The Future Development of Maize and Wheat in the Third World

Cimmyt
1966-1986

20

maize and wheat for the third world

The Future Development of Maize and Wheat in the Third World

Cimmyt
1966-1986
maize and wheat for the third world

The International Maize and Wheat Improvement Center (CIMMYT) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center is engaged in a worldwide research program for maize, wheat, and triticale, with emphasis on food production in developing countries. It is one of 13 nonprofit international agricultural research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR), which 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 40 donor countries, international and regional organizations, and private foundations.

CIMMYT receives support through the CGIAR from a number of sources, including the international aid agencies of Australia, Austria, Brazil, Canada, China, Denmark, Federal Republic of Germany, France, India, Ireland, Italy, Japan, Mexico, the Netherlands, Norway, the Philippines, Saudi Arabia, Spain, Switzerland, the United Kingdom and the USA, and from the European Economic Commission, Ford Foundation, Inter-American Development Bank, International Development Research Centre, OPEC Fund for International Development, Rockefeller Foundation, UNDP, and World Bank. Responsibility for this publication rests solely with CIMMYT.

Correct Citation: CIMMYT. 1987. *The Future Development of Maize and Wheat in the Third World*. CIMMYT, Mexico, D.F.

ISBN 968-6127-16-X

Contents

Opening Address

S.S. Husain
Consultative Group on International Agricultural Research, Washington, DC, USA

I am delighted to be here at this 20th anniversary celebration for CIMMYT, and as I said yesterday congratulations are in order for all of the participants in this very successful research effort. I also want to acknowledge the support and cooperation of the Mexican government in facilitating CIMMYT's work and hosting its headquarters in Mexico. Three of the international centers are located in Latin America and their work is important both regionally and globally. The support given by their host countries, Peru, Colombia, and Mexico, has been very important in furthering the work of these centers.

The accomplishments of CIMMYT during these 20 years, and even before its formal acceptance into the Consultative Group on International Agricultural Research (CGIAR) system, have been monumental in contributing to the self-sufficiency in wheat as well as increased maize production in a number of countries. It is not, however, our intent to dwell on these accomplishments or to be satisfied with these achievements because there remains much to be done to address the world's food problems. This symposium provides an excellent forum to exchange ideas and plans for future development of maize and wheat, two crops that feed so many people now and which are projected to be in even greater demand in the future.

CIMMYT and the entire CGIAR system have been assessing our programs and defining future challenges. To this end, I want to talk briefly about the strengths within the system that will be needed to meet these challenges.

The system was founded with two principal features: independence in pursuit of scientific endeavors and an international commitment. The centers were perceived as institutions that could operate efficiently, without political interference, in the highly turbulent atmosphere of emerging nations. Unlike national research institutions, the centers could keep on with research even when the nations were preoccupied with more immediate concerns. The centers from the beginning were viewed as "centers of excellence." It is this commitment to scientific excellence that has led the way in achieving higher and more stable yields. And it must be scientific excellence that will maintain these yields and even increase them through improved crop varieties and a more favorable production environment.

The accomplishments of CIMMYT during these 20 years have been monumental in contributing to self-sufficiency in wheat and increased maize production.

Good scientific research can and does make a difference to farmers and to consumers. Producing new technology is a major task of research, and farmers depend on a constant supply of new technology to sustain and improve their production techniques and—it is hoped—family income. But it is not just the farmer who benefits from good research. The consumer benefits through assured supplies of reasonably priced, more nutritious food.

Because conditions vary from country to country, each nation needs its own research capacity to recognize and solve its own food needs. One of the strengths of the CGIAR system has been the ability of the individual centers to work with and supplement these national research programs. However, we must continue to explore new and better ways to work collaboratively with both the well-established national programs and with countries that do not yet have strong national programs.

Helping developing countries with their research needs is a daunting task because their needs are moving targets. Food production and supply problems are changing, government policies are shifting, and long-term commitments to research are often hard to come by. It is in such an environment that the centers must work. In this situation continuity in center research can be the ingredient that keeps the national programs' research moving forward. To this end it is imperative that funding for the centers be continuous and long term. Studies in industrial countries indicate that the full impact of successful research usually requires 8 to 10 years following its initiation, and for livestock research innovations, 13 to 15 years are necessary to benefit livestock owners and consumers.

Helping developing countries with their research needs is a daunting task because their needs are moving targets.

What do we see in the future? Continued and rapid increases in population will demand greater increases in food production. Over the next 20 years developing country populations will almost double from 3300 to 6450 million. One of the most distressing facts about this growth is that it will be faster in those areas where land resources are least adequate to meet food needs. Consequently, solutions for adequate food supplies lie not only with increased production but also with improved incomes and better infrastructures for food distribution. And, because land holdings for the lowest income people are also projected to decrease, it will become even more important to look at new ways to increase the productivity of small landholders.

The CGIAR recently adopted a goal statement that reflects these concerns. We consider that international agricultural research and related activities must contribute to increasing sustainable food production in developing countries in such a way that the nutritional level and general economic well-being of low-income people are improved. This means *research* and its related activities, not development or technical assistance activities; *food and feed*, not industrial commodities; *technologies for long-term sustainable production*, not technologies that sacrifice ecological stability for short-term gains in productivity, and *improved nutrition and economic well-being of low-income people*, not solely through increased food production, but also through improved food quality, greater equity in distribution, more stable food supplies, and increased purchasing power.

The shift in the CGIAR's goal toward the concept of sustainable agriculture is significant. Sustainability means a greater emphasis on the land resource base. It means choosing cropping patterns that do not cause declines in the productive capacity of the resource base, such as crop rotations, intercropping, appropriate use of leguminous crops and trees, and development of effective crop and livestock systems. And it means preventing soil loss, salinity buildup, and depletion of water supplies. Achieving sustainability will require a comprehensive program of diverse but interdependent research activities. The challenge is to combine the comparative advantages of the centers in ways that will achieve this goal.

How can we meet this challenge? Some thoughts by Lloyd Evans in a commentary for the 1985 CGIAR *Annual Report* have helped my own thinking here. Lloyd points out that the international centers have had a profound effect on how research is done. For example, the concentration of efforts of outstanding scientists from many disciplines on a single commodity or problem has been very important.

Also, assembling comprehensive germplasm collections in one place, making many crosses between them, and then assessing their performance in many areas have been major activities for international centers. And the concept of broad adaptability of germplasm also fit into the international center context.

As I understand broad adaptability, plant materials developed in one place are capable of performing quite well in other parts of the world. For example, we saw success with Mexican wheats in Pakistan and India during the 1960s. In those early days, broad adaptability was attained rather quickly because yield gains were accomplished through factors such as shorter stature and more effective fertilizer use on the better lands. Since those early gains, the thrust now seems to be toward tailoring new varieties to specific environments. Does this new thrust mean that wide adaptability has reached its limits in certain circumstances, or that agroclimatic limits have been reached in using the wide adaptability strategy?

One question I have is how well wide adaptability has worked in Africa. Can the poor performance in Africa of many materials developed elsewhere be attributed to wide adaptability being less successful there? It may be only a matter of degree, but we do know that environments in Africa are diverse, and pest and disease problems are extensive. Perhaps in such circumstances more breeding programs serving local needs are required. It would seem to me that the question of how well wide adaptability has worked in Africa is an important strategic matter deserving close scrutiny by international experts. I will return to this later.

The crop-related centers must continue to expand gene banks and utilize the wealth of genetic resources contained in them. For some centers, exploiting the germplasm pool will be their major activity in the future. These activities call for scientists who can recognize problems of international importance and who can move upstream in the research process. National program capabilities are improving, and as national programs conduct more and more of the adaptive and applied research to fit more location-specific needs, the international centers will be able to move upstream in research.

At CIMMYT this move to upstream research has already begun, and we are delighted to see the much stronger role you are playing in genetic resources activities. We particularly commend you for increased gene bank efforts in both wheat and maize, your sustained wide cross programs, and your increasing emphasis on biotechnology research in both wheat and maize.

Systematic study of world germplasm collections has revealed an array of sources of resistance to many pests and diseases. Also, the potential for using wild relatives has significantly increased. The International Board for Plant Genetic Resources (IBPGR) and the crop-related centers have made the collection and characterization of wild relatives a high priority. Therefore, it is more important than ever for the free flow of germplasm on a worldwide basis to continue. And it is mandatory that the germplasm that is collected and stored be properly evaluated and documented. No matter how extensive collections may be, poorly evaluated collections are not very useful to breeders.

CIMMYT is located at the center of origin of maize, and the greatest genetic diversity of its wild relatives is here, too. The use of new genetic information as well as new techniques has made it possible to make wide crosses between crops and wild plants. This work should continue, so robust genes from wild plants can be used to improve our crops. At CIMMYT you have made wide crosses in both wheat and maize with promising results, although no new varieties with wild genes have yet been released. I look forward to hearing today of some of the advances that may be possible.

Most of the centers have established effective plant breeding programs and some are also conducting molecular and cellular research. In the future the interface between whole-plant research and cellular and molecular research must increase. To be effective, the international centers will need to strengthen their work in pathology, physiology, and entomology to assure new knowledge and scientific attention for present and future world problems.

I want to commend CIMMYT on its efforts to use its international nursery information in more creative ways to learn as much as possible from both wheat and maize trials. I hope that you will continue this work and that other centers will make a concerted effort to learn as much as possible from the tremendous enterprise that is the international network of crop nurseries.

Nursery testing sites need to be evaluated continually so that reliable comparisons can be made among the numerous nurseries operating all over the world. Evaluating new materials mostly by yield comparisons can no longer suffice; careful environmental and physical characterization of each test site can help us to streamline nursery activities and improve our ability to compare and predict outcomes at different sites, particularly in adapting varieties to marginal lands.

We should be aware that some of the land resources used for food crops will be required not only to meet increased food production demands but also to contribute to energy demands in developing countries. Projections indicate that the number of people without adequate fuelwood will more than double from 1395 million in 1980 to 2986 million by the end of the century. These land demands could be competitive, or they could be complementary if new production systems such as alley cropping or woody shrub production can be encouraged.

The international centers must also stand ready to help in maintaining the yield gains that have already been made. New forms of diseases and insects are constantly emerging that threaten to damage crops and reduce yields, cause food shortages, and sharply reduce farm income. To forestall such losses, maintenance research is needed to identify potential new insects or diseases, to identify sources of resistance to these pests, and to assist national programs in incorporating resistance genes into their own new crop lines. Such maintenance research requires excellent science, continuous effort, and assured funding.

Today we will hear the most recent thinking on whether or not we have reached, or may soon reach, a yield plateau in wheat. This is a very important question, not just for wheat, but also for other crops. It is imperative to know what is the biological potential of crops, and what—if any—possibility there may be for changing that potential through research. Certainly we do know that a good share of the yield gains made during the last two decades or so have come by increasing the proportion of grain to straw. What now, if anything, can be done to increase the total biomass yield of crops? I look forward to learning more about this today.

In conclusion, I would like to put forth two ideas for consideration. First, isn't it time we really examined carefully, on a worldwide basis, our experience and knowledge concerning broad adaptability? We know that broad adaptability was very successful in the 1960s and 1970s, but now many countries are tailoring varieties more and more to suit their conditions. Is this inevitable and logical? Why hasn't broad adaptability worked better in Africa? What does the evidence in Africa show? The CGIAR centers have considerable experience and information concerning broad adaptability. Shouldn't we convene a workshop soon to analyze what we know and don't know about broad adaptability and its limits?

Second, the CGIAR has had tremendous experience in plant breeding in many crops, but especially in cereals. Isn't it time that we discussed and compared our experiences and concepts on breeding strategies for cereals with other scientists? Such a meeting could be of great importance, in that years of international effort could be assessed and integrated with future breeding plans, particularly those that include increased involvement of biotechnology.

In closing, I want again to stress the importance of today's symposium. Wheat and maize together account for 40% of all worldwide cereal production. The demand for wheat is expected to increase in approximate proportion to population growth, while maize is predicted to provide an even greater proportion of human and animal food. The system's support of agricultural research in these commodities is very important.

Accomplishments in Maize and Wheat Productivity

N.E. Borlaug
International Maize and Wheat Improvement Center,
El Batan, Mexico

I have taken author's license to broaden the scope of my assigned topic. Although productivity impacts are – and should continue to be – the major criteria by which the worth of CIMMYT is measured, these, in turn, are the consequences of other factors. Of particular significance have been the development of new research methodologies and the establishment of international networks of maize and wheat researchers, achievements that are institutional hallmarks of the Center.

The Seeds from which CIMMYT Grew

In tracing the evolution of CIMMYT and its contributions to improving the productivity of maize and wheat, one must begin with the Cooperative Mexican Agricultural Program, which was launched in 1943 as a joint undertaking between the Mexican Ministry of Agriculture and the Rockefeller Foundation (RF). Those of us who were members of the research staff of the Mexican Government-Rockefeller Foundation Cooperative Agricultural Program (Office of Special Studies) during the 1943-1960 period are deeply grateful for support from many officials and employees of the Government of Mexico and from the Rockefeller Foundation, which paved the way for the establishment of CIMMYT. Among those who merit special acknowledgment for outstanding support and guidance are Ing. Marte R. Gómez, Ing. Alfonso González Gallardo, President Adolfo López Mateos, and Ing. Julián Rodríguez Adame of Mexico, and the "four horsemen" of the Rockefeller Foundation: Drs. E.C. Stakman, Paul Mangelsdorf, Richard Bradfield, and J.G. Harrar. During this early period, the interest and support of Don Rodolfo Elías Calles was also decisive for the success of the Wheat Program. He organized Sonoran farmers and agribusinesses to establish what is today CIANO (the Northwest Agricultural Research Center of INIFAP, the National Institute of Forestry, Agriculture, and Livestock Research), which has become a research and training Mecca for wheat scientists worldwide. Moreover, he was the founding spirit behind the establishment of the *Patronato para la Investigación Agrícola*, a unique farmer-financed organization that has been highly effective in support of agricultural research.

The Cooperative Mexican Agricultural Program

Contrary to the general public's perception, the research objectives of the Cooperative Mexican Agricultural Program were much broader than the development of high-yielding, disease-resistant crop varieties. Over its 17-year life span, this program not only developed improved crop production technologies, but also helped to build a national research infrastructure to support Mexico's efforts to expand the quantity, quality, and availability of food for her people. Priority was given to pragmatic, interdisciplinary research aimed at overcoming pressing production problems constraining productivity. The products of this research were also shared freely with the global scientific community.

During its nearly two decades of operation, this pioneering program had a significant impact, helping the country to reach self sufficiency in maize and wheat production in the 1950s. The effect of this research on production was achieved rapidly by pursuing a policy of transferring the new production technology from research plots to farmers' fields as soon as significant improvements became available. In the early years, before there was an extension service, the transfer was done by the scientist. This had a triple advantage: (1) it achieved early impact on increasing production, (2) it made the scientist directly aware of the strengths, weaknesses, and risks of the new technology, and (3) it permitted the scientist to rapidly shift research priorities to meet new production problems.

Training local researchers was a major activity from the start and perhaps one of the program's most significant contributions. Over 700 Mexican research workers received in-service training and 200 individuals received Rockefeller Foundation fellowships to pursue M.Sc. and Ph.D. degrees. The educational and training aspects of the program culminated in the establishment of the first postgraduate school for agricultural sciences in Latin America. This institution, now known as the *Colegio de Posgraduados*, was conceptualized and brought to fruition by Dr. E.C. Stakman, with the help of many others at Chapingo, in 1959.

Continuing Production Impacts in Mexico

Since the 1960s, Mexico has continued to make research impacts in maize and wheat through its national research efforts as well as through its research partnership with CIMMYT. Between 1961-65 and 1982-84, Mexican wheat production increased at an average rate of 5.1% per annum and maize production at a 3.0% annual rate. Today, Mexico ranks fifth in maize production and 15th in wheat production in the world. In maize, national yields have increased at a rate of 3.1% per annum since 1970-72, although the total area devoted to maize cultivation has declined slightly. Growing deficits in national maize production have been caused by rapid growth in population combined with the very strong demand for this cereal grain as a poultry and livestock feed. Lest we forget the increase in food demand resulting only from population growth, we should remember that the population of Mexico in 1943 was approximately 23 million; in 1986 it has passed the 80 million mark. In wheat, the current average national yield--approximately 4 t/ha--is the highest in the developing world, and only surpassed in the developed world by a few European countries. Due largely to these productivity gains, Mexico is once again self-sufficient in wheat production, even though a considerable amount of wheat is now being used as animal feed.

Training local researchers was perhaps one of the most significant contributions of the Mexican-Rockefeller Foundation program.

But to remain self-sufficient in wheat over the next 20 years, with the growing demand resulting from population growth and increased per capita consumption, will require an expansion of wheat cultivation into nontraditional wheat-producing regions. The possibility exists to extend the cultivated area southward, during the winter season, into more semitropical areas on the Pacific coast and into the northern humid Gulf of Mexico coast. To achieve this objective will require the development of varieties with a high level of resistance not only to leaf rust but also to *Helminthosporium* spp., *Gibberella* spp., *Septoria* spp., and to a complex of organisms, especially *Sclerotium rolfsii*, that produce root rots. Mexico's need for research to exploit this potential coincides with CIMMYT's international research effort in "tropical wheat" initiated in 1981.

A second avenue for increasing Mexican wheat production is through augmenting the productivity of wheat sown during the summer rainy season at high elevations, especially on the central plateau. Research during the late 1940s clearly established the biologic and economic feasibility of production under these conditions. However, since the harvest from the traditional winter production areas increased rapidly, and was generally adequate to meet demand until the late 1970s, the production potential in areas at higher elevations remained largely unexploited. Within the past five years, the area sown to summer wheat has increased rather dramatically. Expanded cooperative research by CIMMYT and INIFAP to broaden the spectrum of resistance to a number of foliar diseases, as well as to develop varieties with tolerance to high levels of soluble aluminum for some areas, is essential if the full potential of summer wheat production at high elevations in Mexico is to be exploited. CIMMYT also has interest in development of such research for use in the Andean region, in parts of the Southern Cone countries of South America, and in East Africa.

