infection (kg)	% of losses with 1% infection
		Protected	Unprotected	Protected	Unprotected				
1966	Nahda	2.0	14.0	2590	2240	12	350	29.16	1.3
	Yabani 15	3.0	19.6	2240	1890	16.6	350	21.08	1.1
1967	Nahda	3.1	16.0	2310	1820	12.9	490	37.9	2.08
	Yabani 15	4.0	26.0	2450	1820	22.0	630	28.6	1.57
1968	Nahda	7.0	22.5	2450	2105	15.5	345	22.2	1.05
	Yabani 15	9.3	30.3	2100	1805	21.0	295	14.0	0.77
1969	Nahda	11.8	34.5	2750	2140	22.7	610	26.8	1.25
	Yabani 15	14.5	40.5	2355	2050	25.8	300	11.6	0.56
1970	Nahda	12.5	61.2	2478	1512	48.7	966	19.8	1.3
1971	Nahda	37.0	57.0	1835.8	1210	20.0	625.8	31.29	2.58
	Yabani 15	35.1	57.3	1364.7	1104.3	22.2	260.4	11.72	1.06
1972	Nahda	21.7	60.6	2459.5	1501.9	38.9	957.6	24.6	1.63
	Yabani 15	31.6	58.0	1581	1368.9	26.4	212.1	8.03	0.58
1973	Nahda	24.4	81.0	1950	750	56.6	1200	21.2	2.8
1974	Nahda	12.8	30.6	1510	1300	17.8	210	11.7	0.9
1975	Nahda	12.8	30.6	1510	1300	17.8	210	11.7	0.9
1983	Giza 159	16.8	39.9	2300	1700	23.1	600	25.97	1.5
1984	Giza 159	18.1	71.3	2400	1500	53.2	900	16.9	1.12

[a] 1 feddan = 0.42 ha.



1. Distribution of panicle blast infection in the rice-growing governorates of Egypt during the 1984 rice blast outbreak.

about 30% of the rice acreage in Egypt. Under the pressure of this introduction, the population of *P. oryzae* changed and pathotypes able to attack Reiho increased as a result of directional selection of virulent pathotypes (Crill 1977). These pathotypes were distinguished as races IA-11, IA-41, IA-43, IA-105, IA-107, IA-111, IA-127, IB-43, IB-45, IB-64, IC-5, ID-9, ID-10, ID-11, and ID-16. Most of these races had not been detected before. Races IB-43 and ID-9 were the most common, and since they had not been detected before, it is likely that they are mutants from other races. Van der Plank's explanation is that when the vertical resistance gene is present in the host, the pathogen, if it is to survive, must be able to develop races with virulence to match this gene (Van der Plank 1968).

The rate of disease spread (r) on Reiho was six- to seven-fold that on Giza varieties in all the rice-growing governorates.

In Egypt, temperatures and relative humidity had insignificant effect on the spread of blast, while the number of trapped spores, the dew period, and wind velocity showed a significant effect. The number of blast lesions on the leaves of Reiho was fourfold that on varieties Giza 171 and Giza 172. Sporulation of the pathogen on Reiho was fourfold that on varieties Giza 171 and twofold that on Giza 172.

In 1985, Reiho faded out as a commercial variety, and the pathogen population tended to revert to what it originally had been (population unable to attack Reiho).

Thus, infection was low on the small acreage of Reiho fields in 1985 and 1986 and a clear change was observed in the pathogen population.

In 1984, Reiho yielded an average 1.7-4.6 t/ha, instead of the expected 8-10 t/ha; Giza varieties, on the other hand, yielded 5-6 t/ha. The slight effect of the high disease pressure on Giza varieties was probably because they were bred, developed, and selected under local field conditions. Also, genetic studies of these two varieties proved that each has three genes for blast resistance, which are probably responsible for their blast tolerance.

Variability of the pathogen

The extreme variability of the *P. oryzae* pathogen enables new virulent races to appear in response to new host varieties. The need to characterize this variability for efficient blast management has led to the use of the pathometric technique for classifying the pathogen. Based on isolating and inoculating large numbers of isolates from various types of lesions and cultivars, Ou (1980) believed that the fungus is extremely variable.

He attributed the presence on the same leaf blade of resistant, intermittent, and susceptible types of lesions to genetic differences among the spores of the inoculum used, even though the spores originated from a monoconidial culture (Ou et al 1971, Ou 1979).

The number of known races in each country depends on—and increases with—the number of isolates tested (Ou 1972). However, it is difficult to compare the virulence and prevalence of the races identfied in other countries, when different sets of differentials are used. Race identification was standardized by using the international set of eight differential varieties (Atkins et al 1967, Ling and Ou 1969); however, this system was recently criticized because the differential varieties have not included all the possible resistance genes.

A set of nine differentials, each with a known gene for resistance, proposed in Japan (Yamada et al 1976) was a step forward in the study of races, although the differentials are not isogenic lines. Furthermore, since the fungus is extremely variable and the races identified by the Japanese or the international differentials are constantly changing, conventional race identification appears to be of limited value. No relation between the races identified by both sets was observed.

When physiologic races of *P. oryzae* in Egypt were monitored using both the Japanese and international differentials, the most common race found was that coded 000 in the Japanese differentials (Table 2). For more reliable race identification, it is necessary to develop a system of isogenic lines that is widely used and flexible enough to permit adding new differentials to cope with new pathogen pathotypes. Such a tentative system would not be limited to the preparation of a base for genetic studies, but is needed for breeders to adequately utilize diverse gene sources.

This high variability potential of the blast pathogen has been attributed to one or more of the following causes:

- Mutation (Kiyosawa 1976),
- Sexual hybridization (Genovesi and Magill 1976, Tanaka et al 1979),

Table 2. Races of *Pyricularia oryzae* Cav. identified by Japanese and international differential varieties. Giza, Egypt, 1986.

Isolates (no.)	Reaction to differential variety[a]									Race no.	Corresponding international race
	Shin 2 (*Pi-k*, 1)	Aichi Asahi (*Pi-a*, 2)	Ishikare Shiroke (*Pi-i*, 4)	Kanto 51 (*Pi-k*, 10)	Tsuyuake (*Pi-m*, 20)	Fuku-nishiki (*Pi-z*, 40)	Yashiro-mochi (*Pi-ta*, 100)	Pi No. 4 (*Pi-t*, 200)	Toride 1 ($Pi\text{-}z^t$, 400)		
12	R	R	R	R	R	R	R	R	R	000	II, ID15, ID16
2	S	R	R	R	R	R	R	R	R	001	ID16, IC16
4	R	S	R	R	R	R	R	R	R	002	II, IE
5	R	R	S	R	R	R	R	R	R	004	II, IC10, IA128, ID15
2	S	S	S	R	R	R	R	R	R	007	ID16, II
1	R	S	R	S	R	R	R	R	R	012	IE3
1	S	R	S	S	S	R	R	R	R	035	IC4
1	R	R	R	R	R	S	R	R	R	040	IA112
2	R	R	S	R	R	S	R	R	R	044	II
1	R	R	R	S	R	S	R	R	R	050	IF4
2	S	S	R	S	R	S	R	R	R	053	IA67, IA62
4	R	R	R	R	R	R	S	R	R	100	D16, IA112, IA64, II
2	R	S	R	R	R	R	S	R	R	102	II
1	S	S	R	R	R	R	S	R	R	103	II
2	S	S	S	R	R	R	S	R	R	107	II
1	R	S	R	R	S	R	S	R	R	122	–
1	R	S	R	R	R	S	S	R	R	142	II
1	R	R	S	R	R	S	S	R	R	144	II
1	S	S	S	S	S	S	S	R	R	177	IF3
1	R	R	R	R	R	R	R	S	R	200	II
3	S	S	R	R	R	R	R	S	R	203	II, IA128, ID16
1	S	S	S	R	R	R	R	S	R	207	ID14
2	S	S	S	S	R	R	R	S	R	217	1827, 1843
1	R	S	R	R	R	S	R	S	R	242	IA110
2	R	S	R	R	R	R	S	S	R	302	IA128
3	S	S	S	R	R	R	S	S	R	307	ID16, II
1	R	S	S	R	R	R	R	R	S	426	II
1	R	R	R	R	R	R	S	R	S	500	IA128
1	S	S	S	R	S	S	S	R	S	567	IB54
1	S	S	S	S	S	S	S	R	S	577	IF4

[a]The resistance gene and the code no. are in parentheses. R = resistant, S = susceptible.

- Parasexualism (Suzuki 1967, Leung and Williams 1985), and
- Heterokaryosis (Suzuki 1967, Leung and Williams 1985).

Source of primary inoculum and alternative hosts

The conidia of the blast pathogen survive in the straw of infected plants for several years, but their viability decreases rapidly and disappears after 4-5 yr in most cases. Therefore, suitable treatment of infected straw will reduce primary infection.

The blast pathogen can overwinter on many winter and perennial hosts (Asuyama 1965). Wheat, barley, maize, and sugarcane could be hosts for it. Under Egyptian conditions, *P. oryzae* can infect several plants, especially *Cynodon dactylon, Phragmites communis, Imperata cylindrica, Echinochloa crus-galli, Phalaris canariensis, Digitaria sanguinalis,* sweet sorghum, and Sudan grass (Table 3). Cross inoculation proved that *Pyricularia* can cross over to rice plants via

Table 3. Reaction of different host plants to rice blast pathogen *Pyricularia oryzae* Cav. in Egypt.

Host plant	Reaction[a] to *P. oryzae* and method of inoculation			
	Spraying method		Detached leaf method	
	Reaction	Lesion no.	Reaction	Lesion no.
Avena fatua L.	S	+	S	++
Andropogon annulatus	S	+	S	+
Bromus rigidus Roth.	S	+	S	+
Bromus catharticus Vahl.	S	+	S	+
Cyperus rotundus L.	R	–	R	–
Cyperus difformis L.	R	–	R	–
Cyperus alopecuroides Rottb.	R	–	R	–
Cynodon dactylon (L.) Pers.	S	+++	S	+++
Digitaria sanguinalis L.	S	+++	S	+++
Echinochloa crus-galli (L.) Beauv.	S	+++	S	+++
Imperata cylindrica (L.) Beauv.	++++	++++	S	+++
Lolium temulentum L.	S	+	S	++
Panicum repens L.	S	++	S	+++
Echinochloa colona (L.) Link	S	+++	S	+++
Staria glauca (L.) Beauv.	S	++	S	++
Polypogon monspeliensis L.	S	+++	S	+++
Phragmites communis (L.) Trin.	++++	++++	S	+++
Phalaris canariensis L.	S	+++	S	+++
Sorghum vulgare var. *sudanense*	S	+++	S	+++
Sorghum vulgare var. *durra*	S	++	S	+++
Sorghum vulgare var. *saccharatum*	S	++	S	++
Sorghum vulgare var. *technicum*	S	++	S	++
Triticum vulgare L.	S	+	S	+
Hordeum vulgare	S	+	S	+
Zea mays	S	+	S	++
Saccharum officinarum	++++	++++	S	++
Musa sapienturn	++++	++++	R	–
Oryza sativa (var. Yabani 15)	S	+++	S	+++
Canna indica	++++	++++	R	–

[a]– = no visible symptoms, + = 1-5 spots/leaf, ++ = 6-10 spots/leaf, +++ = more than 10 spots/leaf, ++++ = tested by the detached leaf method only. S = susceptible, R = resistant.

these hosts and vice versa, to bridge the off-season. Therefore, eliminating such alternative hosts will also reduce the source of primary infection.

Strategies for rice blast management

The main objective of blast management is to keep damage below the economic threshold, while keeping the costs of disease management also within an acceptable range (Ahn and Mukelar 1986, Ezuka 1972). In coping with rice blast, the most important measures to take are:

1. Exclusion of the pathogen through regulatory controls and effective quarantines;
2. Development of resistant cultivars;
3. Use of effective cultural practices to reduce the incidence and severity of infection;
4. Sanitation through elimination of primary inoculum sources and alternative hosts;
5. Chemotherapy with systemic and nonsystemic protective and eradicative fungicides.

However, a disease control strategy that does not allow the farmer to economically increase yield is of no value, even if the disease is controlled (Crill et al 1982). A successful rice blast control strategy implemented in one country may not necessarily be successful in another. Therefore, blast control strategies must be originated and developed by researchers who are knowledgeable about the potential and limitations of the local crop production practices (Crill et al 1982).

Exclusion of pathogen through regulatory control

The main regulatory control measures could be taken through quarantines to prevent the introduction of new races of the pathogen into an area where they do not exist. It is therefore important to know the existing races of the pathogen in a specific area and also the races of the pathogen in other countries. But present information on the international distribution of blast races is quite limited, and a general quarantine may be useless because the race may already exist within the country imposing the quarantine.

In Egypt, there are several races of the blast pathogen that do not occur in the Philippines and possibly vice versa. During the years of cooperation between Egypt and the International Rice Research Institute (IRRI) in exchange of rice varieties, there has been no evidence to suggest that new races of blast have been introduced into Egypt from the Philippines or vice versa. All seed is treated with efficient fungicides, to control not only blast but also other potential pathogens.

As the exchange of rice germplasm among different institutions becomes more and more extensive, control measures become more important, and regulatory programs do significantly reduce the potential occurrence of a blast epidemic caused by new races of *P. oryzae*. Therefore, an efficient control system, with well-trained quarantine personnel and suitable equipment to test and examine seed samples, is vital.

Cultural practices

The cultural control strategies for blast should be based on a) comprehensive understanding of the existing practices in relation to blast incidence, and b) manipulation of these practices in such a way as to reduce the disease. Farmers should be convinced that such manipulation will work to control blast (Crill et al 1980).

The application of high doses of N fertilizer in the absence of adequate resistance increases the severity of blast infection. Therefore, methods should be evolved of manipulating N, P, K, and micronutrient application so as to increase the yield without increasing the disease incidence.

Cultural practices that do not allow the farmer to increase net yield and income are of no value, even if the disease is reduced. For example, sowing date markedly influences disease incidence and yield. Under Egyptian conditions, early planting allows the crop to escape the disease and increases yields. However, although farmers are quite aware that delayed sowing will expose the rice crop to blast and decrease the yield, they continue to plant late. This is because they sow an additional intermediate leguminous fodder crop before rice in the rotation and the income from this crop exceeds the loss in rice yield.

Therefore, blast-resistant, high-yielding, shortduration cultivars may be the solution. However, before changing existing cultural practices or introducing new varieties, researchers must know the effect of this change on the agroecosystem.

Chemotherapy

Chemical control of blast may be necessary under certain conditions. Weather, host susceptibility or pathogen compatibility and aggressiveness, and pathogen population size are all factors that interact to determine the speed of blast development and, therefore, the need to apply chemical control measures. If any one of these factors is extremely favorable to disease development, blast can occur even if the other factors are only marginally favorable. Therefore, if the interaction of weather, host susceptibility, and pathogen population is expected to be sufficient to allow an intolerable disease level, chemical control may be needed (Fry 1982).

The pathogen population depends on the degree of host susceptibility, which could be determined before planting. Therefore, weather is the most important unknown in determining the need for chemical control, if the host variety is known to be susceptible. In any pathosystem, certain levels of disease intensity require certain actions to be taken. A warning system, to forecast weather conditions favorable to blast development and predict the possible aggressive races and their intensities, should be developed to determine action thresholds (i.e., the disease severity at which control measures should be taken to prevent economic injury to the crop).

The forecasting system for blast disease depends mainly on weather conditions, especially the period of leaf wetness, which is directly correlated with wind velocity and fluctuation in day and night temperatures, which determine the amount of dew precipitation on the rice canopy. Therefore, a strong computer-aided predictive system should be one of the main strategies for blast control.

Chemical control of blast disease was started in Egypt during the 1960s, using mercuric fungicides (phenyl mercuric compounds) and antibiotics (Blasticidin S). During the early 1970s, Benlate, Hinosan, Topsin, Kasumin, Antracol, and Oryzamate were used.

Kitazin G and Blastin were tested in cooperative research programs with the chemical companies. Later Hinosan, Beam, and Kitazin G were recommended and used commercially to control rice blast in farmers' fields, mostly as curative fungicides for leaf blast. Because there is no forecasting system, general spray on the panicles could be a waste of chemical and effort, if infection does not occur.

Development of resistant varieties

A resistant cultivar is a major component of an integrated disease management program. Many rice cultivars have been bred with high degrees of blast resistance in different parts of the world, but the resistance has been short-lived because of rapid shifts in the pathogen population (Ou 1980).

In the assessment of varietal resistance to blast, two categories but different terminology have been used: vertical vs horizontal reistance (Van der Plank 1968, 1982), true vs field resistance, race-specific vs race-nonspecific resistance, complete vs incomplete, or monogenic vs polygenic resistance (Van der Plank 1982).

However, since there are two possibilities for each of these characteristics, there are eight possible classes of resistance: monogenic, complete, or race-specific, all described as "vertical" resistance; and polygenic, incomplete, or race-nonspecific, all described as "horizontal" resistance (Fry 1982). To reduce confusion, we agree with the suggestion of Nelson (1978, 1979) that Van der Plank's definition of vertical and horizontal resistance, which is not consistent, be dropped. We suggest adopting instead the term "durable resistance," which describes resistance that remains effective for a long time under environmental conditions favorable to the disease (John and Bonman 1986, Marchetti and Laixinghma 1986).

Breeding strategies

Local varieties that possess a high level of durable resistance should be detected and used as parents. These varieties possess epidemiologically significant levels of field resistance. Incorporating the important genes for resistance into these varieties through backcrossing is the principal procedure in this approach (Parlevliet 1979). The performance of these varieties can be observed under a range of climatic and cultural conditions before they are released. Varieties that show a high level of resistance should be evaluated on a global basis through the International Rice Testing Program of IRRI and the races of blast that can attack these varieties will be detected. From this information the monogenes conferring resistance to the race that is predicted to evolve will be utilized in the breeding program (Crill et al 1980).

Monogenic resistance

The complete inhibition of lesion development is monogenic resistance, but occasionally the production of hypersensitive reaction, typified as nonsporulating brown spots, is included (Kiyosawa 1967). The use of this type of resistance to control blast disease is risky, as it may cause the resistant variety to be widely cultivated, only to have the resistance break down in a few years (Toriyama et al 1985, Van der Plank 1982). Van der Plank described this type of resistance as perpendicular, qualitative, or vertical, and it is generally governed by a single dominant gene.

High vertical resistance implies that races of the pathogen with the level of virulence necessary to attack the host are rare. Virulent races are kept rare by some force; the stronger the force, the rarer the virulent races and the greater the vertical resistance. This force is the stabilizing selection (Chin 1986).

Race II was the most common race of *P. oryzae* during the blast epidemic in Egypt in 1984 and 1985. It is unable to attack any of the differentials, but attacks the commercial varieties. Also the race coded 000 (Yamada 1979), which is not able to match any of the Japanese differentials, is able to attack the commercial varieties Giza 171 and Giza 172.

Under field conditions, both matching and nonmatching races exist. When climatic conditions favor the disease, the matching races spread and infection can neither be stopped nor modulated by this type of monogenic resistance (Van der Plank 1968). When early infection occurs on varieties with vertical resistance, the progress of an epidemic is unaltered. This filtering effect on the pathogen population introduced by the selection pressure of vertical resistance results in the rise of new virulent races that infect the predominant varieties and multiply quickly. They soon dominate, leading to the well-known boom-and-bust cycle (Crill 1977).

In breeding for vertical resistance, the resistance gene is introduced from different sources. This type of resistance is not stable, and the degree of the breakdown of this resistance is unpredictable when new virulences appear (Kiyosawa 1979). Therefore, pathologists do not recommend breeding for this type of resistance (Van der Plank 1968).

To evaluate vertical resistance, it is necessary to know the percentage of races compatible with the tested entries. Therefore, large collections of isolates from all the rice-growing areas should be inoculated singly into all the tested entries, and the percentages of the compatible isolates estimated (Chin 1986, Notteghem 1986). Then, entries that show low compatibility with virulent isolates could be evaluated for partial resistance.

The reaction to more than 150 isolates of the pathogen was tested in Giza, Egypt, with IRRI varieties, commercial Egyptian varieties, and promising lines (Table 4). Vertical resistance could be used if breeders obtained varieties with high levels of horizontal resistance and incorporated into these varieties, by backcrossing, the chosen genes for vertical resistance. With this strategy, we can hope that virulent races will not spread fast, because most of the time the horizontal resistance is adequate to stop the epidemic, and the occurrence of virulent races is greatly reduced. This strategy of incorporating vertical resistance into varieties that have good horizontal resistance looks promising (Notteghem 1986).

Table 4. Reaction to different isolates of *Pyricularia oryzae* of some IRRI rice varieties, commercial Egyptian varieties, and promising lines of rice. Giza, Egypt, 1986.

Rice variety or line	Isolates of *P. oryzae* tested (no.)	Entries (no.) with given reaction	
		R	S
IR1626-203	149	149	–
IR30	98	83	15
IR36	55	50	5
IR28	145	145	–
IR50	112	103	9
IR19743-46-2-3	55	50	5
IR21820-154-3-2	50	50	–
IR25882-32-1-3	55	50	5
IR25229-74-2	53	46	7
IR25571-31-1	54	52	2
GZ1324-3–3	54	54	–
GZ1343-8-2	103	72	31
GZ1362-5-1-3	94	82	12
GZ1368-5-4	141	141	–
GZ1394-10-1-1	153	126	27
GZ2175-5-1	56	47	9
GZ2175-5-3	55	49	6
GZ2175-5-4	58	46	12
GZ2175-5-6	57	50	7
GZ2175-2-2	57	49	8
GZ1506-8	99	88	11
GZ1564-3-6	95	84	11
GZ2376-24-1	56	32	24
GZ2080-2-4	39	31	8
GZ1546-4-7	56	44	12
GZ1368-5-2	54	49	5
GZ1108-4-1-3	153	111	42
Milyang 49	56	46	10
Giza 171-M94-1-9	55	37	18
Giza 171	125	59	66
Giza 172	127	64	63
Giza 159	115	44	71
Reiho	123	65	58
Suweon 294	56	48	8
Sipi 692033	52	44	18

Polygenic resistance

Polygenic resistance is also termed quantitative resistance, horizontal resistance, or slow blasting. Varieties possessing this type of resistance behave as susceptible and show infection earlier, but the apparent rate of infection or the *r* value is lower, indicating that disease spread is slow. Thus, naturally, the terminal severity is reduced (Nagarajan 1983). Polygenic resistance is required to develop resistant varieties, because so many genes contribute to resistance that the pathogen cannot mutate sufficiently to overcome all of them (Van der Plank 1963).

Screening for polygenic resistance or slow blasting should start in early generations, under conditions favorable to blast, and continue for an extended period to allow polycyclic disease to develop. Determining a pathotype of the pathogen compatible with the tested material is essential, so that major genes for resistance will not mask the expression of slow blasting (Marchetti 1982). A system to monitor resistance genes and pathogenic races is very important. Such a system to identify and designate existing race-specific genes and the type of predominant races should be a focal point of a program to develop blast-resistant varieties (Toripma 1975).

Breeding lines should be evaluated for components of the partial resistance before resistant varieties are released (Ahn and Mukelar 1986, Ahn and Ou 1982, Marchetti and Laixinghma 1986). These components are:

1. Number of lesions per leaf or unit area of the leaf (relative infection efficiency).
2. Size of lesions.
3. Number of spores per lesion or per unit area (sporulation capacity).
4. Latent period of the pathogen in the host.
5. Lesion growth and expansion rate (Parlevliet 1983, Prabhu and Morais 1986).

Some of these factors were estimated in studying the components of partial resistance in some promising lines (Table 5). The cultivars Giza 159 and Reiho had very low levels of partial resistance. Line GZ1394-10-1-1 had a high level, as it showed the smallest and lowest number of lesions and the lowest sporulation capacity and relative infection efficiency; however, it showed race-specific resistance, as it was susceptible to some pathotypes and resistant to others, indicating the presence of both complete and partial resistance. GZ1108-4-1-3 showed similar responses to the pathogen. Other varieties, such as IR1626-203, IR28, and the line GZ1368-5-4, could not be evaluated as no compatible pathotype has been found so far. Thus, resistance in these entries is likely to be monogenic.

In the blast nursery, the periodic estimation of diseased leaf area (DLA) will result in a cumulative disease progress curve that can be expressed as a straight line by using the appropriate transformation equation (Ahn et al 1984). These curves or lines are important in comparing varieties with standards (Fig. 2). Finally, the estimation of collar infection of the flag leaf and panicle infection and the combination of all the measurements will give a real evaluation of the cultivar.

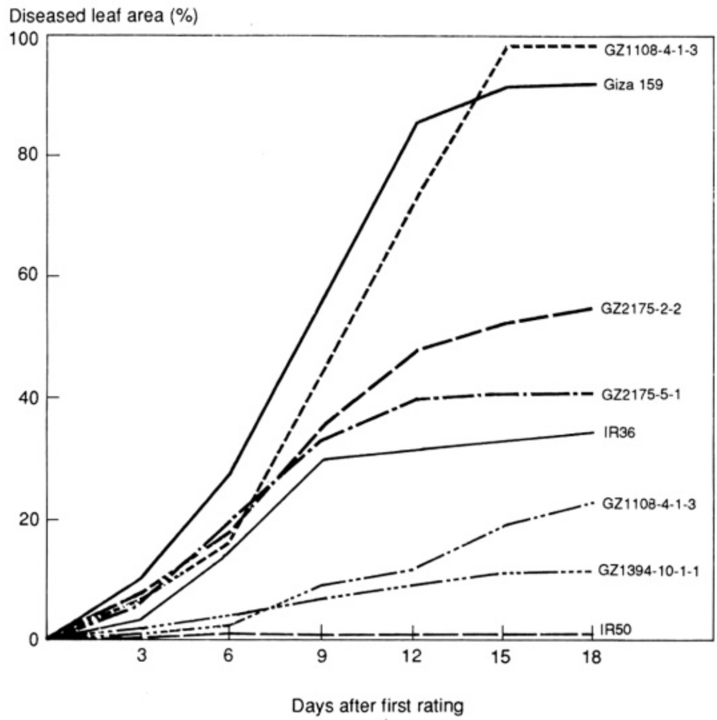
Pyramiding of monogenes

Pyramiding, or adding monogenes for resistance, may considerably increase the utility of a variety and make resistance durable. When a compatible pathotype occurs, a resistant monogene is found and incorporated into an acceptable variety. This process may be repeated many times, with the result that several race-specific monogenes for resistance are incorporated into a single variety. Nelson (1973, 1978, 1979) has evaluated the concept of gene pyramiding in detail and offers the well-grounded speculation that plant breeders should continue to pyramid all genes that control resistance to a specific pathogen, regardless of whether they are major or

Table 5. Relative evaluation system of the components of partial resistance in some rice varieties and lines under greenhouse conditions. Sakha, Egypt.

Variety or line	Isolates tested (no.)	Susceptible reactions (no.)	Components of partial resistance: Av no. of lesions	Av no. of conidia per lesion	Duration of conidial production (d)	Lesion size (mm)	Latent period (d)	Relative coding of components of partial resistance: No. of lesions 10,000	No. of conidia 1000	Duration of conidia 100	Lesion size 10	Latent period 1	Sum of codes	Average
IR30	98	15	12.00	5.2	5	25	6	2	4	4	2	2	24422	0.5519
IR36	55	5	7.00	4.1	6	30	6	1	2	2	2	2	12222	0.2762
IR50	112	9	8.14	4.8	5	28	5	2	2	4	2	4	22424	0.5072
IR19743-46-2-3	55	5	8.75	4.1	7	18	8	2	2	2	1	1	22211	0.5020
IR25882-32-1-3	55	5	3.33	3.2	7	18	7	1	2	2	1	2	12212	0.2760
IR25229-74-2	53	7	2.80	3.3	7	19	7	1	2	2	1	2	12212	0.2760
IR25571-31-1	54	2	5.50	4.1	7	25	7	2	2	2	2	2	22222	0.5022
GZ1343-8-2	103	31	11.43	4.0	6	28	8	2	2	2	2	1	22221	0.5020
GZ1362-5-1-3	94	12	8.90	3.6	6	17	7	2	2	2	1	2	22212	0.5022
GZ1394-10-1-1	153	27	5.86	2.3	8	25	6	1	1	1	2	2	11122	0.2513
GZ2175-5-1	56	9	8.25	3.4	7	26	6	2	2	2	2	2	22222	0.5022
GZ2175-5-3	55	6	6.66	4.2	7	24	6	1	2	2	2	2	12222	0.2762
GZ2175-5-4	58	12	8.91	4.3	7	29	6	2	2	2	2	2	22222	0.5072
GZ2175-5-6	57	7	4.66	3.9	7	26	5	1	2	2	2	4	12224	0.2762
GZ2175-2-2	57	8	8.57	5.3	6	27	6	2	4	2	2	2	24222	0.5072
GZ1506-8	99	1	4.88	4.2	6	24	6	1	2	2	2	2	12222	0.3264
GZ2376-24-1	56	24	8.66	4.1	6	35	5	2	2	4	4	4	22444	0.5072
GZ2080-2-4	31	8	6.37	5.3	5	38	5	1	4	4	2	4	14424	0.3264
GZ1546-4-7	56	12	13.75	4.5	6	38	5	2	2	2	4	4	22244	0.5027
GZ1368-5-2	54	5	12.50	5.5	6	27	5	2	4	2	2	4	24224	0.5479
GZ1108-4-3	153	42	9.88	4.7	7	34	5	2	2	2	4	4	22244	0.5027
Giza 171-M94-1-9	55	18	5.00	3.6	6	35	6	1	2	2	4	2	12242	0.2762
Giza 171[a]	125	66	19.7	5.1	8	39	6	4	4	1	4	2	44142	0.9978
Giza 172[a]	127	63	14.56	5.6	8	36	6	2	4	1	4	2	24142	0.5456
Giza 159[b]	115	71	26.9	6.5	6	35	5	4	4	2	4	4	44244	1
Reiho	123	58	11.0	8.1	4	28	7	2	4	4	2	2	24422	0.5519
Milyang 49	56	10	5.63	2.2	6	24	7	1	1	2	2	2	11222	0.2536
Suweon 249	56	8	4.5	2.1	6	24	7	1	1	2	2	2	11222	0.2536
Sipi 692033	52	18	6.33	2.3	6	24	6	1	1	2	2	4	11224	0.2536

[a]Commercial variety. [b]Highly susceptible variety.



2. Disease progress curves of rice blast on some Egyptian rice lines and varieties, Sakha, Egypt, 1986.

minor. This is one of the strategies that could be workable in Egypt (Nagarajan 1983). The gene *Pi* - Z^t, in the cultivar Toride 1, is effective against more than 70% of the pathotypes of *P. oryzae* and the gene *Pi-ta*^{2} in the cultivar Pi-NO4 is effective against the other pathotypes prevailing in Egypt. Therefore, incorporating these two genes into an agronomically acceptable variety by the modified backcross method is likely to induce resistance to all pathotypes of the blast pathogen. The advantage of this strategy is that when a new variety is developed by backcrossing a resistant source variety into the currently adopted one, the new resistant cultivar differs very little from the adopted one (Nelson 1973).

Gene rotation

The concept of rotating varieties with different genes for blast resistance was first studied by Kiyosawa (1979). However, Crill and coworkers (1982) were the first to link gene rotation with race prediction. The strategy of rotating varieties with monogenic resistance depends on the efficiency of the race prediction system, since the indigenous races of the pathogen in a particular area depend on the genotypes of the varieties grown in that area (Crill and Khush 1979). A mobile nursery that includes varieties with identified monogenic resistance could be useful in this respect. Although only two varieties were used, gene rotation is the principle behind the recommendation to plant Giza 172 in the northern parts of the Nile Delta in governorates with low blast incidence.

The advantage of gene rotation is that the new genes for pathogenicity that arise in the pathogen population will be controlled before they reach major proportions (Crill et al 1982). The disadvantage is that the effect of the gene rotation depends on an extensive disease and pathogen race prediction survey. It also requires a genetic study for resistance and pathogenicity to identify the effective genes in the host varieties. A strong breeding and variety development program, to release many resistant varieties to be rotated, is needed as well.

Multiline varieties

A multiline is a mixture of two or more uniform varieties, each of which differs from the others by the monogene for resistance (Nagarajan 1983). Ideally, the component lines are phenotypically indistinguishable from each other, except for the monogene for resistance. Line mixtures are more diverse in that the components are developed through only two or three backcrosses to the recurrent parent (Goto 1965). When some component in the mixture becomes susceptible to some component of the prevailing pathogen population, disease progress in the mixed stand is slower than that in the susceptible pure stand (Prabhu and Morais 1986). Such a reduction in the rate of disease increase results from the action of the resistant plants, which obstruct the dispersal of the pathogen, thus reducing the size of pathogen population attacking the susceptible component (Bonman et al 1986, Browning 1973).

Disease progress is slowed down because 1) plants of the susceptible component are spatially separated in the mixed stand, and 2) the resistance genes in the mixture reduce the fitness of the pathogen. Therefore, line mixtures induce resistance, because the mixture stabilizes the virulence genes of the pathogen population, prolonging the effectiveness of host resistance and thereby reducing the potential for epidemic disease development. This low rate of disease increase is characteristic of horizontal resistance. Therefore, the mixture of varieties, each with a single resistance gene, behaves in the same way as polygenically controlled or horizontal resistance in an epidemic. When a multiline variety is commercially used, adding or removing any of the component lines could be done according to resistance, susceptibility, and race prediction. It should be noted, however, that widening the genetic diversity within stands of rice by using multiline, line mixtures, or cultivar mixtures is not in itself the solution to blast disease; it is one of a number of tools for blast management.

The disadvantages of the multiline varieties are that they are expensive, agronomically conservative, and a breeding ground for new races, including a possible superrace that could attack all components of the multiline (Browning and Frey 1969).

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Integrated management of rice insect pests

B. M. SHEPARD

Although integrated pest management (IPM) is operational for many crops in developed countries (Adkisson 1986), it is still more an aspiration than a reality in less developed countries (Smith 1983). The philosophy and principles of IPM have been known for over 25 yr, but the concept is very often misunderstood, especially by nonspecialists. Some think of IPM as a simple tactic (such as a new resistant variety) or a neat package of tactics and strategies that can be readily applied in total to any given situation. Some even have the mistaken impression that IPM will replace all existing pest control technologies.

There are several realistic, and closely related, definitions of IPM. Kenmore et al (1985) provided one that is workable: IPM is the farmers' best mix of control tactics based on crop yield, profit, and safety.

IPM grew out of arecognition that total reliance on chemicals for insect control is unsound. The concept originated with the discipline of entomology, evolving from the earlier term "integrated control," which originally meant using biological and chemical means for controlling insects (Stem et al 1959). The IPM concept now embraces all pest control disciplines (including plant breeding for resistance), but insect pests are the major target of most IPM programs in effect today. Pest management on rice has been reviewed by Kiritani (1979).

There are those who argue that IPM is tailored to fit the needs of developed countries (Smith 1983), because, among other reasons, the transfer of technology is seriously limited in less developed countries. It must be recognized, however, that IPM programs need not be complex ones requiring technologically advanced delivery systems. Given the current status of pest control in many rice-growing areas of South and Southeast Asia, there is ample room for IPM implementation even in its simplest form. Resistant cultivars and chemicals are now considered by most to be the major pest control tactics. Some cultural practices are advocated but these, in general, play a minor role in most rice pest control programs. As Kenmore et al (1987) pointed out, Philippine rice farmers have used more and more insecticides during the last 30 yr. Interestingly, insecticide use on rice began *before* the new rice varieties were developed. To summarize, in the early 1950s, insecticide use was very low; by 1965, 60% of the farmers in irrigated rice used those chemicals and by the mid-1980s this increased to over 95% (Kenmore et al 1987).

Unfortunately, the importance of indigenous biological control agents has been largely overlooked. These valuable resources cost the grower nothing, and often maintain insect pest populations below economically important levels. Further, these rich communities of parasites, predators, and entomopathogens are relatively permanent, and in more than 50% of the fields (n = 300) observed in the Philippines, no insecticide applications were needed, largely because of the action of the beneficial fauna. In another study over 330 farmers' crops were used to compare insecticide-treated and untreated fields. Only 50% of the fields showed a measurable yield loss to insects (Litsinger 1984). Major reasons for the lack of attention to biological control is that a) pest control technicians and farmers are not trained to recognize the importance of these species, and b) quantitative information about the efficacy of biocontrol agents is generally lacking.

Exploitation of the full range of IPM strategies and tactics for rice will take time to evolve. However, there is already ample evidence to show its profitability in rice and its benefits in terms of production sustainability and environmental compatibility.

Developing an IPM program for rice requires research, training, and extension; all three of these components are necessary for successful implementation. Several agencies and institutions are involved in different aspects of IPM development and implementation in the Philippines. The Department of Agriculture (DA) has fully embraced the IPM philosophy, and the Food and Agriculture Organization (FAO), the Philippine-German Crop Protection Programme (PGCPP), and the International Rice Research Institute (IRRI) are providing support in the form of training and research.

Developing an effective IPM program

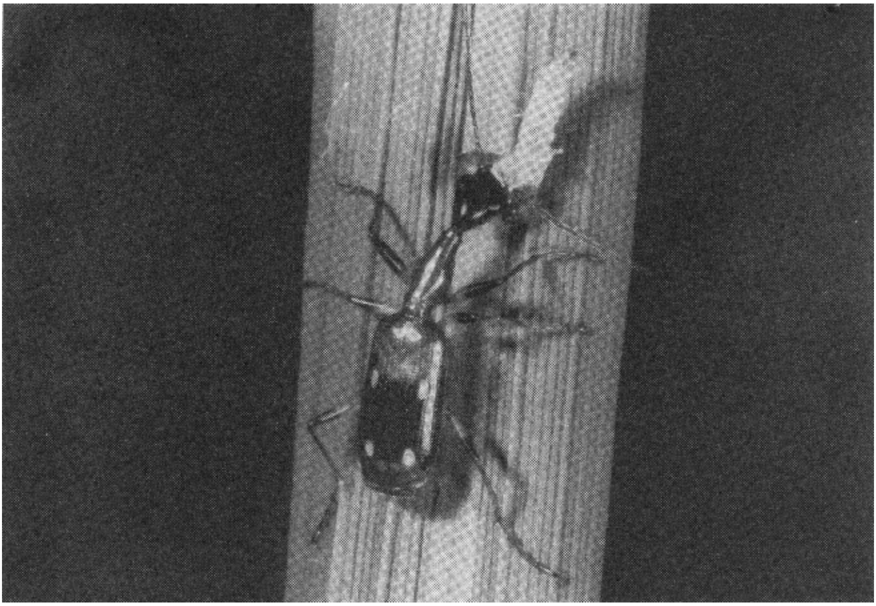
Identify potential pests and major beneficial species

Identifying pests and beneficials is an obvious first step in an IPM program. However, it is alarming that farmers, extension workers, and even researchers are often unable to identify the pest species and, more importantly, to determine if the density of the pest is sufficiently high to warrant control. Proper training must be provided in identifying pest species, and followup surveys should be conducted to determine if the information was retained by the farmers.

Materials to help identify major pests of rice include: 1) *Field problems of tropical rice* (IRRI 1983), 2) *Integrated pest management—rice: pocket reference* (1986), and 3) *Major weeds of the Philippines* (Moody et al 1984).

The importance of indigenous biological control agents (predators, parasites, and pathogens) is often overlooked. Published materials to help farmers and extension workers identify these species include 1) *An illustrated guide to integrated pest management in rice* (Reissig et al 1986), 2) *Natural enemies of insectpests of rice* (a poster) (lRRI/FAO 1984), and 3) *Helpful insects, spiders, and pathogens* (Shepard et al 1987). An example of major beneficial species is *Ophionea nigrofasciata,* a predatory beetle, shown in Figure 1 feeding on a leaffolder larva.

Several thousand farmers have been trained to identify pests and beneficial species by DA, FAO, and the PGCPP. In addition, IRRI's Department of



1. *Ophionea nigrofasciata* beetle feeding on a young larva of leaffolder.

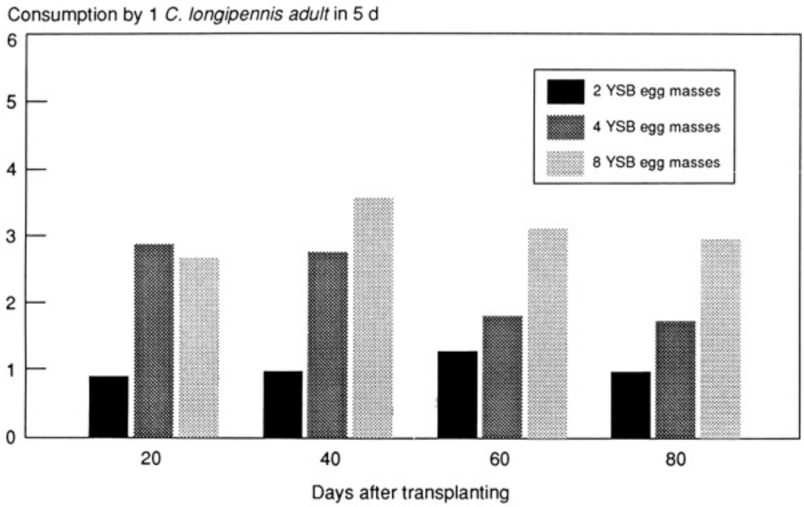
Entomology provides a 17.5-wk IPM short course, primarily for technicians who, it is hoped, will pass on their knowledge to other technicians and farmers.

Although there are rich communities of natural enemies in rice (Yasumatsu and Torii 1968), it is likely that only a few groups actually play a major role in regulating insect pest populations, It is important to identify these and to quantify their effects on pest populations.

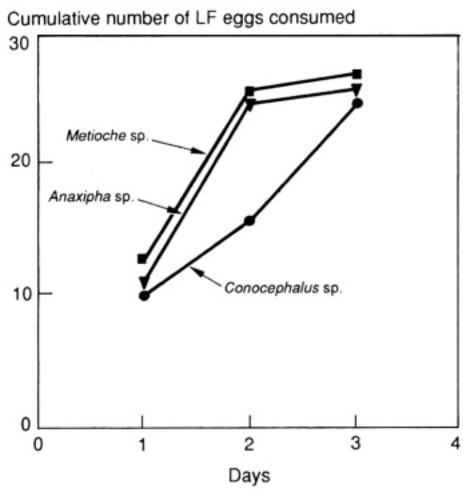
Orthopterans such as *Metioche vittaticollis, Conocephalus longipennis,* and *Anaxipha* sp. feed on eggs and immature stages of several rice pests. *M. vittaticollis* may consume over 100 eggs of the striped stem borer *Chilo suppressalis,* or 5-6 nymphs of the brown planthopper *Nilaparvata lugens* per day (IRRI 1985). *C. longipennis* is a major predator of eggs of the yellow stem borer *Tryporyza incertulas* in the Philippines. A single adult consumes as many as 4 egg masses during a 5-d period (Fig. 2). Cumulative numbers of leaffolder *Marasmia patnalis,* eggs consumed by *C. longipennis, Anaxipha* sp., and *M. vittaticollis* are shown in Figure 3 (Rubia and Shepard, unpubl.).

Field studies have demonstrated the importance of predators and parasites as mortality factors for the yellow stem borer in transplanted and direct seeded rice in the Philippines (Shepard and Arida 1986). Egg parasitization ranged from 20 to over 60%, and predation was over 30% at IRRI farm. Both predation and parasitization were slightly higher in transplanted than in direct seeded rice.

Epizootics of insect pathogens have been noted in many insect pests of rice. In Mindanao, Philippines, outbreaks of the fungus *Nomuraea rileyi* have arrested populations of green hairy caterpillar *Rivula atimeta* (IRRI 1984).



2. Consumption of yellow stem borer (YSB) egg masses by the grasshopper *Conocephalus longipennis.*



3. Cumulative number of leaffolder (LF) eggs consumed by predatory orthopterans *Conocephalus* sp., *Anaxipha* sp., and *Metioche* sp.

Major research directions at IRRI assess the impact of major beneficial species on insect pests. The long-term goal of this research is to develop IPM programs that recognize the importance of predators, parasites, and entomopathogens and to allow adjustments in action thresholds to be made relative to the density and species of natural enemies. This should reduce insecticide use, conserving these natural enemies and resulting in long-term production sustainability.

Determine action thresholds

Determining action thresholds is central to IPM. Usually the action threshold is expressed as pest density—that pest density (or sometimes damage level) which, if left uncontrolled, can reach the economic injury level and cause losses greater than the cost of treatment. In reality it is difficult to determine experimentally, because of the dynamic nature of the crop, pest, natural enemy, and environmental interactions. The occurrence of multiple pest species further complicates the problem.

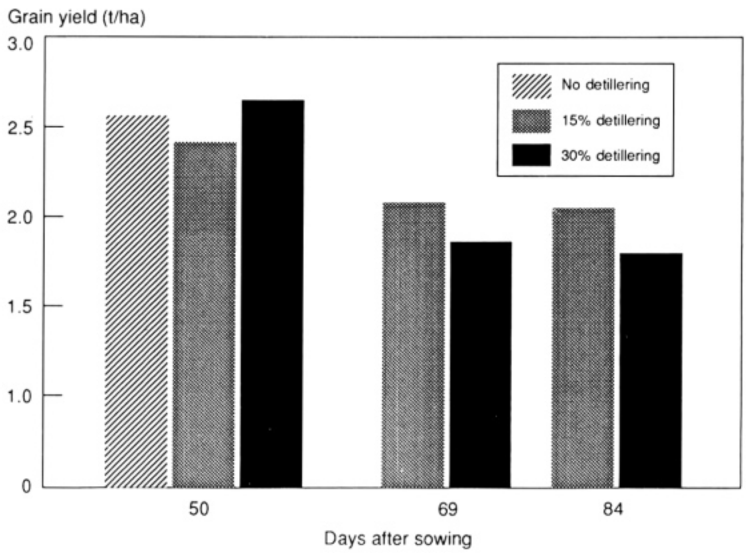
Several experimental approaches have been used to determine action thresholds. Often, a number of insect pests are introduced into cages in the greenhouse or field. Resulting yield losses can be obtained after allowing time for the pests to feed. Sometimes natural populations of pests occur at different densities within a field. Sampling from the whole range of densities allows correlations to be made between pest density and yield loss.

Another approach involves allowing the pest population to build up to different densities in field plots, then treating with pesticides to keep the populations at or below these predetermined densities.

A third approach is to simulate different damage levels by leaf clipping or detillering. This provides valuable data on the plant's response to feeding damage by insects. Computer simulation models also can be helpful.

Two or more the above procedures may be needed to define workable thresholds. These thresholds must then be tested in the field over a range of pest densities and environments.

At IRRI, damage by the yellow stem borer *Tryporyza incertulas* was simulated in IR36 rice variety by cutting and removing 15 and 30% of the tillers at 50, 69, and 84 d after seeding (Rubia and Shepard 1987). Results from this study (Fig. 4)



4. Effects of simulated detillering on yield of IR36 rice grown in upland conditions. IRRI, Los Baños, Philippines, 1986.

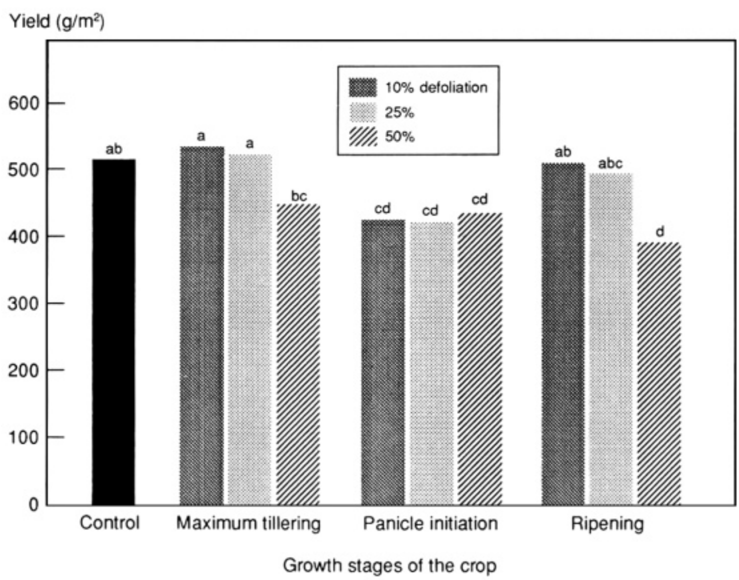
revealed that early season detillering of IR36 grown in an upland environment had little or no effect on resulting yields. However, detillering during panicle initiation and grain-filling stages significantly reduced yields. Similarly, artificial defoliation of IR64 at 10 and 25% at 40 d after transplanting (maximum tillering stage) did not affect yield. But all levels of defoliation at 60 d after transplanting caused significant yield losses (Arida and Shepard, unpubl.) (Fig. 5).

While we recognize that simulated damage does not mimic exactly the actions of insect attack, gross responses by the plant can be observed and thresholds refined. It is likely that early season insect pests cause little, if any, yield loss. However, there is little doubt that occurrence of these early season insect pests, even at noneconomic levels, has triggered needless insecticide applications.

Sampling and monitoring insect pests and beneficial species

Entering the field and taking samples is the only way to make intelligent decisions about whether or not a pest population is dense enough to require control. Even if training has been provided, the sheer tedium of sampling often deters farmers from following plans requiring that a large number of samples be taken.

In cooperation with the Philippines DA and FAO, we have developed simple and efficient sampling schemes for brown planthoppers (BPH) and whitebacked planthoppers (Shepard et a1 1986), and black bugs (Ferrer and Shepard 1987). In addition, a sampling program has been developed that incorporate major predator species as well as hopper pests (Shepard et al 1986). These sampling techniques are based on the mathematical distribution of the insects, predetermined damage thresholds, and the risk level that the grower is willing to assume.



5. Effects of simulated defoliation at different growth stages on yield of IR64 rice. IRRI, Los Baños, Philippines, 1986.

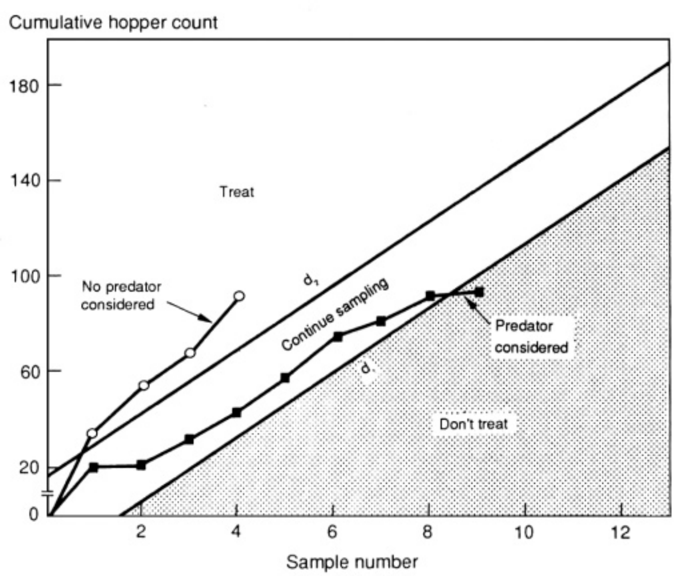
This method is called sequential sampling, because samples are taken in sequence; the number of insects found in a sample determines whether the next sample should be taken. Sequential sampling has been used in several crops, significantly saving time required for a decision on whether to apply a control tactic (usually an insecticide) (Pieters 1978, Shepard 1980).

A typical data set was used to generate Figure 6, which shows results from sampling hoppers and major predators (predaceous beetles, water bugs, and spiders). In this example, the decision without considering predators was to treat the field with insecticides. Because populations of BPH were near the threshold, the model dictated that 10 samples be taken. However, when predators were considered the decision was, “don’t treat,” which resulted in savings of an insecticide application.

In most circumstances, sequential sampling has allowed correct decisions to be made with 80-95% savings in time over procedures requiring a fixed number of samples (Shepard et al 1986). The ease with which this sampling approach can be employed should greatly increase the likelihood of its being adopted by farmers. It has now been tested by extension workers at 14 locations in the Philippines and in other countries. The next phase of this program is to include the sampling scheme as part of the training for farmers.

Selecting appropriate control tactics

Chemical pesticides have spread rapidly in developing countries but proper training to ensure their safe and effective use has not kept pace (Bottrell 1984). Severe consequences of insecticides overuse were recently experienced in Indonesia, where



6. Sequential sampling model showing point of decision to treat with insecticide without considering predators or by considering predators.

more than 50,000 ha were damaged by BPH. In this case, President Soeharto banned 57 insecticides in order to stabilize rice production by avoiding destruction of natural enemies and resurgence of BPH. The overall hectarage was less affected the following season.

A major constraint to moving away from heavy dependence on chemicals is lack of quantitative information on the economic value of nonchemical approaches (Bottrell 1986). It is likely that beneficial species will be considered along with pests in future economic analysis.

In many areas where the history of pest outbreaks is known, a resistant variety may be available. However, except for planthoppers and leafhoppers, resistance to insect pests of rice is limited. In most cases, within-season management decisions are related to whether or not to apply a chemical pesticide. In these instances, the farmer uses whatever is available. Other tactics may include adequate land preparation for weed control, destruction of rice stubble after harvest for insect and disease control, or community-wide programs of synchronous plantings and rodent control.

Integration

In the Philippines, we estimate that the total amount of insecticides applied could be reduced by more than 50% without yield loss. In most areas, it is difficult to see a yield response to increasing frequency of insecticide applications. In Laguna Province, Philippines, we monitored fields of different growers who applied insecticides from 0 to 5 times, yet obtained approximately the same yields in all fields (Crisostomo and Shepard, unpubl.). Likewise, IPM experiments were carried out in Nueva Ecija, Philippines, during the 1985-86 dry season and 1986 wet season. During each season, 6 farms ranging in size from 0.5 to 2.5 ha were divided into halves. Farmers were asked to continue to manage one-half of the farm as per their usual practice. The remaining half was managed by our IPM working group (personnel from IRRI, FAO, the Philippines DA, and the University of the Philippines at Los Baños [UPLB]). Insects, diseases, and weeds were monitored and economic analyses carried out on all operations and materials used on IPM- and farmer-managed portions.

Although yields from some of the farmer-managed portions were slightly higher during the 1986 dry season, the benefit-to-cost ratio was always higher in the IPM portion of the farm. Farmers treated their portions of the fields more frequently with insecticides.

Research and training are key elements in developing effective IPM programs. There is no way of adapting IPM to different geographical locations except by carrying out research at those locations. Shifts in pest importance and differences in abiotic and biotic environments which affect the pests and crop are often location-specific.

IPM demonstration programs, established at several locations in a region, can serve the important function of allowing farmers to observe IPM in action. A major deterrent to successful implementation of IPM is lack of trained extension personnel, lack of support for them, and lack of training for farmers themselves. Research is far ahead of implementation.

Sumangil (1984) concluded from observations of 442 farmers' crops in the Philippines that "if farmers can use thresholds to make insect control decisions, they can increase profitability—over preventive insecticide applications."

IPM activities in the Philippines were stimulated by FAO in the late 1970s. Basically, this effort was to promote pest surveillance (Waterhouse et al 1983). Interestingly, outbreaks of BPH in the Philippines during the 1970s were directly correlated with recommendations for preventive insecticide treatments, a practice which is no longer recommended.

The Philippines DA has recently reviewed its policy of pesticide use. Presently the Bureau of Plant Industry (BPI) within the Department fully embraces the concepts and philosophy of IPM. Key individuals responsible for the present status of IPM in rice in the Philippines include J. P. Sumangil (BPI, DA), P. E. Kenmore (FAO), J. A. Litsinger (IRRI), and Candida Adalla (UPLB). IRRI has provided backup research that has been translated into usable thresholds, resistant varieties, surveillance programs, and identification of natural enemies and definition of their importance. Weeds, diseases, and insects are included in the present surveillance program.

Conclusion

A sequence of steps should be followed in developing an IPM program. The level at which a national program may enter this sequence depends upon the existing knowledge base. Clearly, information generated from research in IPM has not been fully disseminated to the farmers in developing countries. However, efforts are under way in many countries, including the Philippines, to increase adoption of IPM. Rice production will become sustainable only after ecologically, economically, and sociologically accepted methods of pest control are adopted. This must extend further than breeding for resistance; otherwise, emergence of new pests, resistance of pests to insecticides and resurgence of insect populations will continue to threaten the crop.

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Integrated pest management in Egypt

A. L. Isa

The rice crop in Egypt is remarkably pest-free. Of 33 pests listed in a recent survey, only 4 are of any importance: the bloodworm *Chironomus* sp., the stem borer *Chilo agamemnon,* the tabanid larva *Atylotus agrestis,* and the rice leafminer *Hydrellia prosternalis.* Damage symptoms are described, and measures for management suggested. Future research plans are briefly outlined.

Insect problems on rice can be serious in some parts of the world and may severely affect rice production. In Egypt, however, rice insect pests cause relatively little damage and play only a small role in rice production.

Nevertheless, rice entomology has been given much attention in the last few years, particularly through the Rice Research and Training Project.

A survey of rice insects has been completed and a list of 33 rice pests compiled. Only a few of these are considered pests of economic importance; these include the bloodworm *Chironomus* sp., the rice stem borer *Chilo agamemnon,* the tabanid larva *Atylotus agrestis,* the rice leafminer *Hydrellia prosternalis,* and certain leafhoppers and planthoppers.

Chemical treatment to control rice pests is rarely used. Out of about 420,000 ha, the total area of rice in Egypt, only a small portion is chemically treated to control the rice stem borer and the bloodworm. An integrated pest management system is followed against key pests of rice to minimize losses in rice yield and to limit the use of chemical control.

Management of bloodworm

Larvae of *Chironomus* sp. attack rice seedlings in nurseries and in direct seeded ricefields, feeding on the emerging rootlets. Infested seedlings get detached from the soil and float on the surface of the water. The plant stand may be reduced. Sometimes the infestation is so severe that resowing becomes necessary. Larvae may also feed on the starchy contents of germinating seeds and cause poor germination. Rootlets of some seedlings may be partially destroyed, causing weakness. By the time plants are 15 d old, they can tolerate the infestation and no obvious damage is noticeable.

Chironomus larvae are present in every ricefield in Egypt, but they cause economic injury only to seedlings grown in saline soils, or to plants irrigated with saline drainage water. The population size of this insect and thus the degree of damage are markedly affected by soil and water salinity.

Females lay their eggs in the evening of the same day the field is flooded with water. The incubation period averages between 2.2 and 4.5 d, depending upon temperature ranges. After that, hatching larvae start swimming close to the surface of the water and attacking rice seedlings. Duration of larval development ranges between 12.2 d during July and 17.5 d during April.

Studies on the biology and behavior of this insect have led to several practices that result in very satisfactory control.

1. The rice nursery should, as far as possible. be grown on less saline soils, as the insect is harmful to rice seedlings grown in saline soils. Drainage water should not be used for irrigating rice nurseries.
2. Sowing of rice should not be delayed much after the rice nursery is flooded. Delayed rice sowing gives bloodworm eggs a chance to hatch and be ready to attack rice when it is sown.
3. Sowing pregerminated seeds gives the seedlings a better chance to fix themselves in the soil and escape insect damage.
4. *Chironomus* larvae must be in water to survive, so drainage of water from rice nurseries for 1-2 d proved effective in reducing the larval populations. The absence of water also prevents *Chironomus* larvae from moving among rice seedlings. Furthermore, a good number of larvae are swept out during the drainage process.
5. The insect larva is very sensitive to a large group of insecticides. Normally any leftover chemicals that are used to control insects on cotton or a horticultural crop are successfully used on rice to control bloodworm larvae.

Management of rice stem borer

Several boring insects are found in ricefields in Egypt. It was proved, however, that the only borer that attacks rice plants in this country is the purple striped borer *Chilo agamemnon* Bles. Other borers found in ricefields attack only certain graminaceous weeds. *C. agamemnon* is considered the most important pest of rice in Egypt. Besides rice, it attacks maize and sugarcane also.

Infested rice tillers show different distinctive symptoms:

- The deadheart symptom occurs when the rice plant is infested before head development. The larva feeds inside the plant stem, cutting it from below. The inner leaf of the growing point withers and turns yellow. Such tillers die, but new tillers can replace the dead one if rice is still at the early tillering stage.
- The whitehead symptom occurs when the rice plant is infested just after head emergence. The insect feeding inside cuts the stem just above the last node of the stem below the head before panicle formation. The infested head turns white, while sound heads are still green.
- Infested stems but sound heads: Here the larva invades the stem, feeding on its inner lining without cutting it.

Losses in rice yield due to borer infestation are estimated yearly in all rice-producing governorates. Yield losses ranged between 5.5 and 6% in 5 successive years, 1979-83. Losses also vary from one governorate to another, and from one rice variety to another.

Integrated pest management of the rice stem borer is based on different approaches.

Varietal resistance

Rice varieties differ considerably from one another in their susceptibility to the rice stem borer. Susceptibility also differs with growth stage. Certain varieties are more susceptible at the tillering stage, counted as deadhearts, than at the heading stage, counted as whiteheads. Other varieties may behave differently.

Studying the relative susceptibility of all the material in the rice breeding program is done routinely every year. Such knowledge is useful to the plant breeder in developing less susceptible varieties.

Recent investigations on the relative susceptibility of the currently recommended varieties and those considered promising have proved that:

1. Reiho and CR882-2-2-2 were the least susceptible to stem borer.
2. CR587-2-1, Giza 170, Giza 171, Giza 172, CR5875-6-2, and Giza 159 are moderately infested.
3. IR1626-203, CR951-7-1-2, Giza 180, IR8, and IR28 are the most susceptible.

In general, the foreign varieties are more infested than local ones.

Studies on the morphological characters of the rice plant in relation to rice stem borer infestation revealed that:

1. Borer infestation was positively correlated with the width of rice plant leaves.
2. Rice stem diameter was positively correlated with stem borer infestation.
3. Tillering capacity of rice varieties was negatively correlated with their susceptibility to borer infestation.
4. There was a pronounced negative correlation between hardness of the rice plant stem and its susceptibility to the stem borer.
5. Varieties with tight leaf sheaths around the stems proved to be less infested by the borer than those with relatively loose sheaths.
6. Varieties with green or dark green leaves received more egg masses than varieties with light green leaves.

Cultural practices

Certain cultural practices were found to affect stem borer infestation in rice:

1. Ricefields with close plant spacing (10 × 15 cm) were relatively less infested than fields with wide spacing (15 × 20, 20 × 30 cm). Wide spacing produces more vigorous plants, which are more susceptible.
2. Broadcast-sown fields were less infested than transplanted ones.
3. Ricefields fertilized with high rates of N are more subject to borer infestation than fields fertilized with low rates.

Larval hibernation

C. agamemnon larvae of the last generation do not pupate but hibernate as full-grown larvae in rice straw in the stubble left in the field after rice harvest. These hibernating larvae constitute the main source of infestation for the next season.

Between 69 and 92% of hibernating larvae are found in rice stubble; the rest hibernate in rice straw.

Studying the fate of larvae hibernating in rice stubble when rice was followed by different crops revealed that:

1. When the field was left fallow after rice, but frequently irrigated, the larvae that survived to emerge as moths in early summer reached 16.3 and 18.1% in 2 successive years.
2. When faba bean *Vicia faba,* planted with zero tillage, followed rice, 13.7 and 13.4% larvae survived in the 2 yr.
3. When berseem and then cotton followed rice, 6.8% larvae overwintered successfully.
4. When wheat was sown after rice, larval survival was as low as 3.2%. In this case, the land was tilled following the rice harvest, to prepare it for wheat sowing.

It was also found that adding 100 kg of the N fertilizer with calcium cyanide to the soil and plowing to prepare for the next crop was detrimental to almost all hibernating larvae.

Threshing rice after harvest kills 70-85% of the hibernating larvae in rice straw. Pressing straw into bales seems to destroy all hibernating larvae in the straw.

Biological control

Survey of predators and parasites of the stem borer in ricefields has started recently, and a good number of these biological control agents are reported. We hope with further studies on the subject to get the maximum benefit from these natural control agents.

Management of tabanid larvae

Larvae of the tabanid fly *Atylotus agrestis* are found in large numbers in ricefields, particularly when organic manure is used for fertilization. They feed on rice plant tissue at the base of the stem, close to the surface of the water, usually cutting the stem from below. Losses in rice yield from this pest range between 1 and 2%.

Factors affecting *Atylotus* infestation are

1. *Time of planting.* The level of infestation with the tabanid larvae was higher in late than in early rice plantings.
2. *Manuring.* Manure applied at the rate of 95 m^3/ ha before planting rice increased tabanid infestation. Percentages of infestation in manured fields were 5 to 10 times higher than in nonmanured fields, when manure was applied before planting.
3. *Rice variety.* No significant differences in *Atylotus* infestation were noticed among different local varieties; however. Giza 159 showed a tendency to higher infestation.

The chemical treatment applied sometimes to control the rice stem borer seems effective against *Azylozus* larvae.

Management of other rice pests

The rice leafminer

Newly hatched larvae of the rice leafminer *Hydrellia prosternalis* tunnel into the leaf blade, feeding on the mesophyll and making longitudinal straight mines. The mine varies in length from a few millimeters to a few centimeters. Leaves carrying up to five mines do not appear unhealthy. However, mines covering about 40% of the leaf surface in late rice plantings undoubtedly cause a loss in rice yield.

No attempts have been made to control this pest, as the injury it causes to rice plants (so far) does not justify applying control measures. It has been observed that:

1. Rice sown during April and early May is less infested than that sown in late May or early June.
2. Different rates of N and P fertilizers and of organic manure have no effect on the degree of infestation by this pest.
3. Different varieties showed slight differences in their susceptibility to infestation with the rice leafminer.

Leafhoppers and planthoppers

Leafhoppers and planthoppers are among the most common ricefield insect problems in the tropics. Besides transmitting certain virus diseases. they cause serious direct damage by sucking the plant sap. Such damage is not observed in ricefields in Egypt, despite the occurrence of eight species of leafhoppers and one species of planthopper, sometimes in enormous numbers, in rice nurseries and fields.

Our studies have shown that, so far, leafhoppers and planthoppers are not of economic importance to rice in Egypt. Although significant differences were found in leafhopper and planthopper populations among plots treated with insecticide and untreated plots, no differences in yield were detected.

Consequently, no control measures against these pests are recommended.

Approaches to rice pest control

In the future, approaches to rice pest control in Egypt will include:

1. *The use of the sex hormone to control the rice stem borer.* This technique was introduced into Egypt about 10 yr ago. It gave promising results against the cotton leafworm and the pink bollworm on cotton, and has been commercially applied to cotton fields during the last few seasons, Application of the sex hormone has been studied carefully and two techniques are used: mass trapping and confusion. Sex hormones to control other insects, for instance, the potato tuber moth, are also applied.

   However, such work has not been started yet against the rice stem borer, because the sex hormone of this insect is not yet available.
2. *Sterilization by radiation.* Male sterilization by radiation is also practiced in Egypt. A current project to eradicate the medfly uses this technique.

   However, before we can start using such a technique to control the rice stem borer or the bloodworm, we must make a complete study of the mating behavior of these insects and develop a simple method to mass-rear the insects in the laboratory. These studies are planned to start in the near future.

3. *Use of hormones, antifeedants, and repellants.* These are also considered new approaches in pest control. Although none of these have been tested on any of the rice pests, they will be considered in future research plans.

Notes

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Rice-based cropping systems management in Egyptian Vertisols: the ICRISAT experience

J. S. Kanwar

Rice-based farming systems in Egypt must take new directions to meet the challenge of food production for the future, increasing the productivity of the whole cropping system rather than the number of rice crops. Because of serious limitations of land and water and the associated problems of salinity and alkalinity, the possibility of including grain legumes (such as chickpea, groundnut, and faba beans) and crops requiring less irrigation than rice (such as maize, sorghum, and millets) should be explored. This would improve the economy and sustainability of farming and release irrigation water for extending cropping to new areas. About 50% of the cultivated area of Egypt consists of Vertisols, whose full potential has not yet been exploited. The improved Vertisol management technology developed at the International Crops Research Institute for the Semi-Arid Tropics offers new promise for increasing the productivity of these soils.

Rice is the most important crop of the irrigated as well as favorable rainfed areas of the world, particularly the humid, the semiarid, and the arid tropics. Thanks to improved technology, rice yields all over the developing world have been rising steadily, but there is still vast scope for increase in productivity per unit area per unit time.

In Egypt, where all the cultivable area is irrigated and 50% of the cultivated soils are Vertisols, cotton, rice, maize, wheat, sorghum, millets, legumes, forage crops, and vegetables are important crops and their yields are higher than the world average. However, with the rapid increase in population, the dwindling supply of new land, the limitation of irrigation water, and the increasing salinity and alkalinity, it is essential to increase the productivity per unit area and improve efficiency of irrigation water use and residual soil moisture as well as other monetary inputs of agriculture. It is equally important to diversify cropping systems.

A range of crops and cropping systems can be grown in a given environment. Multiple cropping, or the practice of growing several crops on the same piece of land, is an ancient strategy that farmers use to increase the diversity of products and the stability of annual output. However, the traditional system and technology may be inadequate now. Agricultural efficiency can be improved through use of more remunerative crops, high-yielding varieties, inputs, management, and marketing strategies.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has experience in research for rainfed agriculture in the semiarid, tropical (SAT) areas of India and Africa, and I will use this experience to discuss some of the basic issues and new directions in cropping systems.

Our main interest is in dryland agriculture. but our experience in cropping systems and crop and soil management, particularly Vertisol management, will be relevant to this symposium.

All the ICRISAT mandate crops—sorghum, pearl millet, groundnut, chickpea, and pigeonpea—may be of direct interest even to irrigated farming conditions in Egypt and sub-Saharan Africa (SSA). In SSA: sorghum and millet are the predominant crops, and grain legumes are grown io a small extent. However, Egypt has a sizable area under these crops, except for pigeonpea. The possibility of incorporating these crops to diversify agriculture, produce fuel, fodder, and animal feed, and improve the productivity of wheat- or rice-based systems needs to be recognized:

1. All the crops can fit into an intensive cropping system under irrigation or under conditions of limited moisture, or for utilization of residual moisture after a highly irrigated crop like rice.
2. They have less irrigation demand and produce more grain per unit water per unit time than rice, and have a comparative advantage where water is limited.
3. Their requirement for fertilizer and other inputs is lower than that of rice, and they are better adapted to a low- to medium-input situation.
4. They can be advantageously incorporated into a cropping system based on rice, with or without irrigation, on Vertisols, Alfisols, Aridisols, and other soils.
5. With improved Vertisol management technology, these crops can be fitted into various cropping systems to increase their productivity under both irrigated and nonimgated conditions. Fifty percent of the cultivated area in Egypt is under Vertisols or related soils. SSA is reported to have about 113 million hectares of Vertisols; their potential for growing rice and other upland crops is very high, but they are not exploited yet.

Cropping systems defined

The range of systems depends on the farmer's ingenuity, targets, and resources, and economic factors. The important systems are:

- Sequential cropping
- Relay cropping
- Intercropping
- Ratoon cropping.

Sequential cropping

In a sequential cropping system, two or more crops are grown in sequence, the second being grown after the harvest of the first. In the Indian SAT, the first crop could be a rainy season crop such as rice, maize, sorghum, soybean, mungbean, pigeonpea, groundnut, sesame, cotton, or sugarcane. The postrainy or cool season crops can be wheat, chickpea, pigeonpea, safflower, linseed, groundnut, rapeseed or mustard, sorghum, sunflower, lentils, vegetables, forages. Such a variety of combinations exists that, depending upon planning, availability of inputs, and management, a range of cropping systems is feasible.

Relay cropping

In relay cropping a second crop is sown shortly before the harvest of the first crop. This is very attractive because it enables growing two crops; yet, because the second is sown while the first is still standing, the total cropping season is 2-3 wk shorter. This also allows full use of soil moisture for the second crop during the critical stages of germination and early seedling growth. Examples of relay crops are cotton - chickpea, rice - chickpea or safflower, maize - chickpea, and rice - berseem. However, the disadvantage of this system is the difficulty of sowing in the standing first crop, particularly if the sowing is done with animaldrawn implements.

Ratoon cropping

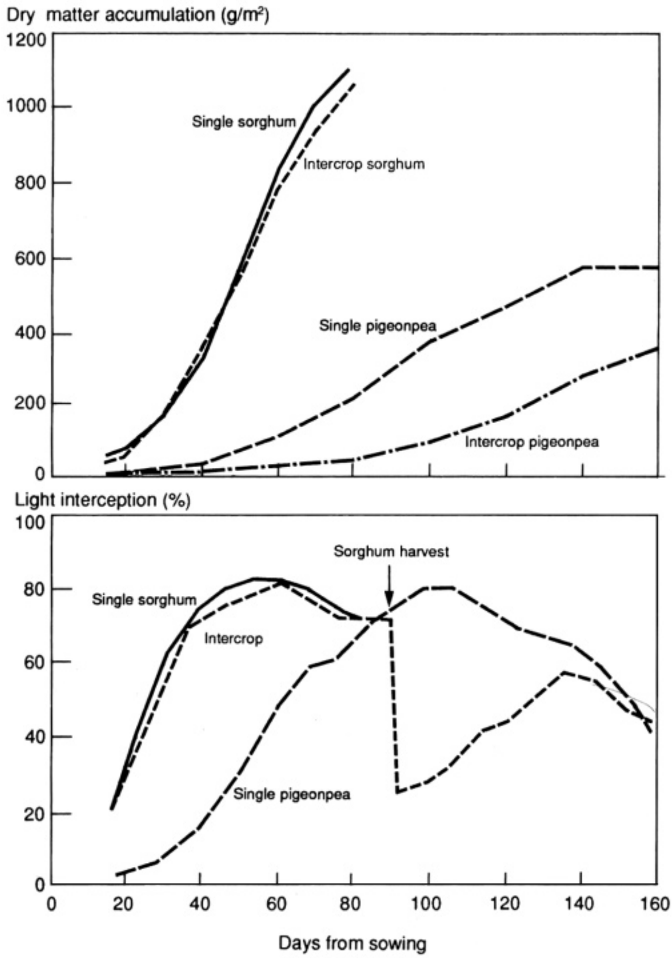
In a ratoon crop, the stubble of the first crop is allowed to regrow to produce a second crop. Only a few crops ratoon well. Pigeonpea or sorghum are effective ratoon crops for Vertisols. In fact, in our experience, pigeonpea variety ICPL 87 (140-d duration) produces more than 5.2 t/ha grain in 3 harvests from June to March.

Intercropping

In an intercrop, two or more crops are grown on the same area of land at the same time. While one of the crops is harvested early, the second one continues growing after the harvest of the first, making full use of the residual moisture and sunlight (Fig. 1). The overall advantage of the system is the complementary use of resources by the component crops. The system offers special advantages under drought and other environmental stresses.

With a potentially long growing period, there is a choice of two types of intercropping systems: temporal and spatial. In the temporal system, a fast-growing and a slow-growing crop are planted together. A sorghum + pigeonpea intercrop is an illustration of this system, in which sorghum grows fast and pigeonpea slowly. After sorghum is harvested in about 120-130 d, pigeonpea continues growing, taking about 180-200 d, making the best use of residual moisture (Fig. 1). Sorghum thus intercropped gives 82% of the yield it would give as a sole crop, and pigeonpea produces 85% of its sole-crop yield; both together give a land equivalent ratio (LER) of 1.67.

The spatial system of intercropping involves growing together two crops of similar maturity but dissimilar canopy and height. If the growing season is long enough for two consecutive crops, spatial intercropping can be done during the first or second crop period, or both. Many such systems have been examined at ICRISAT. Common examples are 1) groundnut + pearl millet (Fig. 2), 2) pearl



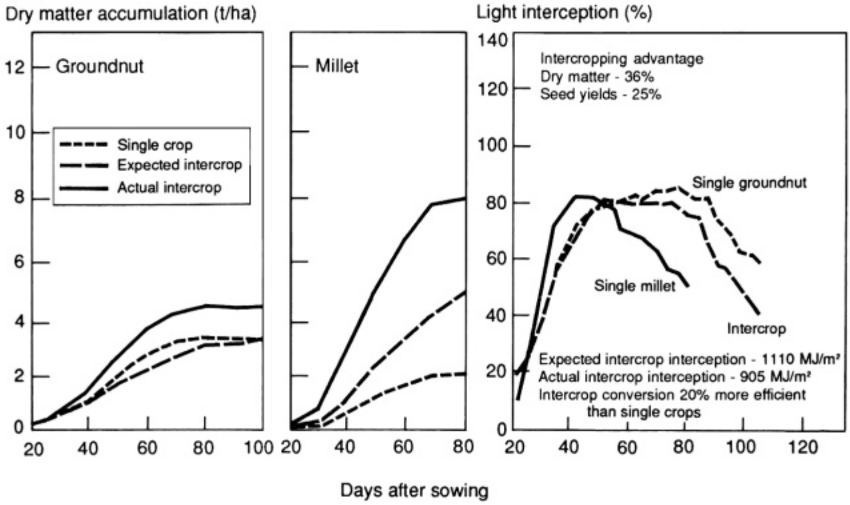
1. Dry matter accumulation and light interception in sorghum and pigeonpea sown as single crops and as intercrops (two rows sorghum: one row pigeonpea), 1977-79.

millet + sorghum, 3) sorghum + groundnut, and 4) pearl millet + cowpea. The pearl millet + groundnut system gives an LER advantage of 20-25% over either grown as sole crop (Reddy and Willey 1981).

Climatic considerations for cropping systems

A climatic approach to designing cropping systems for dryland areas has received increased attention in recent years (Virmani 1979). It involves four basic steps:

1. Description of the rainfall regime of a particular area, involving total rainfall intensities and probabilities.
2. Calculation of potential evapotranspiration and its relationship to rainfall regimes, to identify the water-surplus and deficit periods.



2. Dry matter accumulation and light interception in pearl millet and groundnut as single crops and as an intercrop (one row millet: three rows groundnut), 1978-80.

3. Evaluation of soil water-holding capacity and other soil physical characteristics such as texture, structure, and infiltration rate.
4. Calculation of water balance.

The prospects of sequential cropping, sole cropping, and intercropping on deep black soils at Indore and Sholapur (India) were compared, using rainfall data of 37 yr and a computer-based water-balance model available at ICRISAT (Reddy et a1 1985). At Indore, 105-d sorghum is successful in 100% of the years and there is a probability of having sufficient stored water for a second crop in 51% of the years. However, in half the number of years, the rainfall during the season will be insufficient to moisten 5-7.5 cm of soil to allow the second crop to germinate (Table I). Thus, despite the favorable rainfall and sufficient stored water in the soil profile after 105-d sorghum, successful double cropping is a probability only in 27% of the years. With 91-d sorghum, however, double cropping will be successful in 60% of the years.

A sorghum + pigeonpea intercropping system will be successful in 97% years. The moisture regime favors a maize + pigeonpea intercrop more than a maize - chickpea sequence.

At Sholapur, with 700 mm mean rainfall, the highest probability of success is with 91-d rabi (postrainy-season) sorghum grown on conserved moisture (Table 1). However, at Patancheru (ICRISAT Center), with almost the same rainfall as Sholapur, both sequential cropping and intercropping are successful because of better distribution of rainfall (Table 2).

Potential of some ICRISAT mandate crops

Some of the newly developed hybrids of sorghum and pearl millet have shown high yield potential under both irrigated and nonirrigated rainfed conditions and thus

Table 1. Probability of success of different cropping systems predicted from a water-balance model and long-term rainfall data in India (Reddy et al 1985).

Cropping system	First crop		Second crop (or pigeonpea intercrop)		Total probability of success (%)
	Sufficient moisture for growth (%)	Wet week at harvest (<50 mm) (%)	Sufficient moisture for growth (>200 mm) (%)	Insufficient moisture for establishment though sufficient for growth (%)	
Indore (990 mm, 37-yr data)					
Sequential (1st crop 91-d sorghum)	100	30	73	13	60
Sequential (1st crop 105-d sorghum)	100	24	51	24	27
Relay (1st crop 105-d sorghum overlap 14 d)	100	24	73	13	60
Intercrop (105-d sorghum + 180-d pigeonpea)	100	24	97		97
Sholapur (700 mm, 36-yr data)					
70-d 1st crop	75	17	81	0	81
91-d 1st crop	58	25	81	0	81
105-d 1st crop	58	11	72	5	67
Fallow	–	–	81	0	81

offer great promise for use in intensive cropping systems. They are ideally suited to semiarid conditions, especially for Egyptian and SSA agriculture.

Sorghum cultivars SPH221 and SPV351 in India, Hageen Durra in Sudan, ZMVI in Zambia, and Malk Mash in Ethiopia have shown high yield potential: 5-6 t/ha under favorable rainfall and 8-10 t/ha under high fertility and irrigation.

Even under nonirrigated rainfed conditions at the ICRISAT farm, with 43 kg N and 20 kg P/ha, an average yield of 6.1 t/ha was harvested from a large area of SPH221 hybrid in 1986. Pearl millet, which is a shorter duration crop (<90 d), has yielded 3.5-4 t/ha with ICMH451 and ICMH501, both released hybrids in India.

The improved groundnut variety ICG1 yielded more than 8 t/ha under irrigation in the postrainy season. Pigeonpea variety ICPL87 has recorded yields of 5.2 t/ha in Argentina, 4.8 t/ha in India (at ICRISAT), and 6.9 t/ha in Puerto Rico. The maximum production levels of pigeonpea in various cropping systems are shown in Table 3.

Chickpea ICL8543 yielded a high of 6.4 t ha and an average of 3 t/ha over 8 locations in India during 1985-86. In West Asia and North Africa, in areas with a mediterranean climate, winter plantings of chickpea varieties such as ICL482, resistant to *Ascochyta* blight, have given double the yield of spring plantings (Fig. 3). Chickpea has great potential for cultivation in Egypt, where yields of more than 4 t/ha have already been reported with the best varieties.

Table 2. Yields from different cropping systems in deep Vertisols in Patancheru and Indore, India (Willey 1986).

	Cropping system				
	Traditional	Sequential	Intercrop	Sequential	Sequential
		Patancheru (750 mm)			
1st crop	Fallow -	Maize -	Sorghum +	Mungbean -	Sorghum -
2d crop	sorghum	chickpea	pigeonpea	sorghum	safflower
Cropping period (d)	120	190	180	150	190
Grain yield (t/ha)					
1st crop	–	2.4	2.9	6.3	3.3
2d crop	1.0	1.3	0.9	2.1	0.8
Total grain yield (t/ha)	1.0	3.1	3.8	3.7	4.1
Total biomass (t/ha)	3.3	9.4	9.5	6.8	9.0
		Indore (1000 mm)			
		Maize - chickpea	Maize + pigeonpea	Maize - wheat	Sorghum - chickpea
Grain yield (t/ha)					
1st crop		4.6	4.6	4.5	1.9
2d crop		2.1	1.4	1.8	1.9
Total grain yield (t/ha)		6.7	6.0	6.3	3.8
Total biomass (t/ha)		16.1	16.1	15.8	12.6

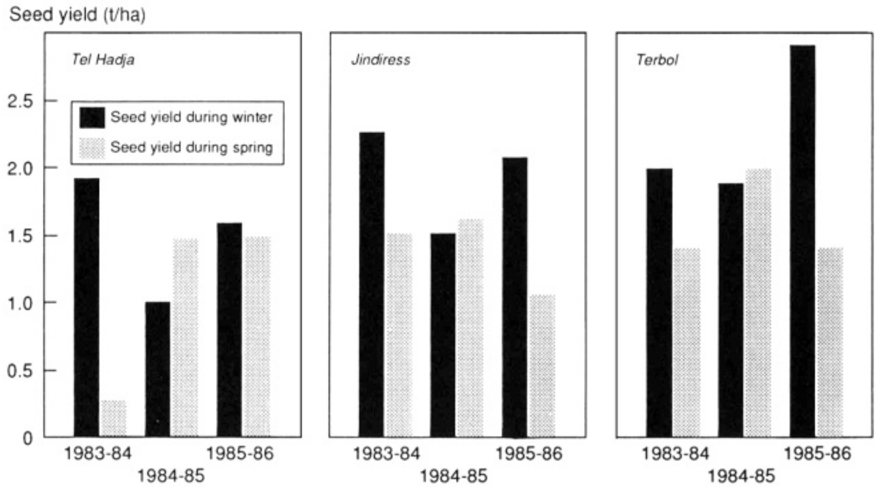
Table 3. Maximum production levels of pigeonpea in various cropping systems (Johansen et al 1986).[a]

Cropping system	Dry seed (t/ha)	Vegetable green pea (t/ha)	Dry stem (t/ha)	Fodder dry matter (t/ha)
Monocrop (short-duration pigeonpea)	8.0	nd	32	2.3
Multiple harvest monocrop (short-duration)	5.2	5.2	8.3	nd
Intercrop (medium-duration)	3.0	5.3	11.3	24
Intercrop (long-duration)	3.6	nd	7.5	nd
Postrainy-season monocrop	3.4	nd	nd	4
Multipurpose perennial	2.1	5.1	nd	57

[a]nd = no data.

ICRISAT experience with rice-based cropping systems

Rice is not included in ICRISAT's mandate crops, but rice is grown in the SAT under irrigated and rainfed conditions, where hydrological environments are favorable, such as valleys, or where rainfall is high. In the Coordinated Agronomic Trials conducted by the Indian Council of Agricultural Research (ICAR), yields in rice-based cropping systems involving 2 to 3 rice crops ranged from 11 to 16 t/ ha (Table 4) (Mahapatraet al 1981). But this system demands very high inputs of water, fertilizers, and pesticides, and exhausts soil fertility.



3. Chickpea yields in winter and spring planting at 3 stations (source: International Center for Agricultural Research in the Dry Areas [ICARDA] pers. comm., 1986).

Table 4. Yield of most productive rice-based cropping systems at different centers in India (Mahapatra et al 1981).

Center and soil type	Rainy season (1st crop)	Postrainy season (2d crop)	Summer (3rd crop)	Total grain yield (t/ha)
Kalyan (alluvial soil)	Rice	Wheat	Rice	10.9
Varanasi (alluvial soil)	Rice	Wheat	Rice	11.4
Maratery (medium-deep soil)	Rice	Ragi (finger millet)	Rice	11.0
Bhubaneshwar (laterite)	Rice	Rice	Rice	11.1
Mangala (laterite)	Rice	Rice	Rice	16.0
Karamana (laterite)	Rice	Rice	Rice	11.4

In search of less demanding and more diverse systems that include only one crop of rice, ICAR, the International Rice Research Institute (IRRI), and ICRISAT have developed a cooperative program for research on rice-based cropping systems. The main cereal crop in the rainy season is rice, followed by grain legumes, on Vertisols. Two varieties of rice (120-d and 100-d duration) were tried as the main rice crop on Vertisols at ICRISAT Center in Patancheru and at nearby Rajendranagar. The postrainy-season crops—sorghum, pigeonpea, chickpea, or groundnut—were raised on residual soil moisture at ICRISAT and with irrigation at Rajendranagar.

Table 5 shows the first year's data from the 120-d rice variety trial. In the second year, 1986-87, rice had been harvested, producing more than 5 t/ha, and the postrainy-season crops were growing now. We have tried in this experiment to optimize the production of the first and second crops and to maximize the water-and fertilizer-use efficiency, as these are costly inputs.

Table 5. Yields of rice-based cropping systems in the Hyderabad area of India, 1986 (Sharma, S. K., Ong C. K., pers. comm., 1987).

Cropping system[a]		Yield (t/ha)	
		Rajendranagar	ICRISAT Center (Patancheru)
1st crop			
Rice variety IET8890		(Irrigated)	(Irrigated)
(120-d, 23 Jul-23 Oct)		5.2	3.4
2d crop			
Alternative 1		(Irrigated)	(Nonirrigated)
Groundnut	ICGS21 (110-d)	2.6	0.3
	ICGS11 (110-d)	2.7	0.5
Alternative 2			
Chickpea	ICCC37 (103-d)	0.8	0.9
	ICCC42 (103-d)	0.9	0.9
Alternative 3			
Pigeonpea	ICPL 270 (123-d)	1.2	0.8
	ICPL 161 (123-d)	0.9	0.9
Alternative 4			
Sorghum	ICSV 1 (110-d)	2.6	3.2
	ICSH 153 (118-d)	2.6	2.9

[a]Rice was harvested on 23 Oct 1986. The 2d crops of groundnut, pigeonpea, chickpea, and sorghum were sown on 13 Nov and irrigated on 14 Nov. A basal dose of 18 kg N and 18 kg P/ha was applied to all plots at sowing, but no fertilizer wasgiven later to the legume crops; sorghum received a topdressing of 62 kg N/ha

As Table 5 shows, a good crop of rice was harvested at Rajendranagar, and about 2-5 t groundnut or sorghum/ ha was harvested with irrigation. At ICRISAT Center, without irrigation, the yield of groundnut was poor, but that of sorghum was good, about 3 t/ ha. In our experience, legume yields were lower after a rice crop than after a nonrice crop. Yield-reducing factors were a) absence of a fine seedbed, and b) drought stress for the legumes, particularly for groundnut, at Patancheru. Yields of all crops except sorghum were low; only sorghum was able to withstand the stress and give reasonably good yields. However, at Rajendranagar, where seedbed preparation was better and all legumes following rice were irrigated, legume yields were higher, but still not as good as yields generally obtained following a nonrice crop.

These data also show that any delay in seedbed preparation and sowing of groundnut after rice on Vertisols seriously reduces yields. In 1985 at Patancheru, a 3-wk interval between harvesting of rice and seedbed preparation for the postrainy-season crop severely reduced germination and affected yield of legumes. In 1986 we were able to reduce the turnover time, which has resulted in excellent crops of groundnut, pigeonpea, chickpea, and sorghum, though these are not mature yet. This system has markedly reduced the demand for irrigation water and fertilizers and better restores soil fertility. It is also more remunerative, as the price of grain legumes is two to three times that of rice. Thus with better soil management and use of new improved varieties of grain legumes, the farmer should be able to diversify rice-based cropping systems profitably.

Growing legumes after rice offers far more challenges than after any other crop. One problem arises because of puddling and continuous submergence of rice soil. The soil after the rice harvest becomes hard and compacted, with poor drainage. Moreover, the shift from submerged to upland conditions brings about significant changes in soil reaction and nutrient availability. particularly of phosphorus (P), iron (Fe), manganese (Mn), and zinc (Zn). Hence, application of fertilizers becomes essential for obtaining good yields of upland crops following rice. Generally, sorghum, mungbean, soybean, urd bean, and cowpea can tolerate a wide range of soil physical conditions, but groundnut cannot.

New possibilities with grain legumes

Grain legumes are the least researched and most neglected crops in agriculture. However, growing demand for vegetable proteins for balanced nutrition, particularly in developing countries, and increasing awareness of the need to diversify agriculture have aroused interest in grain legumes.

Crop improvement research on groundnut, pigeonpea, and chickpea at ICRISAT; on lentils, faba beans, and kabuli chickpea at the International Center for Agricultural Research in the Dry Areas (ICARDA); beans at the Centro lnternacional de Agricultura Tropical (CIAT); and mungbean at the Asian Vegetable Research and Development Center (AVRDC) have opened new vistas for improved cropping systems that include these crops. The choice of crop depends on adaptation, yield potential, stability, consumers' preference, and economic value.

With the availability of short-duration and high-yielding varieties of pigeonpea, groundnut, and mungbean, intensive cropping, raising three crops a year under irrigation, is possible.

The short-duration and dwarf varieties of pigeonpea, such as ICPL151, ICPL187, and ICPL317, can be planted in spring or summer with irrigation, or as a rainy-season or postrainy-season crop in a sequential system such as pigeonpea - wheat or rice - pigeonpea. In fact, the pigeonpea - wheat sequence has become familiar in the wheat belt of northern India. The medium-duration and wilt-resistant varieties of pigeonpea, such as ICPL270, ICPL295, and ICPL8863, are even better suited to intercropping with upland rice.

Chickpea varieties, such as ICCC14 and ICCC41 and NEC989, are suited to late planting and in rice fallows after late rice.

In groundnut, early-maturing 80- to 90-d varieties such as ICGE nos. 21, 30, 52, 56, and 61 are promising crops for growing before or after rice. These varieties are also suited to a rice - potato - groundnut system.