Establishment of International Agricultural Research Centers

With the successful maize and wheat programs in Mexico as a model, and with the keen insight into the worsening food shortages in Asia, Drs. J.G. Harrar (the first Director of the Cooperative Agricultural Program in Mexico and later President of the Rockefeller Foundation) and F.F. Hill of the Ford Foundation helped to establish in 1960 with the cooperation of the Government of The Philippines the first truly international agricultural research institute—the International Rice Research Institute (IRRI) in Los Baños, the Philippines.

By the time IRRI was formed, the Cooperative Agricultural Program in Mexico had achieved its primary objective: the building of a national agricultural research capacity. In 1960, the National Agricultural Research Institute (INIA, now INIFAP) was established by the Government of Mexico as a semi-autonomous public organization. Four years later, after INIA had assumed the national mandate to produce research results for Mexican farmers, the late President of Mexico, Adolto López Mateos, proposed the creation of an international maize and wheat research center to support the work of national programs throughout the world, but with emphasis on the production problems of developing countries. With this as its mandate, CIMMYT was established in 1966 as the second international agricultural research center in a network, now supported by the Consultative Group for International Agricultural Research (CGIAR), which has grown to 13 autonomous centers.

CIMMYT'S Research Contributions

In commenting on CIMMYT's contributions in maize and wheat research, I will treat the achievements made during the years of the Center's predecessor organization as part of CIMMYT's overall legacy. Given the considerable overlap in research personnel from both organizational phases, and the fact that CIMMYT's operational philosophy is modelled largely after its predecessor organization, it is appropriate to view both phases as part of the same continuum. It should be noted, however, that many research breakthroughs attributed to CIMMYT, at least in wheat, were achieved prior to its establishment as an international research center.

CIMMYT occupies a deserved place of distinction within the agricultural research community. Its staff—past and present—have played pioneering roles in the development of commodity-focused agricultural research in the Third World. Its achievements in the development of high-yielding wheat and maize varieties with broad adaptation and enhanced yield dependability, and in the development of the agronomic practices that permit these improved materials to express their high genetic yield potential, have been exemplary.

The greatest commercial benefits of this research have been achieved in bread wheat, *Triticum aestivum*, where the improved technology was married to stimulatory economic policies and readily available production inputs and credit, which promoted rapid adoption of the new technologies and led to increased yield and production in so many countries. But considerable impacts in several countries in maize (*Zea mays* L.) are also on the verge of becoming reality. I also consider the progress to develop triticale as a commercial crop and the efforts to develop nutritionally superior maize materials to be important research achievements. Both of these projects involved medium- to long-term basic research and are now reaching the point when commercial payoffs are possible. Recent efforts to develop varieties with greater dependability of yield under environmental stress and CIMMYT's continuing research in crop management technologies are also significant activities. For the benefit of the invited guests, a brief comment on each of these research contributions is in order.

Broad Adaptation

Until the 1950s, although still present to some extent today, plant breeding dogma held that the only way to ensure the development of high-yielding, well adapted varieties was to select them through all segregating generations in the location where they were to be grown commercially. Faced with the urgent need to develop wheat varieties with acceptable stem rust resistance in Mexico, a decision was made to ignore dogma and use several ecological zones that would permit the growing and selecting of two segregating generations of progeny each year. Since different races of stem rust were present in various locations, multilocational testing permitted the screening program to build up more durable resistance (broad spectrum) to stem rust as well as to other pathogens. Moreover, with two breeding cycles every 12 months, a new variety could theoretically be produced in four years, rather than eight years required with the conventional methods.

To accomplish this, we used two principal locations in Mexico separated from one another by 10° of latitude (and with changing daylengths), with differing temperatures because of a change in planting seasons, and with differences in elevation of 2600 meters. Segregating populations were shuttled between, grown at, and selected in these two very diverse environments. Soon, some unexpected results started to become evident from this unorthodox breeding approach. Progeny from certain individual plant selections from a very few crosses were soon observed in F_3 and F_4 generations to be early maturing and equally well adapted at a number of locations in the high central plateau around Mexico City, in the Bajio region at Irapuato and Leon, and in the Sonoran coastal plain at Ciudad Obregon. Once this unique breadth of adaptation—combined with early maturity—was recognized, the intensity of selection pressure was increased.

By 1948, the Princess of Serendipity had smiled on our unorthodox shuttle breeding effort. Two new varieties, Yaqui 48 and Kentana 48, had proven themselves to be high yielding, early maturing, resistant to shattering, highly resistant to stem rust, and moderately resistant to leaf and stripe rust. Because of this combination of traits, these new varieties could be grown successfully with proper dates of planting over a range of climatic and soil conditions in Mexico. With their daylength insensitivity and broad-based rust resistance, these varieties, or their derivatives, were also later shown to be top yielders in many production areas in other developing countries. In the initial years, this breeding approach also made the tasks of seed production and distribution easier. With only a few varieties needed to serve commercial farmers—rather than the dozen or more that would have been necessary if narrowly adapted varieties had been developed—the work of Mexico's newly formed national seed agencies was made much more manageable.

While I am a proponent of the utility of developing broadly adapted materials, I am not advocating that plant breeders try to develop a single universal variety. This would be unwise from the standpoint of genetic erosion and disease susceptibility, as well as unwise in terms of trying to optimize yield potential, especially in many problem soils. But neither should the emphasis be on the development of materials with such narrow adaptation that they are only suited to very small microenvironments.

In this sense, a crucial research issue in varietal development is the delineation of boundaries for the various broadly generalized production environments.

While we were empirically manipulating photoperiodism through our shuttle breeding techniques, Drs. Hendricks, Borthwick, and Parker of the US Department of Agriculture (USDA) were providing the theoretical explanation of this phenomenon. Through their work on the role of light in plant photoperiodism, seed germination, stem elongation, flowering, and fruiting, they were able to explain underlying principles of varietal adaptation. In the early years of study, they believed that sensitivity to daylight was controlled by one or two major genes. Current evidence indicates that, although there are probably only two major genes involved, there are also a large number of modifier genes. The maturity system is further complicated by the interaction of genes that control maturity and photoperiodism and those that control vernalization (temperatures), making it possible to isolate many different genotypic combinations.

In F_1 and F_2 progeny derived from crosses between Mexican varieties and Norin 10 x Brevor lines, it became evident that a new type of wheat was forthcoming.

Breakthrough in Genetic Yield Potential

Though successful in combining early maturity, disease resistance, and broad adaptation in the improved tall cultivars, we continued to face the barrier that lodging was imposing on grain yield. As the use of nitrogenous fertilizers increased, especially in the State of Sonora, lodging had become the major problem limiting yields.

During 1952 and 1953, we made a concerted - but unsuccessful - effort to find suitable materials with shorter and stronger straw for use as parents in the breeding program. The entire World Wheat Collection of the USDA was screened for straw height and strength. In late 1952, Dr. Orville Vogel's preliminary success with incorporating the dwarfing genes from Norin 10 (a Japanese winter wheat) into US winter wheats were related to me by the late Dr. Burt Bayles, then senior wheat breeder for the USDA, to whom I am deeply indebted for repeated wise counsel and guidance during the early years of the Cooperative Mexican Wheat Program. I wrote Dr. Vogel and requested genetic materials containing Norin 10 dwarfing genes for use as parents in our spring wheat breeding program. In 1953, Dr. Vogel kindly sent me a few seeds from three different F_2 selections from the cross Norin 10 x Baart and a few seeds from each of five superior F_2 plants from the cross Norin 10 x Brevor.

Our first attempts to cross the Mexican materials to Vogel's materials were unsuccessful. Since the Norin 10 Brevor F_3 plants were very late in flowering they were used as the female parents, and being highly susceptible to all three rusts they were killed outright without producing viable F_1 seed. Using the few remaining reserve seeds, a second attempt was made in 1955 and was successful. In the F_1 and F_2 progeny derived from crosses between Mexican varieties and Norin 10 x Brevor lines, it became evident that a new type of wheat - much higher yielding than we had seen before - was forthcoming. In the early generations, progeny derived from the Norin 10 x Brevor x Mexican variety crosses had many deleterious genes. The most obvious and worrisome problem was the high degree of male sterility, especially in the late tillers, which led to much promiscuous outcrossing. In fact, the amount of outcrossing in the first two cycles of breeding was so high that it casts doubt on the reliability of many of the pedigrees. The second serious defect was grain quality. The grain invariably was badly shrivelled, soft, and had weak gluten. A third serious defect was the high degree of susceptibility to stem and leaf rust introduced in the progeny from the Norin 10 x Brevor parents.

Various types of crosses were made and strong selection pressure was exerted to attempt to overcome these problems. By 1962, seven years after the first successful crosses, two high-yielding semidwarf Norin 10 derivatives - Pitic 62 and Penjamo 62 - with broad based rust resistance and adaptation to a range of production environments, were named and released in Mexico for commercial production. While our research objective in using the semidwarf materials was to reduce the incidence of lodging, we obtained an unexpected benefit of markedly higher yield potential, due in large part to the partitioning of more of the total dry matter into grain production. The newly released semidwarf varieties had yields of 6.0-6.5 t/ha, compared to the 4.0-4.5 t/ha of the tall, improved Mexican genotypes that were used in these crosses. Obviously, additional genes were introduced into the formerly so-called "high yielding" Mexican varieties by their Norin 10 and Brevor parents, with both parents contributing to increased yield potential.

Diffusion of Semidwarf Wheat Varieties

Since the early 1960s, more than 400 high-yielding semidwarf spring wheat varieties derived from crosses made at CIMMYT have been released in some 50 countries. These materials, in general, have much better disease resistance than the local varieties that they have replaced. They also produce more grain than local materials under low fertility conditions and have the capacity to yield up to twice as much as traditional varieties under better fertilizer and moisture conditions.

The area in which these semidwarf spring wheat varieties have demonstrated superior yield performance is vast: 50 million hectares in developing countries (half of the total wheat area), as well as approximately 10 million hectares in developed nations. Third World wheat areas share many common traits in terms of varietal requirements. Rusts are the major disease problem, moisture is generally not a limiting factor, and intermediate maturity is the major growth period requirement. The materials developed in Mexico had these characteristics. In addition, their daylength insensitivity and other agronomic characters made them adapted to a very broad range of production conditions. But the current coverage of available varieties also probably delineates the boundaries of these major production environments.

The fact that 50 million hectares in the developing world have yet to be planted to improved varieties is an indication that new gene pools and more specific selection criteria are likely to be needed to develop suitable varieties for these untouched problem areas. These primarily include locations with acid soils and high levels of soluble aluminum, alkaline soils with high levels of sodium, and soils in marginal rainfall areas. Through more recent research efforts, many of the production constraints in such areas are now being overcome. For example, as a result of a collaborative breeding program between CIMMYT and the Brazilian Agency for Agricultural Research (EMBRAPA), the Federation of Brazilian Wheat and Soil Cooperatives (FECOTRIGO), and the Organization of Cooperatives of the State of Parana (OCEPAR), in Brazil, high-yielding varieties with tolerance to soluble aluminum have been developed.

Development of High-Yielding Maize Materials

Local maize varieties in the tropics and subtropics suffered from a problem similar to that of traditional wheat types. They were leafy, grew too tall, were late maturing and tended to lodge heavily when grown under improved agronomic conditions. Compared to US Corn Belt materials, tropical maize materials had very poor harvest indices, with up to two-thirds of their total dry matter partitioned to stover instead of grain. CIMMYT has made significant contributions in improving the harvest indices of tropical and subtropical maize materials. The Center's efforts to develop for the tropics and subtropics more grain-efficient, yield-dependable maize varieties, whose seed can be saved by the farmer for planting the next season without significant loss of vigor, have been an important research contribution.

While a recurrent selection scheme has been the basis for repartioning total dry matter weight in maize toward greater grain production rather than the introduction of a dwarfing gene—the results have been the same: the improved maizes have much higher genetic yield potential then do the traditional local varieties. A system of multilocational testing, first in Mexico and later in dozens of locations in other countries, has broadened the adaptation of these maize materials, not only from the standpoint of photoperiod insensitivity but also in terms of resistance to important foliar diseases and to certain classes of insects. As a consequence of this work, new sources of genetic variability have been supplied to many national maize improvement programs. This germplasm can be readily used—and is being used—to improve locally developed materials. The improved maize developed through this methodology has been a collaborative effort with national scientists throughout the developing world. This research partnership has produced 1000 experimental varieties, and some 150 of these have been released by 30 national governments for commercial cultivation.

Quality Protein Maize

The discovery of the improved nutritive value of opaque-2 maize at Purdue University in 1963 ushered in a period of great euphoric activity directed toward developing maize varieties and hybrids with high levels of lysine and tryptophane. But the euphoria faded to frustration, and this effort was discontinued by virtually all private seed companies and government and university programs, when the unfavorable linkages associated with the opaque-2 gene became apparent.

The CIMMYT Maize Program, with excellent close collaboration between geneticist-breeders and biochemists, has gradually overcome the adverse linkages. Currently, several open-pollinated quality protein maize (QPM) varieties with high grain yield, hard-textured kernels (flint or dent), and good disease and insect resistance have been developed. This work has shown that the adverse linkages conferred by the opaque-2 gene between high levels of lysine and tryptophane and low grain yield, soft grain texture, and susceptibility to ear rots and insect damage can be, and have been, overcome. Open-pollinated QPM varieties are being grown commercially in Guatemala and China, and CIMMYT is now developing QPM hybrids.

It appears to me that the development, acceptance, and use of QPM materials is now similar to that of the semidwarf wheat varieties 20 years ago in India, Pakistan, and the USA—when many noisy skeptics said they would never be accepted. Nevertheless, look what has happened in QPM development during the past 15 years! I predict QPM too will have "its day" in the years ahead.

The New Crop: Triticale

Triticale (X. *Triticosecale* Wittmack) is an amphiploid species developed from crossing wheat and rye (*Secale cereale*), employing either durum (*Triticum turgidum* var. *durum*) or bread wheat varieties as the wheat parent. This man-made new cereal, which now promises to become an important food and feed crop in many areas of the world within the next decade, is currently grown on a total of more than one million hectares in at least 10 countries.

CIMMYT inherited a small triticale research program from its predecessor organization. At that time, all triticales were tall, late maturing, and highly sterile; the grain that was produced was also badly shrivelled. CIMMYT established a large, broadly based breeding program to overcome these defects. Despite criticism of the program and predictions by some theoretical scientists that triticale's defects—especially sterility and shrivelling of the grain—would never be overcome, one by one they have been conquered.

Today, in acid soils, especially in those with high levels of soluble aluminum, triticale is far superior in grain yield to wheat. Moreover, even in many areas with good soils, such as those in the State of Sonora, Mexico, triticale yields as much as the best bread wheat varieties. In the Soviet Union, Poland, Australia, Spain, France, West Germany, Canada, USA, Argentina, and Mexico, where most commercial triticale production is concentrated, the grain is being used primarily as feed. But it also has considerable promise as a food grain. When triticale flour (unlike flour from durum wheat) is properly blended with flour from bread wheat and the dough is appropriately handled during fermentation, good bread will be produced.

The disease resistance of triticale to certain pathogens is also of significance, especially in Mexico. In recent years, in certain seasons when environmental conditions have been favorable for heavy infection with *Neovossia indica* (the causal agent of Karnal bunt), the level of grain infection on bread wheat varieties was heavy enough to adversely affect both the odor and taste of flour and bread. Under these same conditions, grain from durum wheat varieties and triticale varieties was either entirely free of Karnal bunt or only had a trace of bunt. Since it is very difficult to blend durum wheat and bread wheat flour to make satisfactory bread, triticale flour offers a viable alternative for blending with bread wheat flour.

Durum Wheat Research

Durum wheat is used primarily for the production of pasta products and crackers. Although durum wheats are grown on approximately 10% of the world wheat area, perhaps no more than 1% of the worldwide varietal breeding effort on wheat has been devoted to the improvement of this species. Even though the Norin 10 dwarfing genes were successfully crossed into both Mexican bread wheat and durum wheat varieties in 1955, because of shortage of scientific manpower the major effort in the early years was devoted to the development of bread wheat varieties. By 1967-68, it had become apparent that the newly emerging, improved semidwarf durum varieties had unusually high grain yield potential, even though they were still plagued by partial sterility and shrivelled grain. Gradually, over a number of years, these defects have been corrected and early-maturing, semidwarf durum varieties with good milling and pasta-making properties are now available. Although these durum wheats yield as much as the best bread wheat varieties under irrigated as well as rainfed conditions, they have a narrower range of adaptation than the semidwarf bread wheats. The durum wheats currently available are also more susceptible than bread wheats to *Fusarium* spp., *Septoria* spp., and *Helminthosporium* spp., but are either more resistant to (or escape) Karnal bunt.

Today, CIMMYT-derived semidwarf durum wheats are grown commercially in Mexico, Chile, Argentina, Algeria, Tunisia, Turkey, Iraq, and India, as well as in developed countries such as Italy, Spain, Australia, France, and the USA. It is probable that by widening the germplasm base and exerting strong selection pressure on segregating populations, new varieties can be developed which will combine broader adaptation with broader disease resistance, as well as drought resistance. Furthermore, since the most promising CIMMYT triticales are derived from crosses of durum wheat x rye, it follows that an aggressive durum wheat breeding program is an important component for supplying improved parental durum varieties for use in the triticale breeding program.

Crop Production Research

CIMMYT has had a tradition of being farmer focused in its research approach. Although the Center is famous for its contributions in plant breeding, improved germplasm has only been its calling card. We also have seen the need for improved crop management in the different parts of the world and have participated with national program scientists in such research. While the high-yielding varieties have served as the catalyst for introducing higher yielding agricultural technology, the contributions of improved agronomy, especially the proper use of fertilizer and better irrigation and weed control practices, were essential to the yield impacts that have been achieved in Third World food production.

CIMMYT is known for its contributions in plant breeding, but improved germplasm is only its calling card.