Problems affecting efficiency of cropping systems

Sowing date and plant establishment

The ability of seed to germinate and establish when the topsoil is drying out becomes a major difficulty when seed is sown on residual soil moisture or when the onset of the rainy season is unreliable. Deep sowing is an obvious way to reduce the effect of early moisture deficiency, but seedling emergence and subsequent vigor depend on seed size and genotype. In India, chickpea is generally grown on conserved moisture; yields are therefore low, because of poor germination and poor crop stand. Even one irrigation on sowing can make a significant difference in yield. This is important for rice-based cropping systems, where the soil profile may be full of water but the surface soil is usually dry, which affects postrainy-season crop establishment.

Sometimes, farmers broadcast the seed for the next crop in the standing rice crop. This system also does not establish intimate contact of seed with moist layers in the soil profile. Thus, suitable seeding implements are necessary for such relay cropping. However, for crops like berseem, shallow seeding or watering immediately after seeding is quite effective.

Land preparation

Good land preparation is a prerequisite for good crop establishment and yield. In the rice - groundnut system, one cause of poor groundnut yields is poor seedbed preparation. Another problem of rice fallows is lack of land leveling and consequent poor drainage, as small depressions occur where water stagnates, resulting in unequal moisture distribution to the crop.

Seed quality and seeding rates

Low seed viability causes poor germination, hence poor yields. Low seeding rates lead to low population density, again causing poor yields.

Fertilizer and pesticide inputs

Fertilizers, insecticides, fungicides, and herbicides are costly inputs. Often, farmers either neglect them or use them at the wrong times and in the wrong amounts. For instance, insecticide is often used when the farmer can see the insect with the naked eye or when the insect population has become noticeable, but by then the insect may already be past the most vulnerable stage, and considerable crop damage may already have occurred. Likewise, fungicides or herbicides are often applied too late to be of any use, as the damage is already done by the time disease symptoms or weed growth become clearly evident.

The problem of fertilizer use in legumes is even more serious. Legumes need more P, calcium (Ca), and sulfur (S) than cereals, but farmers are not accustomed to using these nutrients and hence fail to attain the full potential of the crop. For example, in groundnut, lack of Ca and S at the pegging stage may seriously reduce yield. This is an important factor to consider in a rice - groundnut system. Deficiency of P and Fe may also become more manifest in groundnut following rice than following any upland crop.

Postharvest management

The quality of groundnut deteriorates rapidly from postharvest negligence. Aflatoxins and pod rot diseases of groundnut make the produce unfit for human consumption, affecting returns to the producer. ICRISAT has developed some lines resistant to aflatoxin, and their use, combined with careful postharvest treatment and storage can reduce the damage. Biotechnology may offer some possibilities of incorporating resistance to aflatoxins.

New directions in rice-based cropping systems

Rice - rice system

The demand for rice is no doubt increasing, but with improved technology the production is increasing faster and many rice-growing countries are faced with a problem of surpluses, which hit the producers hard. Thus in any strategy for agriculture in the future, increasing the productivity of the whole system should be emphasized more than increasing the number of rice crops in the system.

Improving efficiency of inputs

Rice is more wasteful of water and fertilizer than any other crop; therefore it is essential that in an intensive cropping system, crops requiring less water and fertilizer should be introduced to minimize the inputs required and improve the efficiency of those used. Diversification of crops is more desirable for the economy of the system, rational utilization of resources, and health of the soil.

Rice - wheat system

In many countries, rice - wheat or two-cereal cropping systems are becoming popular. Short-term gains from such a system may be attractive, but in the long run this practice will be harmful. A 10-t yield of a rice - wheat system removes 350 kg N, 60 kg P, and 300 kg K from the soil. It exhausts the soil resources of nutrients rapidly, necessitating greater use of fertilizer. On the other hand, inclusion of legumes or crops that restore soil fertility, such as a green manure (45-d crop of sesbania), a forage, or agrain-producing crop (e.g., pigeonpea, chickpea, mungbean, lentil, soybean) in the rice-based cropping system will be beneficial in the long run. However, more efficient use of short-duration, high-yielding cultivars and good management are needed to obtain best results.

Rice - legume or rice - oilseed systems

Modern research has developed high-yielding and shorter duration varieties of many legumes, which can fit into a rice-based system—as sequential crops, before or after rice, as intercrops, or as alley crops. Oilseed crops such as rapeseed, mustard, sunflower, and safflower, can also be profitably fitted into the rice-based system; soybean and groundnut are both fertility-restoring legumes and valuable oilseed crops. Many high-yielding oilseed varieties are now available for use in new cropping systems.

Soil and water management

The change from submerged soil cropping with rice to upland cropping presents problems of tillage, drainage, soil fertility, and timely planting operations. Likewise, the irrigation system suited to rice is not suited to upland crops. Most cereals are more damaged by overirrigation and untimely irrigation than by underirrigation.

Pest management

Introduction of crops other than rice also helps break the disease and pest cycle of continuous rice. We have observed that intercropping of sorghum with pigeonpea reduced wilt incidence in pigeonpea. Similar advantages are available from rotation of other crops, and use of pest-resistant varieties makes the job a little easier.

Using crop modeling

Rice-based cropping systems in rice-growing countries like Egypt should aim at maximizing returns to the farmer through efficient use of water, fertilizer, pesticide, and labor. Though Egyptian agriculture is primarily irrigated, possible water shortages in the future, and problems of waterlogging and salinity make it imperative to use inputs wisely. Good progress has been made in crop modeling to determine the best mix of crops and the best timing for use of inputs. Evaluation of such programs needs consideration in devising new and productive cropping systems.

New directions in Vertisols management

Since Vertisols occupy more than 50% of the cultivated land area in Egypt and cover a significant land area in SSA, discussion of new directions in their management is relevant here. Vertisols and vertic soils occur in diverse agroecological environments in Africa and are used for a variety of purposes. The Torrerts-Vertisols of the arid areas are generally under natural grassland and associated vegetation and are used for extensive agriculture, mainly cattle raising. Where irrigated, these soils are highly productive, and are used to raise a variety of tropical crops.

The management of irrigated Vertisols, however, poses many problems, as inefficient water management makes them waterlogged and saline. In Sudan and Egypt, torric Vertisols are used mainly for growing cotton. In the semiarid areas of Africa with ustic moisture regimes, Vertisols and vertic soils are sometimes used for raising crops such as sorghum, millet, and maize in the uplands, and rice, teff, etc., in the lowlands. In some areas of southern Africa, wheat is also grown on these soils. However, in most instances, the intensity of cultivation is very low. The most common land-use pattern currently is pasture-livestock production systems.

We have calculated the length of the crop-growing season for a few locations of Vertisols in Africa to illustrate their agroecological potential (Kanwar and Virmani 1986). We have also included the data for ICRISAT Center, Patancheru, India, for comparison. The data (Fig. 4) show that except for the torric Vertisols, the Usterts and Uderts have a crop growing season of 130-240 d. The thermal environment of the locations studied is also suitable for growing tropical and subtropical crops.

Under soil and climatic conditions that are somewhat similar to those found in Africa, ICRISAT has shown that through scientific management of Vertisols and vertic soils in the semiarid environment, sustained and high production is possible in dryland farming. We believe, based on the experience gained at ICRISAT, that similar methods can be used on the Vertisols and vertic soils of Africa and their agricultural production significantly increased.

ICRISAT has now assembled a technology for improved management of Vertisols suitable for the semiarid tropics. A detailed explanation of the technology may be found in the papers by Kanwar et al (1982), Ryan et al (1982), and Virmani et al (1985). It facilitates growing of two crops, one in the rainy season and a second in

Soil	Location, country	Growing conditions	Month												Annual
			1	2	3	4	5	6	7	8	9	10	11	12	
Torrerts	Khartoum, Sudan	Rainfall (mm)	0	0	0	1	5	7	48	72	27	4	0	0	164
		Temperature (°C)	22	24	27	31	33	33	31	29	31	31	27	24	29
		Growing period	Undefined -- July - September												
Usterts	Maiduguri, Nigeria	Rainfall (mm)	0	0.3	1	4	34	78	180	227	112	23	0.3	0	659
		Temperature (°C)	22	24	29	31	32	30	27	26	27	28	25	22	27
		Growing period													135
Usterts	Moundou, Chad	Rainfall (mm)	0	<0.3	2	40	118	171	244	303	250	96	4	0	1228
		Temperature (°C)	25	27	30	31	29	27	26	25	25	27	27	25	27
		Growing period													210
Uderts	Addis Ababa, Ethiopia	Rainfall (mm)	24	25	68	93	50	105	228	263	174	41	3	15	1089
		Temperature (°C)	16	18	19	19	20	18	15	15	15	15	15	15	17
		Growing period													240
Usterts	Hyderabad, India	Rainfall (mm)	2	11	13	24	30	107	105	147	163	71	25	6	704
		Temperature (°C)	21	24	27	30	34	29	26	26	26	25	23	21	26
		Growing period													210

4. Rainfall, temperature, and length of growing seasons at some selected sites in Vertisol areas of Africa and in Hyderabad, India (Kanwar and Virmani 1986).

the postrainy season, or growing an intercrop of a cereal and legume or two legumes. Adoption of this improved Vertisols management technology has considerably increased crop production. Where the traditional system has yielded about 0.5 t/ha of sorghum or chickpea, the two-crop combination has consistently yielded a total of some 3 t/ha under the improved system at ICRISAT during the past 9 yr of experimentation (Table 6). Further, in the vertic soils, several intercrop combinations, e.g., sorghum + pigeonpea or millet + pigeonpea, have produced 2-3 t/ha when fertilized with 60-12-0 (medium level) N-P-K. The new system has also resulted in 1) a considerable reduction in soil erosion, 2) much higher in situ moisture conservation and, therefore, in a higher rainfall use efficiency, and 3) much more dependable harvests year after year.

Components of improved Vertisols management

The technology for improved management of Vertisols is a framework consisting of several interrelated components, each of which offers several options. The components of this technology are efficient land and water management, dry season tillage, and dry seeding of crops just before the onset of the rainy season.

Land and water management. Improved land and water management practices are applied to alleviate constraints such as waterlogging, which arise from the physical properties of Vertisols. High rainfall intensity results in a high percentage of

Table 6. Grain yields under improved and traditional technologies on deep Vertisols[a] in 9 successive years, ICRISAT Center, Patancheru, Andhra Pradesh, India.

Year	Cropping period rainfall[b] (mm)	Grain yield (t/ha): Improved system: double crop – 1st crop: Sorghum or maize	Improved system: double crop – Second crop: Sequential chickpea or intercropped pigeonpea	Traditional system: single crop – Sorghum	or Chickpea
1976-77	708	3.2	0.7	0.4	0.5
1977-78	616	3.1	1.2	0.4	0.9
1978-79	1089	2.1	1.3	0.6	0.5
1979-80	715	2.3	1.2	0.5	0.5
1980-81	751	3.6	0.9	0.6	0.6
1981-82	1073	3.2	1.0	0.6	1.0
1982-83	667	3.3	1.1	0.6	1.2
1983-84	1045	3.1	1.8	0.8	0.5
1984-85	546	3.4	1.0	0.7	1.2
Mean	801	3.0	1.1	0.6	0.8
SD	209	0.5	0.3	0.1	0.3
CV (%)	26	16	25	24	42

[a]Available water-holding capacity of 180-cm-deep soil profile is 240 mm. [b]Average rainfall for Hyderabad (29 km from ICRISAT Center) based on 1981-84 data is 784 mm, with a CV of 27%.

runoff and, consequently, severe soil erosion. These soils, when wet, have very poor internal drainage. Under the improved system of management, microwatersheds of 3-15 ha are taken as units for management practices. Surface drainage is improved through drains and land smoothing. To improve in situ water conservation, the graded broadbed-and-furrow systems are laid out along the contour, 50 cm apart, with a 0.4-0.6% slope. The furrows lead into grassed waterways and finally into a dug tank or a drain (Fig. 5). This system facilitates soil moisture storage and controlled drainage of excess water; soil erosion is considerably reduced and water-use efficiency considerably increased (Table 7, 8).

Dry season tillage. Primary tillage to prepare a rough seedbed is best carried out soon after the harvest of the postrainy season or rainy season crops. Land should be harrowed whenever 20-25 mm of rain is received over a period of 1-2 d. When blade-harrowing is done, the clods shatter easily and a satisfactory seedbed is attained.

5. Layout of a small watershed in black soils.

Table 7. Grain yields of some cropping systems grown on vertic soils[a] under low (0-0-0 NPK) and medium (60-12-0 kg NPK/ha) fertility in operational scale experiments, ICRISAT Center, Patancheru, Andhra Pradesh, India (ICRISAT 1983, 1984).

Year	Cropping period rainfall (mm)	Soil fertility	Grain yield (t/ha)				
			Sole pigeonpea	Sorghum + pigeonpea intercrop	Millet + pigeonpea intercrop	Groundnut + pigeonpea intercrop	Sole sorghum
1981-82	1073	Low	0.7	0.9	1.2	1.4	0.5
		Medium	0.9	2.2	3.6	1.4	3.2
1982-83	667	Low	1.0	2.2	2.2	2.2	1.2
		Medium	1.2	4.3	3.2	2.9	2.9

[a]Available water-holding capacity of 50-cm-soil profile is 80 mm.

Table 8. Annual water balance and soil loss for traditional and improved technologies in Vertisol watersheds, ICRISAT Center, Patancheru, Andhra Pradesh, India, 1976-84.[a]

Farming systems technology	Water-balance component				
	Annual rainfall (mm)	Water used by crops (mm)	Water lost assurface runoff (mm)	Water lost asbare-soil evaporation and deep percolation (mm)	Soil loss (t/ha)
Improved system: double-cropped on broad-bed and furrows	904	602 (67)	130 (14)	172 (19)	1.5
Traditional system: single crop in postrainy season, and cultivation on flat	904	271 (30)	227 (25)	406 (45)	6.4

[a]Figures in parentheses are amounts of water used or lost, expressed as percentage of total rainfall.

Dry seeding before the onset of rains. We find that planting of crops in dry soil, just ahead of the rains, ensures early establishment and eliminates planting in a wet, sticky soil. We have noted that dry seeding is successful where the early season rainfall is fairly dependable and seeds are placed 7-10 cm deep. At ICRISAT Center, good stands were established by dry seeding of crops such as mungbean, sunflower, maize, sorghum, and pigeonpea (Fig. 6).

Improved cropping systems

Improved cropping systems provide a continuum of crop growth from the start of the rainy season until most of the available moisture is utilized by the crop. At ICRISAT we have found that this can be achieved by:

1. Intercropping of longduration crops (e.g., pigeonpea) with shortduration ones (e.g., maize, sorghum, soybean).
2. Sequential cropping, e.g., rice, sorghum, or maize, followed by chickpea or safflower.

6. One of the most successful intercrop combinations tested on Hatersheds by ICRISAT: one row pigeonpea: two rows maize on a 150-cm-wide bed.

Such cropping, however, requires management practices that may differ from the traditional farmer's. Proper fertilizer, pest, and weed management and efficient farm machinery are essential.

Fertility management. In the tropics, the management of soil fertility is essential to realizing the full potential of improved cropping systems. At ICRISAT Center we have found that, on Vertisols, management of soil and fertilizer N and application of P and Zn are also required. Our studies have shown that inclusion of legumes in the crop rotation or in intercrop systems has substantially reduced (by about 40 kg N/ ha) the fertilizer N needs of the succeeding cereal crop.

Efficient farm machinery. The improved Vertisols management system requires that all the operations be carried out in time and effectively. Since animal draft is the main source of energy available with small farm operators of semiarid areas in Asia and Africa, much of ICRISAT's work in farm machinery is related to animal-drawn equipment. We have found that the wheeled tool carrier (e.g., Tropicultor or Nikart) is most efficient for use on the Vertisols of India.

Appropriate crop management. The full potential of improved land and water management and cropping systems can only be realized with an appropriate set of crop management practices. Weed control, integrated pest management, placement of fertilizers at the appropriate depth and their application at critical stages of crop growth are some of the crop management factors that could lead to high and sustained yields.

Because most SAT soils are deficient in nutrients like N, P, and Zn, we get good responses to applied fertilizer, when it is applied in the right doses at the right time, by an appropriate method. Kanwar and Rego (1983) have outlined appropriate techniques for the rainfed Vertisols of India.

Synergistic effect of improved technology

One important aspect of the improved Vertisols technology is that the synergistic effect of the various components when applied together far exceeds the effect of individual components, as 10 yr of watershed-based experimental results from ICRISAT have conclusively shown. Kanwar and Rego (1983) and Kanwar et a1 (1984) noted that, though the contribution of fertilizers was highest, yield response was markedly higher when the fertilizer was applied in combination with other improved land and water management and agronomic practices. This observation has great relevance in the African context, where fertilizers are costly and, in most instances, have to be imported.

Adopting suitable cropping systems can thus bring a manifold increase in production, at the same time. considerably reducing erosion of soils and loss of water on Vertisols, which occupy large areas of Egypt and sub-Saharan Africa.

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Agroeconomic opportunities in rice-based farming systems research

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A farming systems research (FSR) perspective offers potential to increase the productivity of high-yielding agriculture as found in Egypt. FSR has a strong farmer focus, has an interdisciplinary problem-solving orientation, and promotes linkages between farmers and researchers in the identification and solution of problems. Profits may be increased as higher-yielding varieties are developed, but cost-efficient methods to increase and sustain rice incomesdeserve particular attention. Cropdiversification, livestock, and greater use of rice biomass also provide farming systems researchers with opportunities to increase farm incomes in rice-based systems. Efficient use of technology is information-dependent. This implies that farmers should be provided with alternatives and the knowledge to make the choices that best meet their needs and circumstances, and so a re-orientation of extension from a package of practices approach. Prices are important determinants of farmers' technology choice and, in turn, adaptive research priorities. It is time for FSR economists to incorporate a stronger policy perspective in their work.

The adoption of innovative techniques in crop and livestock production has resulted in rapid growth in agricultural productivity in favorable areas of Asia, North Africa, and Latin America over the past 20 yr. The adoption of modern rice and wheat varieties and investment in complementary inputs (such as irrigation and fertilizer) contributed to these gains. These spectacular gains in productivity have been demonstrated in the irrigated rice tracts of Egypt, the rice environment of particular concern to this Symposium. This environment is typified by widespread adoption of modem, high-quality rice varieties (and also wheat and cotton) grown under irrigation, with moderate to high levels of fertilizer and cropping intensity. Solar radiation is among the highest of the world's rice tracts (Budyko 1974). Not surprisingly, average farm yields of rice, nearly 6 t/ha, and of wheat and cotton, are among the highest in the world (Table 1).

Rice-based farming systems of the type found in Egypt exist in Pakistan and the Indian Punjab, while similar environments, at least in terms of varieties, solar radiation, and irrigation, are found in the rice tracts of Australia, California, and Spain. Similar conditions—shouldthere be plentiful and controlled supplies of water—also exist in the Middle East and in some parts of sub-Saharan Africa, as the

Table 1. Yields of rice, wheat, and cotton in 10 rice-growing nations with the highest rice yields, 1983-84[a] (FAO, 1986).

Country	Yield (t/ha)		
	Rice	Wheat	Cotton
WORLD	3.20	2.21	1.45
Korea, Democratic People's Republic	6.65	3.33	0.80
Korea, Republic of	6.34	3.53	1.10
Australia	6.21	1.54	3.41
Japan	6.11	3.32	–
Italy	5.60	2.83	0.35
USA	5.60	2.59	1.72
Egypt	5.53	3.68	2.66
Colombia	5.05	1.61	1.74
China	5.27	2.91	2.39
Peru	4.15	–	0.95

[a]Yields are means of 3-year period, 1983-85, countries producing more than 100, 000 ha of rice.

Upper Niger and Lake Chad Basin. Whether or not it is profitable to develop these areas for rice culture is another matter.

The focus of this paper is on farming systems research (FSR) in extremely favorable rice environments—where modern rice technology has already been widely adopted. The issue is not one of technology design or transfer to traditional or transitional farmers, but rather about small farmers already using "modern" inputs, who are closely tied to the market, and continually striving to adjust to changing and complex technical and economic environments. These circumstances are not the traditional domain of FSR, where transfer of technology models have worked well—as attested by the high national yields in Egypt. An important issue, therefore, is whether an FSR perspective can contribute to productivity increases more efficiently than research programs adopting more traditional commodity- and discipline-oriented approaches to research and development.

The organization of this paper is as follows. First, characteristics of FSR as an approach to adaptive research are examined. Second, opportunities for increasing and sustaining farm incomes through a) increasing efficiency, b) reducing input costs, c) crop diversification, and d) improved biomass utilization are examined. Implications for technology transfer are considered in the next, while in the final section, we argue that a greater FSR policy perspective is required, as policies are an important determinant of farmer's technology choice.

Focus of farming systems research

Agricultural research is often classified into a) basic and strategic research, designed to improve the understanding of physical and biological processes; b) applied research, which seeks to discover new inputs or component technologies; and c) adaptive research to adjust technology to the particular needs and circumstances of target farmer groups. FSR focuses on adaptive research wherein an interdisciplinary, problem-solving focus is mandatory; while more "upstream" research tends to have a larger disciplinary content. FSR and disciplinary focused research are not substitutes for each other: they are complements. Disciplinary research provides the building blocks for adaptive FSR, while FSR provides the perspective to identify priority problems that require sharply focused, disciplinary research in laboratories and on research stations, for solution.

The characteristics of FSR that tend to distinguish it from traditional research methods are that it

- has a strong farmer focus;
- has a problem-solving orientation;
- encourages an interdisciplinary perspective in problem identification and solution; and
- promotes an iterative flow and feedback of information between farmers, extension workers, researchers and policy analysts.

An important concept of an FSR approach is that explicit efforts are made to understand the complexity of interactions characteristic of small farmer systems as a basis for planning research, and to involve the farmer as a participant in the research process. A second important point is that the objective of FSR is to devise technology that will solve problems to improve the welfare of the farm household on a sustained basis. That is, increasing crop yields, per se, is not an end of itself. A third important point is that FSR provides a formal mechanism to identify priorities for laboratory and on-station research, and insights into the nature of policies and programs will promote the adoption of desirable technology.

A number of scientists (e.g., Fresco 1984, Gilbert et al 1980, Shaner et al 1982, Simmonds 1984, Zandstra et al 1981) discuss the concepts, models, and implementation of research with a farming systems perspective. But, in practice, the inclusion of the farmer as the central component of FSR has often been lacking. Innovative perspectives by Chambers (1983), Rhoades and Booth (1982), and Richards (1985), among others, provide insights to approaches that include the farmer more effectively in FSR.

The problem-solving orientation and the study of crops and livestock within a farming systems context increase the necessity for a cross-disciplinary approach to FSR—because most farm problems are complex and their solutions transcend disciplinary boundaries. That is, to be effective, FSR should be interdisciplinary in structure and implementation. While most would agree that this should be so, in practice the conduct of interdisciplinary research is not without its challenges (Flinn and Denning 1982). Administrative and departmental structures frequently promote a disciplinary focus; and the evaluation and rewards system often favors disciplinary research. Other difficulties frequently relate to team leadership and management, and the willingness and ability of scientists of different disciplines to work together towards a common goal on a common problem.

Clearly, a challenge for research management is to facilitate and encourage truly interdisciplinary FSR. This requires a willingness to invest in professional training to provide scientists with a holistic systems perspective to research to complement disciplinary oriented training (Dillon 1976). A major constraint to the provision of this perspective in tertiary education is that there are few universities that provide a broad education across disciplines and encourage a capacity and interest among students to integrate these disciplines within a systems perspective to solve real world farm problems.

Increasing and sustaining farm incomes

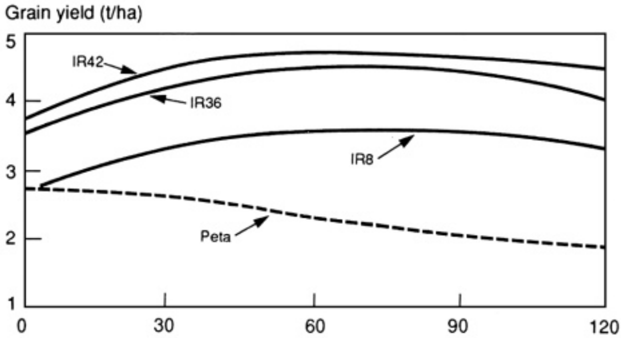
The implied research agenda of farmers may not parallel those of increasing and sustaining rice yields, a major concern of this workshop. The farmer's perspective may differ in several respects. First, farmers may be concerned with increasing and sustaining profits from rice production: that is, physical input-output relationships must be transformed to value terms. Second, they would consider many alternatives to increase farm incomes, given: a) the preferences and needs of the farm household; b) the farmer's resource base, including skills; and c) the farmer's expectations of existing and future market conditions. Third, the farmer would carefully consider the compromises implied between a) increased yields and increased profits within crops; and b) the trade-off if an increase in one enterprise reduced the profits earned from other components of the farming system.

Increased profits in rice production

Rice farmers increasingly face a cost-price squeeze; while rice prices have stagnated in many countries, the prices of the inputs that must be purchased to increase and sustain production have not fallen in a similar manner. Also, yield gains with recent innovations—given that farmers are already realizing high yields—will be less dramatic than when farmers shifted from the traditional to the first round of improved practices. In essence, price incentives are now less favorable, and anticipated yield gains less dramatic. Newer technology, while still profitable, is unlikely to provide the spectacular economic returns characteristic of the first round of modern variety (MV) rice technology. Thus, the successful adoption of new technology will be more sensitive than before to the efficiency with which farmers adopt it.

Increased returns. One of the major sources of yields and income gains in rice production has been the adoption of modern varieties, which give higher yields for the same levels of inputs as labor and fertilizer (e.g., Fig. 1). That is, modern varieties have dramatically increased the technical efficiency of inputs. However, farmers have benefited less than consumers from these productivity increases, because of falling real rice prices (Anderson et al 1986).

Nonetheless, what are the opportunities for yield gains in those areas that have already adopted modern rice technology, as in Egypt? Gains in yield potential using conventional breeding techniques may not be large in the near future—the yield potential of modern rices has not increased markedly since IR8 was released (Dalrymple 1986)—although crop duration has been markedly reduced, and resistance to pests and environmental stress and grain quality characteristics have been vastly improved. Even so, Khush (this volume) argues that the yield potential of



1. Effect of N level on grain yield of 4 rice varieties. Data represent the average for IRRI and 3 experiment stations of the Philippine Bureau of Plant Industry (Maligaya, Bicol, and Visayas), 1976-84 wet seasons. Source: IRRI Agronomy Department.

modern rice may be increased further, using conventional breeding techniques; the Chinese have conclusively demonstrated that yield gains in the order of 15% may be achieved with hybrid rices without additional inputs, in areas where farm yields are already high (He et al 1986).

An FSR perspective may help identify breeding objectives to develop varieties that more closely fit the farmer's needs. There are obvious opportunities to breed varieties that specifically fit the seasonal "niches" where the farmer grows rice. As in Egypt, for example, where transplanting dates deviate from the optimal for maximum rice yields, there may be merit in breeding and evaluating varieties specifically to fit current farming systems. Similarly, farmers may be willing to trade off mean rice yields for other characteristics such as straw for fodder, shorter duration, insensitivity of yield to seedling age at transplanting, and other facets of the rice crop that increase its overall benefit within the farmer's system.

One opportunity, therefore, is to increase yields and so profits by increasing the yield realized by farmers, given current technology. Some argue that the economically recoverable yield gap, given the farmer's circumstances, may be quite small (Herdt 1986). Byerlee (1986a) believes that this yield gap could be substantially reduced if farmers had better information about technology, which in practice is becoming quite complex, and if they had better access to markets. Farming systems researchers may play a central role in: (a) identifying the magnitude of the economically recoverable yield gap; (b) understanding the reasons leading to this yield gap and the resulting loss of profits; and (c) determining whether it can realistically be reduced. Such insights have important implications for planning research agendas and extension strategies, and for considering the impact of existing and alternative agricultural policies.

Profit stability. Farmers tend to be concerned with both the level and dependability or perceived riskiness of profits. The riskiness of a technology may be related to a combination of price and yield risk, or from uncertainty about the performance of a technology. Price risk may be dampened where governments purchase the crop at announced prices, as occurs, for example, with rice in Egypt and Pakistan. Production risk in irrigated environments, as found in Egypt, may be less of a concern than in semiarid environments, as for example, in sub-Saharan Africa or in India. Nonetheless, even in less environmentally risky sites, an FSR perspective provides insights to design technology that reduces the risk of profit loss, in particular; for example, by promoting crop and varietal diversification, and by providing greater flexibility in recommendations to permit farmers to respond better to the dynamics of the environment and the markets they face. Improved on-farm storage and policies such as crop insurance may be other ways to reduce production and income risk, and so influence the attractiveness of a technology from the farmer's viewpoint.

Reducing costs. Profits may be increased by increasing gross revenues, or by increasing cost efficiency, or both. Innovations that have increased the cost-effectiveness of rice technology in recent years include improved pest resistance of rice varieties (reduced dependence on pesticides), direct seeding, integrated pest management (IPM), selective herbicides, and increased efficiency of fertilizer use, both through breeding for more fertilizer efficient-varieties and by improving the methods of fertilizer application. Mechanization (for land preparation, reaping, threshing) has reduced cultivation, harvest, and postharvest costs in many situations. Many of these benefits have been realized by substituting capital (machines, chemicals) for labor, which is of concern from equity and social viewpoints if there are no alternative gainful employment opportunities open to the displaced labor.

Other options to reduce production costs are the substitution of farm-produced inputs for purchased inputs such as fertilizer and pesticides. Research on integrated nutrient management, including biological nitrogen fixation (BNF), was discussed earlier in this workshop (Session IV). Increasing the use of BNF as part of the fertility management strategy appears a good possibility where there is a direct economic return from the nutrient-fixing crop, or where the crop provides soil amendment not readily achieved by other methods, as with berseem clover. However, ifcropping intensity is high, as in Egypt, where there is strong competition for land use between cash crops and green manure, then green manuring may be a less attractive short run proposition, when the net return to land in its alternative use exceeds the net value of fertilizer nutrients, or the yield it substitutes.

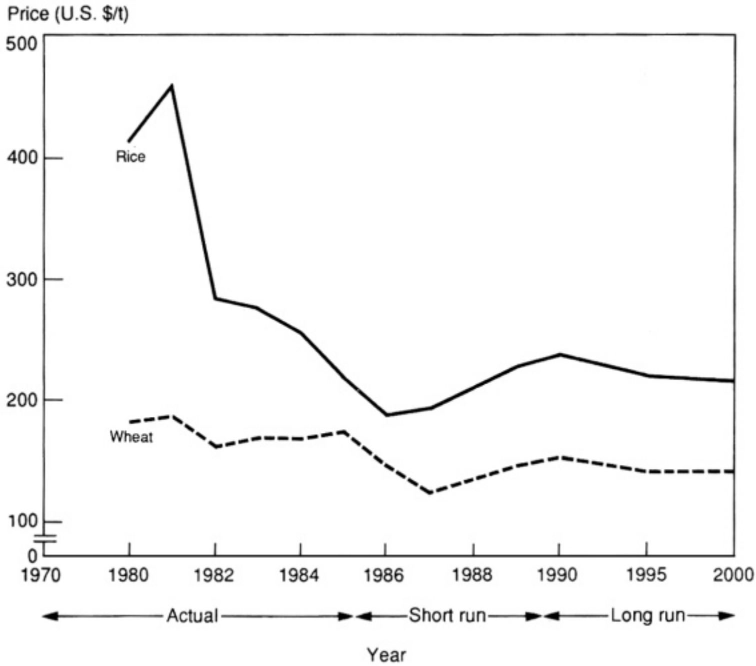
Sustaining profits. Government policies, and therefore prices, are an important determinant of whether the profitability of rice production will increase, remain stable, or fall. Irrespective of whether prices rise or fall, maintaining yields will remain as an important FSR objective, and has become of increasing concern as crop intensification places greater pressure on agricultural systems subject to pests and land degradation. This problem in particular applies to such highly pest-susceptible species as rice and cotton. For this reason, an increasing proportion of plant breeding research is now devoted to "maintenance research" to defend yield gains, primarily against breakdown of pest resistance (Plucknett and Smith 1986). A point of equal concern for FSR is the maintenance of soil fertility, whether this be due to problems of land degradation, salinity, toxicities, or nutrient imbalances.

Strategies to address these issues, as breeding for resistance to pests and stress conditions (e.g., salt tolerance), combined with the use of sustainable crop and land management practices, are discussed elsewhere in this workshop (see Sessions II and IV). But an FSR approach which pursues a mixed strategy of crop diversification and rotations, growing of stress-tolerant crops and varieties, and fertility and water management, will be more likely to develop management practices that reduce pest pressures and maintain or enhance soil fertility in intensively farmed irrigated lands.

Sustainability issues, because irrigated environments are well buffered, have not been a major research issue in many irrigated FSR programs. However, yield stagnation in irrigated areas has been observed (e.g., Johnson 1984) where there are no major yield limiting factors (for example, salinity as experienced in Egypt and the Punjab). Thus, this concern does present a particular challenge to farming systems researchers, requiring a consideration of the broader consequences and long-term implications of proposed technology, which demands a longer term research perspective than is current. It also implies an ex-ante assessment of what may be the long-term consequences of technological options being designed and tested. In many cases, it may also imply a change in perspective of FSR, from a farm level to a community or an irrigation command area level to solve problems requiring group action or institutional change to ameliorate existing and emerging problems in land use or water management.

Diversification. The World Bank predicts that the international price of rice, and other major cereals as typified by wheat or maize, will remain stagnant, at least in the short to medium term (Fig. 2). This is because production of basic cereals, such as rice, has increased more rapidly than has population, particularly in Asia, and because it is a concern of governments to maintain low prices for cereal staples to protect poor consumers. Low rice prices, should they continue, have several important implications for setting priorities for FSR and for the "upstream" strategic and applied research that provides the basis of FSR researchers' technology options. First, new opportunities must be sought to increase a) the incomes of rice farmers, and b) employment in rice-dependent regions. Expanding the production of other staples may do little to solve the problem (either through depressing the price of these crops or, if subsidized, increasing costs to government). Diversification into high-value crops such as vegetables, horticultural crops, and ornamentals, where market growth is predicted—through increased urbanization and higher incomes or through export potential—is a logical subject for investigation. Livestock, poultry, and fish are other commodities for which demand increases rapidly as incomes rise; they also offer opportunities for increasing the use of rice biomass as animal feed, or rice bran for fish food, as well as increasing employment.

Postharvest opportunities. Income derived from rice production may be increased by adoption of techniques to enhance the use and added value of rice by-products. In the present context, rice biomass includes polished grain, bran, hull, and straw. In Asia, the polished grain is used for human food and bran for animal feed; however, huge quantities of straw and hull go largely underutilized. Based on



2. Long-run estimates of global rice and wheat prices, constant 1985 prices.
Source: World Bank, Economic Analysis, Projection Department. Commodity Studies and Projects Division, 18 Aug 1986.

an estimated rice production of 2.3 million (FAO 1986), Egypt produces about 3.5 million t of straw, 460,000 million t of hull and 230,000 million t of bran each year from its rice crop.

In many parts of Southeast Asia—particularly where livestock is less important—most of the rice straw is burnt in the field. In South Asia, the most common uses of straw are as fuel, as a roughage for livestock, as livestock bedding, and as fertilizer-compost. There is a trade-off between yield and palatability: it appears that the palatability of rice straw may be increased, but with loss of lodging resistance and therefore loss of rice yields (Juliano 1985). Even so, the value of rice straw for animal feed can be improved by supplementation with grasses, legumes, and tree leaves, and by alkali digestion, and enrichment with urea and molasses (Ranjhan 1985). Ammonia treatment of straw is practiced commercially in Korea. Although the improved digestibility is less pronounced than with alkali treatment, the ammonia treatment appears to be more practical (Ranjhan 1985). Straw is also used in paper making, as a substrate for mushrooms, as a component raw material in biogas production, and as a raw material for manufacture of chipboards. Additionally, farmers in northern Asia have long used straw for rope-, bag-, and mat-making. Increasing the value added in rice production through the use of these by-products deserves careful study and adaptation of innovations to local conditions where relevant technologies are identified.

Rice hull is the major by-product of rice processing; rough rice is about 20% hull and 10% bran. Like straw, the rice hull is low in protein and digestible energy (Juliano 1985). It is sometimes used directly as fuel (e.g., for parboiling in Bangladesh) or as animal bedding, but is often considered as a waste material of little or no economic value. There is potential for enhancing the value of rice hull by using hull-ash as a cement in soil bricks and hollow blocks (FPRDI 1986a). Rice hulls also have potential for extraction of solar grade silicon for use in the manufacture of photovoltaic cells (Juliano 1985).

One of the most promising uses of rice hull is in the manufacture of charcoal briquettes. The technique, which has been demonstrated at IRRI, involves converting rice hull to char in a carbonizer, mixing with a binder (soil or cassava flour), and molding into a briquette (IRRI 1986). Rice hull briquettes have a low heating value and are therefore suitable for heating and drying operations that require temperatures below 100 °C (FPRDI 1986b). Physical compression of hulls into briquettes for fuel is practiced in parts of Korea.

Bran and polish are derived from the outer layers of the rice caryopsis during the milling process. Because of its high fat and protein content, bran has a high value as a concentrate for poultry, cattle, and pig feed. It is also widely used as a source of food for freshwater fish in Southeast Asia. The immediate extraction of oil allows the processing of edible oil. However, its lipase quickly hydrolyzes the lipids to free fatty acids (Juliano 1985). The latter quality bran oil is used in soap making.

Opportunities exist to improve postharvest management of the rice crop. These include techniques that can be directed to the farm level (such as improved on-farm drying and storage of rice, better straw and hull utilization) and others which require larger scale operations (e.g., silicon extraction from hulls, edible oil extraction from bran). The latter may require considerable capital investment, but could provide a market for previously low valued crop residues and by-products of small-scale rice production.

With the continued decline in income from rice grain production, these opportunities need to be included in FSR and development programs, which, to date, have tended to emphasize production and preharvest opportunities to increase farm incomes. IRRI's Prosperity Through Rice Project, supported by the Asian Development Bank, aims to demonstrate a wide range of opportunities for increasing income and employment in rice farming communities (Denning 1986). The inclusion of postharvest engineers and by-product utilization specialists in FSR teams is planned for the Prosperity Through Rice Outreach Component, which will undertake village-level projects in Bangladesh, Indonesia, Sri Lanka, and Thailand.

Employment generation. An issue of widespread concern in many developing countries—and certainly one worthy of far greater attention—is to increase the employment-generating capacity in the agricultural sector. This is of particular priority in developing countries where the majority of the population is agriculturally dependent. In these countries, which form most of the developing world. agriculturally dependent populations will continue to grow for some time to come, even if there is substantial growth in nonagricultural sectors (Johnston 1966).

Employment generation may be less of a concern in countries such as Egypt, which have or are experiencing a demographic transition and already have half or less of their population dependent on agriculture. In these cases there will be a strong pull to develop labor-substituting technology as, for example, has occurred in Japan and Korea (Hayami et al 1980). While this may be so. we would be remiss not to identify employment generation as a widespread equity and social concern of FSR in development.

Without doubt, the goal of employment generation—particularly among the poorest rural households, and particularly for such disadvantaged groups as women—is justified on both economic and equity grounds. When these two goals are not in conflict, the task of FS researchers is unambiguous. However, there often will be trade-offs between increased income and efficiency of agricultural producers, and employment generation. In such situations, FS researchers are less well equipped, at the margin, to define and defend strategies that are desirable on both equity and economic grounds. The FSR process in the future must be more closely attuned to social value systems, an area where social scientists and political scientists may provide important leadership and perceptions.

Technology transfer

The importance of an effective technology transfer program as an integral part of the FSR approach has been recognized (e.g., Denning 1985). Detailed treatment of this subject is beyond the scope of this paper. Nonetheless, points where a FSR perspective will contribute to improved recommendations for farmers are briefly discussed here.

Recommendations and options

In many cases, recommendations emerging from FSR are presented to farmers as recipes for crop production that do little justice to the complexity of most farm decisions (Gomez 1985). In reality, recommendations are at best guidelines for farmers to interpret and adapt to their individual needs and opportunities. A challenge for FSR is to develop recommendations that are more useful to farmers than prescriptions of what they “should” do. Such recommendations could

- provide the farmer options to choose from. rather than rigid technology prescriptions; and
- be flexible enough to permit farmers to adjust recommendations to their own conditions and to seasonal and market dynamics.

Options. Where new crops or cropping patterns are developed, it may be better to present farmers with a range of options—alternative management practices, crops, and cropping patterns—requiring different levels of investment, risk, and managerial skill. With a “cafeteria” approach that provides alternative recommendations, farmers can select, test, evaluate, and modify technological options to meet their own needs and capability.

An example of this approach is drawn from South Cotabato, Philippines. In the late 1970s and early 1980s, farmers there were exposed to several innovations, including dry seeding of rice, hybrid maize, soybean, and cotton. All these innovations have been promoted by extension at one time or another. Because of the soil type in the rainfed lowlands of that province, all four crops were agronomically feasible alternatives to the more traditionally grown crops—transplanted and wet seeded (puddled) rice and nonhybrid maize. Farmers' responses to these innovations over the past few years have shown that the decision to plant a given crop or sequence of crops varies across fields. farms, and seasons, depending on a complex array of biophysical and socioeconomic factors. Research has therefore served to increase substantially the number of options available to farmers in that area.

This approach is also a feature of IRRI's Prosperity Through Rice Project. which has assembled a range of technological options for improving postharvest crop management and enhancing use of rice biomass. No attempt is made to prescribe packages of technology for farmers; rather, the technologies are made available for farmers to test, evaluate, and adopt, if they meet the farmers' needs. This introduces scope for the farmer to innovate and to participate in the research and development process.

Conditional recommendations. Farmers' choice of management practices is strongly influenced by the state of their farms — whether this be land condition as influenced by previous crops or present or expected moisture status. pest levels, weather, resource base, and needs — and by market conditions. Therefore. it is advantageous to develop recommendations to suit the various conditions that farmers face (Byerlee 1986b). Recommendations may be designed to provide farmers alternatives with respect to conditions that are discrete or continuous in nature.

Recommendations conditional on discrete variables would include the choice of alternative fertilizer rates, depending on previous land use (e.g., for rice after berseem, or wheat, or mustard), or the application of an insecticide when an insect is present. Such conditional recommendations contrast with a recipe approach recommending a fixed fertilizer rate or a prophylactic application of pesticides.

More complex is the specification of recommendations for variables that are continuous in nature. The choice of fertilizer rates based on soil test values. or the application of pesticides based on threshold levels are examples of recommendations based on continuous variables. Goodell (1984) has described how complex conditional (in her example IPM) recommendations may be. Clearly, a challenge is to present this information in a manner which farmers can use. In many cases this will involve educating the farmer in the principles as well as the practices of modern rice technology. "A Farmer's Primer on Growing Rice," now translated into 7 languages, was specifically designed to meet this need (Vergara 1979).

Information gap. A challenge for FS researchers and extension agents is to generate and transmit information and techniques that will promote increased productivity and cost-effectiveness of rice technology. This need for information is becoming increasingly important as the added return per dollar or per unit of energy invested in new technology declines, due to the already high yield levels, and, in general. because of increasing real cost of inputs.

To make better choices, farmers require information that will help them understand new technology; they must also acquire new skills to enable them to use this technology efficiently. For example, understanding the nutrient composition of fertilizers, potential fertilizer carryover effects between crops, nutrient availability in wetland versus upland soils, and symptoms of nutrient deficiency, would materially help farmers adapt fertilizer recommendations to their own needs. Similarly, skills in calculating doses, identifying pests, and calibrating sprayers would materially increase farmers' technical efficiency in their application of new technology.

Yet, although many farmers have adopted modern rice technology, their understanding of the basic principles in rice production and crop management is still limited (Cabanilla and Hargrove 1987). That is, most farmers face a knowledge gap in the application of technology. Rice technology is changing quickly; it is becoming more complex, and the choice of appropriate strategies is more strongly influenced by market conditions. In consequence, extension must give more emphasis on the education of farmers, to permit them to make better decisions, than on extension's traditional role of communicating recommendations.

Farmers' input to recommendations. Elsewhere in this paper we have argued that FSR is farmer-focused; the same perspective is appropriate when developing and extending recommendations to farmers. This applies to the farmer's evaluation of proposed technology generated by the research process, as well as to the researcher's adaptation of farmer's practices.

An example of farmers' innovation contributing to technology development comes from the Centro Internacional de la Papa (CIP) research to develop improved and acceptable potato seed storage techniques (Rhoades and Booth 1982). In their model, the validity of research findings was judged by whether farmers were willing to test and use the technology at their own expense, in their own time. CIP's research in Peru and the Philippines showed that the introduced technique of seed storage was altered and refined by farmers. Rhoades and Booth argued that farmers are more likely to accept new technology if they have actively participated in the formulation of recommendations.

A similar concern of FSR teams is the identification of farmers' innovations which may be extended to other farmers. Farmers' innovations frequently include the development of indigenous technology or the modification of introduced technology (Richards 1985). Information from such sources contributes to the regular process of upgrading and fine-tuning extension messages for farmers.

In South Cotabato, Philippines, farmers were exposed to the use of the aquatic fern azolla, which, through a symbiotic relationship with blue-green algae, fixes atmospheric nitrogen and thus serves as a green manure for irrigated rice. Earlier recommendations were directed to introducing a rather complex production system involving substantial changes in existing farmers' practices. Farmers modified these recommendations to their present form, which requires little adjustment to farmers' current rice-production practices. Monitoring and evaluating azolla adoption and adaptation by farmers have made it possible to identify this farmer-modified system, which has now spread to other parts of the Philippines.

The implication is that extension workers should see themselves as partners in the development process, with a prime role of bringing relevant outside knowledge and skills for joint testing and evaluation with farmers. The extent of the extension workers' battery of innovations will depend on the amount, quality, and relevance of technology generation and adaptation activities (including FSR). Again, recognizing the farmers' interest and ability to experiment and improve innovations, it would be useful if extension workers focused less on "demonstrations," which imply a "proven" technology, and replaced the current use of "demonstration" plots with "joint-evaluation" plots. The emphasis with these "joint-evaluation'' plots would be to increase farmers' knowledge and access to an array of potentially useful technologies, rather than focus attention on one or two innovations believed by the extension service to be broadly appropriate.

Policy perspective in FSR

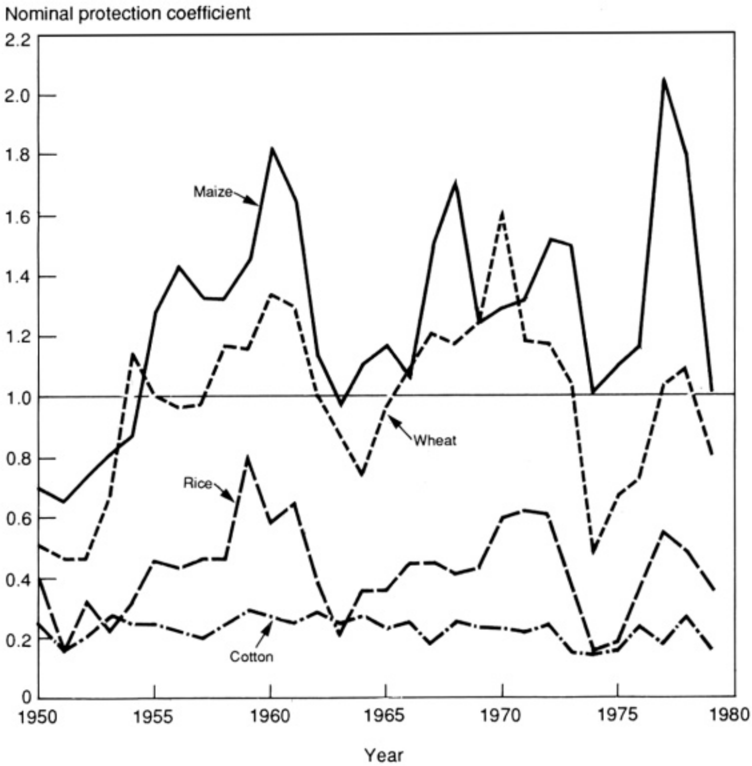
Most FSR groups have a strong micro-orientation, in the sense that constraints are identified and technology evaluated in terms of prices faced by farmers. This is appropriate, since these are the market signals to which farmers respond and which, in turn, help determine, along with comparative crop yields and input levels, whether or not a proposed technology will be adopted.

Market prices of important staples, such as rice, are often largely determined by government in their pursuit of economic or social policies which, they believe, cannot be met through free-market prices and unrestricted trade (Timmer 1975). For example, the price of rice in Egypt is set artificially low with respect to international ("border" prices, to meet a goal of providing adequate rice to all groups of the population, but particularly to those with low incomes (Fig. 3). The outcome is predictable—reduced incentives for farmers to produce rice, and low incentives to adopt productivity-increasing technology.

Alternatively, many governments subsidize agricultural production to increase supplies in the light of self-sufficiency goals, or to increase farmer incomes, or because of pressures from politically active groups. Wheat in Egypt is an example, where prices are above world prices to promote increased production (Scobie 1981). The Common Agricultural Policy of the EEC is an example of the third case, where prices have been kept artificially above international market levels leading to the well-known problems of agricultural surpluses in Europe.

Clearly, a micro-level analysis of government price policies with an FSR perspective provides key information to policymakers in evaluating the supply-side ramifications of agricultural policy options. Such analysis also helps identify changes in policy that would promote desired shifts in farmers' choice of technology (e.g., IPM versus current methods of crop protection), land allocation (e.g., rice versus maize or berseem), or input use (e.g., fertilizer rates), and therefore in crop yields. A holistic FSR approach also provides particular advantage in understanding how prices (policies) with respect to one farm enterprise influence constraints and technology acceptable for another crop or livestock enterprise. For example, Alderman and von Braun (1984) report that subsidies on red meat in Egypt artificially increases the profitability of berseem clover. This encourages farmers to cut a late berseem crop, which, in turn, delays rice transplanting and leads to reduced potential rice yields.

A complementary FSR policy-related area is to compare the financial profitability (using prices received by farmers) with the economic profitability (using border prices as determined by international trade) of existing and proposed



3. Ratio of domestic to world price (nominal protection coefficient) for rice and other major crops in Egypt (Scobie 1981).

technology. This helps identify technologies where the region or country has a comparative economic advantage, nationally or internationally. However, because of government policies, these technologies may not be financially attractive to farmers, and it is important to identify these situations. It is equally important to identify the converse—technologies that are financially profitable to farmers but not economically profitable from a national viewpoint. It is time that farming systems economists provide such interpretation of policy data to help the agronomic research process become more articulate in the policy arena.

In short, the policy environment that surrounds them and which, in the long run, helps determine opportunities for increases in farm income and production must be more explicitly incorporated in farming systems analysis. Three international agricultural research centers—The International Food Policy Research Institute (IFPRI), the International Center for Wheat and Maize Improvement (CIMMYT), and IRRI have initiated collaborative research to develop methods to improve the policy perspective in FSR.

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Wheat: a complementary crop for traditional rice-growing countries of Asia

G. Ortiz Ferrara, B. C. Curtis, D. A. Saunders, and P. R. Hobbs

Rice and wheat are the most important cereal crops in Asia. During 1985, this region produced 92% of the world's rice and 35% of the wheat. Wheat is not intended as a competitor to established crops in Asia; rather, due to its relative water-use efficiency, it is expected to complement rice crops in certain traditional rice-growing countries of the region. Rice - wheat rotation is practiced in temperate and subtropical Asia, including Bangladesh, Bhutan, Burma, China, India, Nepal, and Pakistan. During the last 15 yr, this cropping pattern has rapidly expanded to nontraditional rice - wheat areas, mainly due to the development of better agronomic practices; to the expansion of irrigation; and to the availability of rice and wheat varieties that are high-yielding, early-maturing, photoperiod-insensitive, and pest- resistant. Countries in Southeast Asia are especially interested in increasing wheat production. Two basic situations where wheat may be fitted into existing farming systems, without competing with other crops, are described.

Historically, food production has been increased by three general methods: expanding cultivated land area, raising yields of individual crops, and increasing cropping intensity.

Considerable increases in food production in South and Southeast Asia during the last 15 yr have resulted from higher yields on already cultivated land, which can be attributed to the application of scientific principles and new technologies. For example, the introduction of modern varieties of rice and wheat and the associated improved cultural practices have increased yields throughout tropical and subtropical Asia. However, the national average crop yields in most of these countries remain far below those obtainable with proper management; for example, rice yields in 8 South and Southeast Asian countries ranged from 1.9 to 3.1 t/ha in 1980 (FAO 1981). Herdt and Barker (1979) showed that these yields are much lower than rice yields that have already been obtained in these countries—2.7 t/ha in Thailand to 4.8 t/ha in Sri Lanka.

In most of tropical Asia, the potential for increasing cropping intensity is tremendous. Farmers can grow three to five crops per year on the same land, depending on crop growth duration and water availability. Bradfield (1971) considered it fortunate that most ill-nourished people live in the tropics, where food can be produced all year round. But he also observed that intensive techniques for increased food production have not been widely developed in the tropics. Although intensive cropping patterns have been adopted in several areas, the average cropping intensity in Asian countries is not generally high. It is highest in Taiwan (175%), Indonesia (161%), Malaysia (l58%), Bangladesh (l49%). and China (l45%) (Hoque 1984).

Considering the limited opportunity for expanding arable land area, increased food production must come from land already being cultivated (Chandler 1976) and, indeed, average percent increase per year of rice and wheat yields during the decade 1975-85 has come mainly from increases in yield per unit area (Table 1).

Rice and wheat are the most important cereal crops in Asia. During 1985, this region produced 435.8 million t of rice and 178.0 million t of wheat (FAO 1985). In tropical Asia, where wheat is not a commercial crop, national governments are now encouraging production of wheat, because of heavy imports for local consumption. Since 1960, countries such as Indonesia, the Philippines. Malaysia, South Korea, Sri Lanka, and Thailand have shown a remarkable growth in wheat imports (Table 2). Over a 10-yr period, 1975-85, the level of rice imports has remained unchanged. In two decades, the ratio of rice:wheat imports has switched from almost two to one in favor of rice to four to one in favor of wheat.

Traditionally, rice has been grown in temperate, subtropical, and tropical areas (Carangal 1985), under both rainfed (upland, lowland. and deep water) and irrigated

Table 1. Rice and wheat area, production, and yield in the world and in Asia, 1975-85 (FAO 1985).

	Rice			Wheat		
	1975	1985	Increase/yr (%)	1975	1985	Increase/yr (%)
			World			
Area (million ha)	140.6	146.0	0.4	227.3	231.6	0.2
Production (million t)	347.5	473.4	3.6	383.4	514.7	3.4
Yield (t/ha)	2.5	3.2	2.8	1.7	2.2	2.9
			Asia			
Area (million ha)	126.7	131.8	0.4	74.8	83.7	1.2
Production (million t)	316.0	435.8	3.8	105.9	178.0	6.8
Yield (t/ha)	2.5	3.3	3.2	1.4	2.1	5.0

Table 2. Wheat and rice imports of 5 rice-producing countries in Asia,[a] 1959-61 to 1982-84 (FAO Trade Yearbook, various years).

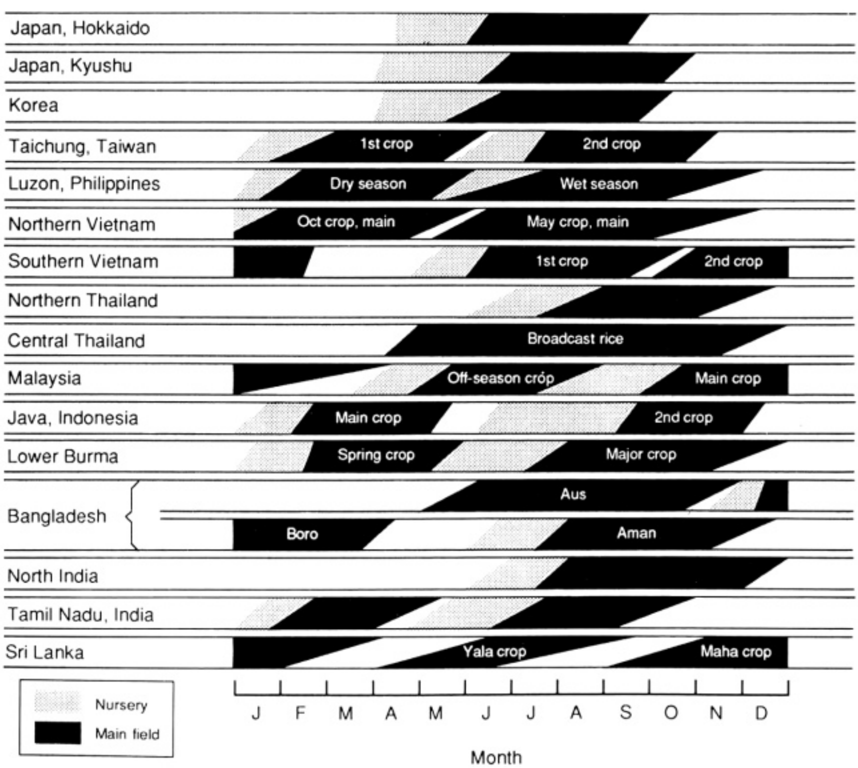
Crop	1969-61	1969-79	1978-80	1982-84
Wheat imports (million t)	1.1	3.7	4.9	11.2
Rice imports (million t)	1.9	2.4	2.6	2.6
Ratio of wheat/rice	0.6	1.5	1.9	4.3

[a]Indonesia, Malaysia, the Philippines, South Korea, Sri Lanka.

conditions (including partial irrigation). Figure 1 shows the diversity in timing and duration of rice crops at several locations throughout Asia (Barker and Herdt 1985). The exact dates of planting and harvest vary from year to year, depending on the environment and cultural practices. Varietal development can shorten or lengthen the crop duration and may even permit the cultivation of an additional crop under appropriate circumstances.

Except in the high-latitude countries, water availability is the principal factor determining when rice is planted. Because of the pronounced monsoon and dry season, even the two-crop locations (Fig. 1) usually produce a second crop of rice only where irrigation is available. In most places, cultivation begins in May or June with the onset of the main monsoon rains. The first crop is broadcast in parts of central Thailand, lower Burma, Vietnam, Bangladesh, and Sri Lanka, and transplanted in most other areas, during June, July, and August. Traditional varieties may need 4-5 mo to mature, while some modern varieties mature in 3 mo. The second rice crop is usually planted in November, December, or January, maturing before the hottest and driest months of April and May.

In Asia, wheat is mainly grown in subtropical and temperate countries, with irrigation, under lowland conditions. Wheat has also been cultivated for many years in small areas. and mainly at high altitudes, in Southeast Asia.



1. Seasonal duration of rice crops in Asia (Barker and Herdt 1985).

Rice - wheat cropping systems research

Rice - wheat rotation is practiced in South Asia mainly in Bangladesh, Burma, China, India, Nepal, and Pakistan. This cropping pattern represents approximately 17.7 million ha, or 28% of the cultivated wheat area of South and Southeast Asia (Table 3).

Wheat is not yet a commercial crop in Southeast Asia, but national programs are intensifying research because of increasing demand and heavy imports.

Collaborating with national programs, the International Rice Research Institute (IRRI) and the International Wheat and Maize Improvement Center (CIMMYT) are researching rice - wheat cropping systems in 14 countries: temperate (China and Korea), subtropical (Bangladesh, Bhutan, China, Nepal, and Pakistan), and tropical (Burma, Indonesia, Malaysia, the Philippines, Sri Lanka, Thailand, and Vietnam). The objectives of the collaboration are to 1) identify rice - wheat cropping systems technology that is suitable for small-scale farmers, 2) identify better combinations of rice and wheat varieties, 3) encourage rice and wheat scientists to work together to identify component technologies that will increase the production of rice - wheat systems, and 4) promote collaborative research in the network on problems common to the region (Carangal 1985).

One of these collaborative projects is the International Rice-Wheat Integrated Trial (IRWIT), which is a varietal evaluation trial of rice (from IRRI) and wheat (from CIMMYT). In IRWIT, entries are compared with varieties from national programs. There are two sets of trials for each crop, subdivided into three maturity classes: early, early and medium, and late. Results from IRWIT 1983-84 (Table 4) grown in one traditional wheat-producing country (Bangladesh) and two nontraditional ones (Thailand and the Philippines) indicate that the yield potential of wheat is higher in the traditional than in the nontraditional ones.

Although the wheat grain yield in the Philippines and Thailand was low, the improved varieties performed better than local varieties in terms of yield and maturity. While it is generally recognized that wheat yields equal to those in the traditional areas cannot be attained in nontraditional ones, wheat appears to be a viable alternative crop for some countries in Southeast Asia. Mann (1984) suggests

Table 3. Total wheat area and estimated percentage of wheat grown after rice in six of the major wheat-producing countries of Asia (Hobbs et al 1987).

Country	Total wheat area (thousand ha)	% wheat after rice	Wheat area after rice (thousand ha)
China	29,468	30	8,978
India	24,395	26	6,392
Pakistan	7,322	20	1,464
Bangladesh	526	85	447
Nepal	472	80	378
Burma	135	10	14
Total or av	62,318	28	17,673

Table 4. Yield and earliness of the highest yielding rice and wheat varieties in the International Rice-Wheat Integrated Trial, 1983-84.[a]

Country and site	Variety	Rice (EM/MM)		Wheat (EM)		Wheat (MM)	
		Yield (t/ha)	Days to flowering	Yield (t/ha)	Duration (d)	Yield (t/ha)	Duration (d)
Bangladesh (T)							
Jessore	Improved	5.7	75	3.33	98	3.81	112
	Local	5.2	84	3.19	96	3.97	109
Joydebpur	Improved	5.1	103	2.70	111	6.51	110
	Local	5.0	109	2.82	109	6.10	108
Thailand (NT)							
Muang	Improved	3.6	109	0.44	86	–	–
Prae	Local	3.5	114	0.30	79	–	–
Chieng Rai	Improved	1.3	103	–	–	1.40	88
	Local	1.1	110	–	–	1.20	87
Philippines (NT)							
Los Baños	Improved	4.1	78	1.89	76	1.02	80
	Local	4.2	80	1.80	90	0.67	93
Isabela	Improved	3.7	126	1.82	83	–	–
	Local	0.7	118	1.48	87	–	–

[a]Adapted from IRRI annual report 1984. Cropping Systems Program. T = traditional wheat-producing country (>1 million ton), NT = nontraditional wheat-producing country (<1 million ton), EM = early maturity; MM = medium maturity.

that low yields in tropical countries must be viewed in the context of earliness to maturity. Measured in production per day, a 100-d crop of 2 t/ha in the tropics corresponds to a 150-d crop of 3 t/ha in temperate zones. In many areas, this forced maturity is a major advantage of wheat, as it facilitates the growing of a second and, sometimes, even a third crop. However, most important for small farmers to know is that small management mistakes, which would normally cause minor yield reductions in temperate traditional wheat-growing climates, can lead to complete crop failures in the tropical nontraditional wheat-growing climates.

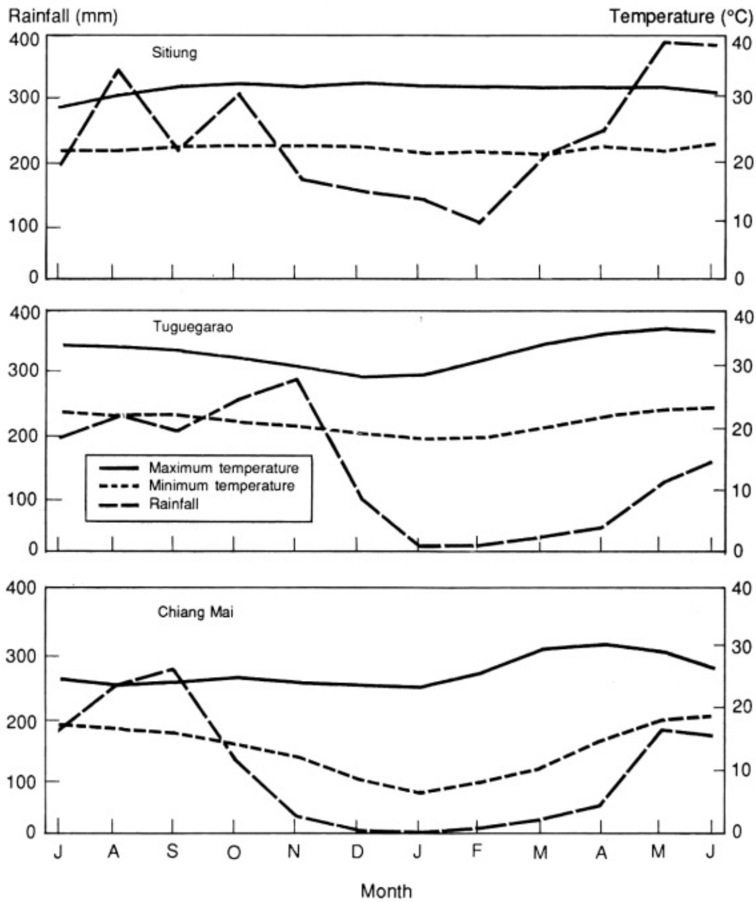
Potential rice - wheat cropping situations

There are two basic situations where wheat may be fitted into existing farming systems without competing with other crops.

On rainfed upland soils

Under dryland/ rainfed conditions on upland soils, irrigation will not normally be available, and the wheat crop must grow on residual moisture plus any subsequent rainfall. Crop water-use studies suggest that 350-400 mm of moisture under these conditions should produce a crop of 1.5-2.0 t/ha where disease pressure is not intense. Preliminary studies in Thailand (Norman 1982) suggest that soils with an available water capacity of at least 250 mm in the top 150 cm are required for this wheat production system. The period 5-15 d before spike emergence is most critical; drought stress at this stage affects grains per spike, and one of the primary factors in the final yield level obtained under rainfed conditions will be the ability of the soil to supply water during the first 50 d following seeding.

This system of wheat production is being researched in northern Thailand to follow upland rice or maize. Yields from sowing in mid-October in an average year have been up to 2.5 t/ha. Seeding date experiments in the past season have indicated that earlier seeding may be advantageous. If this production system is to be studied under Philippine conditions, the seeding date would have to be adjusted to avoid the heavy rains in November (Fig. 2) (Saunders and Mann 1985).



2. Three wheat target areas in Southeast Asia: Sitiung, Indonesia; Tuguegarao, Philippines; and Chiang Mai, Thailand (Saunders and Mann 1985).

On lowland soils, with partial irrigation

The other situation where wheat may fit without competing with other crops is on lowland soils, following rice, where some irrigation water is available, but not enough for another rice crop. Wheat, being more water-use efficient, may produce an economically viable crop under these conditions, although it is unlikely that the water available would be sufficient to allow the crop to be grown completely without stress. For example, experiments in northern Thailand have indicated that booting-anthesis stages were the most sensitive to drought stress (Table 5) (Rerkasem and Rerkasem 1984). Under Chiang Mai conditions, a yield of 2.4 t/ha is possible with just 2 irrigations during the first month of crop growth.

Rice - wheat research constraints

The technical problems associated with the adaptation and introduction of wheat in the rice - wheat cropping patterns of tropical Asia can generally be divided into two research areas: crop improvement and crop management. These problems are summarized in Tables 6 and 7. The existence of genetic variability for most of the breeding characters shown in Table 6—coupled with the availability of suitable screening methods—offers bright prospects for wheat production after rice, especially when better adapted, high-yielding, disease- and insect-resistant varieties currently under development become available to farmers.

Unfortunately, most of the agronomic management problems listed in Table 7 have been researched with wheat as the sole crop (i.e., following fallow), and little information is available on the effects of wheat in a double-cropping pattern with rice. More agronomic research on this cropping rotation is needed to identify the agronomic practices required to grow wheat successfully.

Some preliminary economics research in Thailand and in other Asian countries indicates that though wheat does not now compete with other alternative crops, wheat varieties better adapted to the environment and improved cultural practices,

Table 5. Yields of wheat (Inia 66) following deleted irrigation, Chiang Mai, Thailand (Rerkasem and Rerkasem 1984).

Growth stage of wheat when irrigation was deleted[a]	Grain yield (t/ha)
Crown root initiation (9 DE)	3.3
Tillering (28 DE)	3.3
Booting (48 DE)	3.0
Anthesis (63 DE)	2.8
Grain-filling (77 DE)	3.2
Anthesis and grain-filling	2.8
Booting, anthesis, and grain-filling	2.4
Full irrigation	3.2

[a]DE = days after emergence.

Table 6. Crop improvement problems associated with the adaptation of wheat in tropical countries of Asia and availability (+) of screening methods and genetic variation (Mann 1984).

Character	Genetic variability available	Screening method available
Early heat tolerance	+	+
Late heat tolerance	+	+
Earliness	++	+
Tolerance for late drought	+	+
Tolerance for acid soils	++	+
Resistance to		
Puccinia recondita	++	+
Helminthosporium spp.	+–	+–
Sclerotium rolfsii	–	–
Fusarium spp.	+	–
Xanthomonas campestris	+	+
Aphids, stem borers, armyworms	?	?

Table 7. Agronomic management problems associated with wheat in rice - wheat cropping patterns in tropical Asia.

Agronomic factor	Description
Crop establishment	Complex factor influenced by soil type, quality of land preparation, tillage implements, crop residues, and time
Planting date	Affected either by time needed for land preparation or delayed harvest of the rice crop
Soil type	Latosols, sandy, low-fertility soils, soils with micronutrient deficiencies, high acidity
Waterlogging	Hardpans from ricefields in a wheat - rice rotation, deficiency or nonavailability of nutrients
Seedbed preparation and tillage	Studies needed to evaluate cost, time needed, ability to handle residues, and best implements
Weed control	Appropriate herbicides not yet identified
Harvesting practices	Tendency of rice farmers to harvest wheat prematurely, seed losses resulting from stacking harvested material to dry
Seed production	Seed mixtures, inability of farmers to buy seed every year

could fit well into rice - wheat rotation systems and wheat could become a commercial crop in certain nontraditional rice - wheat areas of Asia. Such preliminary evaluations are encouraging indications that science can be put to work to make wheat a profitable crop in areas where it is not currently grown.

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Rice-based crop - livestock systems in Egypt

T. L. NORDBLOM

The principles and advantages of on-farm research in rainfed barley - livestock systems in Syria also hold true in more complex irrigated crop - livestock systems where rice is grown. Rice researchers need to evaluate new techniques from the farmer's viewpoint of whole-farm profits and constraints.

The primary focus of research at the International Center for Agricultural Research in the Dry Areas (ICARDA) is on rainfed agricultural systems in areas with dry summers and winter precipitation of 200-600 mm. ICARDA is a world center for improving barley, lentils, and faba beans, and a regional center for wheat, with the International Wheat and Maize Improvement Center (CIMMYT); chickpea, with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); and pasture and forage crops (ICARDA 1986).

One example of ICARDA's work is the research on barley - livestock farming systems, in collaboration with the Syrian Ministry of Agriculture and Agrarian Reform. This project has identified profitable packages of phosphate and nitrogen fertilizers with forage legumes to replace fallow in barley - fallow rotations, or to break continuous barley rotations, in areas with less than 300 mm annual precipitation.

Similar studies are to be planned for the near future, in collaboration with the Egyptian Agricultural Research Center (ARC), in the northwestern coastal area, where similar rainfed farming systems are found. This is mentioned here because some principles and research methods will also apply to the rice farming systems in the Nile Delta. Further, it is also known that sheep from the northwest coast are brought to the Delta for grazing crop residues for some months each year; this necessarily has some negative influence on feed supplies available to sedentary livestock in the Delta.

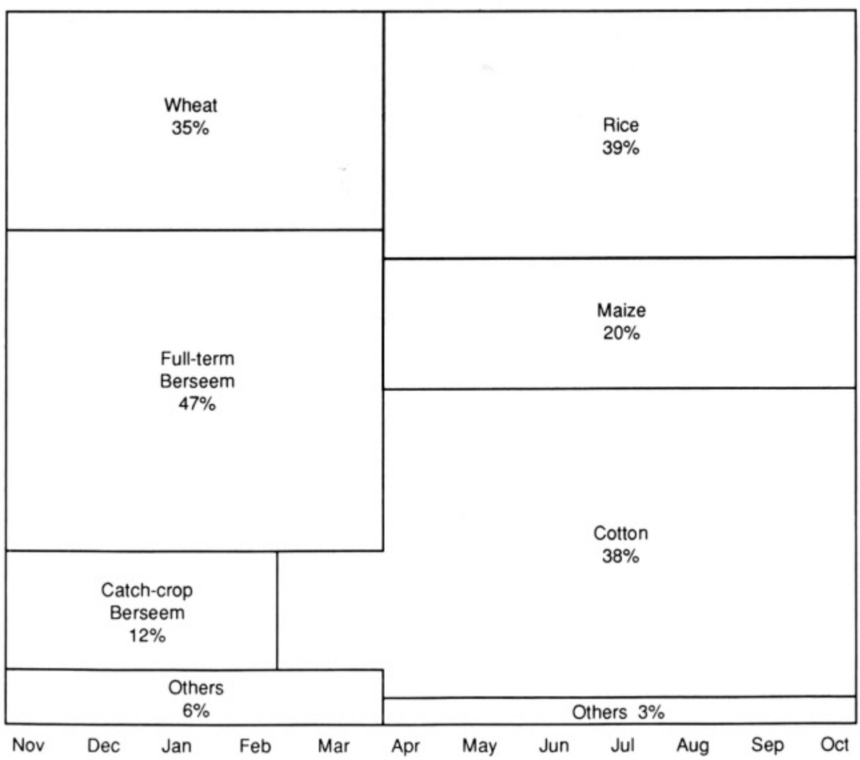
The work in Syria made full use of on-farm research, in collaboration with farmers. We acknowledge the pioneering work of the International Rice Research Institute (IRRI) in developing such on-farm techniques. We are confident that on-farm research will be a most valuable component of rice research in Egypt.

We find, even in the relatively simple rainfed barley systems, that one cannot understand or explain the crop management methods of farmers without reference to the requirements and roles of their livestock (sheep and goats). Likewise, one cannot understand practices of sheep husbandry in these areas without reference to the crops and native pasture (Nordblom and Thomson 1987). This is more true in the complex irrigated farming systems of the Nile Delta: virtually every rice farmer in this area is also a berseem farmer, a wheat farmer. a maize farmer, a faba bean farmer, and a livestock farmer.

Land-use patterns were described in a 1979 survey of villages west of Damanhour in Beheira Governorate (Fig. 1). The survey focused on livestock management in a way that allowed analysis of feeding options in a whole-farm context (Winrock 1980).

Rice was found to be a major land use (39%) in summer, following winter crops of wheat, full-term berseem, and, to a lesser extent, faba beans and other winter vegetables (Fig. 1). Maize and cotton are the other major summer crops. Only about one-third of the cotton is planted in March, as recommended for best yields. Two-thirds of the cotton was planted late by farmers, who preferred instead to have the extra cuttings of full-term berseem, a valuable livestock feed (Winrock 1980).

Crop residues are quite completely used as livestock feed, with the notable exceptions of rice straw and maize stalks, which are chiefly used as fuel. Rice straw in



1. Proportions of total land area devoted to specific crops. Winter crops Nov-Apr include faba beans and other vegetables, in addition to fruit trees. Source: 1979 survey of Zawiet Ghazal and Ezeb Kabeel villages, west of Damanhour, Beheira Governorate (Winrock 1980).

its raw form is less digestible by ruminant animals than wheat straw. However. several studies have been carried out on ways of improving the nutritive value of rice straw by combining it in diets with supplementary ingredients or by treating it chemically. Doyle et al (1986) have effectively reviewed a large body of literature on the subject, primarily from Asia. Other studies have been reviewed by El-Shazly et al (1983), Katagile et al (1981), ARNAB (1986), and Wanapat and Devendra (1985). On-farm trials on ammoniation of rice straw in the Nile Delta have been described by Yackout et al (1985).

No rice farmer can afford to disregard the physical and economic balances between the various crops and between the crops and the livestock. The farmer will certainly have these balances in mind when considering any proposed improvement in rice cropping. Therefore, rice scientists will have a great advantage in finding improved technologies if they take care to evaluate the various alternatives from the farmers' viewpoints. On-farm trials, evaluated in a whole-farm economic context, are convenient vehicles for reaching this goal.

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Relevance of the ICARDA Nile Valley Project on faba beans for rice-based cropping systems of Egypt

M. C. Saxena and A. M. Nassib

Faba bean *Vicia faba* L. is grown on about 116,000 ha annually in Egypt. On almost half this area, bean follows a rice crop, and this sequence affects the choice of variety and production practices for faba bean. The way the bean crop is managed in this rotation affects the overall productivity of the rice-based cropping system. The International Center for Agricultural Research in the Dry Areas (ICARDA), in collaboration with the national programs of Egypt and Sudan and with funding from the International Fund for Agricultural Development (IFAD), has operated an applied research project on faba bean improvement, the Nile Valley Project (NVP), since 1979. Ethiopia joined the NVP in 1985. Leadership and execution of the project rest with the national scientists; ICARDA plays mainly a catalytic role and backstops through logistic and technical assistance. The project emphasizes the on-farm trials, which involve researchers, farmers, and extension workers. The farmers of Egypt have obtained substantial economic gains by adopting the improved production technology that the NVP has introduced. Backup research has investigated special production practices for faba bean following rice. The model followed in the NVP could well be applied to achieve higher sustained production of rice in Egypt.

The International Center for Agricultural Research in the Dry Areas (ICARDA) was established in 1977 to undertake research and training relevant to the needs of developing countries, particularly in West Asia and North Africa. The Nile Valley countries—Egypt, Sudan, and Ethiopia—are an important part of this region. The Center has global responsibility for research on such crop commodities as barley, faba bean *Vicia faba,* and lentil *Lens culinaris,* and a regional responsibility, shared with other international agricultural research centers, for wheat and chickpea *Cicer arietinum.* Faba bean is an important component of the irrigated cropping systems of Egypt and Sudan, where it is a staple food for the masses. ICARDA, with its headquarters and principal research station at Tel Hadya near Aleppo (northern Syria), the heart of an important dryland agricultural region, could not adequately address the problems of irrigated faba bean. Accordingly, a project that could address these problems was established in 1979, with the backing of the Egyptian and Sudanese governments and funding from the International Fund for Agricultural Development (IFAD).

The Nile Valley Project

The overall objective of the ICARDA/IFAD Nile Valley Project (NVP) on Faba Bean has been to improve the productivity of faba bean in Egypt and Sudan through a cropping systems approach.

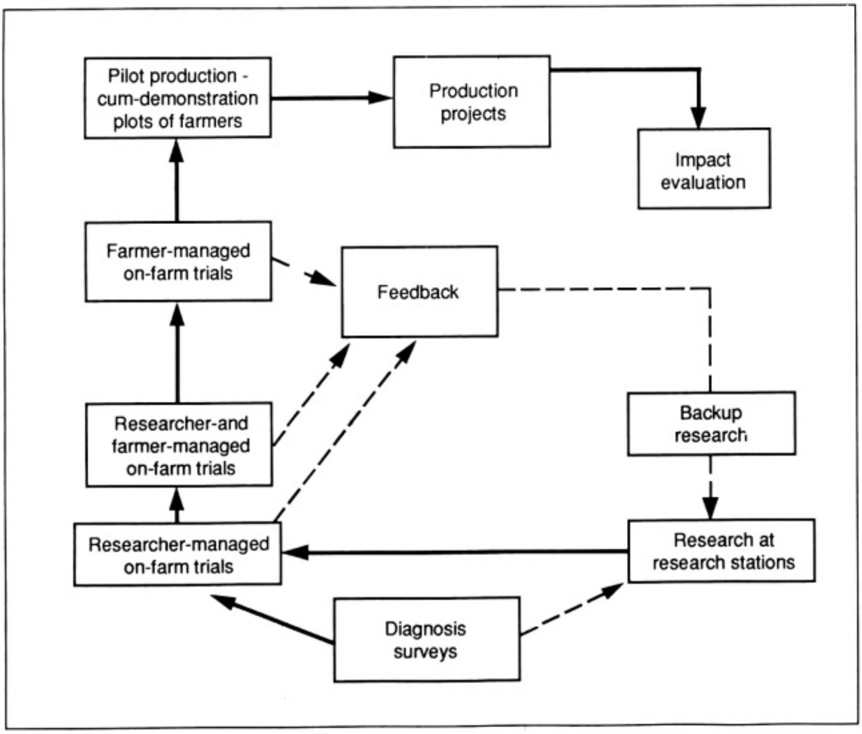
Project Strategy

The strategy of management and cooperation in the NVP has been a unique model of collaboration between the two national programs (Egypt and Sudan), an international center (ICARDA), and a donor agency (IFAD). The Project is a good example of cooperative research between a large number of national scientists, representing different disciplines and institutions, with direct participation of extension workers and farmers in on-farm trials and pilot production plots. The NVP is unlike most other international projects, in that the leadership, coordination, research, and extension activities have largely been the responsibility of the national workers (Hawtin et al 1984, ICARDA 1985). The key performers are the national scientists, working closely with their farmers, mainly through on-farm research to test and validate, under farmer's conditions, the genotypes and production technology developed at research stations.

As a research methodology, the project has used the procedures developed at the International Rice Research Institute (IRRI). Before the start of the project, detailed diagnostic surveys were made of the farming practices in Egypt and Sudan and the research work done by the national programs in these countries was thoroughly reviewed. Based on the information collected, yield gaps at farm level were quantified and on-farm trials developed to identify the factors responsible for the gap. At first, the trials were managed solely by the researchers but later increasingly involved farmers in joint researcher- and farmer-managed trials and solely farmer-managed trials and pilot demonstration plots. Early trials were complex, but were subsequently simplified, based on experience. Results of researcher-managed trials helped to develop simpler (but larger plot-size) trials, to be conducted jointly by farmers and researchers. Finally, the simplest trials (with still larger plot size) were managed entirely by farmers, though monitored by the researchers. This setup gave needed feedback for backup research at the experiment stations, in laboratories, or on-farm (Fig. 1).

Relevance of the NVP to rice cropping systems in Egypt

Faba bean is grown on about 116,000 ha annually in Egypt. The six governorates in the Delta area—Kafr El-Sheikh, Dakahlia, Beheira, Sharkia, Garbaiya, and Damietta—constitute a major region of faba bean production in Egypt, next only to that in Upper Egypt. It is estimated that almost half of the total area of faba bean grown in the country follows rice on deep Vertisols; thus, the productivity of rice in these areas is affected by the management of faba bean. Also a faba bean crop following rice requires management quite different from that required when it follows an upland crop such as cotton or maize. Because of these special effects, the NVP has carried out a series of on-farm trials on faba bean production in rice-based



1. Steps in the research methodology adopted in the Nile Valley Project.

cropping systems in the Delta area; these trials have shown that substantial yield and income increases (about 50%) could occur in this area if farmers were to adopt these practices (Saxena and Stewart 1983). The major components of the improved production package have been optimum plant population, fertilizer, and use of herbicide to control weeds and of fungicide to control chocolate spot (*Botrytis fabae*). In some areas, commercial varieties of faba bean are highly susceptible to the parasitic angiospermic weed *Orobanche* spp., which has virtually eliminated faba bean from the cropping system. However, use of a resistant cultivar (Giza 402, developed by NVP scientists) in combination with sublethal doses of glyphosate gave highly profitable increases in yield, and restored faba bean to the cropping system.

The rice-based system necessitated adjustments in the faba bean cropping calendar. Thus, backup research has investigated dates of sowing and harvest of faba bean, with genotypes adapted to these soil conditions, in relation to the economic returns and quality of the produce. Such information can be used for developing a total cropping schedule for the rice - faba bean rotation.

The high moisture content of the soil after the rice harvest hampers conventional tillage with a chisel plow; sowing of faba bean is therefore delayed well beyond optimum dates. Conventional tillage compacts the soil, leading to poor aeration and therefore poor faba bean growth. The NVP has therefore developed a system of minimum tillage, broadcast seeding faba bean immediately after the harvest of rice, and covering the seed by running a light rototiller that touches only the first 3 cm of soil. With this method, the crop can be planted within the optimum time, without soil compaction, and at much reduced cost because of saving in hand labor. On-farm trials of this practice are now under way in Kafr El-Sheikh Governorate.

Genotypes of faba bean differ in their adaptation to zero or minimum tillage; these differences are being evaluated, to identify superior genotypes that combine adaptation to the rice soil environment with high yield and resistance to chocolate spot and rust. Attempts are also being made to introduce resistance to *Orobanche* spp.

Fertilizer requirements of faba bean in the rice-based cropping system are being examined in relation to minimum tillage. In addition to the use of starter nitrogen dressing and phosphate, the need for application of potassium and sulfur and micronutrients (particularly zinc) is being investigated. The results may lead to recommendations of fertilizer schedules that are entirely different from the general recommendation currently operative for these areas. In collaboration with the National Research Center (NRC), efforts are under way to use foliar analysis as a tool to correct midseason nutrient imbalances in the crop for a given yield target. The concept is being evaluated in on-farm trials.

Because of the generally high water table in the ricefields, the irrigation schedule required for faba bean following rice also differs from that required for bean in a cotton or maize rotation. Detailed studies have been made on scheduling irrigation, using soil moisturedepletion parameters and environmental conditions, and suitable recommendations have been developed.

The NVP research on faba bean has thus generated considerable information on optimum production technology needed for high returns from the faba bean crop in the rice - faba bean cropping system. It has also validated the technology in farmers' fields in Kafr El-Sheikh Governorate and is continuing to do so in other governorates. The model of applied research adopted in this project has proven its value, especially in the conduct of on-farm trials and in enlisting full participation of the farmers. We believe the approach adopted in the NVP on faba bean research can serve as a model for improving the productivity of rice and rice-based cropping systems in Egypt to meet the challenge ahead.

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Notes

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Extending rice cultivation to new areas in Egypt

A. MOMTAZ AND E. A. SIDDIQ

Arable land constituting less than 3.5% of the total land area and a fixed share of 55.5 billion m^3 of irrigation water from the River Nile are the major limitations to horizontal growth of agricultural production in Egypt. New Valley in the Western Desert, with a huge underground water potential, and the Aswan High Dam Lake area are two areas with prospects for expanding cultivation in the coming years. A feasibility study was made of these areas and, on the basis of economically exploitable level of underground water potential and arable land area, two of the three depressions of New Valley-El-Dakhla and El-Farafra—have been found to have considerable potential for expanding rice area. Rice would be an important crop component in the cropping systems of the valley to reclaim new areas and to keep down the salt level in already cultivated areas. Besides expansion of rice area, vast scope exists for vertically improving rice production here. Similarly, on the basis of several years' data on hydrographic features and survey reports on the topography, soil texture, etc., possibilities of growing deepwater and floating rices on flat shore lands in selected khors, or inlets, especially around Khor Questol and Adindan during July-December, are discussed.

At the present level of consumption of 35 kg per capita of milled rice, Egypt’s rice requirement in AD 2000 has been estimated to exceed 3.5 million t of paddy rice from the present level of 2.5 million t. If one assumes that there is no scope for horizontal growth of rice production, the estimated target will have to be achieved wholly by vertical components, i.e., by maximizing yield and productivity. This would require rice scientists and farmers to produce over 9 t ha against the present level of 6 t/ha. Although such a yield achievement is within the realm of reality, as evident from the wide gap between experimental and farmers’ field yields, there is no instance wherein potential yield has been fully exploited. Keeping this in view, prospects of extending rice cultivation to new areas have been explored.

Horizontal growth is possible only in situations where there is considerable scope for expanding arable land area and adequate irrigation potential to cultivate it. In Egypt, except for deserts, which constitute over 96% of its land area, there is hardly any area for substantial expansion. Among the potential areas for future agricultural development, close to 1 million ha, located in the Western Desert. Aswan High Dam Lake Area, Mediterranean coastal strip, and nondesert saline-affected areas in the Nile Valley and Delta are important.

As for irrigation water, the only major source is the River Nile. Nearly the whole volume of 55.5 million m^3 of water annually received as Egypt's share is released downstream for cultivating the entire cropped area of about 5 million ha. According to an estimate of the Ministry of Irrigation, through efficient water management, an improved irrigation system, and reuse of drainage water, about 16 billion m^3 could be saved. Pending the projected increase of another 10 million m^3 after the completion of Upper Nile Projects in Sudan, including the Jongley Canal Project, the net available quantum by AD 2000 is expected to be 73 billion m^3, of which 9 billion m^3 is likely to be surplus for diverting to newly reclaimed areas. Besides, other sources of irrigation water, not yet fully exploited, are over 50 billion m^3 underground water, available in New Valley and other parts of the Western Desert, and scanty rainfall of 100-200 mm along the Mediterranean coast. Further, drawdown flat areas along the khors (inlets) of Aswan High Dam Lake and their suitability for cultivation have not been precisely studied. Thus, both arable land and irrigation water are available for extending the cultivated area to a certain extent. The present exercise is to assess the prospects of extending rice cultivation in the water-abundant depressions of New Valley, as well as to explore the feasibility of making use of periodically denudated-inundated foreshore lands along the khors of Aswan High Dam Lake Area.

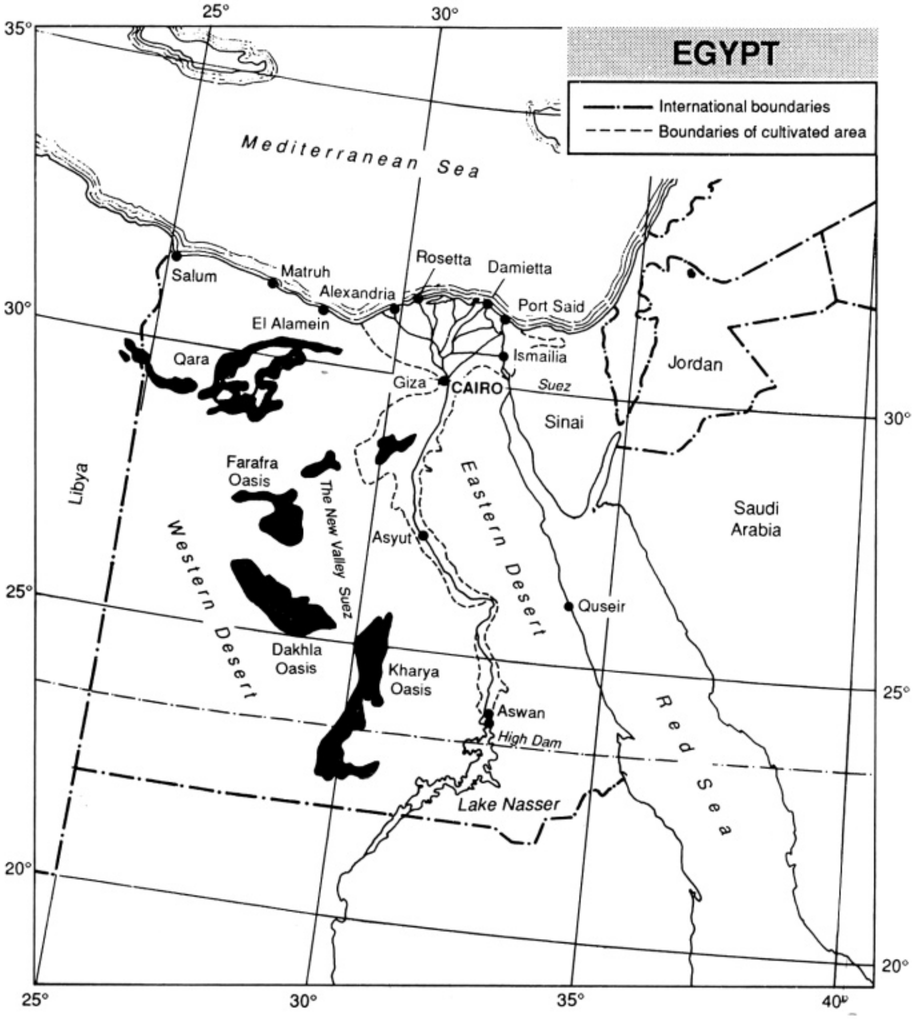
New Valley

The Western Desert, constituting about 68% of the total land area of Egypt, may be divided into northern and southern parts. The southern part, comprising three major depressions—El-Kharga, El-Dakhla, and El-Farafra—is now called New Valley (Fig. 1). With hundreds of natural springs and artesian wells all over, this region had been agriculturally prosperous in the ancient days. But successive invasions of tribes from bordering states forced the natives to migrate to the safer Nile Valley. As a result, once prosperous oases became saline and sand-covered for several centuries, until the present government came to power in 1958 and identified it as the priority area for development.