Since its inception, CIMMYT has sought to employ crop management specialists who are conversant with a broad range of production factors, i.e. breeding, agronomy, water use, weed science, pathology, entomology, and economics. These crop management specialists have been integrated into the crop programs and work beside breeders, pathologists, and economists in the solution of common problems. This integration of research disciplines has been highly effective and has helped CIMMYT to increase cereal production and productivity in many countries of the Third World. The initial agronomy research work in Mexico, the wheat agronomy program in Turkey, the early days in India and Pakistan when the semidwarf wheat varieties were introduced, the spread of improved maize varieties and hybrids in Southeast Asia and Central America, and more recently, the wheat production successes in the Southern Cone of South America, are all examples of national production campaigns in which CIMMYT staff have played important roles as research catalysts and integrators.

In the course of this crop management research collaboration, CIMMYT has also played a leading role in the development of more effective research procedures in which biological scientists and economists work together. The procedures place a major emphasis on on-farm experimentation, since the production conditions of most research stations are not sufficiently typical of the conditions faced by typical farmers, especially the resource poor ones.

CIMMYT's Organizational Innovations

CIMMYT's development of international germplasm testing networks, its in-service training programs, and the Center's efforts to build global and regional networks to facilitate information exchange, have been highly effective institutional innovations that have contributed greatly to putting maize and wheat research on a sounder basis worldwide. A brief review of each of these developments follows.

International Testing

In 1950, the first of four years of successive stem rust (*Puccinia graminis*) epidemics struck the wheat crop in the United States and Canada, reaching a peak in 1954, when 75% of the durum wheat, as well as a considerable part of the bread wheat crop, was destroyed. The primary cause was the virulent race 15B, which was capable of destroying all of the durum and bread wheat varieties then in use commercially. A race similar to 15B was also spreading simultaneously in Latin America. The standard response to such a disease epidemic is the rapid testing of wheat lines to identify resistance to the new race of pathogen, and then the multiplication of the seed of the resistant lines as soon as available while continuing to cross resistant lines to pyramid and broaden the genes for resistance. A race as virulent as 15B demanded the widest possible testing for resistant materials in the shortest possible time.

A disaster of this magnitude forced scientists to search for new solutions, and out of this crisis came initiatives, largely under the leadership of the late Drs. H.A. Rodenheiser, E.C. Stakman, and T. Johnson, that are still benefiting global agriculture. In 1950, the USDA appealed to eight countries — Mexico, Colombia, Ecuador, Peru, Chile, Brazil, Argentina, and Canada — to join the United States in testing 1000 lines of wheat selected from the US World Wheat Collection and some advanced generation lines from several breeding programs as possible sources of resistance to the race 15B. CIMMYT's predecessor organization in Mexico was an active participant and contributed many lines from its breeding program. These 1000 wheat lines were exposed to the stem rust populations present in the participating countries. The results of this 1st International Stem Rust Nursery exceeded expectations and, today, much of the stem rust resistance in commercial wheats can be traced to the breeding materials identified from those early nurseries.

There were other indirect benefits of even greater importance in this international cooperative effort than the identification of germplasm with resistance to race 15B of stem rust. A new mechanism for widespread international testing of germplasm — first in wheat and later in many other food crops — was in the process of formation. Before the 1st International Stem Rust Nursery, many breeders were reluctant to release advanced lines from their breeding programs to fellow scientists for fear that new varieties would be named and released without proper recognition to the breeder or organization responsible. Rarely were early generation segregating materials distributed to other scientists either, largely for the same reasons.

The first attempt to establish a Cooperative International Wheat Yield Nursery was made in 1959, when the Mexican-RF Program volunteered to organize, prepare, and distribute the Inter-American Spring Wheat Yield Nursery. This nursery included the most important commercial spring wheat varieties then being grown in both continents, as well as a number of promising breeding lines from programs in Mexico, Canada, USA, Colombia, Chile, Argentina, and Brazil. The nursery was grown in more than a dozen countries of the Americas. This nursery clearly established the broad adaptation of the Mexican varieties in contrast to the limited adaptation across latitudes of the long-daylength varieties produced in Canada, the USA, and Argentina.

Drawing on the experience of the Inter-American Spring Wheat Yield Nursery, we then organized the Near East-Mexican Spring Wheat Yield Nursery, as part of the Food and Agricultural Organization (FAO)/RF-sponsored North African/Near and Middle Eastern Wheat In-Service Training Program. The nursery included the important commercial varieties from countries where it was distributed, as well as two long-daylength varieties, Thatcher and Selkirk, from Minnesota and Canada, respectively, and a number of promising new semidwarf lines that we were developing in Mexico. Two years later, the Inter-American Spring Wheat Yield Nursery and the Near East Mexican Spring Wheat Yield Nursery were combined to form the International Spring Wheat Yield Nursery (ISWYN), which has continued to this day and whose data serve as an invaluable guide — for those wheat scientists who use it intelligently — in orienting national breeding programs.

Today, CIMMYT serves as the hub of one of the largest germplasm distribution and testing networks in the world. Each year, over one million packets of maize, wheat, and triticale experimental seed — carrying significant amounts of useful new genetic variability—are sent to plant scientists in more than 120 countries. The results of these nursery trials are recorded at each individual test site and then sent to CIMMYT for data processing and analysis. The results are compiled, published, and distributed widely among maize and wheat scientists around the globe.

In addition, CIMMYT's germplasm banks, which are some of the largest and best maintained in the world and contain a treasure of genetic diversity, supply thousands of seed samples to scientists throughout the world.

International testing helped to break down psychological barriers that had tended to separate the efforts of plant breeders in different organizations. It became accepted policy that any line tested internationally could be used by collaborating scientists for breeding purposes or for distribution as a commercial variety, provided the source of the material was acknowledged. Not only did international testing introduce new genetic variability into national breeding efforts, but it also provided individual breeders with the opportunity to evaluate the adaptation and disease stability of their promising new materials in many different environments worldwide simultaneously. I believe it fair to say that the advent of international testing marked the beginning of the modern era in plant breeding.

Training and Leadership Development

CIMMYT has rightly placed a very high priority on its training and leadership development efforts in support of collaborating national research institutions. The Center currently counts some 4000 researchers from 120 countries as alumni of its in-service training courses and fellowship programs for visiting scientists, graduate students, and pre- and postdoctoral fellows. In these training efforts, CIMMYT has sought to complement the theoretical training that agricultural researchers have received in universities and technical schools. The training emphasis has been on actual physical performance of research tasks. This approach has had a positive motivational effect on trainees and research fellows. When scientists work together, struggle together, sweat together, and triumph together, they create bonds of mutual respect and friendship and, in the process, develop a powerful worldwide fraternity of crop scientists dedicated to increasing food production and improving the equity of distribution of its benefits.

Development of Scientific Information Networks

Central to CIMMYT's success has been its close working relationships with national program scientists. Building this global fraternity of maize and wheat scientists has required frequent visits by CIMMYT staff to the offices and research plots of national collaborators, providing training fellowships for scientists from developing countries to come to Mexico and/or helping them obtain funds for graduate studies, and offering a continuing flow of useful scientific information, generally on a cost-free basis.

In an earlier day, much of the staff travel to collaborating countries was done by staff based in Mexico, who travelled widely each year visiting with research collaborators, administrators, and policy makers in many countries. As the number of countries with which CIMMYT had research relationships grew from 60 to more than 120, new institutional mechanisms became necessary to handle these extensive research relationships more effectively. Today, half of CIMMYT's scientific staff are posted to regional programs. Much of their activity is similar to what staff travelling from Mexico attempted to do in previous years. The major advantage to the regional program concept, however, is that CIMMYT has representatives actually living and working in major maize- and wheat-growing environments of the developing world. With more frequent contact, and a more intimate understanding of local research problems and opportunities, the links between CIMMYT and national programs have been reinforced.

Contributions to Increased Food Availability and Agricultural Productivity

CIMMYT's contributions to increased agricultural productivity are inextricably linked with the efforts of many scientists, production specialists, extension workers, policy makers, and farmers. In germplasm development, the staff have worked in a partnership role with national research programs. Even though varieties emanating from this work are joint products, CIMMYT, itself, does not seek to name or release varieties; this is the responsibility of national crop research and seed certification programs. Furthermore, success at the farm level is the consequence of many other components besides improved varieties. Improved agronomy through better use of fertilizers and moisture (either rain or irrigation), plant protection, and greater policy incentives all have played major roles in the productivity advances made by Third World farmers in recent years.

The Green Revolution

CIMMYT was born in the midst, and was largely a consequence of, a world crisis in food production—centered in Asia during the 1960s. With countries lacking foreign exchange to purchase food imports, dire predictions were being made that without perpetual food aid, many Asian countries faced continuing and worsening famines. Political leaders, many with their backs against the wall, became receptive to the then radical advice of a handful of scientists who argued forcefully for the introduction of the new high-yield wheat and rice technologies developed in Mexico and the Philippines. Overruling the counsel of some local researchers, India and Pakistan's national leaders took calculated risks and, after four years of widespread on-farm testing, decided to embark on major production programs to introduce the new seed/fertilizer technologies as quickly as possible. Once tens of thousands of farmers saw the yields of the new wheat and rice materials grown using improved agronomic practices on demonstration plots on their own or neighbors' farms, they themselves became the major spokesmen for increased adoption. The spread of these new wheat and rice varieties is unparalleled in the history of agriculture (Table 1), except perhaps for the spread of hybrid maize in the developed countries during the 1940s, 1950s, and 1960s.

Table 1. Area planted to high-yielding wheat and rice varieties

	Wheat		Rice	
Region	Area (m/ha)	Proportion (%)	Area (m/ha)	Proportion (%)
Asia, developed market economies	25.4	79.2	36.4	44.9
North Africa/Middle East	7.6	30.6	30.6	8.4
Sub-Saharan Africa	0.5	50.6	0.2	29.6
Asia, centrally planned economies	8.9	30.6	33.4	81.0
Latin America	8.3	77.6	2.5	32.9
Total	50.7	51.9	72.6	53.6

Source: Dalrymple, 1986

Increased investments in agricultural research and rural infrastructures have helped to more than double Third World maize production and to more than triple wheat production over the past 20 years. India's wheat production has increased more than fourfold in this same period. Slightly less than 50% of the growth in maize production and 65% of the growth in wheat production have been due to higher yield levels. Over the past two decades, Third World per capita production has increased more rapidly than population for both crops, by 30% in maize and 70% in wheat. In maize, increased per capita production has been destined primarily for livestock and poultry feed and the direct food use of maize has remained constant at 8% of total calories. In wheat, increased per capita production in developing countries has resulted in the marked increase in importance of this grain in human diets in developing countries. In 1961-65, wheat accounted for 16% of total calories in human diets; by 1981-84, it accounted for 26% (Table 2).

Plant species are apolitical. They cannot be coaxed to yield more on a small plot than they are capable of yielding on a large tract of land.

When Third World maize and wheat production indicators are disaggregated into regional statistics, however, it becomes evident that progress in agricultural development between 1961-65 and 1981-83 has been uneven (Table 3). The performance of China has been spectacular, with annual per capita growth rates of 7% in wheat and 5.8% in maize. Strong growth rates have also been registered in other developing market economies of Asia as well. In most of Latin America - the Andean countries being the exception - growth in wheat and maize production has also outpaced population. In the Middle East, wheat production has barely kept pace with population growth, and per capita maize consumption has declined. In North Africa, the growth in wheat yields has been sluggish, although maize yields have increased at a rate of 2.3% per annum. West Africa has had very low growth rates in both maize and wheat yields. Maize and wheat production has exceeded the rate of population growth only in a few Southern and Eastern African countries.

Critics of the Green Revolution

Despite the tremendous production gains achieved in many developing countries in a very short time, Green Revolution technologies have been the subject of intense controversy since their introduction. Many initial reports depicted the new wheat and rice technologies as a wholesale transfer of high yield, temperate zone farming systems to peasant farmers in the Third World. In reality, this was not the case. More accurately, the term "Green Revolution" signifies the beginning of a new era for agricultural research and development in the Third World, one in which modern principles of genetics and plant breeding, agronomy, plant pathology, entomology,

Table 2. Percentage increase in maize and wheat performance indicators in the developing world, 1961-65 to 1981-84

	Percentage increase 1961-65 to 1981-84	
	Maize	Wheat
Total production, developing countries	[illegible]	[illegible]
Average yield	58	97
Per capita production	30	70
Percentage total calories in diet, 1961-65	8	16
Percentage total calories in diet, 1979-81	8	26

Source: 1984 CIMMYT Maize Facts and Trends, 1985 CIMMYT Wheat Facts and Trends.

and economics have been applied to develop indigenous technologies appropriate to the conditions of local farmers.

The really important attribute of the new Green Revolution technologies was that they were cost-efficient, yield-increasing, land-augmenting technologies. It was the introduction of these new technologies, combined with adequate policy incentives, which led to the significant productivity gains - and which helped to stave off famines of gigantic proportions. The combination of the new varieties and higher yielding production technology have allowed farmers (resource poor as well as resource privileged) to increase total farm output through higher yield levels and greater cropping intensity. This technology, coupled with favorable economic policies, gave farmers incentives to produce surplus production for commercial sale. Not only did these innovations increase income levels for farmers, but they helped to lower production costs per unit of output. These more productive farming systems led to the development of new rural industries and new sources of employment. Consumers, however, were the major absolute beneficiaries, especially the urban and rural poor, whose diets depend heavily on cereals. Per capita production increases in wheat, rice, and maize have considerably slowed the rate of increase in food prices. This has permitted improved nutrition, and thus improved welfare, for hundreds of millions of low-income people.

Table 3. Distribution of production and rates of growth in yield and production for less developed countries (LDCs) by region

Region	Wheat			Maize		
	Percent of total LDC production 1984	Growth rates 1961-65 to 1982-84		Percent of total LDC production 1984	Growth rates 1961-65 to 1981-83	
		Yield (%)	Production (%)		Yield (%)	Production (%)
Asia, developed market economies	28	3.7	6.3	13	1.6	3.0
Asia, centrally planned economies	43	6.2	7.0	42	5.2	5.8
Middle East	14	2.2	3.0	2	1.7	1.8
North Africa	3	1.1	1.0	2	1.7	1.8
West Africa	..	0.3	2.0	3	0	1.5
East and South Africa	..	3.0	2.5	7	1.3	2.7
Mexico, Central America, and the Caribbean	2	3.1	4.1	11	2.5	2.8
Andean countries	..	1.1	1.0	2	1.7	0.9
Southern Cone countries of South America	8	1.1	2.7	18	2.1	3.8

less than 1%

Various criticisms have been levelled against the Green Revolution technologies. In the initial years, population doomsayers said that it was already too late in the overpopulated developing countries, that the situation in countries such as India and Bangladesh was hopeless, and that the rich nations would only make things worse in the long run by trying to alleviate suffering in the short run. This group likened the Earth to a lifeboat that could only hold so many passengers without sinking. Moreover, they viewed international assistance efforts in agricultural research as only encouraging more population growth which, as a result, would lead to a disaster of greater proportions later.

I share the concern about the high rates of population growth in many developing countries and the effects that this growth has had on economic development, standards of living, and environmental quality. But the lifeboat argument was and is premature—we have not exceeded the carrying capacity of the Earth. In reality, there are at least two lifeboats and maybe more. One lifeboat carries 20% of the world's people—those who reside in the developed nations—and who, in relative terms, have first class bookings. The other lifeboat, increasingly overloaded and leaky, carries the remaining 80% of the world's people—those of the developing world. It seems cruelly insensitive and short-sighted for those with first class passage—and who have the capacity to help improve welfare in the much poorer nations—to lead the cry for science to turn its back on the plight of the vast majority of humankind. If this approach is pursued for long, it will lead to widespread social rebellion and, in all probability, to the downfall of the present world civilization.

In retrospect, the songs of gloom and doom sung during the early 1970s by this group of articulate Cassandras, I believe, have irresponsibly and greatly contributed to the present mess in the world agricultural, energy, and mineral markets. Too many nations and individuals overreacted to the doomsday sermons of those claiming that the world had lost its ability to produce the food, fiber, energy, and minerals that were needed by the large, rapidly growing population. Those claims gave apparent justification to the agricultural policies that have led to today's surplus production, which has been so detrimental to farmers in both developing and developed countries. What a price the world has paid for listening to these persons!

Another major line of Green Revolution criticism argued that the introduction of the new seed-fertilizer technology would only worsen the distribution of income and wealth, unless redistribution in the means of production occurred first. Critics in this school labelled the high-yielding wheat and rice technologies as being suited only to the rich landowners who could afford the seed, fertilizer, and irrigation needed to obtain maximum yield potential. It was, of course, true that the new technologies increased production costs per unit of cultivated area. What seems to be ignored in this equation, however, was the fact that the new technologies increased output proportionally more than the cost of the inputs. Green Revolution technologies have also been accused of accelerating labor displacement in rural areas, because they encouraged mechanization. While this is partially true for some job categories, it is also true that the new technologies increased employment opportunities greatly in many other job sectors; in other words, the net effect on rural employment was positive.

In many cases, Green Revolution critics have been utopian intellectuals speaking from privileged positions in ivory towers. These persons have never been hungry or ever lived and worked with people living in abject poverty. They seem to convey the impression that science and technology, if properly organized, could correct all of the social ills and inequities that have accumulated from the time of Adam and Eve up to the present. They fail to recognize that similar inequities were present in the hunting and gathering societies that pre-dated the invention of agricultural societies. At that time, the strongest tribes occupied the best grazing ecosystems which, in turn, sustained the largest populations of big ungulates. The weaker tribes were pushed into the less privileged econiches and poorer hunting sites. These inequities in the potential productivity of ecosystems (land) persist in agriculture today. They are most evident in densely populated countries where many agricultural families have been pushed into marginal, semi-arid lands where survival is precarious and poverty is glaring.

The spectacular successes of the new wheat and rice seed/fertilizer technologies have no doubt overshadowed many social and economic problems in the Third World. In this sense, development efforts to correct the serious inequalities found in land tenure, and to redistribute more equitably national means of production, were probably set back. But it is now well documented that resource-poor farmers—with only relatively brief lag times—adopted the new seed/fertilizer technologies about as rapidly as resource-privileged, large-scale farmers. Given the lesser ability of small-scale farmers to take risks, it was probably a good thing that large-scale farmers were the first to test the new technologies, since they could afford to gamble more. While in proportional terms both groups have benefited equally, obviously those with more resources received greater benefits in an absolute sense.

Certainly, in those countries where resource distribution is highly skewed and unequal, long term economic growth and social and political stability is not likely to be sustained without political and economic measures to redress such imbalances. It is a problem, however, that science and technology is not well equipped to handle. Plant species are apolitical. They cannot be coaxed to yield 10 times more on a small plot than they are capable of yielding on a larger tract of land employing the same technology. The redress of social inequalities is a job that must be tackled largely by the politicians of the world, not the agricultural research community.

The agricultural chemicals and fertilizers absolutely necessary to produce the food required by the world's people are like medicine—and should be used with proper caution.

In more recent years, some members of the environmental movement have also become Green Revolution critics. The thrust of these criticisms has a distinct anti-technology bias that is often combined with an idealized view of peasant farming as a harmony between man and nature. Arguments in this vein often imagine conspiratorial relationships between scientists and agricultural chemical and machinery companies. We are accused of trying to get Third World farmers "hooked" on energy-intensive production technologies that are not economically or environmentally sustainable. Greater use of chemical fertilizers, pesticides, herbicides, pump irrigation systems, and farm machinery, in their view, is inherently bad for the Third World. As an alternative, the virtues of more "organic" forms of farming are advanced as the best way to preserve the long-term viability of Third World farmlands and farmers.

Perhaps the single most important factor limiting crop yields in the developing world is soil infertility, due to either natural pre-agricultural infertility, extractive farming practices, or to deficiencies of primary, secondary, and minor elements brought on by more intensive farming practices. The shrinking of the per capita arable land base in food-deficit, densely populated countries has made it impossible to free land from food crop cultivation for green manure crop rotations to help restore soil fertility organically. Fortunately, soil fertility can be effectively and safely restored through the proper use of the right kinds and amount of chemical fertilizer, according to the requirements of different crops, soil types, and environments. Without the restoration of soil fertility, few benefits will accrue from the use of improved varieties and other more productive cultural practices.

Some organic gardening enthusiasts insist that the wide use of organic fertilizer could satisfy all of our fertilizer needs. This, however, is nonsense. The amount of composted organic animal manure (1.5% nitrogen on a dry weight basis) that would be needed to produce the 70 million metric tons of chemical nitrogen used today would be about 4.7 billion tons — quite a dung heap and quite an aroma — were it available. This volume of organic material is equal to twice the weight of the world cereal production and would require a three- to fourfold increase in world animal production, with all the additional grain and pasture feed that such an increase would require. Even now there are many areas of the world where overgrazing is causing serious erosion problems.

Moreover, we should not forget that, less than a decade ago, many doomsayers were preaching that the use of scarce fossil fuels could not be justified to produce nitrogenous fertilizer. Rather, they insisted that the use of legumes in crop rotations and the use of organic fertilizers were the only sustainable viable methods of maintaining soil nitrogen fertility. Despite these dire predictions, today there is a glut of nitrogenous fertilizer on world markets and real prices are lower than at any time in the history of the chemical fertilizer industry.

It is my belief that agricultural chemicals are absolutely essential to produce the food that is necessary to feed today's population of five billion, which is increasing currently at the rate of 82 million per year. Lest I be misunderstood, I would like to stress that agricultural chemicals and fertilizers are absolutely necessary to produce the food and fiber required by our world population, but that they are like medicine, and should be used with proper caution. There is no way that the world can turn back the time clock to the "good old days" of the early 1930s, when few agricultural chemicals and little chemical fertilizer was used — and when world population stood at only two billion. Without increased productivity, how could we have provided the necessary food for the three billion people that have been added to the world population in the last half century? I know of no alternative to the path that we have taken.

This group of critics also leaves the impression that the world is being poisoned out of existence by the use of agricultural chemicals. This opinion defies the facts. The truth is that many more people are living more enjoyable, pleasant, and longer lives than people of any previous generation. In 1900, life expectancy at the time of birth in the USA was 46 years for men and 48 years for women. By 1940, life expectancy at the time of birth had increased to 60.8 and 65.2 years for men and women, respectively. By 1982 life expectancy at birth had reached 70.8 years for men and 78.2 years for women. And it is continuing to increase.

The truth is that life for these elitist critics seems to have become so enjoyable that they would like to extend it indefinitely while also enjoying the vigor, enthusiasm, and health of youth. They fail to realize that each species is endowed with a biological time clock that sets the maximum longevity for each species. It is true that during the past century better nutrition and improvements in medical care, clothing, and housing have collectively increased the average life expectancy at birth greatly. However, this does not imply that the biological time clock, which determines maximum absolute longevity of *Homo sapiens*, has been reset or increased significantly, if any. This unrealistic philosophy prevails because those promoting it have forgotten the basic fact that all that is born into this world must sooner or later die and give way to the next generation.

There is another group of critics who insist that foreign technical assistance programs spawning "green revolutions" are destroying the markets for food-exporting nations. This is a gross oversimplification of facts. In the first place, poor nations and poor people are poor customers. For example, the hungry food-deficit nations of Africa are today largely agrarian subsistence economies in which 80 to 85% of the total population are poor subsistence farmers with very little if any purchasing power. The only way they have of increasing their purchasing power and standard of living is to increase their agricultural production, so that they have some agricultural products to sell, to begin to buy other products and, in the process, join the money economies which will, in time, result in increased trade. Recent trade data for US agricultural products confirm this fact. Those Third World nations with strong growth rates in their domestic agricultural sectors have also had strong overall economic growth. It is also these nations that have increased their imports of US products, not the poor, stagnant developing countries.

The growth that has occurred in human population numbers during this century makes it impossible for us to turn back the clock and use the less intensive production practices that were dominant only a century ago, when world population was under two billion and large expanses of land were available for increased food production. In a world of five billion, in which bringing new agricultural lands into production has become increasingly more difficult and costly, we have no choice but to increase land use intensification on existing farmlands. Such intensification can have adverse environmental consequences, but it doesn't have to. Rather than advocating that we go back to earlier production systems, we should use our scientific knowledge to develop technologies that can increase productivity as well as ensure sustainability of production.

I would be remiss if I did not express my concern about the growing menace of the population monster which threatens the future advancement of mankind on many fronts. We who work on the food production front, I believe, do have a responsibility to warn the political, religious, and educational leaders as well as to educate the general public in all countries, that producing more food and fiber while protecting the environment can, at best, be only a holding operation while the population monster is being tamed. In recent years, the "human rights" issue has generated much interest and debate around the world. It is a utopian issue and a noble goal to work toward. Nevertheless, in the real world, the attainment of human rights in the fullest sense cannot be achieved as long as hundreds of millions of poverty-stricken people lack the basic necessities for a decent, humane life.

It is impossible to turn back the clock and use the less intensive production practices of the last century.

I take issue with those who ignore the growing threats of the population monster, and speak glibly and sanctimoniously about the "right to life," while ignoring the morality of the "quality of life." This only adds confusion to this complex problem for which a solution is imperative. Why does mankind continue to irresponsibly and inadvertently try to see how many additional people can be "heaped" onto the planet earth? Why do we continue to apparently always believe that future, newer, and better technologies will expand the carrying capacity of our planet, while, at the same time, assure an improved standard of living for all? It appears to me that we are behaving in a most irrational and irresponsible manner. Our behavior implies that when we can no longer provide the good life for the ever increasing number of people on the planet earth, we will always be able, at the appropriate time, to dispatch the excess numbers to colonize beautiful, hospitable virgin planets in other solar systems in outer space. Oh, were it so simple!

Maintaining CIMMYT's Vitality

CIMMYT exists to help speed the process of developing improved maize and wheat technologies in the Third World. Therefore, the achievement of wheat and maize productivity impacts on farmers' fields must be the ultimate measure of the value of the Center's work—as well as that of the CGIAR system. Our assigned task is in the final sense to alleviate hunger and human misery, which we must never forget. CIMMYT cannot afford—nor can national program collaborators—to rest on past laurels and achievements. We owe the societies that support and depend upon us a good return on their investment.

No matter how excellent and spectacular the research done in one scientific discipline, its application in isolation will have little or no positive effect on crop production.

I believe that the most efficient and expeditious way to develop improved technology is through an integrated research approach. No matter how excellent and spectacular is the research that is done in one scientific discipline its application in isolation will have little or no positive effect on crop production. It is, of course, more comfortable to stand and work in the shade of the tree of one's own discipline, but the forest is made up of trees of many disciplines. Consequently, what is also needed are a few venturesome scientific leaders who are comfortable and willing to work across the shadows cast by trees of all scientific disciplines in the forest, and thereby produce a technology capable of increasing the overall, sustainable multi-benefit productivity of the "forest." This integration will become increasingly more important in future years as we tackle the problems of the marginal production environments as well as the more-intensively cultivated production environments. A research approach is required that recognizes and appreciates the need to have teams of scientists with different and complementary professional skills, and who are sensitive to the broad range of factors affecting productivity. Unfortunately, effective scientific integrators are a rare commodity. Although I have been privileged to work with a number of such persons in the past, we need to identify, early in their careers, more young scientists who have these latent talents and provide them with a broad background of experiences so that they can become effective catalysts for agricultural change and progress.

Our friend and colleague, T.W. Schultz, underscored the importance of the organizational research structure in a paper he delivered several years ago in Chile. Permit me to quote his statement:

> I am convinced that most working scientists are research entrepreneurs. But it is exceedingly difficult to devise institutions to utilize this special talent efficiently. Organization is necessary. It too requires entrepreneurs. But there is the ever present danger of over-organization, of directing research from the top, of requiring working scientists to devote ever more time to preparing reports to "justify" the work they are doing, and to treat research as if it were some routine activity.... In the quest for appropriations and research grants, all too little attention is often given to that scarce talent which is the source of research entrepreneurship. The convenient assumption is that a highly organized research institution firmly controlled by an administrator will perform this important function. But in fact a large organization that is tightly controlled is the *death* of creative research.

I would add a caveat to this statement. Research, while a necessary condition for improving food production, does not automatically lead to more efficient food production systems. I believe that we have a professional and moral responsibility to see to it that proven research results are used to benefit society. While we should be careful and thorough in our research efforts, we should not become overly timid. It is a characteristic of science that the perceptive researcher often sees the answer before he has all the proof in hand; sometimes, we should be willing to push for the adoption of research results, even though all of the jigsaw pieces of the production puzzle are not in place. That is where the creative research integrator comes into the picture.

CIMMYT's research has been largely unfettered by restrictive bureaucratic and political constraints, has been adequately funded, and is supported by an excellent infrastructure of experiment stations, laboratories, and information and administrative services. The Center has also had excellent collaboration with the Mexican INIFAP/CIANO Wheat Research Program and support from the Sonora farmers' organization (Patronato) that helps to sponsor wheat research. This environment has resulted in high levels of motivation and commitment among the staff. It has permitted scientists to focus their energies on the research agenda at hand and the resulting successes have given the agricultural research profession greater credibility and status in the Third World.

While I accept the fact that CIMMYT cannot be involved extensively at the grass roots level in production-oriented research in the 100-plus countries it attempts to serve, it is essential that the Center staff view impacts on farmers' fields as the primary measure by which they judge the success of their research. Contact with the producer is essential to keep program priorities on track and to maintain the Center's practical orientation. Moreover, such contact mitigates the *erosive* effects of the dangerous institutional viruses of affluence, oversophistication, overspecialization, and complacency. These viruses, which are widespread in research institutions, are highly contagious, lead to early ossification, and are often lethal.

Center staff view results on farmers' fields as the primary measure of the success of their research.

And to the CIMMYT Staff and Families

Briefly stated, our destiny as agricultural scientists is to learn about the known, to discover the unknown, and to communicate our findings effectively. Excellence in each of these elements is essential to our individual and collective success and for our work to benefit humankind. The profession we have chosen is not for the faint-hearted; it requires involvement and it is a demanding taskmaster; it cannot be delegated very far. Nature often manifests small differences in subtle ways. She generally whispers rather than speaks in a loud voice. This requires that scientists maintain intimate, continuous, personal contact with the research program if they are to discern and interpret the minor differences in the complex biological systems with which they are concerned. It requires travelling extensively, often living under spartan conditions, and involves long absences from family and friends. At certain peak work periods, it is necessary to ignore the normal working hours of the clock, as well as the normal working days of the week, in order to complete the task at hand. But there are, I believe, gratifying compensations. As I reflect on the adobe shack with the tar paper roof in Chapingo where CIMMYT's predecessor program was launched 43 years ago, I am amazed at the collective impact it, and the subsequent programs, have had on the improvement in agriculture, first in Mexico, and later in many countries of the world. The road to success has been difficult, sometimes frustrating, and sometimes bumpy and hard to negotitiate. But although the struggle to achieve the target has been demanding, it has brought a better life to untold millions.

While CIMMYT's new training, conference, and information building can help to increase the effectiveness of the Center's work, the building is only a means and not an end in itself. We must ultimately judge our worth, not by the facilities or budgetary resources that we have, or by the number of learned papers we write, but by what we contribute to the improvement of agricultural productivity in environmentally sustainable ways in the Third World. I hope that your order of priorities will always be aimed at the important food production problems and that you will not be distracted by the pursuit of illusory academic butterflies.

I feel flattered to have this magnificent building named in my honor. However, I am a realist rather than a sentimentalist. I know that memories are short and that names, whether embossed in bronze or stone, soon fade and become obscure, if not meaningless. For the past four decades I have been privileged to carry forward, to many parts of the world, the torch which was lit to guide my way by the late Drs. E.C. Stakman and J.G. Harrar. This torch was to foster agricultural research, extension, and production and it has been fueled by the education, broad experience, motivation, enthusiasm, and wisdom that these legendary scientific figures gave me.

It is my hope that in this new building new torches will be lit and carried forward by a new generation of scientists to continue the worldwide crusade against hunger, human misery, and ignorance. Moreover, it is my hope that sometime in the future there will have emerged through the portals of this new edifice an individual — who studied and worked here as a young maize or wheat trainee, a predoctoral or postdoctoral fellow, a visiting scientist, or a staff member — who goes on to win the newly established World Food Prize.

I have struggled for fifteen years to find a sponsor to establish such a prestigious prize for agriculture and food. In May of 1986, this dream became reality when General Foods, Inc. announced the establishment of a World Food Prize, equivalent in monetary value to a Nobel Prize, which will be awarded annually, beginning in 1987, to an individual whose work has made the greatest impact on the improvement in quantity, quality, or availability of food. The prize can be awarded for outstanding contributions to any links of the food chain.

In closing I want to express my gratitude to the hundreds of scientific collaborators and friends worldwide that I have had the pleasure of knowing and working with over the past four decades. Without your collaboration, little could have been accomplished in agricultural improvement. Forty years ago, international cooperation in agricultural research was nonexistent, whereas today it contributes greatly to improving the efficiency and production of food worldwide. Even so, I believe cooperation in agricultural research must be strengthened and expanded if we are to stay ahead of the population monster.

To all of you from many countries where I have worked under the handicap of not being able to speak to you in your mother tongue, or, because of ignorance on my part, have committed cultural errors — I ask your forgiveness. Without exception, despite all of my limitations, you have made me feel at home in your countries. Many thanks. And finally, to my many Mexican friends who have provided me a second home, in which I have spent much more than half of my life, happily working with your scientists, technicians, educators, government officials, and farmers — please accept my most heartfelt thanks.

Finally, may God bless and speed you, the CIMMYT staff, in your important work, which is vital to the well-being of mankind, to the survival of civilization, and to the continued progress of *Homo sapiens*.

The Green Revolution

M.S. Swaminathan
International Rice Research Institute,
Los Baños, Philippines

The term "Green Revolution" was coined in 1968 by Dr. William S. Gaud, Director of the US Agency for International Development (USAID). This phrase immediately found widespread acceptance because of the dramatic impact of the semidwarf wheat varieties originating from the Rockefeller Foundation-Government of Mexico Program (the precursor of CIMMYT) and rice varieties originating from the International Rice Research Institute (IRRI). For example, in India wheat production rose from the previous high of 12 million tons in 1964 to over 17 million tons in 1968. The years 1965 and 1966 saw widespread drought on the Indian subcontinent. A potential famine of disastrous dimensions was averted in 1966 by the importation of nearly 10 million tons of wheat, most of which was supplied by the United States of America under its PL 480 program.

In his own inimitable style, Dr. Borlaug, whose name will find a permanent place in agricultural history for his role in triggering the wheat revolution in many developing countries, has already dealt with recent accomplishments in improving the productivity of maize and wheat. I do not therefore wish to repeat what he has said so effectively and elegantly. Instead, I wish to deal with some issues connected with the Green Revolution which have been in the forefront of public debate in recent years. I shall confine my discussion largely to wheat.

History of Some Past Agricultural Revolutions

The words "agricultural revolution" have been used to describe impressive progress in crop production in many parts of the world and at different times. The history of the agricultural revolution in Western Europe has been described by Grigg (1984) in a recent article. Another author has identified four stages in the British agricultural revolution. First, beginning in the 16th century, a shift took place from subsistence to commercial farming. Second, the introduction of new crop rotations as well as livestock improvement occurred early in the 19th century. Third, the period between 1820 and 1880 was characterized by the purchase by farmers of cattle feeds and artificial fertilizers and by investment in new buildings and drainage. The last stage, after 1914, saw the introduction of the tractor and of labor-saving machinery. Thus the English agricultural revolution that was thought to be a short and sharp break in the history of English farming has now been stretched to cover some 300 years. Because there was no precise definition of what an agricultural revolution implies, it has been described as the transition from traditional husbandry practices to modern scientific agriculture.

What triggers the transition from traditional practices to modern science-based agriculture? Historians of US agriculture say that hybrid maize which gave two to three times more yield than open-pollinated varieties triggered the change in the 1930s. Farmers who took to hybrid maize adopted improved management practices not only for maize but also for all the other crops they grew. Semidwarf wheat varieties originating from CIMMYT had the same impact in parts of India and Pakistan. For example, Punjabi farmers both in Pakistan and India, who started appreciating the value of improved nutrient supply and water management practices for semidwarf varieties of wheat, also extended improved management practices to rice, potato, and other crops included in the wheat farming system. Thus the area of the wheat revolution also became the area of the rice revolution, the potato revolution, etc. The role of catalysts of change in the attitude of farmers is obvious.