Cultivable land area and underground water potential

The potentially cultivable area is 0.73 million ha, on the basis of economically exploitable level of underground water; of this, the Regional Planning Committee has estimated the actually cultivable area to be around 48,000 ha, of which only 17,800 ha are presently under cultivation (Table 1). Of the remaining 30,700 ha, 11,000 ha are located in El-Dakhla and 19,700 ha in El-Farafra. Because economically exploitable underground water sources are limited in El-Kharga, there can be no further expansion there.

Until intensive survey of underground water potential was completed with the technical assistance received from friendly countries, no one knew that the vast stretch of desert land had, paradoxically, a huge natural reservoir of water underneath. The depth of the reservoir has been found to increase from 200 m in the southern part of the valley to 2,000 m in the north, with a proportionate increase in artesian pressure. The total quantity of water stored in the aquifers has been estimated to be around 50,000 km^3, or one-third of the total storage capacity of Nasr Lake. Continuous evaporation in the northern parts at 2 million m^3/d and



1. The major depressions in the western desert of Egypt.

Table 1. Potentially cultivable, economically cultivable, and presently cultivated area in the 3 depressions of the New Valley.

Depression	Land area (thousand ha)				
	Total	Potential	Economically cultivable	Actually cultivated	Area available for expansion
El-Kharga	353	105	1.7	1.7	0
El-Dakhla	212	71	9.7	5.3	4.6
El-Farafra	617	132	8.8	0.5	8.3
Total	1182	308	20.2	7.5	12.9

exploitation for irrigation, though in a small way, for thousands of years, suggest that the underground water cannot be strictly of a fossil source. It is more likely, as experts believe, that the reservoir continues to receive 3 million m^3/d from its original source, the Tapasti and other hills in Chad.

The extent to which the underground water could be utilized for planned agricultural development of the Valley would depend more on the means of lifting the water economically than on its vast potential. It is suggested that, if the quantum of water utilization is well planned to stabilize the annual level of decrease to about 30 cm, what economically could be pumped out in 100 yr would last for 200 yr.

The native wells, which remained the source of irrigation water for years, are old springs in the depth range of 50-200 m. Artesian pressure facilitated natural flow of water from them all these years. Following sinking of deep wells and hence increased discharge, the surface wells ceased to yield water any more in several areas. All the deep wells in El-Kharga have been powered for the last 10 yr. In El-Dakhla and El-Farafra, nearly all the wells are still in the phase of spontaneous flow, which is likely to last for the next 10-15 yr.

At present, there are 535 old shallow and 364 new deep wells, yielding, respectively, 0.187 and 1.06 million m^3/d. The discharge capacity of new wells varies from 3,000-7,000 m^3 in El-Dakhla to 12,000-20,000 m^3/d in El-Farafra (Table 2). The quality of water is superior, with salt level not exceeding 200 ppm.

Soil and weather

Most of the cultivable area has calcareous, heavy clayey soil. In certain parts, it is sandy loam or sandy. In the newly reclaimed areas, the salinity level is around 50-60 dS/m. Because of continuous leaching over the years, salinity is at noninjurious levels in the majority of the cultivated areas. An improved drainage system, now being introduced, helps to reclaim the soil more effectively.

The weather is hot and dry during the summer months, May-September. The monthly average temperature is between 29 and 35 °C, with the maximum touching 50 °C. Relative humidity is 23-30%. Very high temperatures, coupled with very low humidity, make May-July highly unfavorable to any crop, especially at the reproductive phase. High wind velocity during March-April and high rates of evaporation (12-18 mm/d) are some of the other unfavorable conditions.

Cropped area and crops grown

The total cropped area at present is about 21,000 ha, of which 3,360 ha are devoted to summer crops. The major crops include palms and alfalfa among perennials; wheat, barley, clover, faba bean, etc., among winter crops; and rice and sorghum among summer crops.

The rice crop in New Valley

The rice crop offers unique agronomic advantages in newly reclaimed areas. Besides, the rice needs of New Valley are expected to be one and a half times to twice the present level in the next 13 yr, at current levels of consumption.

Table 2. Number of shallow and deep wells and their capacity in different sections of the New Valley, 1983.

Location	Shallow old wells			Deep new wells				Means of lifting water
	no.	Depth range (m)	Total capacity (m^3/d)	no.	Depth range (m)	Discharge capacity range (m^3/d)	Total capacity (m^3/d)	
El-Kharga	72	50-200	30,400	161	600-1000	7,000-12,000	246,700	Powered
El-Dakhla	144	50-200	154,000	159	500-1000	3,000- 7,000	384,500	Artesian pressure
Al-West Mawhoob	–	50-200	–	19		3,000- 7,000	161,000	Artesian pressure
El-Farafra	22	50-200	2.113	18	300- 500	2,000-20,000	195,000	Artesian pressure
Abu Monker	–	50-200	–	7	–	–	70,900	Artesian pressure
Total	535		186,513	364			1,058,100	

Rice as summer crop

Rice, grown now on about 2,100 ha, is the major summer crop in New Valley. Distribution of rice area is confined largely to El-Dakhla (Table 3). The production is about 7,500 t, with an average yield of 3.6 t/ha. Giza 172 is the widely cultivated variety. The crop is customarily raised by drilling dry seed in June.

Reasons for growing rice

Rice has been the most preferred summer crop here for many years, even though it requires more water than any other crop in general and particularly here, with the high evaporation rate. However, there are good reasons for this crop choice: it is the most profitable staple crop, well adapted to adverse summer conditions. Secondly, farmers are aware that growing rice is the best means to leach down the continuously accumulating salts in the soil. Thirdly, leaving the land fallow during summer would facilitate salt accumulation and, as a result, harm sensitive winter crops like wheat and berseem. Thus rice, being a proven reclamation crop, has to be fitted into cropping patterns recommended for newly reclaimed areas.

Avenues for increasing rice production

Rice production could be raised by both horizontal and vertical expansion.

Horizontal expansion. In view of its agronomic advantages, on the one hand, and the abundance of spontaneously flowing water in the new areas, on the other, there is scope for bringing another 6,300 ha under rice in El-Dakhla and El-Farafra in the next 5-10 yr. This would mean, even at the present yield levels, that rice production would triple; additionally, the crop would help to reclaim a sizable area and hence increase production of winter crops.

Vertical expansion. Scope to maximize yield and productivity here is immense. Comparison of the average yield of New Valley with experimental plot yield and the national average shows a wide gap: New Valley farmers' yields average 3.6 t/ha; Egypt's national average yield is 5.5 t/ha; experimental plot average is 7.4 t/ha. The experimental plot yield exceeds farmers' yields by over 100%, underscoring the need to determine and remove, as far as possible, the major yield constraints.

Major constraints to increasing production

Among major constraints to increasing yields in New Valley are the lack of varieties suited to these conditions and lack of consistent and productive cultural practices.

Table 3. Distribution of rice area in the New Valley, 1985.

Total area under rice (ha)	Distribution of rice area (ha)				
	El-Dakhla			El-Kharga	El-Farafra
	West Mawhoob	El-Kasr	Balaath & Muth		
2080	430	640	880	130	–––

1. *Lack of ideal variety.* For a situation like New Valley, rice varieties that are most water-use efficient and least land-intensive would be ideal. For instance, varieties maturing a month earlier than Giza 172 would require less irrigation water. Similarly, a variety that would tolerate some drought stress would equally contribute to water economy. Use of such varieties would enable distribution of the available irrigation water to a larger area. Taking advantage of the absence of blast disease in the Valley, short-duration japonica strains, such as Fujihikari, and early types that can tolerate drought stress, such as IET1444, could be tried. In newly reclaimed areas, to cope with minimum water use, salt-tolerant early types would be preferable.
2. *Lack of a productive package of practices.* Wide variation in crop stand and stage is seen in the Valley, implying a lack of uniformity in planting time and cultural practices. Optimum population, profitable and productive planting methods, efficient fertilizer schedules, and optimization of water requirement are aspects of agronomic management that need to be standardized.

Productivity maximization

Since 1980, the possibility of growing two crops of rice or rice plus soybean/ sunflower during summer, instead of a single crop of rice, has been explored in the Delta. Taking advantage of a long summer, from April to October-November, a similar effort is being made in the Valley by the Rice Research Center, in collaboration with the Directorate of Agriculture, New Valley. Preliminary results showed the total yield of two crops to be 9.9-10.6 t/ha as against the single-crop yield of 6.1-6.4 t/ha from Giza 172 (Table 4). The yield advantage of 3.6 t/ha might, to some extent, be due to the unusually mild summer in 1986. Normally, temperatures exceeding 35 °C during the flowering phase of the first crop might reduce percentage of seed setting and hence reduce yields. While the extent of heat damage to the April-planted crop could be confirmed in the coming seasons, varieties known to be heat-tolerant could be used to overcome the stress effect. Another limitation to double cropping is the prolonged crop duration, which would meanincreased water requirements. However, the economics of yield advantage vis-a-vis the excess

Table 4. Relative performanceof 2 crops of rice during summer in the New Valley, Egypt, 1986.

Rice variety	Crop	Date of sowing	Test locations (no.)	Yield (t/ha)		Mean duration (d)
				Range	Mean	
IR28	First crop, direct-seeded	2-9 Apr	5[a]	2.7-7.2	5.9	130
	Second crop, transplanted	22 Jul			4.0	118
	Total				9.9	248
Giza 172	Single crop	7-10 Apr	2[b]	6.1-6.5	6.3	170

[a]El-Kharga (Munira, Kathara, Kharga), El-Dakhla (Balaath, El-Kasr, Al Mawhoob). [b]El-Gadhida, El-Rashda.

quantum of water needed must be determined before double cropping is practiced—even after the possibility of double cropping is established.

Some practical suggestions for increasing production are:

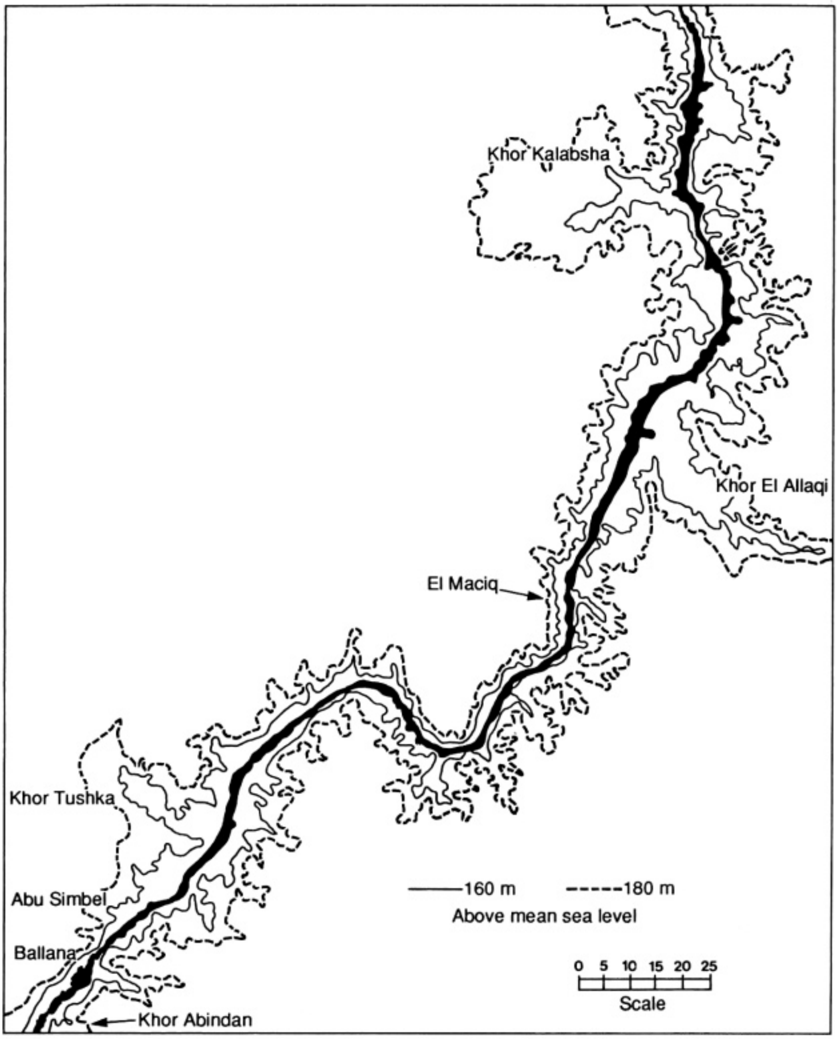
1. Considering the abundance of economically exploitable water potential, El-Dakhla and El-Farafra may be given priority for expansion of rice to about 15% of the area reclaimed.
2. Varieties of shorter duration with some drought-stress and salinity tolerance may be introduced to replace mediumduration Giza 172 and Giza 159.
3. An appropriate package of practices may be developed and popularized.
4. The small experiment station should be further expanded and strengthened as it is important to:
   a. evaluate all introduced varieties and elite breeding lines to identify appropriate types;
   b. improve the package of practices; and
   c. develop most productive and remunerative rice-based cropping systems.

Aswan High Dam Lake Area

Ever since the construction of Aswan High Dam in 1970, cultivation of rice in the lakeshore area has been proposed from time to time by various national and international agencies for the integrated development of Aswan High Dam Lake Area. Divergent views have been expressed on the prospects of growing rice here—some positive, some negative, and others neutral. All those views have been on the basis of generalized hydrographic features, rather than on site-specific details. Early attempts by the High Dam Authority to cultivate rice have been restricted to experimenting with it as an irrigated crop on the shore during July-November. With an appreciable fall in water level of the lake over the years, prospects of shore cultivation, even of hardy forage crops, are getting bleak. However, we undertook this study because interest in making use of the lake area for rice cultivation still persists. Our views on such a possibility are based on personal visits to the area and discussion with officials of the High Dam Lake Authority and others.

Aswan High Dam Lake is one of the world's largest manmade lakes. About 350 km long and a maximum of 18 km wide, the lake surface, within Egyptian territory, is about 5,000 km^2. Its storage capacity is around 156 billion m^3. Its shoreline all along from the Dam site at Aswan to the Sudanese border is characterized by a large number of khors of various sizes, with hundreds of small bays and subinlets (Fig. 2). The topography of the shoreline ranges from rocky to flat terrain. The flat lands are of varied gradients and kinds and thicknesses of topsoil. Kukur, Kalabsha, and Tushkha on the western shore and El-Allaqi on the eastern shore are some of the major khors of agricultural potential.

The High Dam has benefited Egypt by providing perennial irrigation and hence substantially increased the cultivated and cropped area, by putting an end to the annual ravages of floods and by generating a large quantum of hydroelectric power. Ironically, however, it has been of little use in developing the surrounding area as yet. Surveys by several teams in the past have helped to identify areas with agricultural potential.



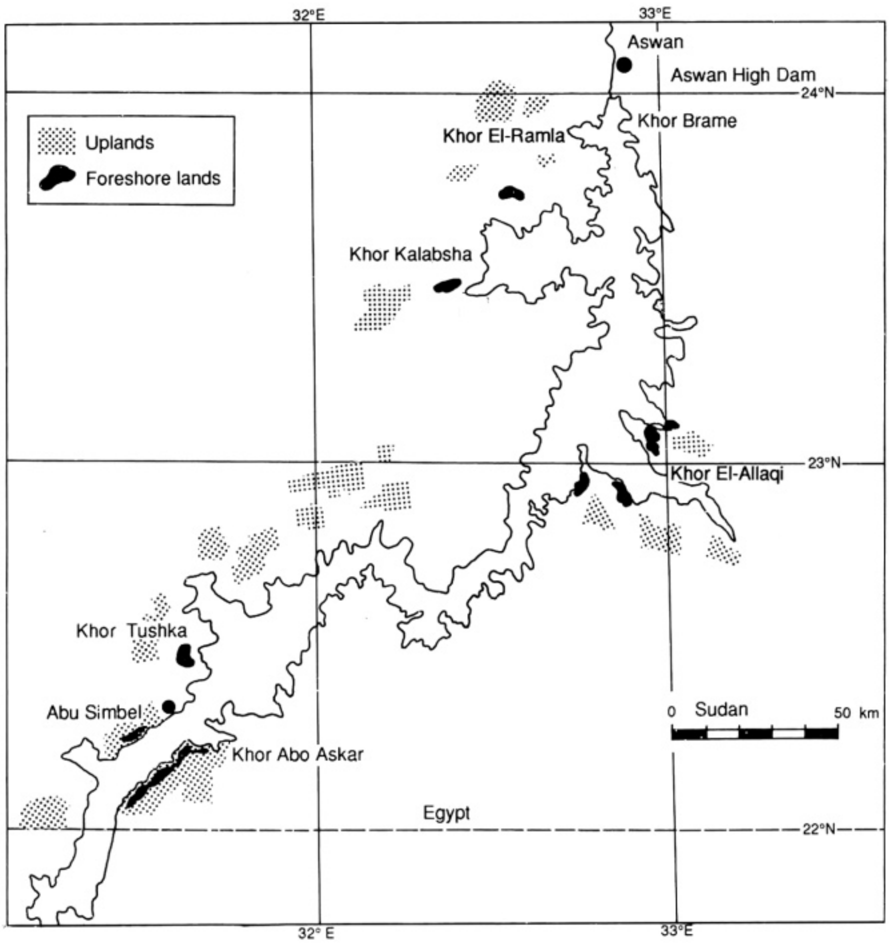
2. Aswan High Dam Lake khors (inlets) and extent of inundation in years of low and medium inflow.

Potential areas for agricultural development

Estimated by soil and aerial surveys by different agencies during 1974 and 1980, potential lakeshore area suitable for agriculture totals about 63,025 ha, of which upland area constitutes 46,220 and foreshore area 16,805 ha. Of this, the economically cultivable portion is just 24,705 ha (Table 5). These areas are located between Khor Tomas and Abu Simbel on the western shore and around Khor El-Allaqi on the eastern shore (Fig. 3). Of the two types of irrigated agriculture, uplands with permanently fixed irrigation facilities are located above the high-water level of 183 m (altitude between 183 and 210 m) in a flood year, whereas the foreshore areas with movable irrigation pumps are in the zone between 175-183 m.

Table 5. Economically cultivable area and locations along lakeshore, Aswan High Dam Lake, Egypt.

Lakeshore area	Location	Distance from shore line (km)	Area (ha)
Net potentially cultivable flat upland and foreshore area		2-45	63,025
Area not economically cultivable	7 locations between Kalabsha and Tomas	10-45	38,320
Economically cultivable area	Between Tomas and Abu Simbel and around Khor El Allaqi	2-8	24.705



3. Aswan High Dam Lake upland and foreshore areas suitable for agricultural development (based on JICA Report 1980).

The most important area, still requiring much attention, is the drawdown zone or area denudated between March and July. The total denudated area, which depends on the annual quantum of inflow and discharge, has come down slightly since 1976, but is still above 84,000 ha (Table 6). The flat and potentially cultivable portion of this area is much less. Whereas the early denudated area could be used for growing quick-maturing forage crops and legumes, the area denudated between mid-July and mid-August would be important for rice. Only this zone, representing a minimum period gap between denudation and inundation, would provide land and water for a crop like rice. Flat lands of relatively low gradient (0.3-0.4%) in this zone, with very little requirement for supplementary irrigation from the shore for a short period—not exceeding 1 mo—would be appropriate for rice.

Hydrographic features

To grow deepwater rices successfully in inundating areas, basic information on the following hydrographic characteristics is essential: maximum water level, depth, and time, as well as rate of water rise.

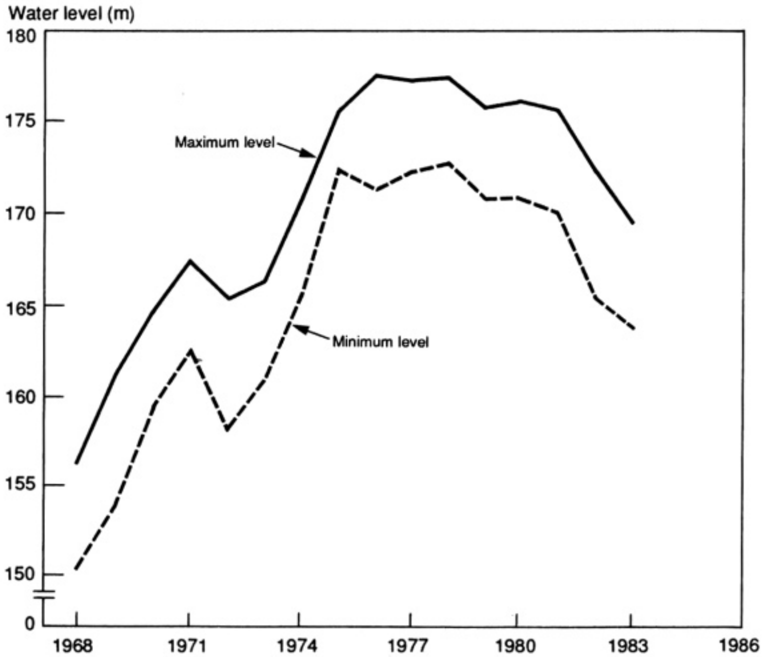
Maximum water level, depth, and time. The water level in the lake depends on the initial level and the quantum of inflow and outflow. In the early years of the High Dam, the water level was as high as 178 m, but has declined during the past few years to 170-173 m (Fig. 4). On the basis of average inflow of a 70-yr period (1899-1968), the maximum level has been computed to be around 176.5 m for medium and 174.7 m for low natural inflows (Fig. 5). But, irrespective of the maximum level, the level of rise of water from the July-August level remains consistently between 4 and 6 m. This depth range is relevant up to the point where the water line is in July-August. Beyond this, the depth would vary, depending on the topography of the lakeshore. In very low-gradient shores, the depth may be close to 4-6 m at maximum water level, while in medium-gradient shorelands, it may vary from <1 to 3 m.

Data of more than 15 yr reveal that the water reaches the maximum sometime around November, beyond which the level remains constant up to January-February. The minimum level, again more consistently, is around July (Fig. 6).

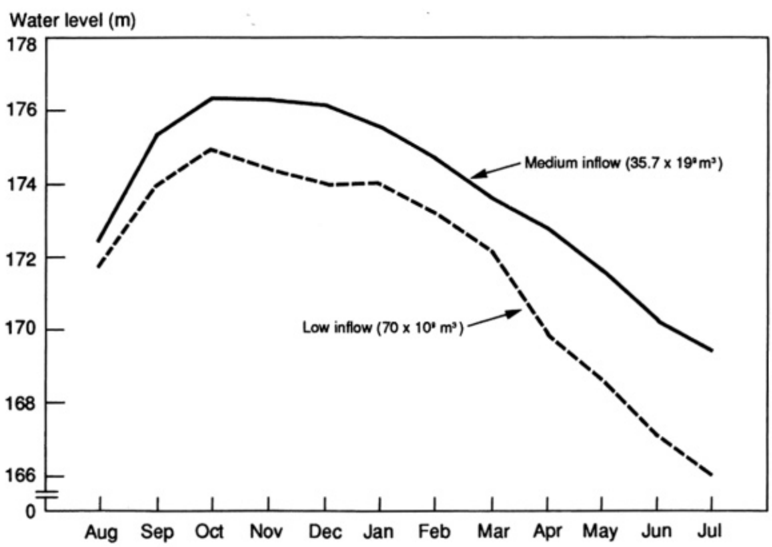
Table 6. Water level and annually denudated area on the shores of Aswan High Dam Lake, Egypt.[a]

Year	Maximum		Minimum		Land denudated (thousand ha)
	Water level (m)	Water surface area (km^2)	Water level (m)	Water surface area (km^2)	
1964-67			Water storage period		
1968	156.55	2580	150.85	2045	54.2
1976	177.55	5653	171.60	4583	108.4
1982	172.63	4760	1 65.64	3674	110.1
1983	169.87	4285	164.00	3454	84.0

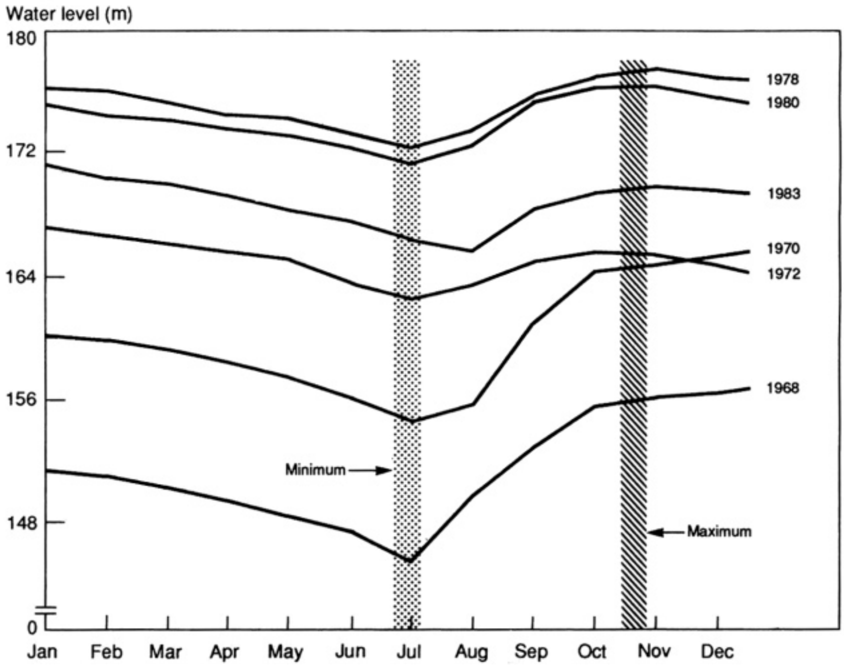
[a]Source: Aswan High Dam Lake Authority, Ministry of Construction, Arab Republic of Egypt.



4. Maximum and minimum water levels in Aswan High Dam Lake.



5. Theoretical yearly fluctuation of Aswan High Dam Lake water level, with medium and low natural inflow. Based on the average inflow over 70 yr, 1899-1968.



6. Maximum and minimum levels of water in Aswan High Dam Lake.

The water level starts rising from mid-July in the years of medium natural inflow and mid-August in years of low natural inflow. Sometime in February, the level starts receding.

Rate of rise of water during the period of inundation. The rate of water rise varies from year to year. Except in abnormal years, the rate generally is low during the first 4–5 wk, ranging from 0.5 to 4 cm/d. The highest rate, exceeding 10 cm (except in abnormal years, when it exceeds 15 cm), occurs between 3 and 8 wk from the date of fist water rise, in September. The high rate of increase lasts for a maximum of 2-3 wk (Table 7).

Table 7. Average rate of rise of water during peak flooding period, Aman High Dam Lake, Egypt, 198185.

Year	Average rate of water rise (cm/d)							
	August		September		October		November	
	1-15	16-31	1-15	16-30	1-15	16-31	1-15	16-30
1981	6.2	11.2	9.5	4.8	0.4	0.8	–	–
1982	–	3.0	6.4	1.1	1.3	1.3	0.9	–
1983	–	0.5	3.4	12.0	1.8	1.0	1.66	1.66
1984	1.3	3.1	2.5	–	–	–	–	–
1985	4.1	12.7	17.4	13.1	3.2	–	–	–

Soil and weather

The soil type ranges from gravelly sand to clayey loam; the predominant type is sandy. Neutral to alkaline pH and high to very high salinity are the features of the clayey alluvial soils. As against this, soil at specific sites around Abu Simbel, which is believed to be the end of the sedimentation zone, is much more fertile, with higher water-holding capacity and of thick layer, relatively better suited for rice, than the other areas.

The weather is generally hot during summer, April-October, with the maximum ranging from 35.7 to 42.3 °C and the minimum from 18.6 to 26.4 °C. In November, the maximum temperature is 32.7 and the minimum, 16.5 °C. Relative humidity ranges from 18 to 29%.

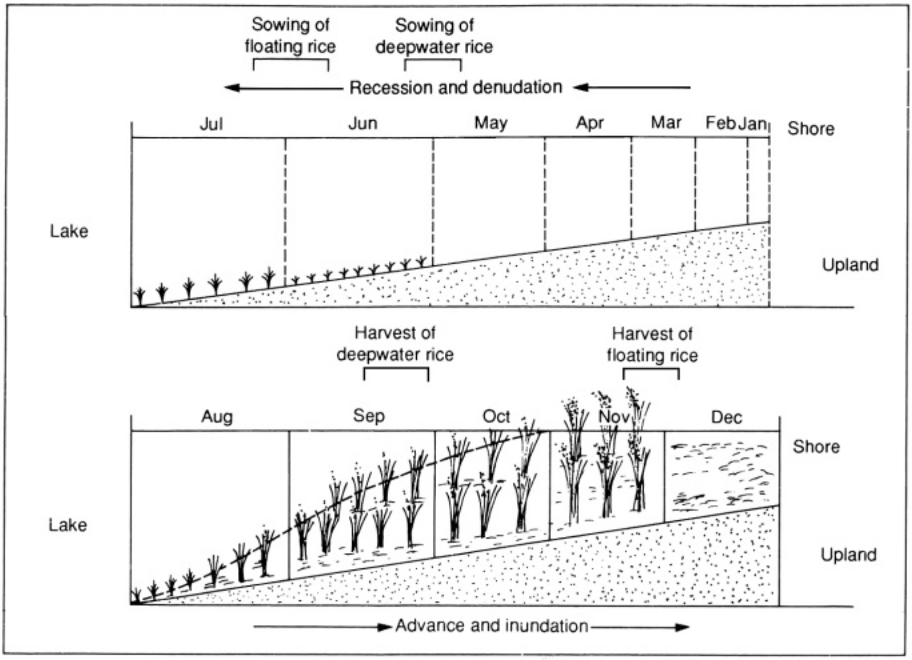
Prospects for growing rice

The Aswan High Dam Lake represents a different situation from that in traditional deepwater or floating rice areas of the world, such as in Bangladesh, India, Thailand, and Vietnam. In the traditional area, rice is normally direct seeded, long before the onset of monsoon. Early showers help germination and crop survival in the early phase until inundation starts. In most areas, the rate of water rise is around 5 cm/d. During the peak phase of the monsoon, the level may rise at a higher rate and submerge the crop for a few days. The photoperiod-sensitive varieties grown flower either before or after the water recedes. In the High Dam area, however, there is no rain; thus, germination and early growth in the denudated areas have to depend entirely on residual soil moisture and/or supplementary irrigation. The rise of water, although slow in the early phase, is quite rapid later. Thus, besides coping with the increasing water level, the plant has to withstand the inflow and outflow currents. The depth in the lake is also greater than that in the majority of the traditional areas, where it might be between 1 and 3 m and very rarely beyond 3 m.

Nevertheless, there is reason to study the extent to which the lake environment could be profitably utilized for rice cultivation, and Figure 7 represents schematically the possibilities of growing deepwater and floating rice in this area.

With water receding from February, wide stretches of land along the shore would remain water-free from May to mid-August. Such denudated areas, especially those remaining close to the water line, could be planted to rice, taking advantage of both residual moisture and the proximity to lake water for providing supplementary irrigation in the first 4-6 wk.

The land may have to be partitioned into several terraces, depending on the gradient. The upper terraces could be planted to deepwater rices in mid-June; the lower ones to floating rices, in mid-July. The sowing period should be precisely determined, based on experiments. The crop may be direct seeded, but transplanting is preferable, as it would enable planting 30- to 40-d-old seedlings, just a month before inundation. The seedlings would get established during this period to withstand the changing level and current of water. The very slow rate of water rise in the initial period would again be advantageous to crop establishment. Both June-sown deepwater rice and July-sown floating rice would require 4-6 wk of supplementary irrigation, either from an underground water source or from the lake. As the former source is not encouraging, the only alternative is the lake water.



7. Schematic representation of possibilities for growing deepwater and floating rices in Aswan High Dam Lake.

As the water source is quite close (about 500 m) to the planted area, irrigation for such a short period could be provided, using movable irrigation pumps.

Appropriate deepwater and floating rice varieties adapted to different water depths, raised at different altitudes, would grow along with the level of water rise from the time of inundation. Deepwater rice would be ready for harvest in the second week of September; floating rice, by the end of November.

Year-to-year fluctuation of denudated and inundated areas, rate of rise, and maximum depth of water—including submergence during normal years—could be taken care of by the genetic plasticity for elongation available in the floating rice germplasm. Hence, special care should be exercised in choosing varieties that flower after the water level becomes stabilized around November. This is essential, as no variety would elongate after flowering. A sizable collection of both deepwater and floating rice strains is available at the International Rice Research Institute (IRRI) and in the national rice research centers of countries that grow rice in deep water. Some of the strains that could be tested under the Aswan High Dam lake conditions are listed in Table 8.

Anticipated problems

The extent of damage to the crop, the reservoir, and the inhabitants of the area due to the following should also be assessed.

1. Violent fluctuations in water level and rate of rise in years of abnormally high floods.

Table 8. Some native and improved floating rices grown in different parts of the rice world.

Country of origin	Varieties	Major features
India	1. BR14, BR46, Dharmi, GS302, Habiganj A-2, Habiganj A-4, Jagar, Jaisuria, Jalmagna, Jaladhi 1 2. Jaladhi 2, Jaladhi 3 Kalangi, CN506-147-2-1	Mature 15-30 Nov. Adapted to depths of 2 m and above Mature 10-15 Dec. Adapted to depths of 2.5 m and above
Bangladesh	Badal 613, Baishbish, Bazail 65, BR1391-72-x3, DWC-B-151-1+1-B, Gilamyte Goda	Mature 15-30 Nov
Thailand	BKN6986-52-1-3, BKNFR76043-7-2-1, HTA7420-110-1-1-3, HTAFR77012-3, HTAFR77012-2, Leb Mue Nahng 111, Khao Nahng Nuey II, Pin Gaew 56, Khao Puang 32	Mature 10-30 Nov. Adapted to floating conditions
Vietnam	Benda, Cula, Nang Tay Nho, Lua Lem, Chang Kong Khman	Mature around 15 Nov
Indonesia	Cisadane	–
Sierra Leone	BH2	–

2. Sudden surges of water for 10-15 d in September.
3. Relatively low temperatures during grain-filling period.
4. Large fish and other aquatic fauna.
5. Plant parts left in water after harvest.
6. Bilharzia.

Specific suggestions

1. Experimental trials may be laid out at selected sites to study the feasibility of growing rice and identify, if established, appropriate varieties for different depths.

   Garb Hassan in the south and Khor Questol, Khor/Beach Adindan, Khor Kayyal, etc., in the north would be ideal sites, to start with, for conducting pilot experiments. Sites where there are human settlements would be preferable.

   A large collection of deepwater and floating rice varieties available at IRRI and other sources may be obtained for screening.
2. A continuous and concerted research effort should be made to develop this program; this would require a joint effort from the Ministries of Agriculture (Agricultural Research Center) and Construction (High Dam Authority).

Notes

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Efficient regeneration of plants from rice protoplasts

E. C. COCKING

For genetic manipulation procedures such as somatic hybridization by protoplast fusion and transformation by direct gene transfer into protoplasts to be applied to rice improvement, efficient procedures must be available for plant regeneration from rice protoplasts. A system has been developed at the University of Nottingham, UK, for the efficient, reproducible regeneration of functional rice plants from protoplasts. The procedures involve the culture of cell suspension-derived protoplasts of embryo, leaf, root, and anther origin in an agarose-solidified medium following heat shock treatment. The resulting colonies when plated directly onto a hormone-free medium produce green plants rapidly, principally through somaticembryogenesis. Regeneration can beobtained as quickly as 7 wk from the time of protoplast isolation for the japonica rice varieties Taipei 309, Fujisaka 5, and Nipponbare.

At the Rockefeller Foundation Rice Program Planning Meeting held at the International Rice Research Institute (TYRI) in October 1986, it was reported that a system had been developed in the Plant Genetic Manipulation Group at the University of Nottingham, in the UK, for the efficient regeneration of plants from rice protoplasts through somatic embryogenesis. The procedures involve the culture of cell suspension-derived protoplasts of embryo, leaf, root, and anther origin in an agarose-solidified medium following heat shock treatment. The resulting colonies when plated directly onto a hormone-free medium produce green plants rapidly, principally through somatic embryogenesis. Regeneration can be obtained as quickly as 7 wk from the time of protoplast isolation for the japonica rice varieties Taipei 309 and Fujisaka 5. Recently, regeneration has also been achieved from protoplasts of Nipponbare, another japonica rice variety, utilizing cell suspension cultures derived from the scutellum of mature seeds.

It is now clear that the combination of a heat shock (Thompson et al 1987), protoplast culture in agarose (Thompson et al 1986), and direct rapid plant regeneration from protoplast-derived callus through somatic embryogenesis (Abdullah et al 1986) provides a generally applicable system for efficient plant regeneration from japonica rice protoplasts isolated from cell suspensions of a wide range of explant origins.

Procedures for efficient regeneration of plants from rice protoplasts

Embryogenic callus was initiated from seedling leaves and seeds of Taipei 309 and from seeds of Fujisaka 5. Linsmaier and Skoog's medium with 2.5 mg 2,4-D/liter (LS2.5) was used for callus induction from the basal part of 7-d-old seedling leaves and from the scutellum of dehusked seeds. Callus cultures were also initiated from anthers of Taipei 309 on N6 medium with 2 mg 2,4-D/liter (N62 medium) and 3-d-old roots on LS2.5 medium.

Organized 2-mo-old embryogenic calli with a compact nodular morphology and white color are used for initiation of cell suspension cultures in AA medium with 2 mg 2,4-D/liter (AA2 medium). Details of callus and cell suspension culture initiation are presented by Thompson et al (1986) and Abdullah et al (1986).

In addition to Taipei 309 and Fujisaka 5, cell suspension cultures of seed scutellum origin have been established for a number of other rice varieties in AA2 medium (Table 1), indicating the general applicability of this medium for the maintenance of rice cell suspension cultures. Finely divided cell lines composed predominantly of small cytoplasmic cells were developed in AA2 medium by routine medium replacement during culture initiation. The cultures, once established—a process taking 3-5 mo—were subcultured weekly at a 1:4-15 (inoculum:fresh medium) ratio.

Protoplasts were isolated from cell suspensions 4 d after subculture, using an enzyme mixture comprising 1% (wt/vol) cellulase RS, 0.1% (wt/vol) pectolyase Y23, 5mM MES, CPW salts (9), and 13% (wt/vol) mannitol, pH 5.6. One gram of cells was mixed with 20 ml of enzyme and incubated on a rotary platform shaker (20 rpm) for 3 h at 23 °C, followed by 2-3 h stationary incubation at 27 °C. The protoplasts were then sieved through nylon screens of 64, 45, and 30 µm mesh size and pelleted by centrifugation at 80 × g for 5 min, followed by 3 washes with CPW medium containing 13% mannitol.

The freshly isolated protoplasts were suspended at a density of 5×10^5/ml in 4 ml of KpR medium (Table 2) in 16 ml glass centrifuge tubes for heat shock treatment, and placed for 5 min in a water bath at 45 °C (see Thompson et al 1987). The tubes were then placed in ice for 10 s. The number of protoplasts intact immediately after the hear shock treatment was determined using a haemocytometer.

Table 1. Rice cell suspension cultures maintained at Nottingham, UK.[a]

Oryza sativa	
Indica	Japonica
IR43	Taipei 309 Fujisaka 5 Nipponbare Yamabiko A-58 (cytoplasmic male-sterile)

[a]All these cell suspensions are maintained in AA2 medium at 120 cpm, 25°C.

Table 2. Composition of rice culture media. [a]

Callus initiation and maintenance (LS 2.5 medium)	
Linsmaier and Skoog medium with 1.0 mg thiamine HCl/liter, 30 g sucrose/liter, 8 g agar/liter, and 2.5 mg 2,4-D/liter	
Cell suspension culture (AA2 medium)	
AA medium containing:	877 mg L-glutamine/liter
	266 mg L-aspartic acid/liter
	228 mg L-arginine/liter
	75 mg glycine/liter
2.0 mg 2,4-D/liter, 0.2 mg kinetin/liter, 0.1 mg GA3/liter	
Protoplast culture (KpR medium)	
K8p medium with 10% glucose as osmoticum with 0.5 mg 2, 4-D added/liter	

[a]For full details of media, see Abdullah et al (1986) and Thompson et el (1986).

Untreated controls were also prepared. The protoplasts were cultured at a density of 3.0×10^5/ml in KpR medium with 0.6 or 1.2% (wt/ vol) Sea Plaque agarose either in drops or using the bead culture method of Thompson et al (1986). Protoplasts cultured in agarose commenced division after 5-10 d in culture, forming compact cell colonies after 14-20 d. In 1.2% Sea Plaque agarose, the plating efficiencies of both Taipei 309 and Fujisaka 5 were markedly higher than in 0.5% agarose-soiidified medium (Table 3). Following the heat shock treatment at 45 °C, the protoplasts commenced division after only 2-3 d, with an effective doubling in plating efficiency at both 14 and 28 d at a range of plating densities (Table 4).

No reduction was made in the osmotic pressure of the protoplast culture medium throughout the protoplast culture period. The cultures were maintained in the dark at 27 °C. After 4-6 wk, microcalli 1-2 mm in diameter were transferred into 25 compartment dishes, each well containing 2 ml of N6 hormone-free medium with 8% sucrose and 0.8% agar (N60 medium). The cultures were maintained in the dark at 27 °C and examined regularly with a dissecting microscope.

Plants were regenerated from protoplast-derived callus principally through somatic embryogenesis. Globular embryoids were observed on the surface of the calli after 5 d on N60 medium. Germinating embryoids were obtained as early as 14 d after the transfer of colonies onto N60 medium (Abdullah et al 1986). The

Table 3. Effect of Sea Plaque agarose on rice protoplast plating efficiency (adapted from Thompson et al 1986).

Variety	Culture method	Intact protoplasts on day 5 (%)	Plating efficiency mean ± s.d.	
			Day 14 (%)	Day 28 (%)
Taipei 309	KpR liquid medium	56	6.5 ± 3.8	0.025 ± 0.01
	KpR + 0.6% agarose	72	9.7 ± 4.2	0.2 ± 0.04
	KpR + 1.2% agarose	83	18.5 ± 6.5	0.35 ± 0.06
Fujisaka 5	KpR + 0.6% agarose	60	10.4 ± 3.7	0.25 ± 0.06
	KpR + 1.2% agarose	76	26.3 ± 8.2	0.52 ± 0.08

Table 4. Survival and division of heat shock (HS) treated and control (C) rice protoplasts[a] (adapted from Thompson et al 1987).

	Protoplast plating density (× 10^5 /ml)							
	1.0		2.0		3.0		4.0	
	C	HS	C	HS	C	HS	C	HS
% protoplasts intact, day 5	30	42	56	68	74	89	67	88
Protoplast plating efficiency (%), day 14	2	7	11	20	21	46	27	35
Protoplast plating efficiency (%), day 28	0	0.02**	0.27	0.65*	0.5	1.1*	0.26	0.45***

[a] Figures represent the mean of 5 independent replicate experiments. The plating efficiencies of control and heat shock treatments were compared statistically, using e paired "t" test. The values obtained following heat shock were significantly different from the corresponding control at the 0.1% (*), 1% (* *) and 5% (* * *) levels, respectively.

germinating embryoids turned green within 2 d of transfer into the light and produced green plants. Plants were regenerated from 10-20% of the colonies (Abdullah et al 1986). An average of two plants was regenerated from each colony. The plants continued to develop on MS hormone-free medium (MSO) and were readily transferred to soil for further growth. Globular and scutellar stage embryoids formed atypical leafy structures if transferred too early into the light, and did not then develop further. No albino regenerants occurred.

There is evidence that culture age is important in determining both plant regeneration frequency and plating efficiency. Satisfactory sustained protoplast division and subsequent plant regeneration were only obtained when cell suspensions had been maintained for at least 6-8 mo, and efficient plant regeneration may then be obtained for a further 3-4 mo.

Recently, green plant regeneration has been achieved from Taipei 309 protoplasts isolated from root and anther callus-derived cell suspension cultures and from a seed callusderived cell suspension of Nipponbare. All of the regenerated plants were normal in appearance and are being grown to maturity in the greenhouse. The progeny of the regenerated plants (R_2 generation) will be field-tested at IRRI for any somaclonal or gametoclonal variation.

The development of finely divided, fast-growing suspension lines was found essential for efficient protoplast isolation, division, and subsequent plant regeneration. AA medium favors the growth of rice cultures containing thin-walled cytoplasmic cells that appear similar to the embryogenic cultures established in other gramineous species.

Sustained division of japonica rice protoplasts was obtained in KpR medium solidified with Sea Plaque agarose. The compact nature of the colonies obtained from agarose, together with no reduction in the osmotic pressure of the culture medium, is believed to contribute to the high frequency of plant regeneration subsequently achieved in these experiments. Plant regeneration directly from rice cell suspension cultures or from rice protoplasts seems to be enhanced by osmotic stress conditions (unpublished observations).

The introduction of a heat shock treatment enabled protoplast plating at lower densities than those otherwise required for efficient colony recovery (Table 4).

Rapid, efficient plant regeneration has been achieved from protoplasts of three japonica rice varieties through somatic embryogenesis, using approaches that may be applicable to a wide range of japonica rice varieties.

Now that efficient plant regeneration from japonica rice protoplasts has been achieved, the remaining challenge is to obtain regeneration from protoplasts of a range of indica varieties. The same overall procedures as those described in this paper may prove useful, with modification to the culture media employed. The response in culture of indica × japonica reciprocal hybrids will also be examined, and may provide new insights into the cultural requirements of protoplasts of the tropical rice subspecies.