Progress in improving wheat yields between 1750 and 1980 in some countries of Western Europe is listed in Figure 1. The sharp increase in yield observed during the last 50 years in the countries included in Figure 1 is largely due to the unprecedented rise in the consumption of artificial fertilizers, the adoption of high yielding cereal varieties, and control of pests, diseases, and weeds. There has been a sharp increase in labor productivity because of the fall in the labor force as a result of mechanization.

It is of interest that in several developing countries food output has increased even more rapidly than in Europe during the last 20 years. In spite of such spectacular progress, we should view the Green Revolution as just the first phase of a new era in tropical and subtropical agriculture.

I have spent some time going into history because some critics of the Green Revolution have tried to insinuate that the new technologies associated with the Green Revolution, such as the introduction of genetic strains of wheat and rice that respond well to good soil fertility and water management, have been specially designed to promote the commercial interests of multinational companies. Recent advances in Indian agriculture will illustrate how the Green Revolution in wheat and rice was really brought about by a series of evolutionary steps.

The Wheat Revolution in India

The period between 1947 when India became independent and 1966 saw three major evolutionary steps in agricultural planning and development. In the first phase, from 1947 to 1960, considerable emphasis was placed on the development of infrastructure such as rural roads, schools and hospitals, irrigation projects, and manufacture of mineral fertilizers. The second phase, from 1960 to 1965, saw the introduction of an intensive agricultural district program (IADP) which was designed to introduce a package of practices such as the cultivation of improved varieties and application of fertilizers and pesticides in areas with assured irrigation. The "package program," as it was popularly called, was introduced in areas with assured irrigation so that the benefits from water could be maximized. Unfortunately, the results during the first few years of this project were

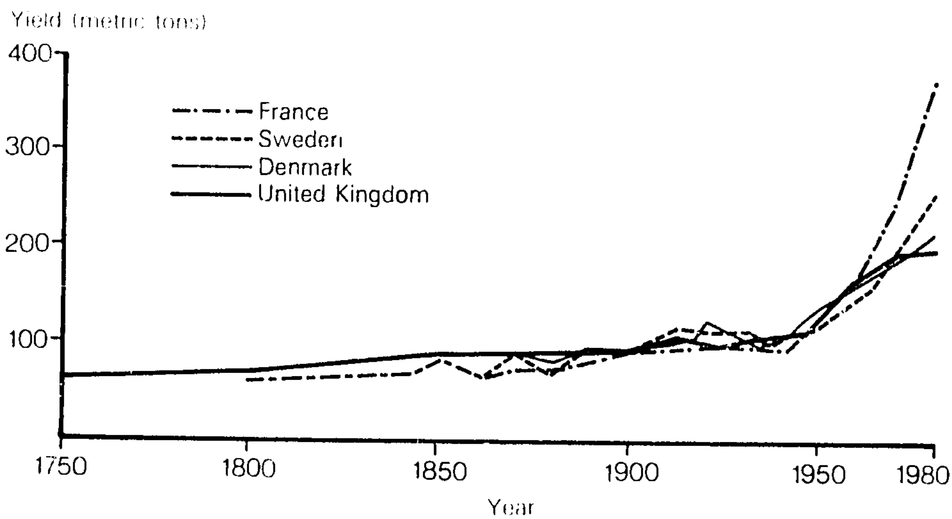


Figure 1. Wheat yields, 1750-1980.

Source: B.R. Mitchell (1975), Bennett (1935); Toutain (1961); FAO (1963, 1980).

disappointing because it was soon found that the "package" lacked genetic strains that could respond effectively to irrigation and fertilizer application.

This deficiency in the package program was resolved in 1966 when the high-yielding varieties program (HYVP) in wheat, rice, maize, sorghum, and pearl millet was introduced. The high-yielding wheat strains initially introduced under HYVP came from Mexico; in the case of rice some, like IR8, came from IRRI and others had been either developed locally or introduced from Taiwan. In the case of maize, sorghum, and millet, hybrids developed under the respective All India Coordinated Research Projects of the Indian Council of Agricultural Research (ICAR) were introduced.

The wheat revolution was the first to occur. There were several reasons for this. First, in the Punjab where the wheat revolution began, land consolidation and leveling, rural communication, and rural electrification had already made much progress before the new technology was introduced. In addition, Punjabi farmers were owners of the land, with the result that they had a long-term interest in the development of farm infrastructure. This is evident from the rapid growth in farmer-owned tubewell irrigation. Unfortunately, such preconditions for new technologies to take root and spread rapidly did not exist in many other parts of India. Hence, regional disparities in the spread of new technology became prominent. For example, the average yield of wheat was 3288 kg/ha in the Punjab, while it was 643 kg/ha in Karnataka during 1984-85.

The growth rate of wheat production in India between 1967-68 and 1980-81 was more than double the growth rate of production of all grains. The contribution of wheat to the total food grain production in the country increased from about 12% in 1966 to nearly 30% now. The 1985-86 wheat production is estimated to be around 46.5 to 47 million tons. Such spectacular progress would not have been possible if the government of India had not provided to farmers a remunerative price and assured marketing arrangements. Agriculture moves forward on a sustainable basis only when mutually reinforcing packages of technology, services, and public policies are introduced.

Agriculture moves forward on a sustainable basis only when mutually reinforcing packages of technology, services, and public policies are introduced.

Progress in Other Countries

Borlaug (1985) has described the progress made by several countries in improving wheat production. A few examples suffice to indicate the extent of progress made.

Pakistan, since 1966, has increased wheat production from about four million metric tons to over 13 million tons in 1983, an increase of more than threefold. Yields have more than doubled in the same period. Although Pakistan's rice production is only about one-fourth that of its wheat production, it has been a rice exporter for the last 12 years.

Turkey has more than doubled its wheat production in the last 10 years and has again become a modest exporter. Bangladesh, although still a small producer of wheat, has made spectacular progress in increasing production in the last five years, growing wheat after rice or jute.

The People's Republic of China has made striking progress in increasing cereal production during the past decade. It has long been the number one nation in rice production and ranks second only to the United States in maize production. In 1984, China harvested 87.8 million tons of wheat and thereby displaced the Soviet Union, which harvested 76 million tons, as the number one wheat producer in the world. Most of the wheat grown in China is from winter varieties; however, the dwarf Mexican spring wheats have been used commercially in the south (along the eastern coast) where winters are less severe, and in the northeastern provinces (especially in Kirin), where they are sown in spring.

CIMMYT's annual reports during the past 15 years give an idea of the impressive progress made by nearly all wheat-growing developing countries.

Balance Sheet of Phase I of the Green Revolution

We can now draw a balance sheet of this first phase of the Green Revolution. First, a most important gain during this phase has been the generation of self-confidence in many developing countries with regard to their capability for achieving food self sufficiency.

Second, agriculture has achieved a higher social prestige, and it is now widely realized that modern farming requires not only brawn but also brain (technology) and bank (financial and other resources). This realization has led to enhanced support for national agricultural research and extension systems and a greater flow of credit to the farm sector. Most political leaders now realize that a dynamic agricultural production program can neither be initiated nor sustained without the support of a dynamic national agricultural research system.

Third, the population-rich but land-hungry countries of South and Southeast Asia have been able to increase production through a vertical growth in productivity, thanks to the rapid spread of high-yielding varieties (Figure 2).

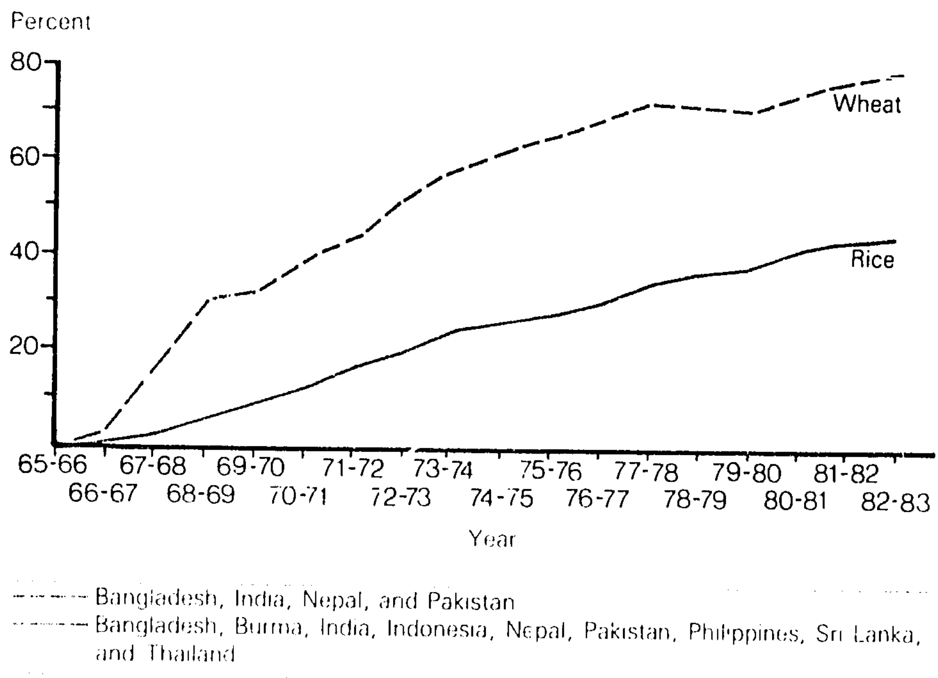


Figure 2. Estimated proportion of area planted to high-yielding varieties of wheat and rice, South and Southeast Asian nations, 1965-66 to 1982-83.

Source: Dalrymple (1985)

Fourth, a higher intensity of cropping could be achieved in irrigated and assured rainfall areas because of the availability of photoperiod-insensitive and short-duration varieties. For example, wheat acreage in Bangladesh expanded from about 120,000 ha in 1974 to more than 600,000 ha in 1984. All of the annual wheat crop in Bangladesh is planted in the winter season, starting in November following the harvest of rice or jute. Altogether new rotations like rice-potato-wheat, cotton-wheat, and sugarcane-wheat became possible. Consequently, plant breeders have started making selections based on per day, rather than per crop productivity.

Fifth, several developing countries could start building national food security systems based on the purchase of surplus home-grown wheat. India, which imported 10 million tons of wheat in 1966, had built a grain reserve of over 10 million tons by 1972 mainly with locally grown and purchased wheat. The government of India's grain stocks now exceed 30 million tons. These include the quantities needed both for food security and public distribution.

Finally, the old view that the illiterate farmers of India and other developing countries would not easily be able to take to new technologies has been disproved. Developing country farmers, whether literate or illiterate, have shown that they will readily adopt improved production techniques and high yielding varieties if they are convinced that these new technologies will help to improve their income and standard of life.

Impact of the Green Revolution

What has been the impact of the Green Revolution on the principal members of the agricultural production team?

Impact on National Food Security

Wheat has become the anchor of the national food security systems of India, Pakistan, and several other developing countries. Hence, it will be useful to consider this relationship in some detail. Food security has been defined by the Food and Agricultural Organization (FAO) as "physical and economic access to food for all people at all times." This definition implies both adequacy of food supply and access to food for all human beings, irrespective of their economic status. In other words, food security requires integrated policies for production, distribution, and consumption.

The old view that the illiterate farmers of developing countries would not easily adopt new technologies has been disproven.

Progress in wheat produc ion helped to destroy many myths and doomsday predictions. For example, it destroyed the myth that India can never feed itself (Paddock and Paddock, 1967). It destroyed the myth that agricultural evolution in developing countries has to be a very slow process and that revolutions in crop production are not easy because of the very large number of small scale farmers whose active involvement is essential to make such revolutions possible. Thanks to the wheat revolution, India could start building a reliable national food security system.

Impact on Researchers

Research is a key component of the food production system. It determines to a considerable extert present levels of potential productivity and indicates the scope for raising further the production potential for the future. In addition to the prestige and self confidence that agricultural scientists in developing countries gained following the introduction of high-yielding varieties, five more lasting benefits have been obtained.

First, the need for multidisciplinary research became obvious. Scientists began to appreciate the fact that purely discipline-centered research would not take them very far in improving the yield of crop plants. In India, soon after the introduction of high-yielding wheat varieties, it became clear that several basic changes in agronomic techniques were essential for the new strains to reveal their full yield potential. Some of the changes were shallow sowing, application of first irrigation at the crown root initiation stage, spot application of fertilizer, and efficient weed control.

If the political will exists, the pace of agricultural progress can be accelerated.

Second, scientists saw the advantage of multilocation testing to arrive at reliable conclusions more quickly. Even during 1963, the first year of introduction into India of four semidwarf wheat varieties from Mexico, the strains (Sonora 63, Sonora 64, Mayo 64, and Lerma Rojo 64-A) were tested at Delhi, Ludhiana, Pantnagar, Kanpur, Pusa, and Indore. The following year, the testing was done at many more locations using 250 tons of seed imported from Mexico. Based on two years' data from multilocation testing, the decision was made in 1966 to import 18,000 tons of seeds of Lerma Rojo 64-A and Sonora 64 from Mexico. Subsequent events have confirmed the wisdom of this decision.

Third, the wide adaptability of the Mexican semidwarf wheats revealed the value of shuttle breeding techniques involving diverse environments in the development of varieties with wide adaptation.

Fourth, exchange of genetic materials and their testing in international observation and yield nurseries permitted breeders everywhere to share the best available gene pool in the world. These nurseries also helped provide early warning on potential pest and disease problems.

Fifth, agricultural research managers realized that unless personnel policies were introduced to help attract and retain good scientists, it was not possible to meet the new challenges which constantly arise when agriculture starts moving forward. Policies that promote lifelong specialization by scientists became essential to build strong national research systems.

Impact on Extension Workers and Mass Media

Before the introduction of the high-yielding varieties program, extension workers in such countries as India had almost nothing to extend, either by way of new knowledge and skills or the inputs necessary for increasing production. The Green Revolution enhanced the prestige of extension workers, and led to the synchronization of efforts to transfer knowledge and supply inputs. Furthermore, the feedback process between extension and research workers was strengthened and both groups started respecting each other.

Impact on Political Leaders

The Green Revolution showed that if the political will exists, the pace of agricultural progress can be accelerated. Since the population in most developing countries is predominantly rural and since agriculture is the major occupation of rural people, political leaders realized that they now had an opportunity to help improve the quality of life of the rural population. Consequently, agrarian reform and rural development measures started to receive greater attention at the political level.

Impact on Consumers

Consumers have probably derived the maximum benefit from the progress made during the last 20 years in the production of wheat and rice. This is because in low-income countries the bulk of adjustment to fluctuation in food supplies is made by the poor. I quote John Mellor's Foreword to International Food Policy Research Institute (IFPRI) Research Report No. 18 (1980):

> In low-income countries the bulk of adjustment to fluctuation in food supplies is made by the poor. The direct price and indirect employment effects of a 10% decline in foodgrain

supplies reduce foodgrain expenditure by as much as 40% in real terms for the lowest 10% of the income distribution. In contrast, with the same decline in production, the reduction in foodgrain expenditures is only 1% in real terms for the top 5% of the income distribution. And yet it is the poor who are least able to withstand such privation. The poor spend such a high proportion of their income on food that price increases induced by shortages greatly reduce their capacity to buy foodgrains, whereas the more well-to-do compensate by spending less on other goods and services, thereby further decreasing the income of the poor through reduced

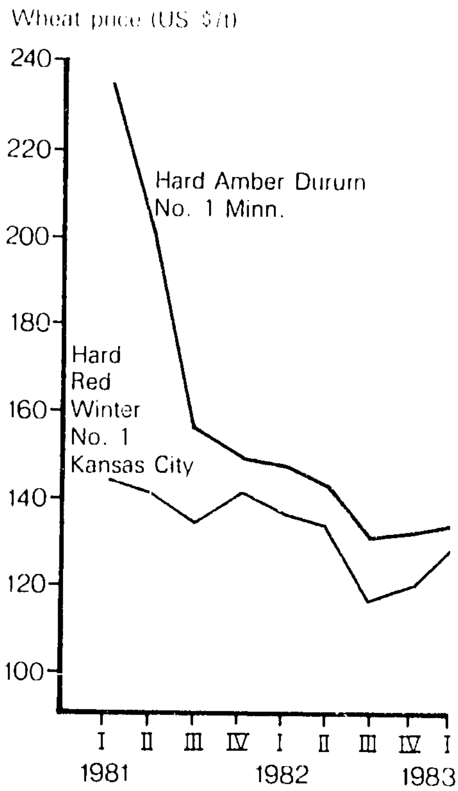


Figure 3. Wholesale prices of wheat in the United States, 1981-83.

employment. Because the food intake of the poor is already so close to the minimum level, supply shortages result in increased malnutrition.

Thus one of the most important actions that can be taken to improve conditions for the poor is to reduce fluctuation in food prices and supplies.

International prices of wheat and rice are still declining, partly because of the large stocks in the world and partly because of the large subsidies being given to farmers in developed countries (Figure 3).

Literate or not, farmers are sound economists. To them, seeing is believing.

Impact on Farmers

Ultimately, it is farmers who decide what to grow and how to grow it, when to sow, how much to invest, and how to market their crop. All others can only support the farmers. In many countries of South and Southeast Asia, because of very small land holdings (average farm size ranges between 1 and 2 ha in countries like India), the active participation and assistance of a million farming families may be needed to produce an additional million tons of wheat or rice. Farmers have shown that they will readily take to new technologies provided they are convinced that such technologies will increase their income. Whether literate or illiterate, farmers are sound economists. To them, seeing is believing. This is why the National Demonstration Programme organized in India in 1964-65 and in later years was so very effective in convincing farmers that they were entering a new era in wheat yield. These demonstrations were laid out by scientists in the fields of small-scale farmers. The choice of small-scale farmers for organizing demonstrations is important, because higher yields obtained by large scale and affluent farmers will be attributed more to their financial status than to technology.

Today, farmers in both developing and developed countries face serious economic problems. Developing countries will have to organize appropriate social security systems for small-scale farmers if production is to be sustained at the needed level.

Phase II of the Green Revolution

While the positive gains have been many, there has been serious concern about the economic and ecological sustainability of the high yield technologies associated with the Green Revolution. In addition, the accessability of new technologies to smallholders has also been questioned. Many of these doubts arose following the steep escalation from 1972 onwards in the price of inputs based on fossil fuel derived feedstocks.