Genetic manipulations using rice protoplasts

Under a Rockefeller Foundation-sponsored program of genetic engineering in rice, IRRI is undertaking a study for the transfer of desirable genes from wild species of *Oryza* to commercially useful varieties (Table 5), using embryo rescue through appropriate tissue culture techniques. As described by Swaminathan (1986), two other techniques are feasible in the area of transferring genes across normal sexual barriers, namely, protoplast fusion followed by hybrid protoplast regeneration and differentiation, and the use of DNA vectors such as Ti-plasmids. Because it is now possible readily to regenerate plants from rice protoplasts, both the other techniques can be assessed in rice. In this respect, protoplast fusion is now being undertaken in

Table 5. Wild species of Oryza with useful traits (adapted from Swaminathan 1986).

Wild species	Useful trait
O. perennis	Tolerance for stagnant flood and acid sulfate soils
O. nivara	Resistance to grassy stunt virus and blast
O. officinalis	Resistance to BPH, WBPH, and GLH [a]
O. australiensis	Resistance to BPH and drought
O. barthii	Resistance to bacterial blight
O. longistaminata	Floral characters for out pollination
O. coarctata	Tolerance for salinity

[a] BPH = brown planthopper, WBPH = whitebacked planthopper, GLH = green leaf-hopper.

rice to transfer both nuclear and cytoplasmic encoded genes. Opportunities exist for producing somatic hybrids between cultivated rice and wild rice species with useful traits such as salinity tolerance and resistance to a range of plant diseases and insects (Table 5), and for the transfer of cytoplasmic male-sterility leading to the production of cybrids (Kumar and Cocking 1987), of use in producing hybrid rice.

Now that it has been found possible in tobacco to produce fertile interspecies gametosomatic hybrids by the fusion of somatic protoplasts with pollen tetrad (gametic) protoplasts (Pirrie and Power 1986). it will also be possible to assess whether fertile interspecies rice gametosomatic hybrids can be produced by fusing protoplasts isolated from rice cell suspension cultures with those from rice pollen. If so, this could enable the ready production of alien chromosome addition lines of cultivated rice having one or more chromosomes of the wild species listed in Table 5. Protoplast fusion may also enable the transfer of apomictic genes from species of *Pennisetum* into rice. The availability of apomictic rice would enable the mass production of rice F_1 hybrid seeds from F_1 hybrid plants.

Opportunities for the application of recombinant DNA technology to rice will depend on how readily genotype and phenotype can be related, and the ease with which desired gene sequences can be isolated and cloned. Now that techniques exist for transformation of rice protoplasts (Uchimiya et al 1986), the remaining challenge is to have the "gene-in-hand." Transfer of single-gene traits such as those for herbicide resistance, as already accomplished in certain dicotyledonous species, is now technically feasible with rice. The major challenge for direct DNA-mediated transfer into rice is to achieve those agronomically desired improvements in yield, pest and pathogen resistance, and stress tolerance that involve many genes of unknown identity (Cocking and Davey 1987).

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Plant genetic engineering and valuable gene traits

J. D. KEMP

Manipulating genes is nothing new: the earth's first farmers practiced it when they selected plants that produced more or better grain, or were larger, stronger, or more pest-resistant than others. More recently, scientists have discovered other ways of engineering plants at the level of the DNA molecule, a technology that offers a twofold advantage. First, the search for beneficial traits is not limited to the species as it is in classical breeding; traits from animals, bacteria, even viruses, can be utilized. Second, genetic engineering in the laboratory is much faster than traditional breeding, requiring only a single generation for the expression of an altered gene, and it can produce combinations of traits that might never result from natural or artificial selection. At the Plant Genetic Engineering Laboratory, New Mexico State University, scientists are concentrating on three types of desirable traits, which are responsible for a) environmental stress tolerance, b) disease resistance, and c) valuable products, such as liquid wax or balanced proteins. This work is briefly described. Classical plant breeding is still the cornerstone of crop improvement but, combined with the new techniques, it can give results with a speed and versatility previously beyond imagination.

Farmers and plant breeders have been improving crops for centuries by selecting and breeding the largest or the strongest or the most disease-resistant variety. Though they may not have known it, they were applying the principles of genetics. Today, recent discoveries have enabled scientists to move pieces of information (genes) from one organism to another. This ability to transfer genetic information is known as genetic engineering, a technique by which scientists are attempting to do at the molecular level what plant breeders have always done: combining genes in new ways to improve crops.

The development of recombinant DNA has provided a genetic engineering tool that allows the direct manipulation of DNA, the genetic information inside each cell that dictates every characteristic of a living organism. Genetic engineering has many advantages over traditional breeding techniques. Versatility is one. The search for beneficial traits is no longer limited to the species being improved, as with classical breeding; it is limited only by our access to the genetic secrets of other living organisms. The gene pool from which scientists can draw now comprises plants, animals, and microbes—the entirety of life on earth.

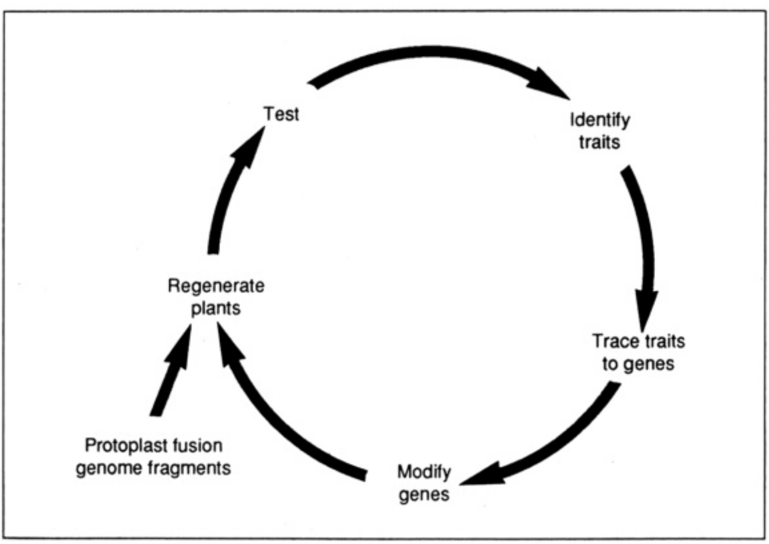
Precision and speed are two other advantages. In traditional cross breeding, all of the genetic information—both desired and undesired—from both plants is combined. However, genetic engineering enables scientists to isolate specific genes controlling specific traits from one organism and transfer those genes into another. Genetic engineering also accelerates nature's gradual selection process by producing, in just one generation, the expression of an altered gene and new trait, which may or may not result from natural or artificial selection.

Plant improvement through genetic engineering involves five basic steps (Fig. 1): 1) identify traits, 2) trace traits to genes, 3) modify genes, 4) regenerate plants, and 5) test the plant to determine if the new trait is stable.

Our scientists at the Plant Genetic Engineering Laboratory (PGEL) are concentrating on three types of desirable traits: those that protect a plant against environmental stress, such as that caused by heavy metals, salt, temperature, and drought; those that protect a plant against diseases, such as nematodes, insects, fungi, bacteria, and viruses; and those that produce valuable products, such as liquid wax and balanced proteins.

Once a desirable trait has been identified, the trait must then be traced to a specific gene or group of genes and those genes must be isolated before they can be modified and transferred to the new plant. Modifying the genes for transfer also requires the addition of regulatory sequences that control and direct the expression of those genes. The gene is transferred into cells placed in tissue culture using a plasmid vector such as the Ti (tumor-inducing) plasmid. The next steps are to regenerate the modified plants from cultured cells and then evaluate the plants to determine the permanence of the trait.

The southwestern USA, part of the arid and semiarid regions that cover one-third of the earth's land surface, has unique agricultural problems stemming from its harsh environment. One solution to the problems of southwestern



1. Plant improvement through biotechnology: five steps involved in genetic engineering.

agriculture is to replace conventional crops with new crops. Researchers are investigating methods to genetically alter conventional crops for better stress tolerance. They are also identifying arid-adapted native plants that have not been grown as crops before but which, under closer scrutiny, prove to offer some economically valuable product. And scientists are working on yet-unnamed plants with entirely new combinations of characteristics, produced by genetic engineering.

Our laboratory has active research programs under each of the three useful trait categories I have mentioned:

- protection of plants against environmental stress,
- protection of plants against disease and pest damage, and
- valuable new products.

Protection of plants against environmental stress

The expertise available at the PGEL at New Mexico State University (NMSU) places this center in a strong position to emerge as a world leader in plant biotechnology aimed at environmental stress tolerance. However, research on environmental stress is complex and difficult. Extremely specialized equipment is needed for the controlled environments required to study the effects of a given stress. And although the payoffs in this kind of research are very long-term, the research is crucial for the survival and development of agriculture in New Mexico and other arid and semiarid regions of the world.

One necessary approach to the study of environmental stresses is to simplify the complex stress situation into individual components. For example, morphological components like root structure or salt glands aid in plant adaptation to drought or salinity stress. Biochemical components like detoxification of toxic ions or production of nontoxic organic solutes counteract drought stress. On the other hand, no single component appears to be solely or even primarily responsible for stress tolerance, so eventually all of the component information must be integrated into a meaningful set of connections. Moreover, many of the environmental stresses interact with each other, making it even more difficult to simplify or understand them. For example, we view drought as essentially waterdeficit stress, but it also raises internal salt concentrations. Similarly, salinity stress influences water availability within the plant. Heat stress has a profound effect on the metabolic machinery in a plant, literally burning it out, but heat also influences water relations in several ways. A necessary part of our understanding of stress physiology is attempting to sort through the myriad possible interactions and mechanisms to identify those that are most meaningful.

We have a major research effort aimed at the understanding of drought, salinity, and heat stresses on plants, and their interrelationships. To a large degree, this basic research on stress physiology and biochemistry is necessary before valuable tolerance mechanisms can be correlated with genetic traits. However, to try to speed this correlation, we have incorporated a genetic comparison between varying degrees of tolerance or susceptibility into our stress physiology research. A description of our efforts in drought, salinity, and heat tolerance research and a summary of prospects follow.

Water-deficit stress tolerance

Plant breeders at NMSU have developed a series of alfalfa populations that are genetically related but differ in their degree of water-use efficiency; these are being studied intensively. These lines have been compared and found to differ significantly with respect to polyamine content, which provides tolerant lines in a protective mechanism to the stability of cellular membranes and metabolic machinery. The susceptible lines do not show the same polyamine content. These observations hold both for whole plants and corresponding cells in culture.

We are also studying the differential alfalfas with the aim of integrating all of the component information available with computer models. We are estimating energy cost/ benefit balances for various biochemical (such as polyamine synthesis, CO_2 concentration) and morphological traits as developed in mathematical computer models. The model for water-use efficiency is the most comprehensive in existence and will permit optimization of plant engineering for the best economic balance of traits when trade-offs occur between yield and stress tolerance. The model currently estimates that water-use efficiency in alfalfa can be improved by 25% with no penalty in yield.

Salt tolerance

Differentially tolerant or susceptible strains of salt grasses and tomatoes are being studied, and researchers have found that one important effect of salinity stress is increased production of ethylene, which speeds the aging process. Interestingly, ethylene and polyamines are believed to be synthesized from the same chemical, and their respective concentrations are usually inversely proportional. Increase of CO_2 concentration appears to alleviate the problems caused by ethylene and salt stress. We are beginning to extend the computer model to salinity tolerance, observing that the CO_2 concentration seems to play an important role in both waterdeficit stress and salt stress. These models will be challenged by data generated with tumbleweed and saltbush, because these plants are extremely salt-tolerant and, in fact, even require salt for optimal growth and biomass production.

Heat tolerance

A set of cotton strains that are genetically related but differ in degree of heat tolerance is being studied. Again, polyamines appear to represent a significant component of heat tolerance. We have determined that only one or two genes play major roles in this trait, and it is therefore a good candidate for gene isolation and transfer. Heat shock proteins appear in many plants in response to heat stress, but it is unclear whether any of them plays a role in heat tolerance. We are studying the relationship between heat shock proteins and heat tolerance at the molecular level.

Breeding for environmental stress tolerance

Our research on environmental stress tolerances suggests that there may be a common biochemical pathway that plays an important role in drought, salt, and heat stresses. As additional components (probably unique to each type of stress) are identified and incorporated into our computer models, we will hopefully be able to develop highly efficient criteria for breeding environmental stress tolerances into crop plants for improved production in desert regions. Some of this information can also be used to develop cell selection criteria and to isolate genes at the molecular level for gene transfer experiments. In this way, biotechnology will speed the development of stress-tolerant crops.

Protection of plants against diseases and pests

In the second category of useful traits are those that protect plants from disease stress. There are five classes of disease-causing organisms: insects, nematodes, fungi, bacteria, and viruses. Each class requires a different approach to its control. For instance, a useful trait that may control an insect infestation will not have any effect on a fungal disease and vice versa. In fact, some useful traits are highly specific; for instance, the *Bacillus thuringiensis* (B.t.) toxin kills only one particular family of insects but no others. Such specificity is valuable, because we can target a particular pest without any impact on beneficial organisms. We have chosen two: the B.t. toxin gene to control lepidopteran insects (moths) and the collagenase gene to control nematodes.

Insect diseases

A major problem of crop production is damage caused by insect feeding. Consequently, much effort by entomologists and plant breeders has focused on developing insect-resistant crop plants. Genetic engineering is an additional tool that hopefully will allow us to transfer resistance genes from nonrelated organisms into plants. Crops containing insecticidal proteins, such as the B.t. toxin, would resist insect feeding, resulting in healthier plants and increased productivity.

Acquired from Agrigenetics Corporation, the B.t. gene still needs to be tailored with plant promoters (or regulatory signals), because it is normally found in a bacterium and bacterial regulatory signals do not function in a plant. This year, PGEL researchers have removed the unrecognizable bacterial signals and have inserted potentially useful plant signals in an attempt to modify the gene for correct expression in plants. This gene construction has been introduced into tomato and petunia plants, which are now ready to be tested to ascertain if the B.t. gene is expressed and functioning properly by killing insects feeding on the leaves of the plant. Because of our recent success in regenerating Afghan pine from tissue culture, we have decided to target tip moth in pine as our first improvement of an economically important plant.

Nematode diseases

We have also identified a useful trait that may protect plants from nematode diseases, which attack virtually all important crops. The trait is correlated to a single enzyme called collagenase, which is secreted by a predator fungus that uses the enzyme to digest nematodes for a source of food. We intend to transfer the gene that codes for the production of collagenase into plants, as a mechanism to protect them from nematode invasion.

To date, the collagenase protein has been purified from a culture of the predator fungus. Preliminary experiments have shown that the purified collagenase from the fungus is effective in killing root-knot nematodes. However, it will be a year or so before the gene itself is isolated and characterized to the point where gene transfers can be considered. When the collagenase is available, we will transfer it first to tomatoes and test them for resistance to the root-knot nematode. Chili peppers, a crop important to New Mexico, may be another plant that would benefit from the collagenase gene.

Valuable new products

The first two categories of useful traits we have discussed—protection against environmental stress and against disease stress—both relate to plant protection. The third category of useful traits consists of those that produce a valuable new product in the plant. Again we are not limited by our imagination but by our base of scientific knowledge. We would all like to have nitrogen-fixing plants that would not have to be fertilized, or plants that produce a cheap source of fuel oil. But scientifically, these traits are very complex and will require many years of study before genetic engineering technology can be applied.

Based on current scientific understanding, we have identified two valuable products: one is liquid wax and the other a balanced seed storage protein that will improve nutritional quality; we believe the ability to manufacture these can be introduced into crop plants.

The desert shrub jojoba produces a wax useful for a wide variety of products ranging from cosmetics to lubricants. Recently, we have developed a convenient tissue culture system for regeneration of oilseed, rapeseed, and crambe. This culture system is now suitable for use in gene transfer experiments and research is under way to optimize the transfer process.

A major deficiency of all food crops is their low-quality protein content for animal and human nutritional needs. For example, maize seed proteins are deficient in the amino acid lysine, whereas bean seed proteins are adequate in lysine but deficient in methionine. Humans circumvent these deficiencies by mixing maize with beans in their diet. A novel approach to solving this problem is to use genetic engineering to transfer maize seed protein genes into beans, producing a "new" bean with both maize and bean proteins. Our center is working with the phaseolin protein, and recent research has resulted in successfully transferring phaseolin into tobacco plants, where it is expressed at the proper time and in the correct place—tobacco seeds. This demonstrated that seed protein genes can be moved from plant to plant by recombination DNA techniques and those genes can be regulated correctly in the new plant.

Conclusion

Classical plant breeding is still the cornerstone of crop development. But programs that combine traditional plant breeding methods with the new recombinant DNA techniques will allow scientists to engineer genes for crop improvement with a speed and versatility previously beyond imagination.

Notes

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Biofertilization using blue-green algae in rice

M. N. Alaa El-Din and S. N. Shawn

Research on blue-green algae in Egypt has expanded considerably since its beginnings in the 1950s, when two strains imported from Japan were tried as the first algal inoculants. Various studies are conducted on isolation of local blue-green algae and evaluation of their impact on nitrogen economy and rice yields. In 1975, the Egyptian Ministry of Agriculture established a national project to produce enough blue-green algae to use on about 0.4 million ha of rice annually. The technology developed is quite simple. Methods of production and application and economic returns to the farmer and to the government are discussed. The use of *Azolla*—introduced in Egypt in 1977—and nitrogen gains and benefits to farmers are touched on briefly.

Rice is grown in Egypt on about 0.5 million ha annually, requiring large amounts of nitrogen (N) fertilizer. Nitrogen-fixing blue-green algae (BGA) could make a significant contribution to the N economy of rice, reducing the costly reliance on energy-intensive chemical fertilizer and also improving soil characteristics to benefit subsequent crops.

In submerged ricefield soils, biological N_2 fixation is essentially an algal process, contributing about 20-30 kg N/ ha. The N_2 fixed and liberated by BGA is taken up by rice plants. Besides fixing N, the blue-green algae also synthesize and liberate growth-promoting substances such as auxins, vitamin B_{12}, and amino acids, which help the growth of rice plants.

In recent years, the Aswan Dam has deprived the Nile Delta of the fertile silt previously brought by annual flooding. Accordingly, algalization could be of critical importance to the fertility of Egyptian ricefields.

This paper reviews research done on N_2-fixing BGA by Egyptian workers from 1958 to 1984, especially on 1) the Egyptian flora of BGA, 2) ecological and physiological studies of some of those species, 3) N_2-fixation under laboratory and field conditions, 4) cellular exudates of N_2-fixing BGA, 5) mass cultivation of BGA, 6) response of rice to algalization, 7) economic studies on algalization, and 8) future investigations.

(For comprehensive reviews of work on all aspects of BGA worldwide, see Henriksson and Da Silva 1978; Reynaud and Roger 1978; Roychoudhury 1979; Srinivasan 1979; Venkataraman 1979a, b, c, d; Watanabe et al 1978a, b.)

The blue-green algae in Egyptian soils

Egyptian workers have isolated a wide range of BGA, including many N_2-fixing species, from Egyptian soils (Table 1). N_2-fixing capacity of these isolates was assessed by the Kjeldahl or acetylene reduction methods.

Numerous ecological and physiological studies on the N_2-fixing BGA have been carried out (Table 2). Growth and N_2 fixation and other enzymatic activities were assessed as affected by nutritional requirements and environmental conditions.

Nitrogen fixation in the laboratory

Amounts of N fixed by BGA under laboratory conditions vary with the species, type of medium, period of incubation, method of determination, etc. Table 3 summarizes the data available on this aspect.

Table 1. Genera and species of blue-green algae isolated from Egyptian soils.

Isolate	Reference
Calothrix, Anabaena *Hapalosiphon fontinalis*	El-Nawawy et al 1962
Anabaena variabilis *Calothrix elenkinii*	Taha 1963a
Anabaena variabilis *Nostoc muscorum* *Nostoc commune* *Calothrix clavata*	Taha and El-Refai 1963a
Nostoc muscorum *Phormidium fragile*	Shakeeb 1970
Calothrix thermalis, Nostoc humifusum *Calothrix parietina, Nostoc sphaericum* *Calothrix scopularum, Anabaena anamola* *Calothrix contarenii, Anabaena naviculoides* *Nostoc calcicola, Anabaena oryzae* *Nostoc entophytum, Cylindrospermum muscicola* *Nostoc* sp., *Anabaena sphaesica* var. *tenuis* *Nodularia harvenyama* var. *sphaerocapsa* *Anabaena variabilis* var. *ellipsispora* *Anabaena variabilis* var. *kashiensis*	Eisha et al 1972
Anabaena oryzae, Anabaena variabilis *Anabaena naviculoides, Nostoc muscorum* *Nostoc rivulare, Nostoc minutum* *Nostoc sphaericum, Nostoc calcicola* *Nostoc commune, Calothrix braunii* *Anabaena variabilis* var. *ellipsospora* *Anabaena variabilis* var. *kasbiensis* *Calothrix marchia* var. *intermedia* *Cylindrospermum muscicola*	Khadr 1975
Nostoc paludosum, Nostoc piscinale *Nostoc linckia* var. *arvense* *Cylindrospermum* sp.	El-Borollosy 1972
Microcystis, Anabaena, Oscillatoria *Lyngbya, Nodularia*	Ramadan et al 1973
Anabaena sp., *Aulosira* sp., *Nostoc sp.* (1) *Nostoc sp.* (2) *Nostoc sp.* (3)	Shalan 1974

Nitrogen fixation in the field

International reports indicated that BGA fixed about 15-49 kg N/ha (De and Mandal 1956) or 22 kg N/ha (Watanabe et al 1951). In Egypt, some studies were conducted to evaluate the algal biomass and hence the N fixed by BGA in different soils. The introduction of BGA to different types of soil significantly increased the N content of both rice plants and soil (Khadr 1975, Salem 1980). Ghazal (l980) showed that the algal biomass depended on soil type and strain of algae used.

Table 2. A summary of Egyptian ecological and physiological studies on N_2-fixing BGA.

Topic	Reference
Environmental conditions	Abd El-Hafez et al 1980
	Alaa El-Din et al 1980
	El-Nawawy et al 1962, 1968, 1975b, 1976
	El-Sayed 1973, 1978
	Faiza 1983
	Hamdi et al 1970
	Ibrahim 1970
	Ibrahim et al 1975
	Khadr 1975
	Mahmoud et al 1975
	Salem 1980
	Shalan 1974
	Shalan et al 1984
	Shatta et al 1984
	Taha 1963c, 1964b
	Taha and El-Refai 1963b
Nutritional requirements	El-Nawawy et al 1968, 1972, 1973
	El-Refai et al 1974
	El-Sayed 1973, 1978
	Hazem et al 1980
	Mahmoud et al 1975, 1980, 1982
	Shalan 1974
	Taha 1963b, 1964a
	Taha and El-Refai 1962b
Cellular exudates	Shalan 1980, Taha and El-Refai 1962a
Enzymatic activity	Alaa El-Din et al 1980a, 1980b
	El-Haddad et al 1980
	Ghazal 1980
	Hazem et al 1980
	Mahmoud et al 1980
Algalization	Abou El-Fadl 1967
	Abou El-Fadl et al 1964
	Alaa El-Din et al 1984
	Eid et al 1962
	El-Nawawy et al 1958
	Hamissa et al 1978
	Hassan et al 1984
	Ibrahim et al 1971
	Khadr et al 1978
	Mahmoud et al 1974
	Shalan 1974, 1980
	Shalan et al 1984
	Taha et al 1972
	Yanni et al 1984

Table 3. Amounts of N_2 fixed by different BGA isolates in liquid culture.

Species	Period (d)	N_2 fixed (ppm)	Reference
Hapalosiphon fontinalis		220	Taha 1963b
Anabaena variabilis		270	
Calothrix elenkinii		570	
Tolypothrix tenuis	60	1420	El-Borollosy 1972
Nostoc commune	60	710	
Nostoc linckia var. *arvense*	60	910	Taha et al 1972
Nostoc piscinala	60	870	
Cylindrospermum sp.	60	790	
Nostoc paludowm	60	620	
Aulosira sp.	30	152	Shalan 1974
Anabaena sp.	30	82	
Anabaena naviculoides	55	830	
Nostoc sphaericum	55	770	
Anabaena variabilis	55	930	Khadr 1975
Nostoc calcicola	55	990	
Nostoc muscorum	55	1010	
Anabaena oryzae	55	1170	
Anabaena naviculoides	45	1540	Alaa El-Din et al 1980a
Nostoc muscorum	45	1760	
Anabaena oryzae	45	2700	
Nostoc calcicola	45	1870	

Cellular exudates

The nature of nitrogenous products formed in the cells and culture solutions of *Nostoc commune* was investigated by Taha and El-Refai (1962a), who found that 13% of the cellular N was present in soluble form, with aspartic acid, glutamic acid, and alanine as the only free amino acids. The extracellular N amounted to 30% of the total fixed. Glutamic acid and aspartic acid predominated in the filtrates.

Abd El-Hafez et al (1980) found that 23% of the N fixed by *Anabaena naviculoides* and 31.2% of that fixed by *Nostoc muscorum* was excreted in soluble form in the filtrates of their cultures. The same two organisms excreted 9.5% and 14% of the soluble form of N as free amino acids. *A. naviculoides* excreted 32.7% and *N. muscorum* 21.6% of the dry algal material in the form of carbohydrates. Applying filtrates of the two algal cultures clearly stimulated rice seedling growth.

Mass cultivation of blue-green algae

An extensive review on the engineering, biological, and operational aspects of mass-cultivating BGA is presented by Venkataraman (1969). The Japanese technology (Watanabe et al 1959) includes growing BGA in shake, tank closed circulation, and gravel culture systems. In India, BGA is grown in dry sand culture and open-air soil culture. Other methods of mass cultivation of BGA include batch culture in 10-liter bottles (Haysted et al 1970), continuous culture (Bone 1971), and open basin culture as reported by Florenzano and Materassi in 1964 (cited by Soeder 1976).

In Egypt, a modified version of the Indian open-air system is used to mass-produce algal inoculants. The merit of this system is that it is simple enough for the farmers to use in preparing their own inoculum. The basic principle is to grow the algae using natural sunlight. A thin (2.5 cm) layer of soil is spread in a rectangular tray of galvanized iron (60 × 90 cm) or of plastic (30 × 70 cm) and flooded with 2.5 cm of water. After the soil settles, the specific strains of algae are inoculated into these trays with phosphate (0.2 g $NaHPO_4$/liter) and molybdenum (0.2 mg MoO_3). The trays are kept in the open and within 4-5 d. the entire surface of the water is covered with a copious growth of the inoculated algae. The standing water is then allowed to dry up, when the dried algal mat cracks and flakes off. This dried material is collected, homogenized, and stored in plastic bags, in amounts of 100 g, or enough to inoculate 1 feddan of land (0.42 ha). An average of about 20 g dry wt/m^2 per d can be produced by this method, and a continuous operation can be maintained. with a 10-d collection schedule.

The disadvantage of this method is that during winter, growth rate of the algae slows down, and production may have to be suspended entirely during the rainy season. However, the overall climate of the tropics, the high rate of production during clear, warm days, and the low operational costs of this method outweigh these limitations.

Algal nursery beds can be laid out in farmers' fields and enclosed by earth embankments. Useful strains of algae can be inoculated into the nurseries just before the rainy season or, where water is available. the beds can be kept waterlogged. Prior to inoculating, the beds may be given a dressing of lime, phosphate. and molybdenum to promote inoculum growth. Even insoluble phosphate, such as rock phosphate, can be used. The resulting algal mat can be scooped out, dried, and used for broadcasting over the main field. It may also be possible to direct the inflow of irrigation water over the nursery beds so that the algal material is evenly distributed over the entire ricefield.

At present, the BGA inoculum is centrally produced at the laboratories and greenhouses of the Agricultural Microbiology Research Section, Soils and Water Research Institute. Agricultural Research Center (Egyptian Ministry of Agriculture). We have two greenhouse sites, 2.1 ha each, 1 in Giza, near Cairo, and 1 in Sakha in the middle Delta; by 1992 we plan to set up 4 more, at key locations in the rice-growing areas of the Delta, each able to produce enough inoculant for about 84,000 to 105,000 ha annually.

Response of rice to algalization

Worldwide data indicated that inoculation of ricefields (algalization) increased rice yield: 10 to 15% in India (Venkataraman 1972), 13 to 20% in the USSR (Shtina et al 1958), and 24% in China (Ley et al 1959). In the Philippines, 23 successive crops of rice were grown during 12 yr without any added N with no decline in the rice yield of 3-4 t/ha per crop.

In Egypt, El-Kawawy et al (1958) inoculated 1 g (dry wt) of *Tolypothrix tenuis* into lysimeters (20 × 20 m), planted with rice, to give a final concentration of 476 g/ha, which was found to satisfy the N requirements of the rice. Abou El-Fadl et al

(1964) studied the response of rice to inoculation with *T. tenuis* plus four types of fertilizer: ammonium sulfate, compost, straw, and superphosphate. In general, inoculation with *T. tenuis* significantly increased soil N but had no effect on rice yield. The response varied with the type of fertilizer applied: ammonium sulfate inhibited N_2 fixation, but organic matter (compost or straw) stimulated it. Superphosphate, together with either ammonium sulfate or organic matter, markedly inhibited N_2 fixation.

Ibrahim et al (1971) studied the effect on rice yield and soil N of adding *T. tenuis,* P, and N fertilizer. Algal inoculation increased grain, straw, and soil N. Inoculation alone, without fertilizer, increased grain yield by 4.2% and straw by 19.3%. With added P, these increased 7% and 56.6%, the maximum yield being obtained with *T. tenuis* plus 0.5 g P/pot.

El-Borollosy (1972), evaluating the response of rice to six BGA isolates, found that the highest total N levels in the plants and in sand culture, as well as the highest fresh and dry weights of 115-d-old rice plants, were obtained with *T. tenuis.* The local isolate *Nostoc linckia* var. *arvense* was the next most effective.

Field experiments on the inoculation of rice with *T. tenuis* were done in two successive years (Abou El-Fad1 et al 1967). In the first year, rice followed a bean crop; in the second, a wheat crop. Two levels of algal inoculum (238 and 476 g/ ha) and ammonium sulfate (24 and 48 kg N/ha) were added. These treatments were repeated once with and once without added calcium superphosphate (36 kg/ ha = 16 kg P/ha). The average rice yield following beans was much higher than that following wheat. When no phosphate was added, the application of algae or N at the two levels gave approximately similar results. A 19.6% yield increase was obtained with 238 g of *T. tenuis* /ha.

Abou El-Fad1 et al (1967) studied the response of rice to algal inoculation as affected by crop rotation and time of application of N and P fertilizers. In general, the greenhouse and field experiments indicated that BGA served as a useful N source for rice growth. For example, algal inoculation gave a yield similar to that obtained with 10-20 kg N/ha. With superphosphate applied 2 wk before and ammonium sulfate 4 wk after transplanting, algal inoculation gave a 23.1% yield increase. With only two-thirds the recommended dose of ammonium sulfate, algal inoculation gave higher yields than the recommended maximum dose of ammonium sulfate alone; thus, use of BGA could profitably reduce N fertilizer needed on rice.

Khadr (1975) showed that N content of rice plants increased as a result of algal inoculation, with mixed cultures of BGA giving better results than any single isolate. With inoculation plus N fertilizer, highly significant increases in N content of rice plants were recorded. *Anabaena naviculoides* plus N gave the highest mean value (96 mg N/ pot).

Field trials in Egypt (Hamissa et a1 1978) compared the merits of a local isolate, *Anabaena oryzae,* and an imported culture, *Aulosira fertilissima,* used both with and without N fertilizer. *A. oryzae* significantly increased rice grain + straw yield (31.6%) and N uptake by the plant (25-42%). But *A. fertilissima* did not significantly stimulate rice response as N uptake. Algalization plus 36 kg N/ha gave the best results–72% yield increase—significantly higher than that obtained (45.6%) with N fertilizer alone.

In another study, Khadr et al (1978) showed that *T. tenuis* increased the yield and N uptake of rice grown in three different soils of Egypt. Addition of N (36 kg/ ha) and P (16 kg P/ha as 36 kg P_2O_5/ha) further increased the response of rice to algalization.

Alaa El-Din et al (1984) tested two inoculants—*T. tenuis* alone and *T. tenuis* plus *A. oryzae*—on rice grown after a legume crop and a nonlegume crop. *T. tenuis* (476 g/ha + 24 kg N or 238 g inoculant + 48 kg N/ha) increased rice yields up to 71.5% after a legume and 25.8% after a nonlegume. The mixed inoculation (at 238 g/ha + 24 kg N/ha or about 120 g + 48 kg N/ha) gave yield increases up to 54.1% after the legume crop and up to 23% after the nonlegume crop.

Hassan et al (1984), using a mixture of five strains of BGA recommended for field use in Egypt, determined that rice inoculated with the algae and grown after a legume crop needed no N fertilizer; rice inoculated with BGA and grown after a nonlegume required only half the recommended dose of N.

Algalization of ricefields

Methods for inoculating ricefields

Some algal inoculants contain a single algal strain; others, a mixture of two to five highly efficient N_2-fixing strains. The idea of using a mixture is to offset the ecological and edaphic changes to any one strain at a given location, although the ultimate proportion of individual strains in the ecosystem may be unpredictable under field conditions.

Strains that have proven competitive ability under field conditions and are usually used in mixtures are *T. tenuis, Cylindrospermum muscicola, A. fertilissima, Nostoc* sp., *N. muscorum, N. calcicola, Anabaena* sp., *A. oryzae,* and *A. naviculoides.*

Inoculation methods differ with the type of inoculant and the rice growth stage at which it is used. The rate also varies with the location. In India, Singh (1961) recommended broadcasting algal fresh biomass mixed with lime onto transplanted ricefields, while Sankaran (1971) recommended spreading algal suspension, mixed with washed sand, 1 wk after rice is transplanted. Venkataraman (1972) mixed the multistrain soil-based inoculant in a bucket of water containing sodium molybdate (0.5 kg/ ha) and sprinkled it uniformly on the water surface in ricefields 1 wk after transplanting.

For direct seeded rice, the seed is mixed with an algal soil-based culture suspension; the inoculated seed is then rapidly mixed with finely pulverized calcium carbonate (lime), at 2-3 kg lime/ 10-20 kg seed, until evenly coated, then air-dried before sowing.

In Egypt, we have tried these methods: 1) algal sand culture (2.4 kg/ha) broadcast either in the rice nursery or in the field 1 wk after transplanting; 2) dried, pulverized algal biomass suspended in water, applied 1 wk after transplanting. This method has proved successful and was being used on an area of about 4,200 ha by 1986.

The optimal quantity of inoculum applied also depends on the type of inoculant and method of inoculation used. Rates vary from 10 kg/ ha soil-based dry inoculum

(Venkataraman 1979d) to 25-50 kg fresh algal inoculum/ha, which contains 90% moisture (Alaa El-Din 1978). In China, fresh algal inoculant is applied at the rate of 750 kg/ ha; however, this figure seems unduly high, although the major part of the inoculum is propagated in the field.

In Egypt, we have found 240-480 g air-dried algal biomass/ha as satisfactory as the 10 kg/ha soil-based inoculum used in India. The costs of preparing, storing, distributing, and applying 0.25-0.5 kg inoculum are also much lower than those in India for 8-10 kg inoculum/ha.

Economics of algalization

Algal technology has been introduced as a package of practices to rice farmers in India and Egypt. In India, especially in Tamil Nadu, BGA inoculum is produced at rice research stations, state seed farms, village-level *panchayat* unions, and on individual farms. Production costs and net returns depend on the method followed and the scale of production. Many farmers use shallow dug-out pits, lined with polyethylene sheets, to grow the algae at a rate of about 10 kg/d. Returns on investment are fairly high, especially if farmers produce their own inoculum. In large-scale field trials, the cost of about 25 kg N fertilizer/ha could be saved; additionally, yield increases averaging 300 kg/ha raised the cost:benefit ratio to 1:13.3 (1978 figures cited by Venkataraman).

In Egypt, field application of BGA dates back to the 1950s; in 1987, 21,000 ha of rice were inoculated, and we expect to expand this area to about 420,000 ha by 1992.

In large-scale field trials (1,680 ha distributed over 4 governorates), we found that 100 g of this algal inoculant could substitute for half the recommended dose of N fertilizer. Inoculated fields also yielded about 1.6 t/ha higher than noninoculated ones (7.7 t/ha vs 6.1 t/ha).

Potential economic returns (Table 4) from the use of algal inoculants work out to: a) for the government, a cost:benefit ratio of 1:33, or 33 million Egyptian pounds (LE) total per year for the entire rice area; b) for the farmer, a cost:benefit ratio of 1:48.3, or a total of 48.3 million LE per year earned by all the rice farmers in Egypt.

Potential for developing countries

The use of BGA inoculants in ricefields holds considerable potential for developing countries. As India and Egypt (the two countries that have adopted the use of BGA) have found, this technology can

- increase rice yields;
- save on expensive N fertilizer, which is often imported at high cost and paid for in hard currency;
- maintain—even improve—soil fertility;
- reduce environmental hazards from leaching of ammonia, nitrate, and nitrite-N from chemical fertilizer into the groundwater; and
- earn good economic returns for the capital invested in establishing and operating the process.

Other advantages are the ease of handling small quantities of algal inoculant (100-200 g) versus the problems of handling 100 kg of N fertilizer, plus the high cost

Table 4. Economic returns to the government and the rice farmer in Egypt from using N_2-fixing blue-green algae in ricefields.

Economic value	Fertilized with mineral-N only (95 kg N/ha)		Fertilized with 238 g BGA + 48 kg mineral N/ha		Total economic
	t/ha	LE/ha	t/ha	LE/ha	(LE)
To the government					
Cost of mineral-N units		38.56		19.28	
Cost of algal inoculant		–		2.38	
Total cost of fertilization		38.56		21.66	
Economic return from supplementary algalization					16.9
Average yield (paddy)	6.1		7.7		
Yield of seed (white rice)	4.3		5.4		
Price paid to the producer		360.90		455.58	
Selling price to the consumer		594.21		750.37	
Economic return from the yield		234.31		294.79	61.26
Total economic return					78.1 6
To the farmer					
Cost of mineral-N units		24.66		12.33	
Cost of algal inoculant				2.38	
Total cost of fertilization		24.66		14.71	
Economic return from supplementary algalization					9.95
Average yield (paddy)	6.1		7.7		
Yield of white rice	4.2		5.4		
Average selling price		399.80		504.67	
Economic return from the yield					104.88
Total economic return					114.83

Notes for estimating the above economic study:

1. N_2-fixing capacity of the algal inoculant (238 g/ha) is 48 kg N/ha.
2. Per kg price of 1 N-unit is 0.405 LE nonsubsidized, and 0.259 LE subsidized (LEI = US$1.07).
3. The cost of algal inoculant production is 1.00 LE, the same as the selling price to the farmer.
4. The yield of white rice is 70% of the total yield of paddy.
5. The average yield of algalized fields is 7.7 t/ha; of nonalgalized fields about 6.1 t/ha.
6. The price paid to the producer by the government is 85 LE/t.
7. The selling price to the consumer by the government in the local market is 140 LE/t.
8. The average selling price to both consumer and government by the farmer is 94.2 LE/t.

of manufacturing or importing, and the difficulties of storing, transporting, and applying the N fertilizer. The efficiency of chemical fertilizer in waterlogged fields is also low.

However, developing countries have been slow to adopt the use of BGA, primarily because 1) its potential contribution to rice ecosystems is not widely appreciated; 2) funds are not available for equipment and training; and 3) there is a shortage of trained soil microbiologists with a special interest in BGA, and hence an absence of locally produced inoculants.

Thus there is a need to promote BGA technology in developing countries where rice is, or is likely to be, cultivated.

Research needs

Algalization of ricefields should not be considered in isolation but as part of a multidisciplinary approach, demanding the involvement not only of soil microbiologists, but also of soil fertility experts, agronomists, and economists.

Immediate research is needed to:

a. Determine the need for inoculation in various soils and climatic conditions.
b. Start a program of isolation, testing, and culture collection. This should be actively pursued and a culture collection of useful N_2-fixing BGA maintained.
c. Assess the magnitude of biological N_2 fixation.
d. Assess the limiting factors (P, Ca, Mo, S, pH, physical conditions, management).
e. Produce algal inoculants.
f. Establish quality control measures for algal inoculants.

Medium- and long-term research is needed to:

a. Determine persistence and efficiency of inoculant strains.
b. Select strain combinations for adverse soil conditions such as strains with salt and acidity tolerance, and phage resistance.
c. Develop inoculation methods to suit different farming systems.
d. Assess the role of wild BGA in regeneration of soil fertility in fallows.
e. Investigate other systems of biological N_2 fixation, both symbiotic and nonsymbiotic, e.g., *Azolla, Azospirillum, Clostridium, Azotobacter,* etc.

Training and extension

Immediate training and extension needs are for:

a. Postgraduate scientific training for candidates expected to lead the work in national and regional laboratories. This covers short-term training as well as that leading to a higher degree.
b. Applied short-term training courses for agronomists and extensionists involved in national programs in the field.

Medium- and long-term training is needed as:

a. Formal university courses in soil microbiology.
b. Training of BGA inoculant manufacturers and quality controllers.

Recommendations

To help the spread of BGA technology in developing countries, we make the following recommendations.

To governments:

a. Develop national capability in BGA manufacture and use by encouraging and funding training and education.

b. Seek bilateral assistance and help allocate funds to provide the needed facilities.

c. Expedite implementation of technical assistance programs.

d. Encourage cooperative programs with neighboring countries.

To international technical assistance programs:

a. Train nationals at the various levels required. The Food and Agriculture Organization (FAO) and the International Rice Research Institute (IRRI) should provide scholarships for postgraduate training in BGA and take full advantage of know-how already available in the region, e.g., Egypt for Africa and India for Asia, with IRRI playing a central coordinating role.

b. Provide help to initiate trials and demonstrations for BGA inoculation in the field where possible.

c. Strengthen existing soil microbiology programs with personnel, equipment, and transport.

d. Organize seminars, workshops, conferences, and training courses within the rice-producing countries and create a coordination machinery for the technology.

Azolla-blue-green algae association

Azolla spp. are not native to Egypt. *Azolla* was introduced in the country after a team visited the People's Republic of China in 1977 on an FAO study tour. Research was then started at the Agricultural Research Center on adaptation of *Azolla* strains to Egyptian conditions, environmental and nutritional factors affecting their growth, and practical methods to preserve, grow, and transport *Azolla.* The work, carried out in close cooperation with the FAO, has now been scaled up to reach rice farmers in four governorates of Egypt. However, it is still at an experimental stage.

Widespread application of *Azolla* must wait for development of a cheap application method. Trials to use herbicide to harvest *Azolla* and apply as a green manure are now in the experimental phase. Other options could be considered in the future.

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Utilization of biotechnology in the production of cereals

L. Munck

The plant breeder works empirically as a selector in the interface between science and society. Biotechnology tools based on genetics, biochemistry, and physiology as well as downstream processing are of immediate interest to the breeder. Techniques such as gene transfer, tissue culture, and detection of virus DNAs by specific probes could help the plant breeder work much more efficiently but would not substitute for conventional plant breeding, finding the optimal gene background with regard to yield for plants with new specific genes. Utilization of the whole plant for food, feed, and manufactured products sets specific quality requirements for the crop. By exploiting the whole crop harvest (grain + straw), new working opportunities could be created so that the spirit of the Green Revolution could be extended to a broader society. This development can be induced on the incentive of dedicated plant breeders but must be implemented by governments, farmers, and private enterprises. There is need for a balanced strategy to utilize fully the many options of biotechnology within limited resources, with cereal plant production as a vehicle to improve the quality of human life. The international plant breeders are the pioneers in this development.

The present developments within the two different disciplines of biotechnology with which plant breeding starts and ends, molecular biology (see review by Wettstein 1983) and downstream processing (see review by Rexen and Munck 1984), have during the last decade provided the breeder with many new potential options to be discussed seriously.

The symbiosis between molecular biology and plant breeding

Molecular biotechnology gives two main options to the plant breeder. First, it provides new tools that can be used empirically as the other tools of breeding. Secondly, it can explain the biological basis on which breeders work: why, from the biological machinery point of view, they have succeeded in creating new specific varieties, and suggesting new methods to proceed more efficiently.

The tools

Several new tools are now available to the plant breeder; for instance, organ and tissue culture, gene transfer, and new screening methods.

Organ and tissue culture. Embryo culture has long been used to rescue plants in wide crosses between species such as wheat and barley (Kruse 1974). The proceedings of the Symposium on Biotechnology in International Agricultural Research (IRRI 1985) held by the International Rice Research Institute (IRRI) demonstrate clearly that organ/tissue culture already is incorporated as an important tool also in the regular breeding work in cereals (Khush and Virmani 1985, Zapata 1985). Now that regeneration of plants from rice protoplast cultures seems possible (Abdullah et al 1986, Cocking, this volume), new options are created for gene transfer and selection on a cellular basis, as well as a free exchange of cytoplasm, mitochondria, and chloroplasts with different cell nuclei by micromanipulation; e.g., breeding chloroplasts for efficiency (Bornman et al 1986, Wettstein 1983).

Gene transfer. Transferring genes to cereals from distantly related or unrelated plants or even from microorganisms is now within reach (van Montagu, unpublished). Genes have been transferred to maize plants with plasmids from *Agrobacterium turnefaciens* as vector (Graves and Goldman 1986, Grimsley et al 1987) and to protoplasts of *Triticum monococcum* (Lörz et al 1985). Plasmids have also recently been proved to transfer DNA when injected into young floral tillers of rye (*Secale cereale*) (Peña et al 1987). Other techniques, such as microinjection of DNA direct into protoplast (Flavell and Mathias 1984), can now be tested in rice protoplast tissue culture.

New screening methods applied on plant and single-cell level. By imposing a selective environment on the plant, IRRI plant breeders have successfully bred for disease and insect resistance and tolerance for drought, cold, and problem soils (IRRI 1985, Khush and Virmani 1985). Now, selection for aluminum and salt tolerance can conveniently be made in tissue culture on a large scale (Abrigo et al 1985).

Other interesting tools for the plant breeder are antisera, which can be used to detect specific proteins from plants (Rasmussen 1985) or from pathogens, as well as DNA probes, which can be used in Southern blotting techniques to verify the successful transfer of genes (Flavell 1985) or the presence of a specific virus.

Evaluation

The empirical work with the new tools in integrated plant breeding programs will prove or disprove the usefulness of the methods and will further reveal their final place in the arsenal of tools for plant breeding.

The role of individualgenes. Individual genes play a decisive role in survival—a role as important as that of unique combinations of hundreds of genes. (Evolution would be difficult to understand, otherwise.) There are single Mendelian genes that cause drastic changes, with hundreds of pleiotropic effects, in the morphology and metabolism of plants. Mather (1954) named such characters "major" genes as opposed to "minor" genes, which express more limited effects, such as absence of pigment in seeds. We might now tentatively call these genes regulatory and structural, respectively, even though we must caution that we have obtained this knowledge mainly through the study of microorganisms. Besides these, there are "minor" regulatory genes with an additive effect on quantitative characters, such as yield, called polygenes (Nilsson-Ehle 1911). Understanding gene regulation in Eucaryotes will have a revolutionary impact on plant breeding and plant production (Munck 1985). As an example, the Green Revolution in rice and wheat was set in motion by just a few major genes for erect plant stature and daylength insensitivity, which, together with adequate application of fertilizers, pesticides, and water, led to a huge increase in productivity. Of course these genes were adapted to various gene backgrounds suitable for local conditions by careful and intensive crossing and selection on a mass scale at the site, but still, the Green Revolution would have been impossible without the complex pleiotropic effect of these major genes.

The experience from mutation breeding. Other examples of major genes are most of the so-called high-lysine mutants available in barley, maize, and sorghum, which improve the nutritional quality of endosperm protein. Some of these, the *lys 3a* gene from the 1508 mutant in barley (Ingversen et al 1973) and Opaque 2 in maize (Mertz 1976), provide drastic changes in a range of characters affecting cell structure, protein and amino acid composition, enzyme content, and embryo morphology in seeds (Mertz 1976, Munck and Wettstein 1976). In fact, the amino acid composition of the 1508 mutant in barley is nearer that of the pig (man) than to that of barley (Munck 1985). It certainly is a major gene.

Treatment with chemical mutagens, such as sodium azide, causes several mutations per genome, most of them being deleterious for yield; therefore, the selected mutants have to be "cleaned" by backcrossing. It is further possible that the mutation event itself has caused effects on genes adjacent to the mutation site—effects that have to be corrected by trial-and-error breeding for a compensated gene background. Finally, because of their controlling role—expressed in their pleiotropic effects on, e.g., yield parameters—regulatory genes and mutants, to be productive, need a specially tailored genetic background bred for each environment.

It has taken us 14 yr to obtain a stable, moderately high-yielding line of the mutant gene 1508 in barley (Bang-Olsen et al 1986, Munck 1986a, Munck et al 1986). The new line Ca700202 was obtained by crossing and selection on a large scale, which was possible without chemical analysis for lysine because we could use the large germ, pleiotropic to the *lys 3a* gene, as a selection criterion. Likewise, my colleague, Diter von Wettstein, at the Carlsberg Laboratory, has succeeded in correcting the yield of proanthocyanidin-free mutants in barley (Wettstein et al 1985). Proanthocyanidins cause haze in beer. The metabolism of these secondary metabolites has been investigated in detail by studying the mutants. The proanthocyanidin genes of barley should in most cases be regarded as less complicated than the high-lysine genes. They seem to be of the minor gene category, with a structural function coding for a specific protein (enzyme). Still, most of these mutants yield less than the mother variety and this has to be corrected in conventional plant breeding programs. It could then be anticipated that most mutants or even transformed genes, especially those with a pleiotropic effect, must have a gene background specifically bred for them, for optimal yield performance. If so, the eventual success of transforming genes into cereal plants would place an even heavier working load on traditional plant breeders than they carry today. The experience with mutation breeding and with the major genes that constituted the Green Revolution demonstrate the need to work consistently and dedicatedly on a mass scale.

The importance of a balanced genome to obtain a productive plant. In many cereals such as barley, there are large parts of the center of the chromosomes that are blocked for recombination. If these "stiff" areas could be made more flexible, e.g., introducing new genes enabling recombination, plant breeding work would become much more efficient. Another option would be to transfer genes from these blocks to obtain recombination. However, classical plant breeding has shown that the diversification of the genome has quite narrow limits if we want to retain a productive plant. Thus, in 2-row versus 6-row barley and in spring versus winter barley, crosses rarely give useful results. We say that they have a poor combining ability. The 2-row/6-row and spring/winter characters depend on only one or on a few sets of genes. The genomes of the populations characterized by these genes have drifted away, being separately selected by man over many thousand years in this self-pollinated crop. These genetic differences are expressed in the large variability of the outcrosses, which makes selection for specific characters difficult. It is obvious that crosses now possible between much more unrelated plants would be even more difficult for the plant breeder to exploit. In such cases, we must aim at recovering specific genes with specific screening methods, widening the gene pool in key characters, both for major and minor genes, and using classical breeding methods to tailor the gene background as needed.

How to define and select genes of practical interest. There are rapidly increasing libraries of DNA sequences and protein sequences, stored in computers. These libraries, available worldwide, contain both data for proteins of well-known function and sequences where the protein counterpart has never been isolated. In the last 8 yr, my department has been involved in the study of the structure and synthesis of water and salt-soluble proteins in the different tissues of the developing and germinating barley seed (Mundy et al 1985, 1986; Mundy and Fincher 1986; Mundy and Rogers 1986). To our surprise, we have found that many of these proteins are enzyme inhibitors of both endogenous enzymes and of enzymes produced by insects, bacteria, and fungi (see review by Munck and Mundy 1986). We have thus isolated and sequenced a barley a -amylase/ bacterial subtilisin (protease) inhibitor ASI (Mundy et al 1983, Svendsen et al 1986) with two reactive sites. The synthesis of this inhibitor is stimulated by abscisic acid in the germinating aleurone layer (Mundy 1984). Likewise, we have studied a unique chymotrypsin inhibitor CI-2 (Jonassen 1980, Svendsen et al 1980). One of the most exciting results is the identification of a new enzyme produced in the barley seed that can degrade chitin, the skeleton and cell-wall lining of insects and fungi (Leah et al 1987).

From our studies we can conclude that several percentages of the proteins in the barley seed have effects against invading organisms; presumably, effects of the more broad and unspecific general resistance type. Many genes are involved. In my example with the barley seed, structural genes as those for CI-2 and ASI code for specific proteins, while major genes situated on other loci and chromosomes control them. The gene for CI-2 in chromosome 5 is overexpressed in the high-lysine barley Hiproly (Jonassen and Munck 1981) but controlled by the regulating action of the gene *lys 1* in chromosome 7. We have also found that the high-lysine mutants M7 and M1508 (in chromosome 7) in an isogenic background stimulate the production of CI-2 in the growing endosperm of mutant 7 at an early and mutant 1508 at a late stage (Desler, pers. comm.). With the two regulating genes together, the double recessive combines to produce CI-2 at a high level during the entire development period of the seed.

We are still far from identifying the gene sequence and primary function of the major genes on which the Green Revolution was built, such as the Norin 10 dwarfing genes *Rht1* and *Rht2.* We know that plant hormones like gibberellic acid (GA) are involved and that GA may control certain promoters in the genome that can switch on genes. With aneuploid techniques in wheat (Law 1986), it has been possible at the Plant Breeding Institute in Cambridge, UK, to locate enhancing and inhibiting genes for plant height to the different chromosomes. With the help of protoplast culture and DNA techniques now available in, for instance, rice, a whole range of transformations, from extracted native DNA or DNA transcribed from extracted RNA to vector-transformed DNA coding for specific genes, is within reach.

Thus, the International Center for Maize and Wheat Improvement (CIMMYT) (Mujeeb-Kazi and Jewell 1985) prefers experiments with transferring extracted whole DNA from *Tripsacum* spp. to maize by soaking maize pollen, while others (Gerlach et al 1985) favor the transfer of specific genes. We are then again coming back to the basic problem of how to trace and define the regulating major genes. There is no doubt that wheat is a good choice as a model plant in this context, because chromosomal/cytological and molecular techniques can here be optimally combined (Law 1986).

However, my personal estimate at present is that, from the breeder's point of view, it is even more important to obtain specificity in the screening/selection techniques than in the gene transfer step. Here, molecular screening techniques on the DNA level (Flavell 1985) seem most promising if they could be conveniently performed on a mass scale.

The living plant and its tissues are our dynamic battlefield. Isolated DNA and RNA fragments are quite interesting for information; but isolated, they are essentially dead; therefore, we must test them as part of the whole system. We have broken the first seal of the genetic code, revealed as amino acid sequences of specific proteins. Now we must break the second seal—howthe structural genes are regulated.

Cereal production efficiency and downstream processing

The basic structural problems

Modern agriculture is based on technology that was developed when energy was extremely cheap. The world market price of maize has decreased rapidly in relation to oil prices, in spite of the recent drop in oil prices, because of the international trade surplus in grain. Rationalization of grain production will bring down the cereal prices, expressed in oil units, still further. Even presently, both maize and palm oil residue fractions could compete with oil in the world market as a fuel. With these pressures, the input of energy and raw materials in agriculture will decrease further in spite of increased yields from new biotechnology techniques in controlling plant and environment. The international plant breeding institutes are instrumental in this development.

The population pressure is also increasing rapidly: world projections are an increase from 4.4 billion in 1980 to 6.1 billion in 2000. With the help of the Green Revolution, cereal production has kept pace with population increase in most developing countries, with the sad exception of Africa. In 1984, world production of rice was 470 million t; by 2000, this will have to rise to 640 million t (Swaminathan 1985). There is also produced about 700 million t of rice straw (Barber et al 1981).

The essence of development in Europe, for example, is the success in industrializing the manufacture of cereal-based food and semimanufacture, based on old traditions. While foods and local raw materials today in Europe fit together, this matching has become extremely poor in Africa. where the African city culture has taken over western food habits without the necessary raw material production, because climatic and ethnographic conditions are different. Africa is lagging behind in the Green Revolution because there is little market for Africa's own sturdy, drought-resistant cereals, sorghum and millets. The fine local foods made from these cereals have not been industrialized to compete with refined wheat 2nd maize flour produced in mills in the urban areas (Munck 19865).

We have studied local food habits in Africa (Bach Knudsen and Munck 1985; Eggum et al 1981, 1983) and have developed dehullers, milling machines, and processes adapted to the unique properties of sorghum and millets (Hallgren and Murty 1983; Munck et al 1981, 1982). Countries like Nigeria are showing increasing interest in becoming self-sufficient in foods because the lack of hard currency limits imports. Therefore, Nigeria now restricts import of wheat and barley malt, stimulating local production of foods from local cereals such as sorghum and maize. Through our subsidiary, United Milling Systems. we have developed the necessary technology and have now delivered sorghum mills for *Kisra* flour in Sudan and for *Ogi* and brewers' grits in Nigeria, as well as maize mills for brewers' grits in Nigeria and the People's Republic of China. Establishing these mills has been hard work, but now the future seems brighter because the governments are realizing the necessity of self-sufficiency, not only to save foreign currency but also to obtain employment in rural and urban areas.

In Asia, food production matches the consumption pattern in the urban areas much better than in Africa, but the still higher population pressure both in the cities and in the countryside necessitates the creation of jobs locally, especially for landless families, also involving the women.

Agriculturalrefineries

We have completed a study for the European Economic Community, reviewing cereal crops for industrial utilization (Rexen and Munch 1984).

New harvesting and treatment centers are needed to open up new product applications in the interface between industry and agriculture. We have called these centers agricultural refineries (Munck and Rexen 1985; Rexen and Munck 1984,

1985) because they will be able to collect, treat. and produce a wide range of raw materials and products, as well as to fractionate different whole crops into intermediate products of defined quality, tailored to be used as raw materials in industry.

A rice refinery collects and separates the botanical components of the rice plant. e.g., divides straw into internodes (stem), nodes, and leaves, to be distributed to industries as semimanufactured materials for particle board, paper, and chemicals. We have developed a process that can separate the internodes from the leaves by making the latter into flour. The leaf meal is high in protein and hemicellulose but low in cellulose, making it a good feed pellet for ruminants if sprayed with 1.2% NaOH just before pelleting. It can also be used directly as a fuel source. The internode chips containing more cellulose than the leaves make an excellent fiber board pressed with ureaformaldehyde glue modified with isocyanate. The chips are also good for making paper much better than that made from unseparated straw.

If we consider starch and cellulose—the two major biologically produced polymers—available in approximately equal quantities in a cereal field, their world market price (in 1985) is, astonishingly, about U.S.$0.20/kg for starch and about U.S.$0.30/kg for cellulose, which is becoming more expensive than starch. The raw material price that could be paid for straw to make fiber board and paper in competition with wood is as high as U.S.$0.044.07 kg.

The major problem is that of entropy. how to effectively collect the dispersed straw to feed the comparatively large factories needed. However, this should not be impossible if an incentive in the form of a reasonable price for straw could be realized. Today in the Philippines, the price of feed is so high that 150 kg of straw per day collected free and delivered to an alkali pellet factory would pay enough to feed a family.

Conclusion

When Drs. Borlaug, Swaminathan, and coworkers launched the Green Revolution by combining a few major genes in wheat and rice with fertilizers and pesticides and sold the “package” to the small farmers and to governments, very few people believed in their concept at the outset. We all remember the pessimism of the “Club of Rome” in the early 1970s, forecasting a worldwide famine disaster in the 1980s. Still, the challenge is even greater now than 20 yr ago.

There are many enthusiastic and constructively critical people who want to contribute, so it is much more difficult now to obtain a general consensus for a consistent program that can be explained to the public. I am convinced that it is the international plant breeding community that could bring order to this potentia! chaos.

Surely the success of future work requires an even higher degree of cooperation between the plant breeding institutes—international and national—and governments, farmers, universities, and industries. The community of plant breeders must, however, feel and be free to select from the wealth of options given, concentrating on plant breeding and its tools but also to be able to take new initiatives like those in the first Green Revolution. They must also have facilities to evaluate and to demonstrate to decisionmakers the principles and the value of a coherent technological/social approach (Swaminathan 1985).

Some social scientists (like Buttel et al 1985) feel that genetic engineering techniques launched in the private sector of western countries could lead to a monopolized international plant breeding, so that public agricultural research would become nonexistent in the next 20-40 yr. I am not that pessimistic. I think, as I have outlined in this paper, that there would be even more need for the skills of the up-to-date classical plant breeder when new molecular techniques make their breakthrough. Just as the fertilizer and pesticide industries contributed and made their profit from the Green Revolution (also introducing some problems, which are going to be corrected), the gene industry will find it highly useful to cooperate with the international plant breeding institutes because only these institutes can provide the knowledge of the needs and constraints of farmers and the necessary approach that will lead to a broad technological success.

Likewise, local and international equipment industry will, on the incentive of plant breeders, realize the huge potential market for the industrialization of local foods made from local raw materials. It will also become increasingly clear that creating rural agricultural refineries will lead to local self-sufficiency in energy for cooking, in building materials, in paper and packaging material made from byproducts such as rice straw.

Industrialized countries must realize that self-sufficiency in foods and basic materials is the prerequisite for purchasing power on the international market for developing countries; additionally, that food and job security will play a key role in controlling population growth and preventing international distress.

To realize these perspectives, there is a need to give the incentives and credits to all contributors to work in the right direction by showing the public how the symbiosis between man and his cereals could develop. The international plant breeders are the pioneers in this development.

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Rice processing and handling technologies

M. R. El-Amir

The rice milling industry in Egypt was nationalized in 1962. Following a countrywide survey soon after, the industry was modernized by phasing out obsolete units and replacing them with up-to-date efficient units to handle increased production and to reduce losses during storage and milling. Current and future strategies are outlined for improving storage conditions; testing quality and purity of rice received; installing modern equipment for shelling, drying, sieving, and whitening of rice, especially the new high-yielding and long-grain types, and expanding use of electronic sorting equipment. New ways of using milling by-products, such as brokens, husks, and bran, are being introduced. The Rice Technology and Training Center in Alexandria plays an important role in the modernization process, with research backup and industrial extension programs.

Postharvest activities for rice in Egypt include government procurement of rough rice from farmers, processing, and marketing. Present policies require each rice producer to deliver 1.5 t of rough rice to one of the procurement stations scattered throughout the rice-growing regions in the Delta area and in a small region in Upper Egypt.

Although average rice yields in Egypt are among the highest in the world, considerable losses occur between harvest and delivery to the procurement stations. Preliminary studies indicate that about 15% of the product is lost when it passes through this part of the marketing channel. Often rain during the delivery season, especially in the northern Delta area, adds to these losses. At the procurement stations, facilities for storing the rice for processing are inadequate and subject to wind and weather, contributing further to loss.

The first step in our plans to reduce these losses is to build a new integrated network of procurement stations, equipped with modem silos and appropriate facilities to receive the rice brought there, to assess its quality and purity, to provide weatherproof storage, and to use bulk transportation methods to carry the rice from the storage point to the rice mills. Manual labor for loading and unloading will be reduced to a minimum.

Milling

In 1962, the rice milling industry in Egypt was nationalized; thus, in describing the processing operations, we distinguish two distinct periods, before and after nationalization.

Before nationalization

Before nationalization in 1962, the rice milling industry in Egypt consisted mostly of individually owned factories, large and small. The majority of these units were antiquated, not capable of producing exportable quality rice or rice products. Productive capacity was low or not fully utilized; storage facilities were poor. Additionally, buildings and power sources were inadequate or inappropriate.

Milling machinery was mostly obsolete, using single- or double-pass Engelberg whitening machines, and by-products were a mixture of germ, brokens, bran, and husk, which could not be separated into individual components.

After nationalization

In 1961-62, decrees were issued to nationalize 87 factories, with an estimated total milling capacity of 4,000 t white rice/d. Since then, milling units have been divided into public sector and private sector mills.

Private sector mills. We estimate there are about 6,000 small private sector units, scattered throughout the rice-growing regions, which mostly process the rice for the farmers' home consumption. These Engelberg-type units are locally manufactured and about half of the annual rough rice production of the country is milled here. The Rice Technology and Training Center (RTTC) in Alexandria plans an industrial extension program to improve the efficiency of these units.

The private sector also owns relatively larger commercial hullers and mills. Before nationalization, the operators of these mills dealt directly with the farmers to procure rice; by current regulations, however, they are allocated certain quotas of rough rice for processing, through the government procurement centers. The white rice produced must be turned over to the appointed public sector mills; however, the private operators may keep the by-products. This system has been in effect since 1973.

The total capacity of these mills is estimated to be about 64,000 t of rough rice, producing about 43,000 t of white rice.

Public sector mills. Immediately after the milling industry was nationalized in 1962, a complete survey was made of the existing facilities. Of the 87 mills, 16 had stopped production, several others were working at very low capacity, and, because of nonstandard equipment, none was working at full capacity. Based on this survey, and considering that the Aswan High Dam project was expected to supply irrigation water that would bring an additional 420,000 ha under summer rice, an overall plan was evolved to update the milling industry.

The first step was to phase out gradually the low-producing uneconomic units. At the same time, the plan called for increasing the total capacity of milling in Egypt by building modem and efficient factories, and replacing obsolete and inefficient machinery in the old units. This new policy has resulted in an updated industry capable of handling over 1 million t of rough rice annually. By 1969, the newly built units were producing about 750,000 t of highquality white rice that was exported to European, Gulf, Southeast Asian, and African countries. Ten new mills have added a daily capacity of 1,470 t/d.

More recently, the milling industry has had to make further adjustments and modifications to cope with the new high-yielding varieties of rice (e.g., Giza 171, Giza 172, Giza 173) and the long-grain varieties introduced into Egypt by the Ministry of Agriculture. These new types, especially the long-grain ones, give a high percentage of broken grain if milled by the old methods, using desk shellers to husk rough rice and vertical cones with abrasive materials.

Therefore, the old Italian and German technology have been replaced with more efficient Japanese systems adapted to the modem rice varieties; these use

- rubber huskers instead of underrunner desk shellers to significantly reduce the percentage of brokens;
- horizontal whitening equipment that increases the output of white rice by about 80 kg/t of rough rice, in the long-grain varieties.

Secondly, the technique of parboiling has been introduced to modify the taste of long-grain rice to suit the Egyptian consumer. This technique also increases the nutritional value of rice with added vitamins thiamin and riboflavin, for instance, and results in less broken rice. Three parboiling units are operating at present—two in RTTC in Alexandria and one at Somoha Rice Mill, also in Alexandria. A fourth is under construction in Kafr El-Sheikh governorate, with 110 t/d capacity.

Future of rice milling in Egypt

Planning for the future in rice milling must take into account expected changes in rice production in the short and long run. Little change is expected in the major rice-producing governorates (Beheira, Kafr El-Sheikh, Gharbia, Dakahlia, Sharkia, Damietta, and Fayoum), as these are already producing to capacity on the maximum area allocated to rice. Potential expansion of production area lies only in Menoufia and Kaliohia governorates, where rice will be competing with summer maize over an area of about 42,000 to 84,000 ha.

Under these circumstances, we expect that additional production will amount to about 250,000 t, yielding 160,000 to 170,000 t of white rice. The current milling capacity could handle this.

Therefore no addition to the current capacity is expected in public sector mills until the year 2000. However, modernization of milling facilities in the public sector will continue and is provided for in the new five-year plan. Shelling, sieving, drying, and whitening equipment, especially, will be modernized, and electronic sorting machinery, which aids in the production of highquality rice, will be expanded.

Parboiled rice will increase to 25% of the total rice produced by public sector mills.

Other projects to reduce waste and loss and maintain high production include:

1. Building a system of silos to improve storage facilities for dried rough rice received from procurement stations in the mills.

   Twelve silos are planned in different rice mills of the public sector, with individual capacities ranging from 3,000 to 10,000 t, or a total capacity of about 86,000 t in the short run; this is expected to rise to about half a million tons in the long run.
2. Handling techniques will be improved, and mechanized handling of stored rice will considerably reduce manual labor in the mills and increase efficiency.

3. Improved packing, using 1- or 2-kg cartons or plastic bags, will be extended to include 80% of the white rice produced.
4. Production of rice substitutes—e.g., macaroni, artificial rice—will be increased. Factories are already being built by public sector mills to produce macaroni, noodles, and artificial rice, using rice brokens, wheat flour, soybean, mineral salts, and vitamins. Four such units are being built by public sector milling companies in Alexandria, Rashid, Sharkia, and Dakahlia.
5. Several projects are planned for utilizing rice-milling by-products.
   a. *Rice husks.* Crushed rice husks, enriched with 1.5% urea as a protein source, will be used for making animal feed, of which there is a shortage in Egypt. The two feed mills currently operating in Zagazig and Sherbine together produce about 270,000 t/ yr. Six more factories are planned, for a total capacity of 1.14 million t annually.

      We are also studying the possibility of using rice husk in generating the electricity needed for the rice mills and for drying rice.
   b. *Rice bran.* We are studying the use of rice bran to extract edible oil, with the by-product to go into animal feed.
   c. *Rice germ.* Rice germ oil can be used in different industries and germ cake used for animal feed.
6. Because rice milling is a seasonal industry, several public sector mills are branching out into supplementary activities to generate income during the slack season—for example, packaging of vegetables and fruits, manufacturing ice, and supplying cold storage.

Notes

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Basic rice seed production in Egypt

J. M. Swagerty

The basic rice seed production program under the Egyptian Ministry of Agriculture and Land Reclamation is responsible for maintaining varietal purity and for multiplying seed of newly released varieties to make it available to farmers. The goal of the program is to provide 50% of the seed requirement each year for the entire rice area. The Seed Team's activities in improving yields and quality of foundation and breeders seed, training personnel to maintain the required standards for certified seed, and introducing new cultural practices and harvesting and storage facilities are described.

The rice seed production program in Egypt is designed to maintain varietal purity and to multiply the seed of newly released varieties to make it available to farmers.

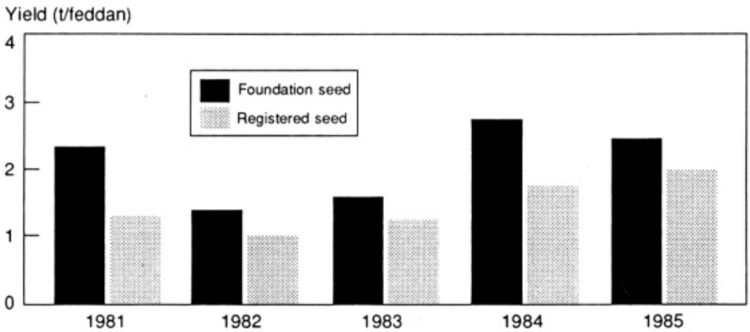
The basic seed program is responsible for producing the "head rows" to maintain varietal punty and for producing all foundation seed. Registered seed is produced by the State Farm managers, with the Seed Production Team serving only as consultants and advisors.

Certified seed is produced by contract growers through the Ministry of Agriculture, Seed Department. The goal of the Ministry of Agriculture is to provide 50% of the requirement of planting seed each year for the entire rice area.

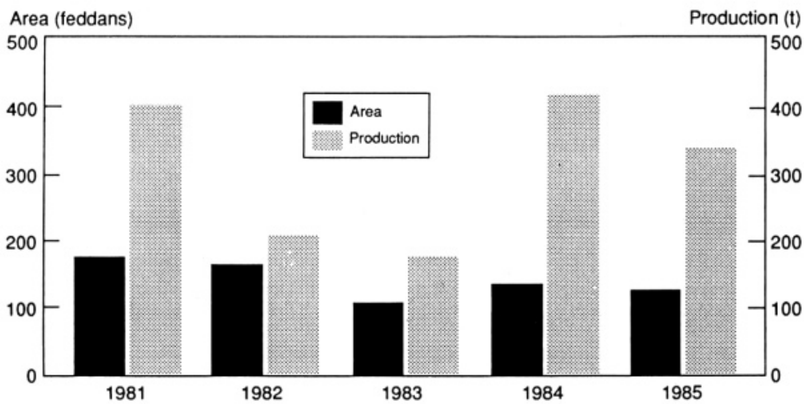
The seed production program

When the Rice Research and Training Project (RRTP) started in 1980, seed production on the State Farms was very low—approximately 2.4 t/ ha. Not enough foundation seed was produced to plant all the area (about 1,260 ha) for registered seed. There was also contamination in the fields from off-types and red rice, even in the foundation seed.

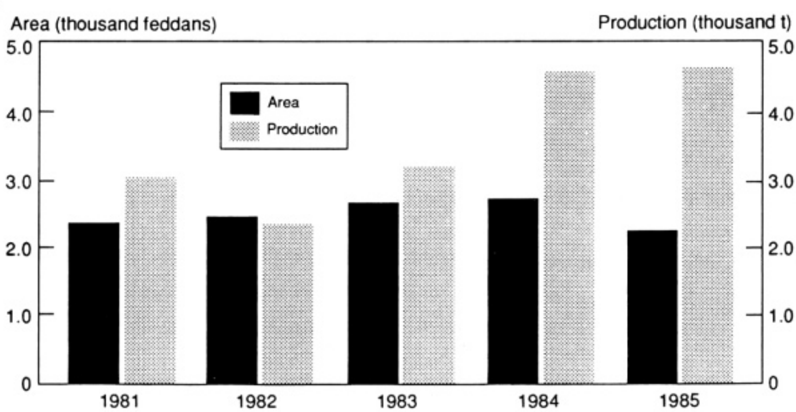
Seminars and classroom meetings were held with the farm managers to improve this situation. With 6 yr of effort working individually with the farm managers and demonstrating proper cultural practices, the RRTP Seed Production Team has helped increase average seed yields substantially (Fig. 1), and the off-types and red rice have been eliminated from all foundation and registered rice seed fields. Figures 2 and 3 show the increase in area and production of foundation and registered seed in Egypt over the 5-yr period 1981-85. In 1986, for the first time in the seed production program, all registered fields were planted with foundation seed.



1. Yield levels of foundation and registered seeds. 1 feddan = 0.42 ha.



2. Area and production of foundation rice seed, 1981-85. 1 feddan = 0.42 ha.



3. Area and production of registered rice seed, 1981-85. 1 feddan = 0.42 ha.

The Seed Production Team purchased a complete line of large field equipment to prepare the fields for planting and combine harvest. The Seed Team has totally produced the crop from field preparation to harvest on about 252 ha/ yr since 1983 to demonstrate proper cultural methods. Direct seeding by broadcasting and drilling was also successfully introduced, and is being adopted by the State Farm managers to reduce labor and costs.

To eliminate red rice and off-types, all fields are rogued at least twice, once after heading and again at full maturity, just before harvest.

The certified seed fields planted and harvested by contractors are still a problem. In 1982 the Seed Team, in collaboration with the Extension Program, trained 90 members of the National Seed Production Board to rogue contractors' fields. In 1983, another 50 personnel were trained for roguing. Unfortunately, these people are not provided with transport. So many contract growers are small farmers, it is not possible to inspect all the fields. Therefore, only about 35% of the contractors' fields have samples of rice that pass the certification laboratories with no off-types or red rice. Consequently, the Seed Board is forced to accept lower standards of seed that is not totally free of contamination.

Seed production suffered a severe setback in 1984, when an epidemic of blast hit all rice production. Variety Giza 172 was dropped from the seed increase program. The blast eliminated the newly released variety of Reiho and three new lines that were under seed multiplication. Therefore, large tonnages of ordinary seed had to be utilized for farmers' plantings in 1985.

This difficulty was overcome by again planting Giza 171 and Giza 172 in most of the area in 1986, with IR28 and IR1626 planted in smaller areas. Four promising new lines are being increased in 1987 for possible release.

Thus, the Seed Production Team has succeeded in increasing yields on the State Farms by about 35%. The contamination by off-types and red rice have been eliminated through registered seed production.

Direct seeding methods and improved cultural practices have been adopted by the State Farm managers, although a shortage of irrigation facilities prohibits further adoption on the State Farms as well as farmers' fields.

Faster harvesting has also improved yield and quality. With the addition of new and larger capacity combines, the harvest is now completed in early November, where previously it was not completed until some time in January, with heavy losses in yield and quality.

The RRTP is constructing seed-cleaning facilities and storage that will be capable of handling all the State Farm production of foundation and registered rice seed production. These facilities should be operational for handling the 1986 crop.

Future program

The Seed Production Team will continue to produce all breeders and foundation seed, and bear the responsibility for maintaining varietal purity.

There will be a continuing program to consult with and advise the State Farm managers on cultural practices and management to increase seed yields.

Efforts will be made to further increase direct seeding practices, enabling us to reduce costs and time of planting on the State Farms.

With the new seed-cleaning facilities and field equipment on hand, we anticipate that harvesting can be converted to bulk handling to eliminate sacking from the combines. This would about double the harvesting rate of the combines in the field. A good 50% of harvest time is lost sacking the grain at the combines, which now harvest approximately 4–5 ha/ d each. With bulk handling, this can be increased to 8–10 ha/d and eliminate the cost of about 15 people in the field doing the sacking.

The newly harvested grain can then be passed through the cleaning plant at the time of harvest. The grain will store better with all waste materials removed before storage in the warehouse.

Notes

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Certified rice seed production in Egypt

A. F. EL-Azizi AND A. A. Gomaa

Egypt currently produces enough certified rice seed to cover about 50% of the rice area annually and aims to increase this to 60-70%. The Rice Seed Production Program applies to all registered varieties recommended by the Egyptian Ministry of Agriculture and is supported by an annual government premium of 20% to encourage certified seed producers. This paper outlines the present system of certified seed production, identifies the constraints, and makes recommendations for improving the efficiency of certified seed production in Egypt.

Rice—introduced in Egypt around AD 600 by the Arabs—is today one of the major crops in Egypt. It is a basic food and provides important export earnings.

The crop was initially recommended in the north-central areas of the Nile Delta where widespread salinity made cultivation risky and productivity low. Rice was used as a crop for reclamation of the saline areas. By now, the cultivated area has increased to more than 400,000 ha and includes fertile and semifertile soils in addition to newly reclaimed land.

Rice has always played an important role in the Egyptian economy, and it became essential to improve production and quality of rice varieties and to maintain their genetic purity. The Ministry of Agriculture started in 1917 to breed high-yielding, good cooking quality rice varieties and to maintain the genetic purity of the developed varieties.

Seed certification enactments

Pure seed is one of the major requirements for higher production. Therefore, the Ministry of Agriculture has developed a fairly comprehensive seed program over the last three decades. Many seed acts were proclaimed—in 1926, 1932, 1946, and 1950—to regulate seed production and marketing. In 1960, an act was proclaimed, covering all crops and introducing seed certification. Finally, a revised and complete legislation was included in an all-inclusive Agriculture Act (Law No. 53 for 1966). This law covers all the aspects included in the previous laws, with different chapters on controlling seed production and marketing, new varieties registration, etc. The first 5-year plan 1960/61-1964/65 aimed to produce and distribute enough rice seed every year to cover one-third of the rice area; later, this was modified to cover more than 50% of the rice area.

Agencies involved in certified seed production

The Rice Research Section of the Field Crops Research Institute, under the Agricultural Research Center, does the plant breeding and produces the breeders seed and foundation seed. The Agriculture Production and Experiment Station Sector (State Farms) produces the registered seed on State Farms under the supervision of rice researchers.

The Central Administration for Seed (CAS) produces certified seed through contracts with individual farmers, agrarian reform cooperatives, and other agricultural cooperatives. The CAS is further responsible for seed testing and seed certification, including the selection, supervision, and inspection of contract fields, roguing off-type plants, sampling for seed testing, and distributing certified seed to the farmers. The CAS works closely with several other departments and agencies within and outside the Ministry of Agriculture.

The CAS has two rice-seed cleaning stations (Sakha and Gemmeiza) to clean foundation and registered seed. Seed produced on contract and by other agencies is processed in six cleaning stations belonging to the Egyptian Agricultural Organization. All these operations are under the technical supervision of resident representatives of the CAS. There are two official seed-testing stations (Giza and Tanta). The Giza station is a member of the International Seed Testing Association. Each station handles more than 80,000 seed samples annually. The Agricultural Cooperative Credit Banks handle financing, purchasing, transporting, and supplying seed to the agricultural cooperatives.

Distribution of seed

Farmers have full access to their own seed crop, and this has to be considered in any seed program. Egypt currently produces enough certified seed to cover about 50% of rice area annually and aims to increase this to 60-70%.

The new rice varieties are designated for planting in specific governorates: Giza 171 in Sharkia, Gharbia, and Beheira; Giza 172, a salt-tolerant variety, recommended for newly reclaimed areas with salinity problems, in addition to Damietta, Dakahlia, Kafr El-Sheikh, and Fayoum; and IR28 and IR1626, long-grain, short-statured varieties grown in selected areas of all governorates. Giza 175, a new variety of short grain and short stature, was approved for release to replace Giza 172, which is highly susceptible to blast. This separation of varieties by location prevents mixtures and ensures a homogeneous supply of rough rice to each milling complex.

The Rice Seed Production Program applies to all registered varieties recommended by the Ministry of Agriculture and is supported by an annual government premium of 20% over the current market price, in order to encourage the certified seed producers.

Table 1 presents the acreage and production in the different multiplication cycles of five commercial varieties. Production of registered seed is sufficient to plant more than 25,000 ha of certified seed, which is sufficient for more than 60% of the total rice area.

Table 1. Area planted to 5 rice varieties for seed production in Egypt, 1986.

Rice variety	Class of seed	Area (ha)
Giza 171	Foundation	17
	Registered	517
	Certified	12,658
Giza 172	Foundation	17
	Registered	303
	Certified	5,664
Giza 175	Foundation	5
	Registered	6
	Certified	–
IR28	Foundation	6
	Registered	115
	Certified	4,739
IR1626	Foundation	5
	Registered	142
	Certified	2,100

Seed-testing rules and regulations are in general those followed by the International Seed Testing Association. Standards for rice are as follows:

Off-type (maximum)—0.1% in foundation seed; 0.3% in registered seed; 1.0% in certified seed.

Red rice—None.

Weed seed (maximum)—0.3%.

Germination (minimum)—85%.

Constraints to certified seed production

Existing varieties have become contaminated and should be purified. New varieties should be released. The CAS contract growers are to produce certified rice seed. However, no complete inspection of fields is carried out and certification relies on samples taken after threshing. Samples are taken from lots of 6 t and are tested for off-types and red rice. Approved seed lots are cleaned and sampled for grain weight, color, insect and disease damage, purity, and germination. The CAS is under severe pressure to provide enough seed to plant 50% of the rice area. Therefore, a "class B" seed of lower purity is also released. This procedure increases the percentage of red rice and off-types, and millers complain about the low quality rice.

This situation occurs for the following reasons:

1. The seed cleaning plants are old and are inadequate for the job. Hulled grain is not removed, and the percentage of small, unfilled grains and weed and grass seed is too high.
2. Field inspection is almost impossible and control of transport and storage is very difficult, because many contract growers have less than half a hectare of land.

3. Grower identity is not maintained. Many small lots are involved, and a single 6 t sample represents several seed growers.
4. Certified seed growers receive only a small premium, which does not encourage farmers to produce seed. Rice production is highly subsidized, and each grower is required to sell approximately 3.7 t/ha to the government at a low price. This system restricts the quantity of certified seed available for seed purchases. A larger acreage is needed to produce the necessary amount of certified seed.
5. Insufficient transport facilities make inspection, sampling, and delivery of seed difficult.
6. The State Farms, where the breeders, foundation, and registered seed is produced, have a record of production far below the national average. This constrains multiplication of registered seed because of the limited available acreage. The State Farms also lack adequate machinery and budget to effectively follow the required production practices.

An effective program was carried out in 1986 by CAS for inspecting the certified fields. Fields that included red rice plants were rejected. Samples from the accepted fields only were tested for red rice in the Seed Testing Laboratories. The data obtained indicated much improvement in the certified seed quality in 1986. As a result, certified seed free of red rice has risen to 43.7% in 1987, from 8% in 1985 and 12% in 1986 (Table 2).

Recommendations

We suggest the following measures to improve and increase certified seed production in Egypt:

1. Each contract field area should be at least 2 ha, to reduce the number of contractors and ease the inspection of fields.
2. Field inspection should be done at least twice before each harvest.
3. Contracts should not be renewed with growers who fail repeatedly to produce certifiable seed.

Table 2. Expected distribution of certified rice seed in Egypt, 1987.[a]

Variety	Total amount (t)	Amount of pure seed[b] (t)	Amount (t) of seed expected to contain indicated percentage of red rice					
			0.1%	0.2%	0.3%	0.4%	0.5%	0.6-1.0%
IR28	6,000	5,400	600					
IR1626	3,000	2,400	600					
Giza 171	18.000	5,280	7,920	1,560	1,080	360	840	960
Giza 172	12,000	3,960	6,840	1,080	120			
Total	39,000	17,040	15,960	2,640	1,200	360	840	960

[a]Expected planting rate = 140 kg/ha (60 kg/feddan). [b]Certified seed containing 0% red rice,

4. The sampling system should be modified to be sample representative, 6 t/lot instead of 12 t/lot. This may save several growers from rejection.
5. Seed should be packed in lots of 60 kg, rather than 80 kg as at present, to match the recommended seeding rate (60 kg/feddan, equivalent to 140 kg/ha).
6. The old and inadequate seed-cleaning plants should be replaced with modern ones.
7. The government might review the premium scale for contracting certified seed and offer stronger financial incentives to be close to the free price.
8. The fixed price for commercial rice should be based on milling recovery percent, quality, and moisture percent. That will force the growers to deliver better quality grain to the mills.
9. Storage should be designed and maintained with care to maintain seed viability.

Notes

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Heterosis in rice *Oryza sativa* L.

A. A. El-Hissewy, A. E. Aly, M. I. Shalaan, and M. A. Maximos

Heterosis for grain yield per plant and 5 agronomic characters (number of panicle-bearing tillers per plant, panicle length, culm length, 100-grain weight, and heading date), as well as 4 grain quality characters (grain shape, hulling percentage, chalkiness, and gelatinization temperature), were studied in an 8-parent diallel cross. The heterosis effects were computed as increase or decrease in mean values over midparent and better parent values.

Positive and highly significant heterosis for grain yield per plant was observed in eight cross-combinations over the midparent. The cross Giza 172/Giza 180 gave the highest heterosis effects over the midparent, followed by the cross Giza 171/Ratna. However, heterosis effects estimated over the better parent for grain yield per plant were insignificant. Of 28 crosses, only 4 showed a highly significant and positive heterosis effect over the midparent value for number of panicle-bearing tillers and 100-grain weight. Only Giza 171/Giza 180 gave highly significant heterosis effects over the better parent.

For grain shape, negative and highly significant heterotic effect values were found in 13 crosses as deviation from the midparent, but only in 3 crosses as deviation from the better parent. The heterotic effect values for hulling percentage were positive and highly significant in 14 cross combinations as deviation from midparent and in 4 crosses as deviation from better parent mean values. In respect of chalkiness, 3 cross combinations exceeded the midparent value toward the translucent parent; while none of the crosses was better than the best parent, In the case of gelatinization temperature, highly significant heterosis effects were estimated in only 3 crosses as deviation from the midparent; no positive values were estimated in comparison with the better parent.

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Genetic behavior of induced earliness in rice

S. S. Soliman, A. S. Mandour, A. H. Fayed, and M. A. Ismail

The genetic behavior of heading date was studied and the importance of each of the mutants in crop improvement programs was determined.

Diallel analysis of F_1 and F_2 of crosses involving four parents—Nahda, E252, E705, and Bluebelle—led to the following conclusions:

- Additive and dominance effects played a major role in the determination of heading date.
- Nonallelic interaction was absent, and the direction of dominance was toward lateness. Overdominance appeared in some cases for lateness.

- The graphical and statistical analysis confirmed that the additive effects were more important than dominance effect for this trait in E253/2.261 and E705/Bluebelle and their respective F_1, F_2, and F_3.

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Performance of some rice mutants

A. G. ABDEL-HAFEZ AND M. S. EL-KEREDY

Five mutants selected from gamma-ray treated populations of Giza 172 and IR579-48 were evaluated in the M_5 and M_6 for earliness at three plant densities. Their parents and IR28 were included in the experiment as checks.

Two of the mutants, 1a and 3a, appear very promising, with semidwarf stature, upright leaves, and relatively higher resistance to rice blast. Their yields were comparable with those of their parents. Mutant 3b also showed these characteristics, with higher yields than the parent, but was markedly susceptible to stem borer. Mutant 8a is morphologically similar to Giza 172 but with more lodging-resistant stems. Its yield is similar to that of its parent, it is as susceptible to blast as its parent. Mutant 9a, selected from mutagen-treated IR579-48, is taller and produces longer and heavier grains than the parent, but its grain yield is lower. The short and nonlodging habit of these mutants should make them ideal for mechanical harvest. The mutants are being evaluated extensively at different fertilizer levels in several locations to determine the consistency of their performance.

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Partial resistance to blast disease in some rice varieties

S. M. KAMEL, M. S. BALAL, T. A. EL-BIGAWI AND Z. H. OSMAN

Partial resistance to rice blast was investigated in a set of rice varieties, using the conventional parameters diseased leaf area, number of lesions, relative infection efficiency, and sporulation capacity. The highest number of lesions occurred on Reiho and Giza 159. Very low numbers were recorded on Giza 1394-10-1. Number of lesions increased with decreasing leaf age.

Relative infection efficiency (RIE) as measured by number of lesions per unit leaf area gave more reliable information than the number of lesions per leaf. RIE was higher on younger leaves, and varied with variety.

Sporulation capacity differed among entries. Giza 159 and Reiho showed the highest sporulation capacity, closely followed by Giza 171 and Giza 172; GZ1394-10-1-1 showed the lowest, followed by GZ2175-5-6 and GZ2175-5-4. Size of lesions of leaves did not differ significantly among varieties, but those of line GZ1394-10-1-1 were the smallest.

Disease progress varied considerably. IR28, IR1626-203,and GZ1368-5-4 did not show any disease symptoms, indicating the absence of compatible races. Giza 171, Giza 172, and Reiho showed severe disease symptoms and blast developed very fast. GZ1394-10-1-1 showed symptoms of slow spread of the pathogen inside the host cells, resulting in a very small diseased leaf area.

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Inheritance of resistance to rice stem borer *Chilo agamemnon* Bles

A. R. DRAZ, S. A. ABDALLAH, AND H. E. GAUL

Inheritance of resistance to stem borer was studied in F_1, F_2, and F_3 of 14 crosses involving 3 resistant (Yabani M55, TKM6, and Giza 172) and 3 susceptible (Belle Patna, Brazos, and RM17) varieties at vegetative and reproductive phases. Deadheart percentage was used as the resistance index at the vegetative phase; whitehead percentage as the index at the reproductive phase. Parents, F_1s, F_2s, and F_3s of three groups of crosses—resistant/resistant, resistant/susceptible, and susceptible/susceptible-were studied during 1980-82.

The segregating patterns of F_2 and F_3 of the three groups of crosses for deadheart incidence revealed that three genes–$R1_{dh}$, $R2_{dh}$, and S_{dh}–were controlling resistance. Among them, $R1_{dh}$ and $R2_{dh}$ were found to be dominant for resistance, while S_{dh} was dominant for susceptibility. The data also suggested that $R1_{dh}$ was epistatic over both $R2_{dh}$ and S_{dh}, while S_{dh} was epistatic over $R2_{dh}$.

The same three groups of crosses were screened for whitehead incidence at reproductive phase. Resistance was found to be controlled by one, two, or three pairs of genes, viz., $R1_{wh}$, $R2_{wh}$, and S_{wh}, of which $R1_{wh}$ and $R2_{wh}$ were dominant for resistance, while S_{wh} was dominant for susceptibility. The data further suggested that $R1_{dh}$ was epistatic over $R2_{wh}$ and S_{wh} while S_{wh} was epistatic over both $R2_{wh}$ and S_{wh} while S_{wh} was epistatic over $R2_{wh}$.

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Relationship between leaf and neck infections of rice blast disease *Pyricularia oryzae*

I. A. Aidy, A. E. Draz, A. A. Rahman, and E. A. Siddiq

Fifteen rice varieties with varied levels of resistance to blast disease were studied for five successive seasons 1980-85 to determine the nature and strength of relationship between leaf and neck blast incidence under natural conditions, in completely randomized block design with three replications. Correlation level varied with method of analysis. It was highly significant when average values of all test entries were analyzed. When analysis was on the basis of individual varieties, the correlation was highly positive and significant only in the more susceptible varieties. The less susceptible ones, like Giza 171 and Giza 14, showed nonsignificant correlation.