I would like to deal with a few of these issues. However, before going into detail it might be worthwhile to draw attention to the recent projections made by IFPRI on the food requirements of the Third World up to 2000 (Paulino, 1986). A trend scenario of the food situation in the year 2000 based on data from 1961 to 1980 for production and 1966 to 1980 for consumption projects a Third World production shortfall in basic food staples of about 70 million tons (76 million tons excluding China). This gap represents about 5% of the Third World's projected demand for basic food staples in the year 2000 and is one third larger than the food deficit of developing countries in 1980. There is therefore no time to relax in our efforts to increase food production, to quote a favorite saying of Dr. Borlaug.

I shall deal with the emerging issues in three parts: first, those dealing with increased wheat production on a sustainable basis; second, those dealing with the economic well being of wheat farming families, and finally, with increasing the consumption of wheat by the rural and urban poor. I shall conclude with describing some of the major scientific challenges that CIMMYT and national research systems will have to face in the coming decades.

Producing More Wheat

A popular misconception about high-yielding varieties of wheat and rice is that they cannot be grown without heavy inputs of fertilizers and pesticides. All the available data show that the semidwarf, high-yielding varieties of rice and wheat as well as sorghum hybrids can yield more than the old tall varieties at all levels of nitrogen application. This is because of the ability of the high-yielding varieties to partition more of their dry matter to the formation of grain (Figure 4). During this century, much of the progress in improving yields of wheat and other crops has come primarily from the improvement of the grain harvest index (Figure 5). While the per capita availability of arable land is going down in many Asian countries, the proportion of irrigated area is going up (Figure 6). Therefore, there is need for optimizing the benefits from water through synergetic interactions between nutrients and varieties. The relevance of high-yielding varieties will increase with expansion of irrigation and escalation in the cost of mineral fertilizers. In this context, the results of the work of CIMMYT in bringing about a continuous improvement in yield are of great importance (Figure 7).

Those who advocate going back to old varieties and old technologies, which were quite relevant when the pressure of population on land was low, will be

Table 1. Nitrogen (kg/ha) required for 4 t/ha grain yield with varying protein content

	Protein content (%)		
	12.5	13.75	15.0
Grains	80	88	96
Straw	20	29	32
Total	100	117	128

doing a great disservice to their countries by creating the impression that high yields can be obtained with varieties that are inefficient in the utilization of nutrients. The nutrient requirements for a 4 t/ha wheat crop at three different protein levels are given in Table 1. The international prices are very much influenced by protein content and grain quality (Figure 8). Therefore, the supply of adequate nutrients is essential for improving yield and quality. What can be done, however, is the partial replacement of mineral fertilizers with farm grown biofertilizers. Green manure crops such as the stem-nodulating *Sesbania rostrata*

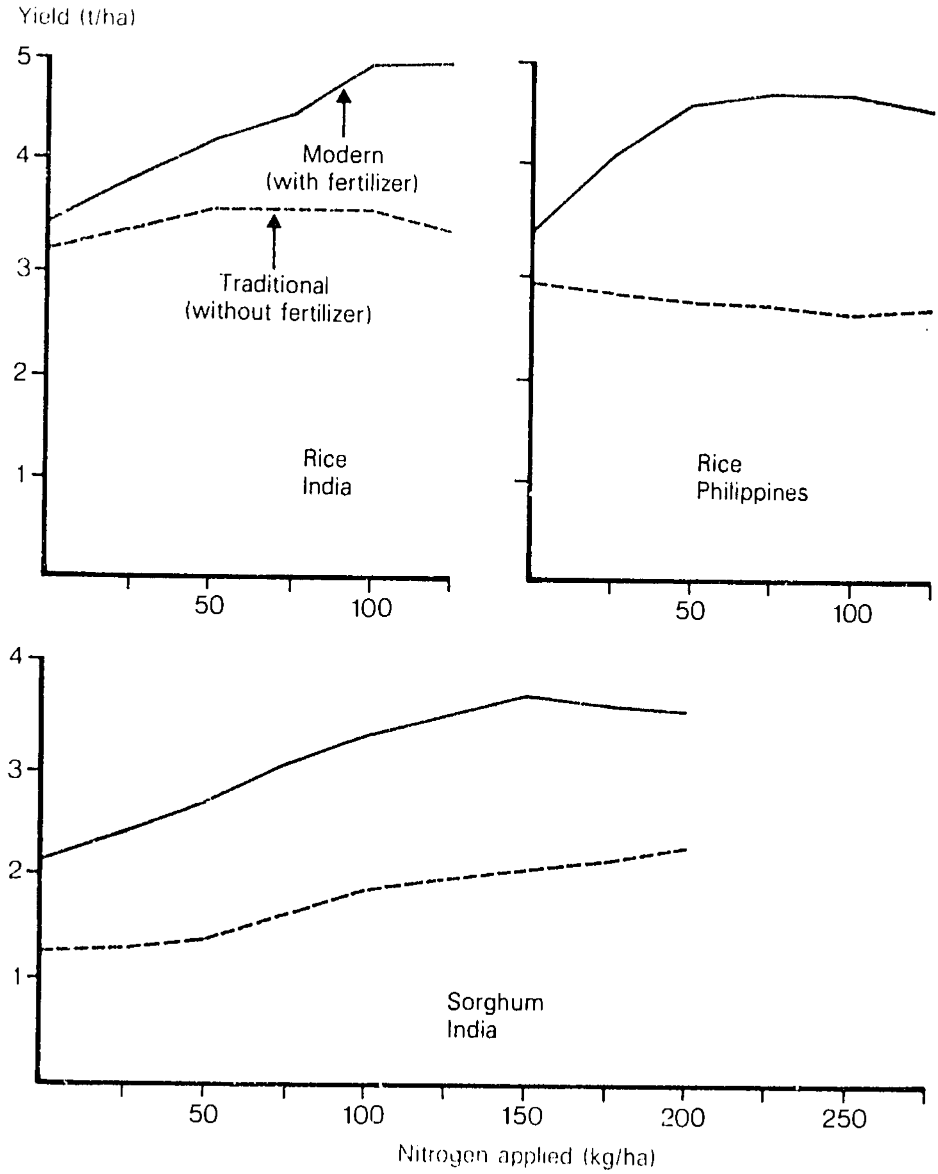


Figure 4. Yields of rice and sorghum with and without fertilizers.

Source: CGIAR (1985)

deserve greater attention (IRRI, 1986). Most of the high yielding varieties have built-in resistance to a broad spectrum of pests and pathogens. In fact, the ready acceptance of semidwarf wheat varieties received from Mexico in India in 1964-65 was in part due to their resistance to most of the races of leaf and stripe rusts which were then important.

To develop a strategy for further increasing production, the following eight items deserve attention.

1. Characterizing environments and tailoring varieties and management techniques to specific growing conditions. To derive full benefit from a given environment, detailed work will have to be done along the lines of the analyses indicated in Tables 2 to 6 with regard to different wheat ecologies in India. The production constraints and research needs indicated in Tables 2 to 6 are neither complete nor comprehensive, but they illustrate the kind of detailed work required for determining research priorities and strategies.

Fortunately, recent advances in genetic engineering provide an opportunity for transferring genes across sexual barriers and for producing new recombinants. Wheat scientists should derive maximum benefit from the new opportunities now open for generating variability through tissue culture and genetic engineering techniques (Swaminathan, 1986). Recently it has been shown that the bacterial chloramphenicol acetyltransferase (CAT) gene can express itself in protoplasts of wheat (Ou-Lee, Turgeon, and Wu, 1986). In Canada, a

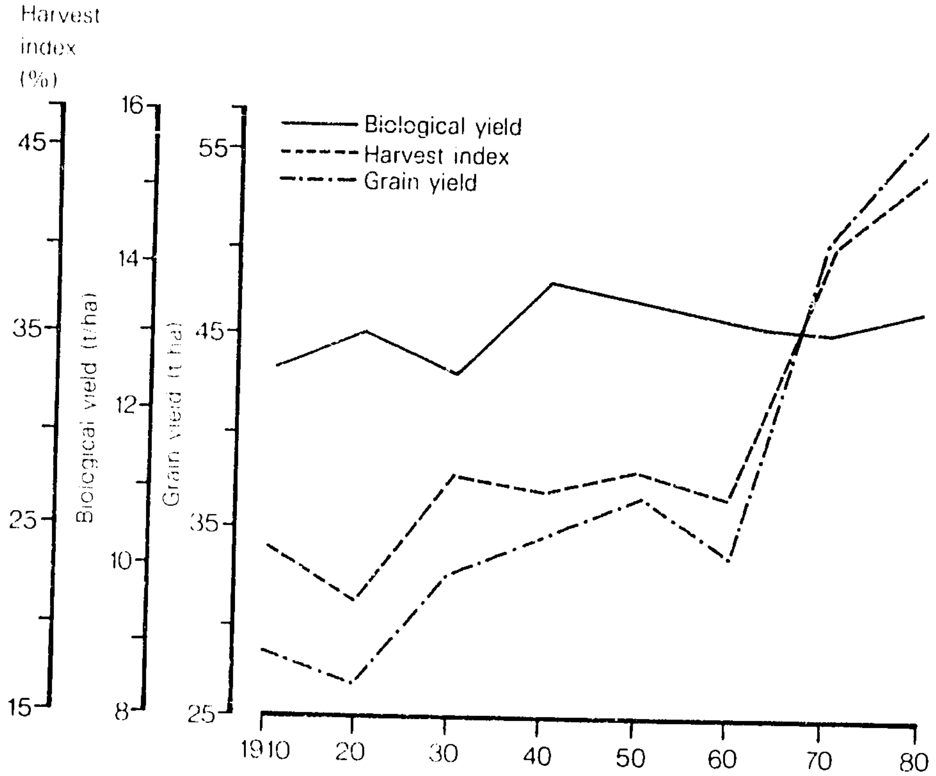
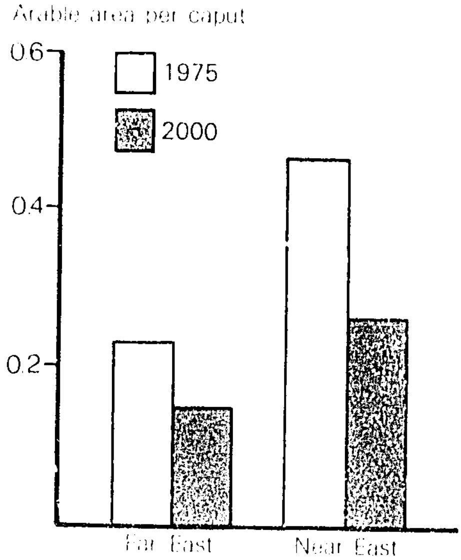


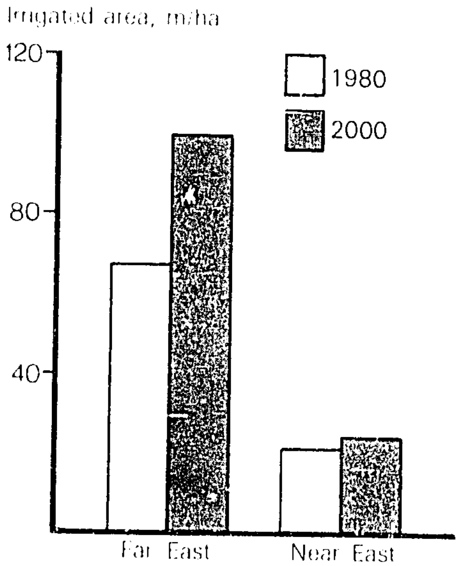
Figure 5. Trend of varietal grain yield in relation to its two parameters, 1910 to 1980.

Source: Kulshrestha and Jain (1983)

high plant regeneration efficiency has been reported from immature embryos of Neepawa, a widely cultivated wheat variety.

2. Improvement of durum wheats A major effort is needed to improve durum wheats (*Triticum turgidum* var. *durum*). Ethiopia, considered to be a center of origin of wheat, has a climate similar to that of peninsular India. The wheats of this region until recent years were almost all tetraploids, mostly durum and emmer. The essential absence of hexaploid wheats suggests that durum wheats are more adapted to higher temperatures than are bread wheats (*Triticum aestivum*). The durum wheats have a large mass of awns relative to total spike mass. This is helpful, because at higher temperatures the photosynthesis system of awns relative to leaves is more stable. At higher temperatures the rate of grain filling in durum wheats is much higher than in bread wheats. In view of these adaptations, tetraploid wheats must be screened with greater vigor for cultivation in central India. The disease and lodging susceptibility of earlier durum wheats is no longer a serious problem with the availability of disease-resistant and semidwarf varieties. Durum wheat can be improved further by incorporating genes for disease resistance from wild relatives as well as from *T. aestivum*. We also need to enrich our germplasm base by collecting durum wheat lines from early cultivation areas.





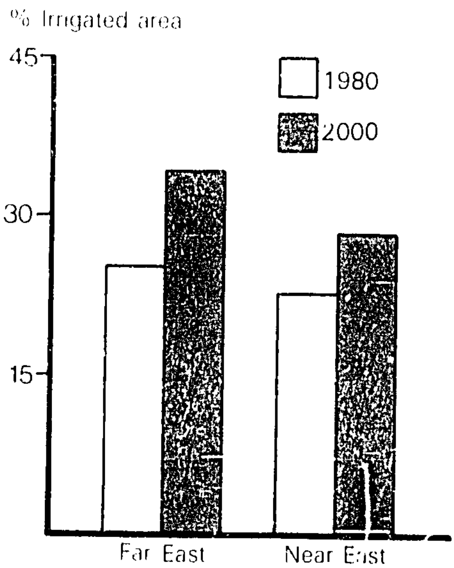


Figure 6. Proportion of irrigated area, Far and Near East.

Source: FAO

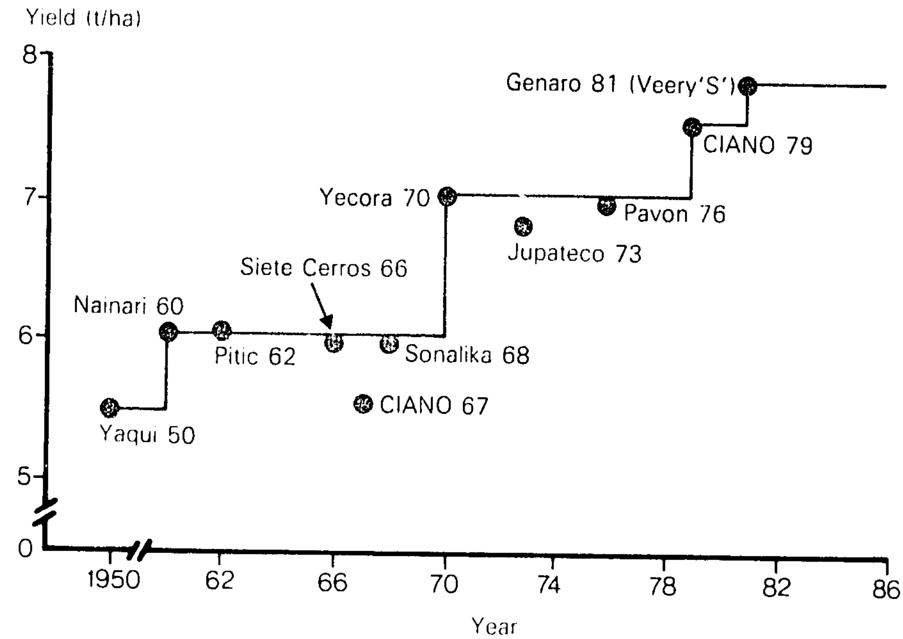


Figure 7. Average yield of Mexican varieties under favorable management conditions.

Source: CIMMYT

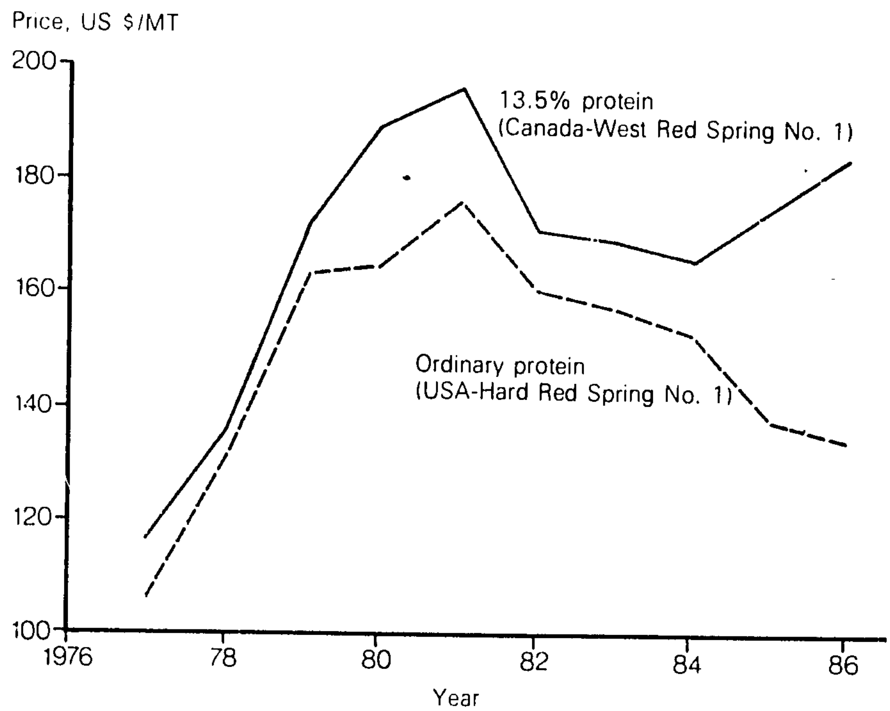


Figura 8. International prices as influenced by protein content and grain quality.

There is considerable variation in protein content of durum wheats. Studies at the University of Nebraska indicated a range of 7.3% to 21.7% with a mean of 12.75% and SD of 2.86%. The lysine content also varied from 0.29% to 0.59%. It should be possible then to breed for higher protein content. Quite frequently, an increase in protein content leads to a calorie penalty. Hence, great care should be taken not to lose grain yield potential while breeding for higher protein content. The bread making quality of hexaploids is regulated by the D-genome. Selective incorporation in durum wheats of the D genome's quality related chromosomes such as 1D may help to improve bread-making quality of durum wheat grain. The recent techniques of chromosome and genetic engineering may help in developing new recombinants (Payne, 1986).

3. Soil and water care Nature has endowed many Asian countries with good soils and ample water resources. The water resources are increasingly being harnessed for irrigation. In the last few years, the area under irrigated wheat has greatly expanded. In the Punjab and Haryana States of India, practically the entire wheat area is now under irrigation. However, this resource is not being utilized efficiently. The easy availability of irrigation water has often led to over-irrigation, resulting in increased problems of waterlogging, salinity, and alkalinity (Table 7). The magnitude of these

Table 2. Wheat production constraints and research needs, Northwest Region of India

Problem	Possible solution
Sowing gets delayed - yield is reduced	Develop short-duration varieties with high yield potential
	Increase heat tolerance at grain filling
	Increase resistance to rusts
Increasing problems of waterlogging, salinity, and alkalinity	Improve water management systems (particularly drainage)
	Breed for tolerance to salinity
Micronutrient deficiencies	Increase the use of farmyard manure
	Promote balanced fertilization
Grain quality	Increase nutrient uptake efficiency
	Genetic engineering
Raising yield potential	Improve dry matter production
	Examine scope for fixation of heterosis through anther culture and genetic engineering
Weeds: wild oats and *Phalaris minor*	Adopt suitable rotations
	Weed control measures

problems can be considerably reduced by improving the on-farm management of water as well as the drainage system. The alternative approach is to develop salt-tolerant varieties. There is thus an increasing need to identify genes, if any, for salt tolerance in wheat and related plants.

Table 3. Wheat production constraints and research needs, Central Region of India

Problem	Possible solution
Low yield despite increased irrigation	Synergy in input use—increase fertilizer use and area under high-yielding varieties
Short duration	Develop photosensitive wheats with durable resistance to rusts
	Increase heat tolerance
Unstable yields due to drought	Improve moisture conservation
	Evolve isogenic lines of varieties varying in root length
	Winter x spring wheats
Low yields of durums	Enrich germplasm base and develop high-yielding varieties
	Breed for resistance to stem, leaf, and stripe rusts

Table 4. Wheat production constraints and research needs, Eastern Region of India

Problem	Possible solution
High temperature	Develop short-duration varieties with high yield potential
	Increase tolerance to high temperatures
Poor crop stand due to heavy-textured rice soils	Develop simple machines and implements for tillage and seeding
Problem saline soils	Improve drainage
	Reclamation measures
	Develop salt-tolerant varieties
Low input use	Increase distribution of credit
Alternaria and *Helminthosporium* spp. diseases	Breed resistant varieties
Good quality seed	Develop storage methods to keep seed dry

Intensive cropping also leads to soil erosion and consequent loss in native fertility. Although such soil degradation problems are not of recent origin, exploitative agriculture may accelerate the pace of damage to soil health. Therefore, we need to develop cropping practices such as minimum tillage to check the valuable loss of soil resources. Continuous cropping and high productivity levels also result in soil exhaustion, particularly of micronutrients. There are increasing reports of zinc, iron, manganese, sulfur, and copper deficiencies in areas of intensive agriculture. Many of these problems are in part due to decreased organic matter in the soil and can be rectified to some extent by increased use of farmyard manure. It will also be important to use fertilizers with an optimal nutrient balance.

Table 5. Wheat production constraints and research needs, Western Region of India

Problem	Possible solution
High temperature	Increase heat tolerance
	Develop photosensitive varieties with durable rust resistance
Low plant population	Use higher seeding rates and varieties with fewer tillers
	Intercrop with adapted crops

Table 6. Wheat production constraints and research needs, Southern Region of India

Problem	Possible solution
Very high temperature	Select alternate crops
Stem rust and other disease problems	Develop resistant strains for cultivation in the Nilgiri hills

Table 7. Annual increase in waterlogging and soil salinity in some irrigation projects in India (000 ha)

Project	State	Waterlogging	Salinity
Gandak	Bihar and Uttar Pradesh	3.50	36.40
Ukai-Kakrapan	Gujarat	0.63	0.32
Mahi-Kadana	Gujarat and Rajasthan	3.90	1.70
Chambal	Madhya Pradesh and Rajasthan	7.59	3.08
Tawa	Madhya Pradesh	-	1.11
Rajasthan Canal	Rajasthan	3.92	2.65
Sarda Sahayak	Uttar Pradesh	5.72	0.94
Ramganga	Uttar Pradesh	27.90	50.40

Source: Joshi and Agnihotri. 1984. Indian Journal of Agricultural Economics, v.39.

4. Plant health – Eternal vigilance is the price of stable agriculture. In particular, constant vigilance is needed to guard against damage to the crop by pathogens, pests, and weeds. Joshi, Singh, and Srivastava (1986) have described how certain diseases which were not important before have now become important in the wheat crop in India and vice versa. For example, Karnal bunt (*Neovossia indica*) of wheat has now become important in northwestern India, although until recently it was considered to be a disease of minor importance. Research on methods of achieving stable resistance through such approaches as multiline breeding, cultivation of diverse genetic strains thereby avoiding genetic homogeneity, and breeding for horizontal resistance needs to be stepped up. At the same time, disease monitoring and surveillance systems should be given adequate support. This is where the international observation and yield nurseries distributed by CIMMYT assume particular significance.

5. Increase in protein content – We have four options available to increase protein content.

- Introduce genes for higher protein content into desired lines by conventional breeding or genetic engineering,
- Increase the partitioning of nitrogen (N) in favor of grains (increased nitrogen harvest index, utilization efficiency),
- Increase the amount of N fertilizer applied, and
- Increase the uptake of soil nitrogen (uptake efficiency).

The final grain yield and protein content of a wheat grain represents the result of a number of physiological and biological processes occurring over the growth period. The level of protein can be increased if more nitrogen is made available for plant uptake. By providing unchanged nitrogen availability, protein yield can be increased by either improved nitrogen uptake from the soil (uptake efficiency) or by increased mobilization of nitrogen from vegetative organs to the grain (utilization efficiency). A grain yield of 4 t/ha with a protein content of 12.5% needs 100 kg N/ha to be harvested by the crop (assuming 75% nitrogen harvest index). If the same yield is needed with 15% protein, then the crop will need to scavenge from the soil at least 128 kg N/ha. Alternatively, the nitrogen harvest index will have to increase from 75% to 96%. The latter might not be practical since it is likely to induce rapid breakdown of leaf proteins and increase the rate of leaf senescence, thus reducing the grain yield. Therefore, breeding for increased utilization efficiency does not appear to be practical. However, screening can be done for increased uptake efficiency. To some extent, genetic variability is available for this character. Cropping practices that minimize nutrient losses should also be standardized.

6. Increased efficiency of farming systems – In Bangladesh, Pakistan, and northern India, rice-wheat rotation has become predominant. The two crops appear to be complementary for optimum use of soil resources since rice derives its nutrients largely from the surface layers whereas wheat has a much larger feeding zone. Compacting light-textured soils for rice in the monsoon season might also be advantageous to wheat in terms of water and nutrient retention. Despite this complementarity, wheat yield after rice is generally lower than after maize. We have to find out the reasons and identify solutions. The possible reasons may include rice crop residues, plow pan, turnaround time, tillage, seedbed preparation, and delayed rice harvest. All of these factors will lead to the delay in sowing time of wheat. This will expose the crop at the grain-filling stage to higher temperatures, which are known to reduce yield (Figures 9 and 10). Therefore, it is necessary to develop varieties having tolerance to higher temperatures at the grain-filling stage. There is also a need to breed rice varieties characterized by a high per-day productivity which will enable the planting of wheat at the optimum time.

We have to reorient breeding programs to meet the needs of an entire cropping system, rather than of only one crop in the rotation.

Screening for low-maintenance respiration might be a good approach. This has been used successfully in soybean and ryegrass, and therefore it should be possible to select for low maintenance respiration rates in wheat as well. Pubescence of leaves and other deposits on leaf epidermis are additional mechanisms by which leaf temperature can be reduced. Since awns have a higher temperature optimum for photosynthesis, selection for larger awn mass may be helpful. Heat shock proteins have recently been identified in many crop plants. Thermotolerance is the proposed function of these proteins. We will have to study if these can be characterized and incorporated in breeding lines without changing their yield potential. Physiologists and breeders need to work more closely to screen both genetic stocks and segregating material.

In view of the increasing pressure on land for supporting an ever growing population, we will have to design efficient land use plans. Crop rotations will have to receive greater attention based on both national needs and soil productivity maintenance. These plans have to be ecologically sustainable and economically viable.

7. Resistance to preharvest sprouting- In the last couple of years, unseasonal rainfall in northern India in April and May resulted in a considerable loss in grain quality. Often grains germinate in the spikes. The projected delay in wheat sowings and harvest may further increase the probability of grain being affected by rainfall at the time of maturity. Therefore, it is desirable to develop lines resistant to sprouting.

The phenomenon of sprouting in the spikes is a complex process involving a number of steps. Many of these are affected by the environment. Two main

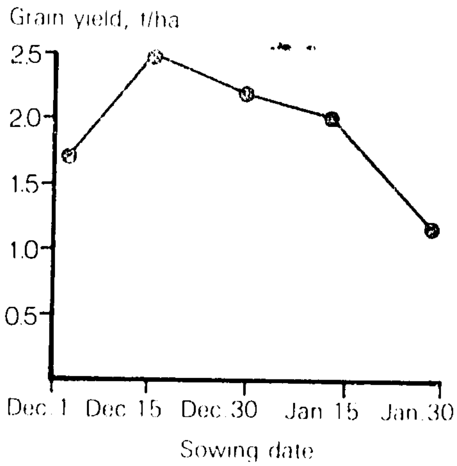


Figure 9. Response of wheat to dates of sowing in Los Baños (14°N), Philippines.

Source: Aggarwal *et. al.* (1986)

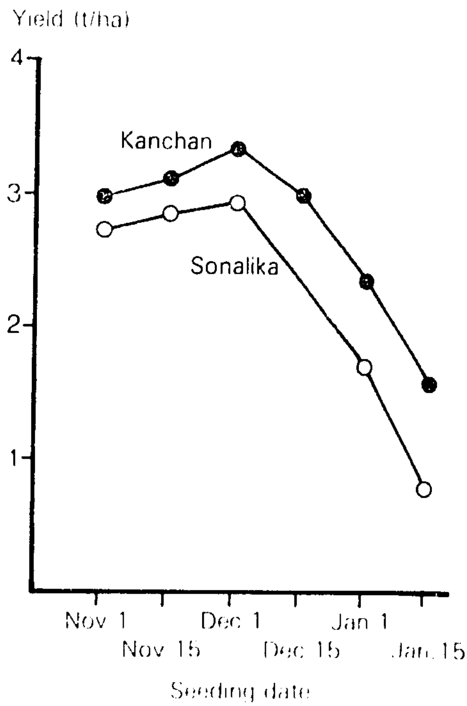


Figure 10. Yield response of Kanchan and Sonalika at six planting dates in Bangladesh.

Source: Butler, I. (personal communication) groups of alpha-amylase isozymes are related with sprouting. The two isozymes appear to be under independent genetic control. There exists substantial genetic variability with respect to susceptibility to sprouting. A thorough screening of wild relatives might lead to the further identification of useful gene donors. In the future, we will have to know more about the physiological mechanisms, particularly in relation to phytohormones, that regulate the basic metabolic events in the sprouting process. Simple but reliable analytical tools need to be developed that would enable breeders to rapidly screen large numbers of materials.

8. Improved postharvest technology
The moisture content of wheat grain is a critical factor from harvest until its processing. Wheat can be safely stored for a few months only if the moisture content is below [illegible]. Therefore, it is necessary to develop small scale grain driers based on solar energy and crop residues. It is equally important to develop energy efficient and yet economical systems for large scale storage of buffer stocks. Sometimes, water seeps into the storage vessels, leading to the sprouting of the seeds. We therefore need to incorporate short term stable dormancy in wheat seeds. Fortunately, considerable genetic variability exists for this trait.

Increasing Income of Wheat Farmers

It will be difficult for developing countries to give farmers prices that will necessitate heavy subsidies at the consumer end because of the vast dimensions of the undernutrition problem in most of these countries. On the other hand, the net "take home income" of farmers with 2 ha or less land remains very low, so we should develop a strategy for improving the income of wheat farmers. Some components of the strategy are:

- Production cost should be reduced without reducing yield. For example, research designed to promote farm grown substitutes for market-purchased chemicals like fertilizer and pesticides will have to be stepped up.

- Wheat farming systems should be so designed that maximum sustainable income can be obtained from the available land, water, labor, and credit resources. In this context, the rice wheat rotation of northwestern and eastern India, Pakistan, and Bangladesh, as well as cotton wheat, potato wheat, and other crop rotations that are possible under irrigation, will have to be developed in such a way that all crops in the rotation can perform in a physiologically efficient manner. We need more research on wheat farming systems to improve the efficiency of the system as a whole.

- Research and development efforts in biomass utilization need to be strengthened. For example, a wide array of value added products can be prepared now from straw, leaves, and grains. Studies by Munck and Rexen in Denmark (1986) have shown that there is considerable variation in the chemical characteristics of the straw. One interesting finding is that some of the plant samples have a high production of both starch and cellulose measured as yield per hectare. Studies at several institutions in India have shown that the quality of wheat straw can be further improved through treatments with anhydrous ammonia and fertilizer grade urea. It is important that the new opportunities now available for preparing value added products from every part of the wheat plant are studied carefully, and suitable choices are made based on marketing opportunities.

Stimulating Consumption

Some developing countries like India have built up substantial wheat and rice reserves at a heavy cost. Unfortunately, the availability of surplus wheat and rice in India is rather skewed in terms of geographical spread. Heavy transport costs are involved in moving grain from surplus to deficit areas.

Krishna and Chhibber (1983) have constructed models for determining the needs of the public distribution system in India in good and unfavorable crop years. Government stocks are steadily increasing and storage losses compound the financial burden arising from capital immobilization. Whatever the cost, the quantities of grain needed for maintaining a food security reserve and for operating an effective public distribution system will have to be stored. What can governments do with the balance?

A desirable solution to this dilemma is the planned use of wheat as cash to meet a part of the wage component of labor in development projects. Policies should be developed for integrating cash and grain while preparing the budget for development projects. In other words, we have to move one step further from the "Food for Work" approach and develop policies and procedures for using home grown surplus grain as an important budget resource. Grain quality control will be essential if such an approach is to find acceptance among those who receive grain instead of cash. Ezekiel (1984) has shown how India's grain surpluses, far from being a problem, provides an opportunity for overcoming the twin challenges of hunger and unemployment.

To sum up, Phase II of the Green Revolution will need for its sustenance and success a blend of knowledge, intensive technologies, and biological and chemical inputs. We can say that the first phase of the Green Revolution, starting in 1966 and ending in 1986, has helped to disprove the prophets of doom and gloom, and has led to the birth among developing nations of a new confidence in their agricultural capabilities. We are now entering the next phase where new problems will have to be faced and solved.

First, we need to step up our research and training efforts, which can help increase and stabilize the production of wheat, maize, and other crops, and improve the economic well being of small-scale farmers through diversified employment opportunities resulting in the generation of greater household income.

Second, we should try to raise further the ceiling to yield under irrigated conditions. In this context, there is a revival of interest in hybrid wheat. Knudson (1986) has summarized the state of the art in relation to hybrid wheat development. A major factor will be the commercial viability of hybrid wheat technology. According to Knudson (1986), to produce the same amount of seed, approximately twice as much land is needed for hybrid wheat seed production (10,125 ha) as for conventional wheat seed programs (5,265 ha). Further studies alone can show whether hybrid wheat is likely to become a commercial reality.

The barrier between poverty and relative prosperity can be removed more through the application of science and technology than through any other means.

The various factors involved in increasing crop productivity are summarized in papers presented at "An International Conference on Crop Productivity Research Imperatives Revisited" held in Michigan in 1985. From a strictly biological point of view, it may be possible to increase the yield potential of wheat further if the total biological yield can be increased by distant hybridization followed by efficient partitioning of the total dry matter. In our legitimate desire to increase yield, we should not sacrifice resistance to pests and diseases. Stability of production is equally important. In this context, the role of genetic engineering techniques needs careful analysis.

Finally, the Green Revolution in developing countries essentially has been a public sector enterprise. The era of "gene revolution," which looms large on the horizon because of advances in molecular genetics is predominantly a private sector enterprise in the developed world. The rapid spread of Green Revolution technologies became possible because the research results were disseminated with the sole motivation of helping farmers to increase production. Emerging technologies associated with the broad area of biotechnology may provide opportunities for adding a dimension of resource neutrality to scale neutrality in technology development. Will these new opportunities become available to small scale farmers in developing countries in the same way as the Green Revolution technologies in the 1960s? It is in this context that the role of CIMMYT as a nonprofit, nonpolitical, autonomous scientific organization becomes so important for developing countries. Through its collaborative arrangements with similar advanced institutions, CIMMYT can help in the speedy transfer of the benefits of the latest tools of science and technology to the national research systems of the Third World.

While I have dealt only with wheat in this paper because of my personal involvement in wheat research and production over the past 30 years, CIMMYT's work on maize has been equally praiseworthy. According to the Consultative Group on International Agricultural Research (CGIAR) Impact Study Team, maize varieties derived from CIMMYT material cover six million hectares in over 15 countries. CIMMYT's Tuxpeño group of maize lines has been notable for disease resistance. The incorporation of resistance to streak virus in some new maize materials by the International Institute of Tropical Agriculture (IITA) has deservedly been recognized through the award of the King Baudouin Prize for 1986 by the CGIAR.

The wall that separates people living in poverty from those who enjoy relative prosperity can be removed more through the application of science and technology than through any other means. CIMMYT, by bringing to Third World farmers the best that mission oriented multidisciplinary team research can produce, has contributed to improving the well being of numerous rural families in the tropics and subtropics.