Reaction to blast in Reiho fluctuated from resistance to susceptibility during the last two seasons, while that of IR28. Giza 180, Toride 1, Toride 2, IR1626-203, and YNA282 was consistent.

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Effect of spore density and environment on rice blast epidemic

M. S. Sehly, S. M. Kamel, Z. H. Osman, and T. Abdel-hak

A rice blast epidemic is mainly affected by the cultivars grown, the virulent races/isolates of the pathogen available, and the environmental conditions favorable to disease development. Although Giza 171 and Giza 172 have been cultivated over 85% of the rice area since the 1970s, the spread of blast was slow because of their tolerance for the disease. But with the introduction and cultivation of the japonica variety Reiho on about 84,000 ha, blast appeared on an epidemic scale in 1984, with Reiho suffering the most, Immediate study of the problem during the epidemic year revealed that the relatively higher spore production on Reiho was the major reason for the higher rate of disease development on this than on Giza varieties. Race identification studies indicated the occurrence of some new races.

The number of spores of the pathogen trapped during the period from July to October was studied in relation to changing temperature and relative humidity, for three years 1983-85. The number of trapped spores was significantly higher in the epidemic year than in normal years. Temperature was not markedly different from season to season, except that night temperature was relatively low in 1984. Relative humidity was suitable for successful infection in all the seasons studied. It was concluded that the abrupt increase in planting of highly susceptible variety

Reiho, the possible evolution of new virulent races compatible with the new variety, and the prevalence of relatively low night temperatures were the major causes of the 1984 epidemic.

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Modeling parasite: host:environment specificity

T. M. Shehab El-din and L. E. Browder

Specificity is a well-known phenomenon in many parasite:host systems. Many investigators have modeled specificity in one environment, assuming that environment has no effect. We propose a Boolean algebraic approach to modeling specificity. Parasite and host come together to form a third entity, the aegricorpus. A definitive parasite genotype interacts with a definitive host genotype to produce a definitive aegricorpus genotype that functions in a definitive environment to produce a definitive phenotype. The definitive phenotype results in resistance in some cases and susceptibility in others. Nondefinitive at one or more of the variables results in a nondefinitive phenotype.

The basic model and its expansion illustrate different characteristics of the specificity system. Six different formulae are used to calculate the parameters—number of individuals, number of aegricorpus genotypes, number of phenotypes, number of individuals with a given definitive phenotype, number of individuals with nondefinitive phenotype, and expected ratio of phenotypes.

The basic model and its expansion confirm the importance of genetic diversity where definitive phenotypes result in resistance. The frequency of definitive genotypes increases with increasing number of sets of corresponding gene pairs, regardless of the other variables. Partial function of definitive aegricorpus genotype in a nondefinitive environment is the likely basis of "horizontal resistance" and "slow rusting/blasting." In many parasite:host systems, the aegricorpus phenotype behaves like a quantitative character. It is controlled by many sets of corresponding gene pairs and is greatly influenced by environment. Thus it can be studied quantitatively.

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Brown spot disease of rice in Egypt

M. K. El-Kazzas and Z. H. Osman

The most conspicuous symptom of brown spot disease in rice is brown oval spots with grey centers on leaves and glumes. Neck and uppermost internodes are also blighted, but symptoms resemble neck rot infection caused by blast fungus.

Various aspects of the disease were studied, including yield loss as related to stage of infection, influence of environmental factors on disease development, and interaction between blast and brown spot pathogens. Artificial inoculation of rice plants with *Cochliobolus miyabeanus,* the causal organism, atflowering and milkystages reduced yield the most, but almost no yield reduction was observed from inoculation at maturity stage.

Relative humidity, dew period, and number of trapped spores showed positive correlation with disease development. Means of day-night relative humidity as well as daytime trapped spores appeared to be closely associated with disease development.

Disease incidence significantly increased on both leaves and grain when plants were not supplied with nitrogen fertilizer, compared with plants that received 40 or 80 kg N/feddan. The rate of 40 kg N/feddan was optimal, giving the lowest disease index and highest grain yield. Neither phosphorus (at 0 and 15 kg P/feddan) nor potassium (at 0 and 24 kg/feddan) showed any effect either on disease development or grain yield.

A study of the interaction between *H. oryzae* and *P. oryzae* revealed that the lowest number of blast lesions after 48 h was induced on seedlings preinoculated with *H. oryzae,* rather than with *P. oryzae.* Brown spots decreased with prolonged time between successive inoculations up to 6 d. Inoculation with a mixture of *H. oryzae* and *P. oryzae* significantly decreased the number of blast lesions, brown spot was not influenced at all.

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Estimated yield losses due to rice root nematode and management strategies

M. F. M. Eissa, F. F. Moussa, A. M. Korayem, and M. M. A. Youssef

Losses of rice grain yield due to rice root nematode were estimated for 1985 over the rice-growing area of the Nile Delta. The infested area, estimated to be over 40,000 ha, was mainly in the northern parts of Damietta, Dakahlia, Kafr El-Sheikh, and Beheira Governorates. Yield losses exceeded 50,000 t.

The strategies for integrated rice root nematode management in Egypt include development of nematode resistant varieties; cultural practices, such as leaving the land fallow, tillage, mechanical disturbance of the soil immediately after harvest, regular crop rotation, and fertilization by ammonia injection; treatment of rice nurseries with suitable nematicides; and, above all, suitable legislation compelling farmers to adhere to major recommendations.

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Effect of planting method on level of rice stem borer *Chilo agamemnon* Bles. infestation

A. M. TANTAWI, F. E. ABDALLAH, A. A. RAHMAN, AND S. B. BLEIH

A field experiment was conducted for two successive years to examine the effect of five planting methods on rice stem borer infestation in three rice varieties. The planting methods were hand transplanting (20 × 20 cm), machine drilling on dry soil followed by flooding, machine transplanting using the IRRI transplanter, machine transplanting using a Japanese transplanter, and broadcasting of pregerminated seeds. Giza 173 (Reiho), Giza 172, and IR28 were the varieties studied.

Plant samples drawn from each treatment at harvest time were examined for borer infestation. Percentages of deadhearts, whiteheads, and infested stems with sound heads were recorded, and yield loss for each treatment was computed.

Planting methods exerted a highly significant effect on borer infestation level. In general, transplanted rice was found to suffer higher infestation than direct seeded or drilled rice, irrespective of variety. Machine transplanting resulted in higher infestation than hand transplanting.

In the transplanted plots, those planted with the Japanese transplanter suffered the highest borer infestation, with a yield loss of 10.48%, followed by those planted with the IRRI transplanter (7.35% yield loss) and hand transplanting (6.8% yield loss).

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Testing pesticides for genetic hazards to rice

A. Z. EL-ABIDIN SALAM

In recent years, chemical pesticides have been widely and intensively used to protect the rice crop against major pests such as rice blast and stem borers. Although chemicals have been found quite effective in controlling the rice pests, the fact that pesticides could cause genetic hazards to nontarget plants and to animals and human beings is generally overlooked.

The genetic effect of a chemical is usually expressed by its mutagenic potentialities. The mutagenic effect is measured in turn by frequency of point mutations and/or cytological aberrations. The latter event is classified into clastogenic and turbagenic effects.

On the basis of studies carried out in the genetics department at Ain Shams University, we suggest that testing pesticides for relative mutagenic effect before their use would help in choosing less genetically hazardous ones.

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Yield and productivity of local and IRRI rice varieties in different districts of Beheira Governorate

M. D. El Centriecy and M. Y. G. Mousa

Evaluation of modern high-yielding rice varieties in farmers' fields in Beheira Governorate in the early 1970s showed no distinct yield advantage over tall local variety Nahda. This was largely because the farmers had no information about the optimum time of planting and harvest and improved cultural practices.

Early variety IR28 was tried extensively 1983-86, with the recommended package of practices. It gave higher yields, with Mahmudia district averaging 10.1 t/ha. The suitability of IR28 for double cropping was also studied on 535 ha. Total yield for both crops averaged 10.3 t/ha–the first crop, planted 25 May, yielding 9.3 t and the second, planted 15 Aug, yielding 1 t/ha.

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Effect of date of sowing and management on seedling characters

S. E. El-kalla, M. H. El-Hindi, M. S. Balal, and A. M. El-Serafy

We investigated the effect of different sowing dates and methods of raising seedlings on seedling characters of Giza 172 (a tall japonica variety) and Giza 180 (a dwarf indica variety). The experiments at Sakha Agricultural Research Station included four sowing dates—20 Apr, 5 May, 20 May, and 5 Jun—and three methods of raising seedlings—wet-bed, dry-bed, and dapog. The important findings are as follows:

- Delaying date of sowing to 5 Jun resulted in increased seedling height, more leaves per seedling, and higher fresh and dry weights/100 seedlings in both varieties.
- The wet-bed method gave the tallest seedlings and maximum fresh and dry weights/100 seedlings; the dry-bed method gave the most number of leaves per seedling in both varieties.
- The interaction between sowing date of 5 Jun and wet-bed method gave the tallest seedlings and highest fresh and dry weights/100 seedlings; the interaction between sowing date of 5 Jun and dry-bed method gave the highest number of leaves per seedling in both varieties.

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Effect of algalization by increased inoculum rates of soil-based blue-green algae on growth and yield of transplanted rice

Y. G. Yanni and M. I. Zidan

A field experiment at Sakha Agricultural Research Station studied the effect of inoculum rate of blue-green algae (BGA) on growth and grain yield of rice. IRRI rice line IR1626-203 was inoculated with soil-based algae in ascending rates of 100, 300, 600, and 1200 g/feddan. Two rates of mineral fertilizer N (urea), namely 15 and 30 kg N/feddan, were used 1 mo after transplanting.

Unlike straw yield, grain yield increased gradually but nonsignificantly with increasing rate of the inoculum up to 1.2 kg/feddan. Mineral N fertilization at 15 kg N/feddan, in combination with 600 g BGA inoculum/feddan gave maximum grain yield N content. Algalization at 1.2 kg/feddan was found necessary for obtaining a significantly higher grain yield N content with mineral N fertilization at 30 kg N/feddan. Under mineral N fertilization at 15 kg N/feddan, straw yield N content responded only to algalization at 600 g inoculum/feddan. A maximum of 26.3 kg N/total grain + straw yield from a feddan was found to originate from biologically fixed N_2 by BGA when 15 kg fertilizer N/feddan was applied along with 600 g of dried BGA soil-based inoculum.

Plant height at harvest, number of effective tillers/hill, and percentage grain yield did not significantly change because of BGA or mineral N fertilization rates. Delaying fertilizer N application to 25 d after broadcasting of the BGA inoculum prevented significant interaction between mineral fertilizer doses and BGA rates.

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Method of application and rate of urea hydrolysis and movement

A. T. Badawi, A. Abshahi, A. A. R. Hafez, and D. S. Mikkelsen

Movement of various inorganic N ion species through mass flow or diffusion or both and their concomitant distribution in a soil profile play a significant role in availability of applied N to the rice plant. This prompted the study of movement and distribution of NH_4-N and urea-N following deep placement of ^{15}N-labeled urea by different methods of N application in wetland rice.

The general movement after deep placement of ^{15}N urea was predominantly downward rather than upward from the placement site. The downward movement was prevalent with deep N application than with wet soil application. The peak concentration of NH_4-N was near the placement site; it decreased gradually with time due to more downward than upward movement.

Fertilizer placed at 4 inches by banding or incorporated with 4-inch-deep soil produced peak NH_4-N concentration at 8-inch soil depth. With surface application of urea on dry soil, high concentration of NH_4-N was found at 6-inch soil depth. N placement either by banding 4 inch deep in soil or incorporation and surface application resulted in fertilizer movement to 9-inch soil depth.

Wet soil treatment kept the peak concentration of NH_4-N near the placement site (1-inch soil depth) itself. This facilitated increased pH and ammoniacal N concentration in the floodwater, which in turn were associated with increased ammonia volatilization. Wet soil N application recorded the highest NH_4-N concentration as compared to deep N application. It is desirable to place N fertilizer at greater depths to minimize NH_4-N concentration in floodwater.

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Effect of nitrogen sources and method of application on ammonia volatilization in flooded soils

A. T. Badawi, A. Abshahi, and D. S. Mikkelsen

Ammonium N occurs in varying concentrations in the floodwater of fertilized lowland, depending on rate, source, time, and method of application of N fertilizer. In floodwater, a part of the ammonium N may exist as hydrated ammonia, ammonium carbonate, or ammonium bicarbonate, depending on pH, total alkalinity, carbon dioxide-created acidity, and total carbonate concentration. The pH of the water is influenced by the level of equilibrium that exists between photosynthesis and respiration of aquatic biota.

Under field conditions, it is possible for significant amounts of ammonium N to be lost into the atmosphere as gaseous ammonia, depending on environmental conditions, N source, and method of application. In our experiments, up to 10% of the N applied was lost from the soil/plant system by ammonia volatilization. The initial movement of fertilizer, which is affected by method of fertilizer application and irrigation practices, greatly influences the magnitude of loss. Urea broadcast on the soil surface is most prone to volatilization loss, while incorporation and banding greatly reduce such losses. Ammonia volatilization is generally less when ammonium sulfate is used as nitrogen source, but losses depend on fertilizer, soil, and water management practices. When fertilizer N is well incorporated or banded in the soil, ammonia volatilization losses are largely eliminated from flooded rice culture.

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Using tracer technique to measure effect of rate, timing, and method of application on fertilizer nitrogen use by rice

M. R. HAMISSA, F. MAHROUS, M. NOUR, AND E. A. WAHAB

A field experiment was conducted in 1983 on a clayey soil at Sakha Experimental Station, Nile Delta, using N-15 labeled ammonium sulfate. The main objectives were 1) to study the response of rice to different N rates and the efficiency of fertilizer N as affected by rate, time, and method of application; and 2) to measure the carryover effect of various fertilizer treatments on the succeeding crop. The experiment used rice variety Giza 172 and the succeeding crop was barley. The following were the major findings and conclusions:

1. N application had a significant effect on crop yield as well as did the level of uptake of total and fertilizer N by the rice crop. The effect tended to increase with increased N rate.
2. The fertilizer N was used by the crop more efficiently when it was applied by one of the following methods in descending order:
   - Point placement 10 cm deep in the soil day after transplanting (DT)
   - Topdressing 2/3 35 DT + 1/3 at panicle initiation (PI)
   - Dry application banded in the soil
   - Dry application, 2/3 banded in the soil + 1/3 topdressed at PI.

   Neither broadcasting in the water before transplanting nor the traditional method of topdressing 2/3 15 DT + 1/3 at PI permitted efficient use of fertilizer N.
3. Fertilizer N uptake was rapid between the early tillering and rapid tillering stages of growth. During this period, utilization percentage from the applied fertilizer was about 60%; at early booting stage, percentage utilization amounted to another 10% of the total applied fertilizer N.
4. The succeeding crop of barley utilized some of the fertilizer N that was applied to rice. However, the percentage recovery from the original amount of fertilizer added was very little and did not significantly affect the yield of barley.

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Denitrification in rice

A. A. El Massry and S. A. Gaafer

A greenhouse sand culture experiment studied the effect of different pH levels on degree of denitrification as well as on growth and yield of rice plants.

The pH levels were 4, 5, 6, 7, 8, and 9. Hoagland and Arnon nutrient solution was used. Results obtained from the two treatments, i.e., with and without NO_3-N in the nutrient solution, are as follows:

1. Nitrate ion was in low concentration (from 5 to 8 mg/liter) on the first day, up to pH 6, in the treatment that received nutrient solution without NO_3-N source. However, the concentration increased on the second and third day. The nitrite ion concentration increased from pH 7 to 9, even from the first day.
2. The nitrite ion was in moderate concentration (11-14 mg/liter) on the first day, up to pH 6, in the treatment that received nutrient solution with NO_3-N. It increased then on the second and the third days (19-23 and 28-32 mg/liter, respectively). The nitrite ion accumulation was very high beyond pH 6.
3. In general, a highly significant positive correlation was found between pH values and nitrite ion accumulation on the three successive days following irrigation (r_1=0.98** and 0.96** while r_2=0.95**, 0.96**, and 0.95** treatments with and without NO_3 form, respectively).
4. The pH of the media showed a highly significant negative correlation with plant height and number of tillers in both treatments.
5. A highly significant negative correlation was found between pH and grain dry weight in the two treatments.
6. Increase of nitrite accumulation was associated with decreased growth and yield of rice plants.

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Effect of fertilizer elements on rice yield

Abd El-kawy and M. El-tanga

The majority of farmers in the Nile Valley traditionally apply only N fertilizer to the rice crop. Modern agricultural practices, however, advocate balanced application of fertilizer elements in order to obtain the highest yields. An experiment was carried out to study the effect of N, P, and K fertilizerson yield of two varieties, Giza 172 and Nipponbare. The results of

6 treatments revealed that a maximum amount of 80 kg N, 60 kg phosphate, and 30 kg K per hectare was needed to obtain the highest grain yield in the 2 rice varieties.

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Relative efficiency of nitrogen and phosphorus fertilizers for rice in Egypt

M. R. HAMISSA, M. S. BALAL, AND F. N. MAHROUS

Two field trials at Sakha Experimental Station during the 1981 crop season studied a) N use efficiency in wetland rice, and b) rate and sources of P for rice under flooded condition.

The trials were conducted in collaboration with IRRI through the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) coordinated research program.

The following were the most important findings:

- The rice crop responded significantly to N application. Crop yield increased gradually as N rate increased up to 108 kg N/ha. However, the difference between 54 kg N and 108 kg N/ha was not significant.
- Sulfur-coated urea followed closely by placement of urea briquettes gave higher yields over best split, broadcast and incorporated urea, under different rates of N application.
- Averaging the indicated urea broadcast and incorporated gave yields comparable with those with urea applied in split doses.
- Rice responded positively but not significantly to P application at the rate of 48 kg P_2O_5/ha regardless of the source.

Although there was no significant difference between different P sources, triple superphosphate and guano rock phosphate seemed to be relatively more effective sources than the others tested.

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Response of some rice cultivars to different rates and split applications of nitrogen

A. A. LEILAH AND S. E. EL KALLA

Two field experiments at Mansoura Experimental Station during the 1985 and 1986 seasons studied the effect of rates and split applications of N fertilizer on the performance of four rice cultivars. The main findings may be summarized as under:

- Rice cultivars differed in their response to N. The grain yield increased with increase in the rate of applied N, up to 60 kg N/feddan in the tall variety Giza 171, and 75 kg N/feddan in the dwarf varieties IR28, IR50, and IR9752.
- IR28 was the highest yielder, closely followed by IR50; Giza 171 was the lowest yielder.
- Split applications of N fertilizer in two or three equal portions (1/2 on dry soil before transplanting and 1/2 at tillering stage, or 1/3 on dry soil before transplanting, 1/3 at tillering, and 1/3 at panicle initiation stages) slightly increased grain yield, especially in Giza 171, compared with a single dose on dry soil before transplanting.
- The highest grain yield of 10.5 t/ha was obtained from IR28 fertilized with 135 kg N/ha added in 2 equal portions: 1/2 before transplanting on dry soil and 1/2 at tillering stage. The lowest grain yield of 5.4 t/ha was obtained from Giza 171 fertilized with 72 kg N/ha, added in a single dose before transplanting on dry soil.

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Integrated weed control in broadcast seeded rice

S. M. Hassan. A. A. Rahman, and A. T. Badawi

Integrated cultural practices with herbicidal treatments for weed control in broadcast seeded rice were evaluated. Weed populations, especially of *Cyperus difformis* and broadleaf weeds, decreased significantly with increased rice seeding rates. High levels of N fertilizer were found more beneficial to rice when applied with effective herbicides. Increasing N level from 36 to 108 kg/ha increased the yield 0.21 t/ha in the weedy check and 2.5 t/ha with thiobencarb + propanil (2.4 + 2.6 kg/ha).

Lowering of floodwater to shallow depths favored weed growth and intensified weed competition in broadcast seeded rice. The greater the water depth, the better the weed control. Spray of thiobencarb + propanil (2.4 + 2.6 kg/ha) at two- to three-leaf stage of *Echinochloa crus-galli,* followed by one hand weeding, yielded:

- 10 t/ha with continuous deep flooding,
- 9.4 t/ha with intermittent (6 d deep flooding and 2 d draining) deep flooding,
- 7.5 t/ha with continuous shallow flooding, and
- 6.1 t/ha with intermittent (6 d flooding and 2 d draining) shallow flooding.

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Effect of oxadiazon, pretilachlor, and their combinations on control of rice weeds

M. H. EL-DEEK

Herbicidal efficacy was studied in manually transplanted rice during 1985 and 1986 at Belbeis, Sharkia. Oxadiazon at 1.5 kg ai/ha, pretilachlor at 0.8 kg ai/ha, tank mixture of the 2 herbicides at 1.5 kg oxadiazon + 0.8 kg pretilachlor, and mixture of the 2 at 1.9 kg + 1.0 kg/ha were tested in comparison with hand weeding and an untreated check. Major findings were:

Either oxadiazon at 1.5 kg ai/ha or pretilachlor at 0.8 kg ai/ha, applied 4 d after transplanting, eliminated the growth of barnyard grass and common weeds completely and gave excellent control of yellow nut sedge and small flowered umbrella plant.

Oxadiazon had no harmful effect on rice plants and gave the highest grain yields and heaviest test grain weights.

Although pretilachlor gave heavier panicles, it injured rice plants, significantly reducing the number of panicles/m^2.

The mixture of the two herbicides at recommended doses controlled barnyard grass and umbrella plant up to 2 mo from transplanting and gave good control of yellow nut sedge; rice grain yields were higher than in the untreated check.

The mixture of oxadiazon at 1.9 kg + pretilachlor at 1.0 kg prevented the growth of umbrella plant and sharp rush and gave satisfactory control of common weeds and yellow nut sedge. However, rice grain yield did not differ statistically from the check, probably because of poor crop stand caused by the high doses of the two herbicides.

Hand-pulling of rice weeds three times during the growing season provided satisfactory control of most rice weeds, resulting in fairly high grain yield.

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Compatibility of fenoxaprop with selected herbicides for the control of rice weeds, with special reference to barnyard grass

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Fenoxaprop is a new experimental herbicide that controls grass weeds in rice, but fails to control broadleaf weeds. It gives no residual control. Three greenhouse experiments were conducted at the University of Arkansas to evaluate the efficacy of fenoxaprop when applied tank-mixed with selected herbicides. Fenoxaprop (0.04, 0.08, and 0.17 kg/ha) was applied alone and in tank-mixture with bentazon (0.42 kg/ha), acifluorfen (0.08 kg/ha), thiobencarb (1.7 kg/ha), lactofen (0.11 kg/ha), or bromoxynil (0.14 kg/ha) to barnyard grass *Echinochloa crus-galli* L. Beauv.

All treatments with fenoxaprop alone and in tank-mixtures reduced the fresh weight of barnyard grass, as compared with the untreated check. Fenoxaprop alone reduced fresh weight by 95-98, 71-91, and 32-63% when applied at the 2-3 leaf, 4-5 leaf, and tillering stages, respectively. When applied alone at 2-3 leaf stage, thiobencarb gave 80% reduction in fresh weight, but the percentage of control decreased with advanced growth stage of barnyard grass. All broadleaf weed herbicides applied alone gave unsatisfactory growth reduction of barnyard grass. With tank-mixtures, fresh weight was reduced by 85-98, 36-94, and 29-83% (average of all rates and herbicide treatments) when applied at the 2-3 leaf, 4-5 leaf, and tillering stages, respectively. Efficacy of the tank-mixtures on barnyard grass was in the order of thiobencarb > bromoxynil > acifluorfen > lactofen > bentazon.

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Tile drainage design for areas with rice in the crop rotation

M. S. Abdel-Dayem, M. Q. Abdel-Aliem, and M. A. Abdalla

Rice is cultivated in the Nile Delta within a crop rotation that includes other summer crops, such as cotton and maize. Water management for ricefields differs distinctly from that required for other crops. Presence of gravity subsurface drainage would imply excessive water loss from ponded ricefields. Consequently, farmers are inclined to block the tube drains to prevent water loss. Such unorganized blockage leads to overpressure in the drainage system, which may cause drainage maintenance problems and serious damage to other standing crops served by the same collector drain.

A modified drainage system design based on crop consolidation scheme has been introduced and tested on 2,100 ha in the Delta. In this system, each crop unit is provided with a separate subcollector drain, with a closing device. When a particular crop unit is cultivated with rice, the concerned subcollector is closed, leaving the units with other crops open, with free drainage. In this system the design drainage rate is reduced from 4.0 mm (the rate in the conventional system) to 2.0 mm/d by eliminating unnecessary water losses. Monitoring and evaluation of the system for a period of over 3 yr proved that there was no problem of salt accumulation and no adverse effect on crop yield. The drainage system remains trouble-free.

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Effect of sowing date and method of raising seedlings on rice yield and its components

S. E. El-Kalla, M. S. Balal, M. H. E. Hindi, and A. M. El-Serafy

Rice varieties Giza 172 and Giza 180 were studied for the effect of different sowing dates and methods of raising seedlings on yield and its components. The experiments were conducted at Sakha Agricultural Research Station and the important findings could be summarized as follows:

- Number of days from sowing to heading gradually decreased from the first planting date on 20 Apr to the last planting date on 5 Jun. The dapog method took the longest sowing-to-heading period; the wet-bed method, the shortest. The dapog sown on 20 Apr took the longest period to heading; the wet-bed sown on the fourth planting date (5 Jun), the shortest.
- The plants were relatively taller in the treatment of the earliest sowing date. The treatment combination of the first date of sowing with the dapog method, however, gave the tallest plants for both the varieties.
- Sowing on 5 May gave the maximum number of tiller per plant. As for the method of planting, the effect varied with the variety, with the dapog method giving the maximum tillers per plant in Giza 180 and the wet-bed method in Giza 172.
- The 5 May sowing also gave the heaviest panicles, and the dapog method gave the highest panicle weight in Giza 172.
- The highest grain number and straw yield per hectare were obtained with the 5 May sowing for both varieties. Effect of methods of raising seedlings varied with variety, with Giza 172 showing no difference and Giza 180 giving the maximum grain by dapog and the highest straw yield by the wet-bed method. The 5 May sowing in combination with the wet-bed method gave the maximum straw yields per feddan in both the varieties.

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Yield response of some rice varieties to different planting times

M. EL-HITY, M. S. EL-KEREDY, AND A. G. ABDEL-HAFEZ

A study was planned to determine the genotype × environment interaction with reference to different dates of sowing. Twenty-four exotic varieties along with the local variety Giza 171 were evaluated at three dates of sowing, covering the rice-growing season in Egypt during the 1985 and 1986 seasons. When sowing was delayed beyond 15 May, grain yield was reduced by 5-15% in most of the varieties. In Giza 171, sowing on 5 Jun reduced grain yield by 28% (2.38 t/ha) in 1985 and by 15% (about 1.4 t/ha) in 1986. When sowing was done on 25 Jun, yield reduction ranged from 8 to 61%, irrespective of growth duration of the variety.

The highest yielding cultivar over the 2 yr was Toyonishiki, though it responded adversely to later sowings. Other high-yielding cultivars were also more sensitive to delayed sowing than lower-yielding cultivars. It was obvious that early sowing is important to obtaining maximum grain yield. Suitable rice cultivars, not too sensitive to climatic changes, must be recommended for late sowing after the harvest of winter crops like wheat.

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Effect of some agronomic practices on yield and its components

A. A. ASSEY, A. A. ABD EL-GUELIL. H. E. HL-HATAB, AND A. T. BADAWI

Six separate field experiments were conducted at Sakha Agricultural Research Station during 1979 and 1980 to study the effect of sowing date, method of planting, and method of N fertilization on grain yield and its major components in tall japonica variety Giza 171 and dwarf indica variety IR579. Three dates of sowing—25 Apr. 15 May, and 5 Jun—, three methods of planting—transplanting, drilling, and broadcasting—, and three methods of N application—subsoil, surface, and no fertilization—were tried. Both early sowing on 25 Apr and medium sowing on 15 May resulted in higher grain yields than late sowings. Transplanting gave the highest grain yield followed by broadcast sowing; drill seeding yielded the lowest. Plots given subsoil and surface N fertilization gave 46 and 28% higher yields, respectively, than unfertilized plots. Yield-contributing variables also followed the same trend as grain yield in respect of various treatments.

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Effect of time of transplanting on growth and yield of rice

F. I. El-nemr

Rice is an important crop component of a 3-yr rotation system in the Nile Delta. The cropping season is regulated by time of harvesting of the preceding crop and sowing of the succeeding crop; therefore, in mechanized rice cultivation, it is very important to determine more precisely the appropriate transplanting dates that optimize paddy yield.

Three varieties of rice—Akihikari, Reiho, and Giza 172—were used. Transplanting was done at 5-d intervals, from 15 May until 15 Jul.

The results showed wide variation in vegetative period because of difference in date of transplanting. Reiho was most affected. The most appropriate transplanting dates were from mid-May to mid-Jun. The appropriate date of raising the seedling nursery was determined to be between 25 Apr and 25 May.

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Improved nursery beds for mechanical transplanting of rice in Egypt

M. S. El-keredy, A. G. Abdel-hafez, F. A. Sorour, and M. M. El-wehishy

The usefulness of field soil mixed with different proportions of raw rice hulls, burnt rice hulls, and sawdust was studied in comparison with field soil and “Tamya Baladi manure” for raising a rice nursery for mechanical transplanting. The performance of each nursery medium was measured in terms of germination percentage, seedling height, leaf number, root length, and seedling dry weight observed at weekly intervals for 5 wk. Seedbed characteristics like bulk density (g/cm^2), soil reaction pH, rice nursery weight, and shear strength of soil and roots (kg/cm^2) just before transplanting were also recorded. The measurements recorded in the fourth and fifth weeks showed clearly the treatment differences. The modified nursery media were more promising than field soil. Better quality and more uniform seedling mats could be obtained in the nursery medium that contained 20 and 50% raw rice hulls with field soil. The relation between seedling growth and seedbed characteristics were also studied.

On the basis of their superior performance, the modified nursery mediums are recommended in raising seedlings for machine transplanting.

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Effective field efficiency of some types of rice transplanters

A. F. SAHRIGI AND M. Y. ABD EL-MAWLA

In recent years, different types of transplanters have been introduced in Egypt. As each type had its own advantages and disadvantages, it was necessary to study the suitability of these transplanters for the local conditions.

Three types of Japanese-made Yanmar transplanters, namely, a) 4-rowwalking type, b) 6-row mounted type, and c) 8-row mounted type have been tested to determine their relative field efficiency.

The field efficiency of the 4-row walking type did not differ very much from that of the 6-row and 8-row mounted types. Yet its advantage over the two other types was its low investment and operating costs. The excessive fatigue the operators suffer under local conditions appeared to be its only limitation.

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Economic analysis of rice planting methods

Z. H. Z. WISSA, A. F. EL SAHRIGL, AND O. KAMEL

We compared the relative cost-return of three different rice planting methods: manual transplanting, planting by Nordsten seed drill mounted on a 60 HP Nasr tractor, and mechanical transplanting by Yanmar self-propelled transplanter. The analysiswas based mainly on the results of an experiment carried out during 1985 by the Research and Development Center on the Gimeza farm in Gharbiya Governorate. Instead of using the traditional method based on interest and depreciation, the capital recovery method was used to calculate the ownership costs.

Manual transplanting incurred the highest costs; seed drilling and mechanical transplanting the lowest. However, hand transplanting gave the highest revenue, followed by seed drill and mechanical transplanting.

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Effect of milling methods on grain quality

K. M. EL-SAYED, A. E. ALY, M. I. SHAALAN, AND SOUD ABDUL-HADY

We studied the effect of some processing factors, like pregrading and period of milling on hulling and milling characteristics of 11 local and IRRI varieties or cultures. Random 5-kg samples of rough rice were cleaned and graded. Hulling was manual and using 1.6- and 1.8-mm mesh sieves. Mesh sieving was superior to manual cleaning, giving markedy improved physical grain characteristics and components of hulling. The same samples were milled for 2.0, 2.5, and 3.0 min. Mean values of physical characteristics of grain decreased when milling time increased beyond 2 min, with 2.5 min the optimum for realizing the highest milling return and head rice recovery, as well as the best consumer acceptability.

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Edible oyster mushroom cultivation on rice straw

M. H. EL-KATTAN AND B. H. MAHMOUD

The value of rice straw as a substrate for cultivation of *Pleurotus* spp., a protein-rich mushroom, and the effect of supplementing rice straw with certain protein-rich additives, such as wheat bran, dried berseem, and soybean meals, on mushroom yield were studied. *Pleurotus* yellow type Somycel 3040 yielded 18.5% more with wheat bran supplement, 36.6% more with the dried berseem, and 63.6% more with the soybean meal. The study suggested that the spent compost could also be used either as animal feed or as a soil conditioner.

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Symposium recommendations for rice research in Egypt

The challenge

His Excellency Dr. Youssef A. Wally, in his inaugural address, said:

> "Rice enjoys a place of paramount importance in the economy of Egypt—as the most important staple after wheat, as the second major foreign exchange earning agricultural commodity, and as the effective and profitable means of reclaiming hundreds of feddans of salt-affected lands."

He also drew attention to the gradually deteriorating situation in matching food supply with the needs of a population expanding at 2.7% a year, and quoted H.E. the President of the Arab Republic of Egypt: "Whoever does not command the means to feed himself can neither feel freedom nor dignity."

Dr. Wally urged the scientists participating in the symposium to assist in drawing up a strategy for increasing rice production as an integral part of the national strategy for achieving food security on a sustainable basis.

In quantitative terms, Egypt will have to produce 40% more rice in year 2000 than it does today to meet the needs of consumers. Annual production will have to go up from the current 2.5 million t to 3.5 million t. This is a challenging task. A multipronged strategy will have to be adopted, aiming at higher productivity per unit of land, labor, time, and water on existing land and at extension of rice cultivation to new areas.

The opportunity

Productivity improvement

To improve productivity, research is needed in four broad areas.

1. Identify areas in the country where the current average yield is less than 50% of the potential of about 8 t/ha. Conduct an interdisciplinary constraints analysis as an aid to bridging the yield gap at current levels of technology.
2. Increase cropping intensity so as to achieve higher productivity per day and per unit of water. For this purpose, develop shortduration varieties coupled with appropriate agronomic management techniques. For the second crop, tolerance for cold weather will be essential. Intensify research on direct seeding and different methods of planting.

3. Increase research on rice-based cropping systems to identify crop combinations that would result in maximum production and income. Develop and popularize suitable farm machinery for the optimum use of available land. Intensify research on raising the ceiling to yield by
   a. exploiting hybrid vigor, particularly in indica-japonica hybrids, as well as in japonica and indica types;
   b. fixing heterosis in indica-japonica hybrids through anther culture induced haploidy followed by chromosome doubling; and
   c. developing methods of achieving greater fertilizer response in the japonica and indica plant types.

Expansion of area under rice

Three regions in Egypt offer scope for research on rice production:

1. *New Valley.* There are arable and water-abundant areas in El Dakhla and El Farafra depressions in New Valley in the Western Desert. There may be hope for the cultivation of rice in such areas, provided very short-duration (about 90 d or less) and water-use efficient varieties and suitable agronomic practices can be developed.
2. *Nondesert, salt-affected, newly reclaimed areas.* Here again, appropriate high-yielding varieties and management practices are needed.
3. *High Dam Lake foreshore areas.* Low-gradient or flat foreshore lands can be identified in the normally inundated zone between mid-June and mid-August. Areas around Khor Questol and Khor Adindan (close to Abu Simbel) may be suitable for experimentation. The deepwater and floating rices of Asia could be tried and suitable breeding programs developed.

Since arable land is the most limiting factor in Egypt, every effort should be made to take advantage of areas where water is available and where rice may be the crop of choice from the ecophysiological standpoint.

To take advantage of these opportunities, a research and training strategy will have to be developed in three time dimensions:

- Short term (1987-1990)
- Medium term (1990-2000)
- Longer term (2000-2025).

The excellent research and training infrastructure developed at Sakha should be maintained at the highest level of efficiency and effectiveness so that maximum advantage can be derived from these valuable facilities.

The strategy

Productivity improvement

In the short term, an average yield target of 8 t/ha can be aimed at, based on the best varieties and management techniques available. The following aspects of crop management, however, will need greater research and extension attention.

1. Integrated nutrient supply involving mineral fertilizers, biofertilizers like *Azolla,* and green manure crops like *Sesbania rostrata.* The aim should be to

provide balanced nutrition based on the fertility status of the soil. It will be helpful for Egypt to take an active part in the International Network for Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) operated by the International Rice Research Institute (IRRI).

2. Integrated pest management, involving an optimum blend of biological, genetic, cultural, and chemical methods of control. The following areas of research will need added attention:
   a. Continue work on yield losses caused by *Chilo agamemnon* and *Chironomus* sp. This is basic to a sound insect control program. It would be best to determine the effects of these pests on yields (not damaged hills) based on yield cuts within plots of at least 5 m^2. This work will be important for developing damage (action) thresholds.
   b. Develop an efficient sampling/surveillance program for the major insect pests, which is appropriate at this time. This should include in-field techniques as well as areawide surveillance programs.
   c. Determine the role of key beneficial species against *C. agamemnon* and *Chironomus.* This information will be useful for modifying damage thresholds and for conserving and/or augmenting these natural enemies.
   d. Do not overemphasize insecticide testing. It is important to nave effective chemicals available and to test their efficacy against pests (as well as natural enemies), but other aspects of the program, e.g., determining damage thresholds, are more important.
   e. Develop methods for culturing important insect pests and for mass-screening rices for pest resistance.
3. In the case of blast, the potential for manipulating cultural practices—such as nitrogen fertilizer rate and time of application and water management—in such a way that blast incidence is reduced, needs study. Research on the components of partial resistance such as spore:lesion ratio (infection efficiency), fecundity, and latent period, should be continued.

In the longer term, breeding efforts to accommodate genes contributing to durable race-nonspecific resistance will have to be stepped up, in collaboration with plant pathologists.

Crop intensification

In the short term, the aim should be to achieve a 300% cropping intensity. The following areas of research and field-testing are relevant in this context:

1. Grow crops such as sunflower, soybean, or mungbean between the winter crop and rice.
2. Develop and introduce short-duration varieties of rice that can help the cultivation of two crops of rice and a winter crop. Breeding early-maturing varieties characterized by a high productivity per day should receive high priority. Experience in Egypt and elsewhere shows that the yield potential of varieties of 120- to 125-d duration equals or exceeds that of presently grown varieties with 150- to 160-d duration. At the same time, research will have to be intensified on agronomic practices such as direct seeding, age of seedling

at transplanting, nutrient supply, and weed control. The breeder and the agronomist should work together so that management practices that can help a short-duration variety to express its full genetic potential for yield are available when a variety is released.
3. Study water management practices for an entire cropping system in relation to soil physical and hydrological properties.
4. Breed varieties with ratooning ability. The management of a ratoon crop will need the integrated attention of agronomists, breeders, and plant pathologists.
5. Introduce scientific methods of processing rice straw and other agricultural biomass into good-quality, nutritive animal feed. At present, farmers hesitate to delay the planting of berseem for fear of getting the first cutting late. The availability of acceptable and efficient green fodder substitutes will encourage farmers to grow a second crop of rice instead. Vast scope exists for making such green fodder substitutes as well as for preparing other value-added products, since Egypt produces over 3.5 million t of straw, 500,000 t of hull, and 250,000 t of bran every year.

Rice farming systems

Egyptian rice farmers also cultivate wheat, berseem, faba bean, and other crops, in addition to raising livestock. Fish farming is also becoming popular. Hence, farming systems research will have to look at crops, livestock, and fish as an integrated production system. This will imply breeding rice varieties and developing agronomic practices in the context of an entire system, not for rice alone.

New farming systems will have to be based on sound principles of ecology and economics. Integrated nutrient supply and pest management systems and scientific water management practices will have to be tailored to suit the needs of each major farming system. For this purpose, farming systems research will have to be undertaken jointly by scientists and farmers. The emerging techniques, which often involve the substitution of biological inputs for chemicals, are knowledge-intensive. The active participation of farmers in farming systems research will help in the rapid dissemination of ecologically sound management practices. This will help to ensure the long-term sustainability of high levels of productivity.

Problem soil areas

Both in the Nile Valley and the newly reclaimed areas, problems of salinity and low fertility occur on about 63,000 ha. In areas of low soil fertility, a detailed study of soil physical and chemical properties will be needed for suggesting methods of upgrading productivity. A precise characterization of such sites by an interdisciplinary group of scientists should be undertaken immediately.

For salt-affected soils, intensive breeding and management research is needed. It will be useful for Egypt to join the network that IRRI has recently initiated to develop varieties and management practices for soils affected by toxicities and deficiencies.

Expanding the area under rice

Scope exists also for extending rice cultivation to new areas.

1. *New Valley.* The Agricultural Research Center (ARC) has established an experiment station at El Kharga. Experiments should be started immediately at this station in the following areas:
   - Breeding high-yielding varieties with the desired maturity period.
   - Agronomic management.
   - Soil fertility studies, including micronutrient status.
   - Pest and disease management.
   - Water management.
   - Farm machinery and postharvest technology.
2. *Aswan High Dam Lake area.* Breeding research should be initiated jointly with IRRI to develop deepwater or floating rices for the khors with flat land occurring on either side of the long lakeshore.

The survey already initiated for identifying potential rice areas should be continued, and a detailed site characterization from the point of view of rice cultivation should be undertaken by an interdisciplinary team of scientists. Pilot studies on the performance of deepwater/floating rices can be initiated after preliminary screening of suitable varieties from the material to be sent by IRRI.

Forward edge: biotechnology

Thanks to generous support from the Rockefeller Foundation, an international network on genetic engineering in rice now exists. Results from this network will be available to all countries, including Egypt, for immediate use in national biotechnology efforts. The following program is recommended for implementation at the Rice Research and Training Center at Sakha, in collaboration with IRRI:

1. *Short term.*
   a. Develop and use anther culture techniques to produce high-yielding recombinant lines of indica-japonica hybrids. Utilize the wide-compatibility gene identified in Japan to increase fertility in such hybrids.
   b. Train breeders in such anther culture techniques.
2. *Medium term.*
   a. Continue to develop indica-japonica sexual hybrids with heterosis to increase yield.
   b. Develop protoplast fusion to hybridize for increased salinity tolerance, utilizing wild rice species.
   c. Investigate whether apomictic genes can be transferred from species such as *Pennisetum* into cultivated rice by protoplast fusion. If successful, they should enable F_1 hybrid rice seed to be mass-produced.
   d. Begin to utilize rice tissue culture systems (including protoplasts capable of plant regeneration) to transfer genes for herbicide and insect resistance, using either Agrobacterium-mediated transfer or direct plasmid uptake.

3. *Long term.* Investigate the actual isolation and cloning of apomictic and salinity-tolerance genes and transfer them, using suitable vectors, into rice. Transfer of genes affecting yields could also be handled similarly.
4. *General.*
   a. A suitable training program should be undertaken to develop a critical mass of high-level scientific effort.
   b. An agricultural biotechnology working group, consisting of scientists who are familiar with the limitations and potentials of plant biotechnology would be useful. It could serve Egypt as a focal point for national action and international interaction and information exchange. Such a group would be able to implement various aspects of this program if developments take place more rapidly than expected.

Training and technology transfer

New frontiers of rice research must be explored and more efficient means of technology transfer adopted.

Effective research in Egyptian agriculture must include means of formalizing regular exchanges among researchers, producers, and users. Formal and informal communication could take such forms as seminars, symposia, and postdoctoral training.

Training should be based an identified needs of 1) researchers—academic and nonacademic, 2) extension staff, and 3) farmers.

Training should be considered an integral portion of the whole program. A systematic approach to disseminate research to farmers should be encouraged. A feedback loop should be established among farmers, extension workers, scientists, and policymakers.

Short-term needs in training

Short-term training is needed in:

Molecular biology techniques in plant breeding

- Disease and pest resistance breeding
- Plant physiology
- Deepwater and floating rice culture
- Computerization in research
- Technology training methodology
- Biomass utilization
- Rice farming systems
- Socioeconomic studies of new technology
- Soil and water management.

Technology transfer

Three areas of technology transfer need attention:

1. Establish a subject-matter specialists group to work closely with researchers and extension workers at the governorate and village levels.

2. Strengthen and improve the technology transfer capabilities of extension workers.
3. Develop software for technology transfer through mass media, particularly television, radio, and newspapers.

Egypt's international role in rice research and training

Egypt has developed a strong national capability in rice research and training. The Rice Research and Training Center at Sakha has fine facilities for good quality research and for training. Egypt should therefore play a leading role in assisting other rice-growing countries with similar agroecological conditions. To begin with, we recommend the following programs:

1. Research. Serve as the regional center of the International Rice Testing Program (IRTP) for North Africa and the Middle East. The IRTP Regional Center at Sakha can be jointly coordinated by the IRRI rice breeder to be located there and a senior Egyptian rice breeder. The Center should help to generate material for yield and observation nurseries, specifically tailored to the target environment of this region.
2. Training. Two training programs can be organized at Sakha for participants from sub-Saharan Africa and North Africa and from rice-growing Arab nations:
   a. Rice production course in the context of a farming systems approach for irrigated arid environments. This could be organized in collaboration with IRRI, the International Center for Agricultural Research in the Dry Areas (ICARDA), the International Wheat and Maize Improvement Center (CIMMYT), the International Institute of Tropical Agriculture (IITA), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).
   b. Genetic evaluation and utilization (GEU) course to be organized with IRRI.

Conclusion

Egypt has a strong international comparative advantage in rice production by virtue of its endowments in soil and water, favorable temperatures, low incidence of pests, good research and development infrastructure, excellent arrangements for international cooperation in science and technology, and, above all, a hard-working farming community. The country has therefore the potential not only to maintain national food security but to export several hundred thousand tons of rice. Egyptian rice farmers, like those in other parts of the world, respond to opportunities for increasing their income and quality of life. Therefore, improved packages of technology and services will have to be coupled with government policies that can stimulate greater rice production, through higher productivity and higher cropping intensity.

Egypt needs more research on the implications of different policy options for enhanced rice production. The Ministry of Supply should be willing, for example, to procure indica rices as well as japonica varieties. Also, marketing and pricing policies need careful study. Agriculture moves forward vigorously only when packages of technology and packages of government policies become mutually reinforcing.

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