References

Aggarwal, P.K., J.P. Liboon, and R.A. Morris. 1986. A review of wheat research at the International Rice Research Institute. IRRI Research Paper, Los Baños, Philippines. (In press.)

Borlaug, N.E. 1985. The magnitude and complexities of world food problems during the next doubling of population. The Nathaniel H. Grace lectureship in agriculture, 22 October 1985, University of Alberta, Edmonton, Canada.

Ezekiel, H. 1984. India's food surplus. Three articles reprinted from The Economic Times, Bombay, India, October 31-November 2, 1984. International Food Policy Research Institute, Washington, D.C., USA. 11 pp.

Gibbs, M. and C. Carlson (eds.). 1986. Crop productivity - Research imperatives revisited, an international conference held at Boyne Highlands Inn, October 13-18, 1985 and Airlie House, December 11-13, 1985.

Grigg, D.B. 1984. The agricultural revolution in Western Europe. *In* Understanding Green Revolutions, T.P. Bayliss-Smith and S. Wanmali, eds. Cambridge University Press, Cambridge, England. Pp. 1-17.

International Rice Research Institute. 1986. IRRI Highlights 1985. IRRI, Los Baños, Philippines. 101 pp.

Joshi, L.M., D.V. Singh, and K.D. Srivastava eds. 1986. Problems and progress of wheat pathology in South Asia. Malhotra Publishing House, New Delhi, India. 401 pp.

Knudson, M. 1986. The research and development on a biological innovation: The case of hybrid wheat. University of Minnesota Strategic Management Research Center. 57 pp.

Krishna, R. and A. Chhibber. 1983. Policy modeling of a dual grain market. The case of wheat in India. Research Report 38, International Food Policy Research Institute, Washington, DC, USA. 75 pp.

Mellor, J.W. 1980. Foreword. *In* The Economics of the International Stockholding of Wheat. Research Report 18, International Food Policy Research Institute, Washington, DC, USA.

Munck, L. and F. Rexen. 1986. Report from the EEC Projects 1985-1986. 20 pp.

Ou-Lee, T.M., R. Turgeon, and R. Wu. 1986. Uptake and expression of a foreign gene linked to either a plant virus or *Drosophila* promoter in protoplasts of rice, wheat and sorghum. *In* Proceedings of the National Academy of Sciences. Cornell University, Ithaca, NY, USA. (In press.)

Paddock, W. and P. Paddock. 1967. Famine—1975. Little, Brown & Company, Boston, MA, USA. 276 pp.

Paulino, L.A. 1986. Food in the third world: Past trends and projections to 2000. Research Report 52, International Food Policy Research Institute, Washington, DC, USA.

Payne, P.I. 1986. Varietal improvement in the bread-making quality of wheat: Contributions from biochemistry and genetics, and future prospects from molecular biology. *In* Biotechnology and Crop Improvement and Protection. Monograph No. 34. BCPC Publications, UK. Pp. 69-81.

Swaminathan, M.S. 1984. Nutrition and agricultural development: New frontiers. Food and Nutrition 10(1):33-41.

Swaminathan, M.S. 1986. Plant research and world agriculture. Plant Molecular Biology Reporter 4(1):1-17.

Accomplishments and Challenges: Policy Environment Issues

G.E. Schuh
Agriculture and Rural Development, The World Bank, Washington, DC, USA

I am honored to be on the program celebrating the 20th anniversary of this strategically important institution. CIMMYT is a symbol of the creativity of man, and at the same time an example of how international cooperation can further the welfare of all of mankind. It is sad that such cooperation is not more widespread than it now is. But let's honor what we have and congratulate CIMMYT and its staff, not for having survived for 20 years, but for their many accomplishments in that period.

I am also pleased to be invited to discuss one of my favorite topics - issues of the policy environment. The assignment given me was to discuss both accomplishments and challenges. In point of fact, however, I will concentrate on challenges, and leave the accomplishments to be handled by implication. In that way I can avoid the chronic tendency of economists to be like military generals, always fighting the last war, and instead focus on the future. This is important, because the challenges we face in the future will indeed be great.

I have chosen to organize my remarks today around six challenges: (1) the challenge of agricultural development in a changed international economy, (2) the challenge of growing abundance, (3) the challenge of raising the per capita income of rural people; (4) the challenge of global policy reforms; (5) the challenge of diversification; and (6) the challenge of science and technology policy. At the end I will have some concluding comments.

The Challenge of Agricultural Development in a Changed International Economy[1]

These last 25 years have witnessed remarkable changes in the configuration of the international economy, and in the economic forces that drive it. Four of these changes and developments are of particular significance: (1) the growth in international trade, which is usually described as an increased dependence on trade; (2) the emergence of a large, well-integrated international capital market; (3) the shift from the Bretton Woods fixed exchange rate system that governed international relations in the post-World War II period to a system of bloc-floating exchange rates in 1973; and (4) the emergence of a great deal of monetary instability starting in 1968.

Unfortunately, the significance of these changes is all too poorly understood, both by policymakers and economists alike. These changes have truly given us a New International Economic Order, even though it isn't the one the United Nations Conference on Trade and Development (UNCTAD) has been pursuing. They have enormous implications both for policymakers concerned with short-term policy issues and for those concerned with the long-term objectives of promoting agricultural development. For these reasons I would like to focus for a few moments on the implications of these changes and developments.

Consider the growing significance of international trade. With the exception of a few years, international trade has throughout the post-World War II period grown faster then world Gross National Product (GNP), but in the decade of the 1970s its growth really accelerated. In the case of agriculture, this growth in trade has given us a true international food and agriculture system. Agriculture is the most well-integrated sector of the international economy. Almost all countries either import or export agricultural commodities; some do both.

This system gives all countries either a market for their agricultural output or a source of supply to meet the demands of their domestic economy. It has also virtually eliminated famines except in those cases in which national governments do not let the international economy know about them, or advise them only after it is too late to deal effectively with difficult logistical problems.

Another important consequence of this increased dependence on trade is that it makes national economies more open to the forces of international trade. What this means, of course, is that national economies are increasingly beyond the reach of domestic economic policies. This is a poorly understood phenomenon, but it is the cause of much of the frustration with domestic policies and their deficiencies around the world. Agriculture in particular is all too often still thought about as a closed economy, focusing on domestic economic policies alone. That creates a great deal of analytical and policy mischief.

Next consider the emergence of a well-integrated international capital market. This market is now huge. In 1984, for example, total international capital flows amounted to US$ 42 trillion, while the total flows of international trade were only US$ 2 trillion. It is flows of capital that now drive foreign exchange markets, not international trade. Moreover, almost all countries use this market, with the result that international interdependence is reflected as much or more in linkages through capital markets as it is through trade.

Two consequences of this market are important. First, changes in the values of national currencies can completely mask underlying comparative advantage for extended periods of time, presenting a serious challenge to policymakers promoting agricultural development. Second, the availability of this capital market imposes a dual constraint on policymakers, with capital flows by definition having to offset trade deficits or surpluses. This broadens the options for policymakers under some circumstances. But under other conditions it forces international burden-sharing on a scale not witnessed in the post World War II period. To put it in its most obvious form, if the lending countries want their past loans to be paid off, they will need to accept imports from the borrowing countries, and this imposes at times severe adjustments on the developed countries. Note in passing, moreover, that this is probably the first time in recent history in which there has been domestic pressure in the form of trade liberalization. Those bankers really do want to get paid!

Agriculture is all too often still thought about as a closed economy, focusing on domestic economic policies alone.

The shift to a bloc floating exchange rate was of enormous significance, but that significance is only now being realized. In most countries the exchange rate is now the single most important price in the economy. Moreover, if the exchange rate is permitted to float, it provides the means whereby the effects of external shocks can be spread widely in the domestic economy, thus facilitating domestic adjustment to changed international realities. At the same time, however, it can be an important source of external shocks in its own right, as when perverse monetary and fiscal policies in a country such as the United States lead to a large rise in the value of the US dollar.

There are three other implications of the shift to bloc floating exchange rates that are worth mentioning. First, the combination of a flexible exchange rate system and a well integrated international capital market causes agriculture, as a trade sector, to bear the burden of adjustment in response to changes in monetary and fiscal policy.[2] This is a marked changed from the earlier period when agriculture was almost completely exempt from changes in such policies. Second, there is now a strong link between financial and commodity markets. And third, there are strong third-country effects of exchange rate realignments due to the bloc floating nature of the exchange rate system.[3]

Changes in the economic environment of world agriculture broaden the agenda for agricultural policy.

Finally, consider the issue of increased monetary instability. With agriculture now more vulnerable to changes in monetary and fiscal policies because of the changes discussed above, the increase in monetary instability takes on even greater significance. The US agricultural export boom in the 1970s is a perfect example. Ironically, the boom at the time was attributed to the weather and to the efficiency of US producers. The United States' loss of export shares in the 1980s has been due in a similar way to the unprecedented rise in the values of the dollar, coupled with rigid commodity programs. In each case there were complementary effects from other factors such as changes in per capita income.

To conclude, what we see are enormous changes in the economic environment in which world agriculture finds itself. These changes broaden the agenda for agricultural policy, with monetary and fiscal policies, exchange rates and exchange rate policy, international capital markets, and trade policy generally now being far more important than the more familiar domestic commodity programs.

The Challenge of Growing Abundance

A global food supply crisis tends to appear about once every 10 years. CIMMYT was created in the midst of one of those episodes — the 1965-66 crisis in Asia. The crisis that followed about a decade later, in the early mid-1970s, provided the incentives to establish the Consultative Group on International Agricultural Research (CGIAR) system itself. In fact, both the 1960s and the 1970s were periods of widespread concern that rising population in developing countries was creating a Malthusian world for us.

The data, of course, tell a different story. Figure 1 shows the real or inflation-corrected price for maize and wheat extending back more than 100 years. If food were becoming increasingly scarce, its real price would be trending upward. If it were becoming more abundant, its real price would be trending downward.

The figure tells a dramatic story. Rather than trending upward, the price of wheat — a widely consumed food grain — has been trending downward for well over 100 years. Clearly, there are periodic upturns, but the trend is downward — and by a significant amount. By the beginning of the 1980s, the real price of wheat was roughly half what it was 120 years earlier in 1860. Moreover, the price has declined significantly since the beginning of the 1980s.

The price of maize has shown a similar downturn, although its slide started only during the post-World War II period with the spread of hybrid maize. Maize is a food grain in Mexico and in large parts of Africa. More generally, it is a feed grain and the decline in its price has made possible a large expansion in the livestock and poultry sectors around the world. Poultry itself has experienced a large decline in real prices in the post-World War II period, as have other commodities.

This growing abundance is due in part to the work of such centers as CIMMYT, especially in the last 20 years. More generally it is due to the growing capacity for agricultural research, and the new production technology that is the output of that capacity. In any case, it represents an enormous increase in the welfare of mankind, and has prevented countless millions from experiencing the pains of malnutrition and eventual premature death. This growing abundance, however, is becoming a challenge to policymakers. The US press is filled with stories about "a world awash in grain," about surpluses, and about the decline in trade in agricultural commodities. This in turn has led to questions about the rationality of providing continued support for agricultural research, both in national programs and to the international system.

Nothing, of course, could be more senseless. All the evidence we have is that investments in agricultural research are some of the highest payoff investments either a nation or the international community can make. The challenge to policymakers, then, is to create the institutional means whereby the agricultural surplus in the Nichol's sense -- that production above what is required to feed the rural population at prevailing prices -- is mobilized for the development of the economy as a whole. This will require the development of viable domestic capital markets, the development of effective fiscal systems, and the liberalization of international trade -- a topic I will return to below.

Nothing is likely to be more important in most developing countries in the decades ahead than this ability to mobilize the so-called agricultural surplus and to use it for the development of the economy as a whole. Similarly, nothing is likely to be more important in terms of realizing the full benefits of the emerging international system of agricultural research. And to the extent that poverty is in most countries the main cause of hunger and malnutrition,[4] nothing is likely to do more to reduce these plagues of humanity.

The Challenge of Raising Per Capita Incomes of Rural People

CIMMYT and the other international agricultural research centers (IARCs) were created in the crucible of an international cooperative crusade against hunger. Although many problems remain, that crusade -- as noted above --

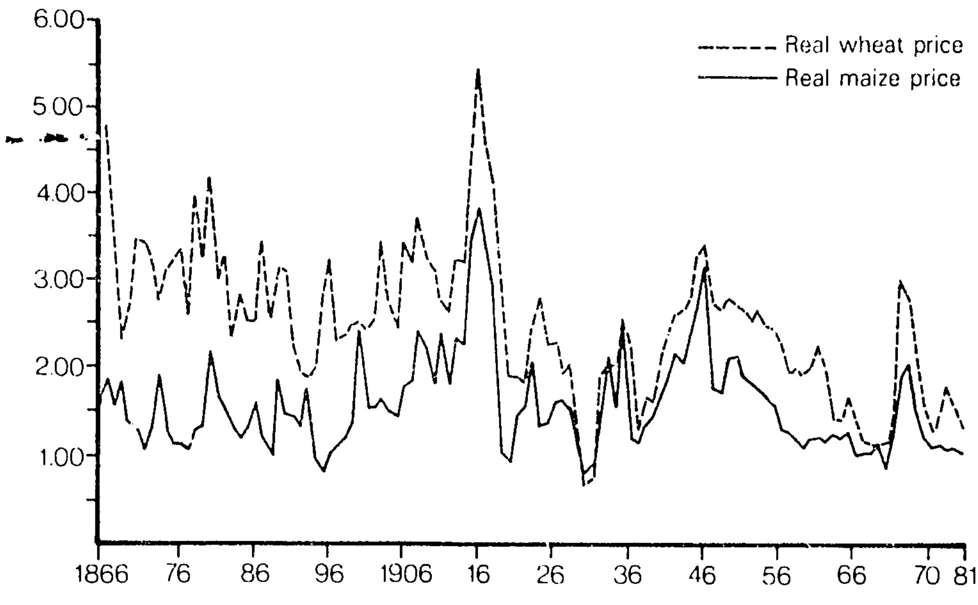


Figure 1. Inflation-corrected prices of maize and wheat, 1866-1981.

Source: Martin, M.V. and R.F. Brokken. 1982. Grain prices in historical perspective. Mimeo. Department of Agricultural and Applied Economics, University of Minnesota, USA.

has in many respects been a remarkable success. The global capacity to produce and distribute new productive technology is growing steadily, and production in most parts of the world is growing apace. In fact, our success has been so great that our rhetoric of combatting hunger may become counterproductive, especially in light of the growing recognition that the hunger and malnutrition problem in most countries is an income problem, and not a production problem per se. Unfortunately, the CGIAR system, and other agricultural research systems as well, tend to put most of their emphasis on the productive side.

In the previous section I discussed the importance of mobilizing and using the agricultural surplus for the development of the economy as a whole. The problem of poverty in rural areas is a special case of that problem. The bulk of poverty in most countries - even in such nations as the United States - is in rural areas. Moreover, the disparity in per capita incomes between the rural and urban sectors in most countries is a factor of two or three.

The CGIAR system has recognized this problem in part by the attention it gives to the small scale farmer. But in its overall research strategy it has given much less attention to the fact that the success of its biological and physical research programs makes it necessary for more and more people eventually to move out of agriculture if they are to receive incomes comparable to those in the nonfarm sector.

Again, the challenge to policymakers in the decade ahead will be great. The labor adjustment problems as we look to the next decades will be enormous in most countries, with the severity of the problem directly associated with the success in the agricultural research program unless international trade should take up the slack. The challenge will be to deal with this problem in such a way that labor does not have to bear all the adjustment costs and so that negative externalities are not imposed on rural areas.[5] This will require incentives for the decentralization of the industrialization process into areas where labor is abundant, and will also require training, education, and relocation programs to promote labor mobility.

The Challenge of Global Policy Reforms

An important characteristic of the policy environment for global agriculture is that governments in developing countries tend to discriminate against their agriculture, while those in the developed countries tend to subsidize theirs. Subsidies on the part of the developed countries are creating increasingly serious problems for producers in the developing countries as they dump their surpluses abroad and drive world prices down.[6] They create problems for the developed countries. At the same time, lost resource efficiency and large treasury costs at home impede economic growth.

Interestingly enough, the international debt crisis is putting significant pressures on the governments of developing countries to reduce their discrimination against agriculture. The demand for foreign exchange to service that debt is the driving force. These pressures are reinforced by the lending conditionality of the International Monetary Fund (IMF), the World Bank, and bilateral donors, which requires a rationalization of trade, exchange rate, and agricultural policies, and for the most part a more outward-looking perspective toward the international economy.

These policy reforms can be a significant stimulus to agriculture, especially when new production technology is available. Given the size of distortions in its economy, China may not be the best example, but it certainly shows what can happen when market forces are allowed to operate more freely. In the short term, devaluation of national currencies, removal of explicit export taxes, reduction of tariffs and other protective measures, and other reductions in tariffs can create strong international competitive pressures. As these measures lead to more rapid rates of economic growth, however, the tendency will be to absorb a fairly large share of the increased agricultural output in the domestic economy.

Bringing about the needed reforms is not easy because major redistributions of income are often involved. That is the same problem the developed countries face. The difference is that the developed countries do not have economic forces driving them towards liberalization. Moreover, by virtue of being rich, they can probably better afford the loss in incomes these policies create than can the low-income countries. The combination of treasury costs and sacrificed economic growth is becoming quite large, however.

A final part of the policy environment in the decade ahead is likely to be another round of General Agreement on Tariffs and Trade (GATT)-sponsored multilateral trade negotiations. Probably never in history have these negotiations been so important for the developing countries. And probably never before has it been so important to the developing countries for agricultural issues to be front and center on the GATT agenda, and for there to be actual trade liberalization in agricultural trade.

The Challenge of Diversification

Successful efforts at agricultural and in turn general economic development can be expected to bring about three major trends of diversification. Some of these have been alluded to earlier, but their relative importance justifies additional discussion in the context of the diversification problem.

Probably the most serious diversification problem in world agriculture today is the need to diversify out of rice. Two factors are at work. The first is the success of the International Rice Research Institute (IRRI) and national research systems in Asia in raising yields so that demand can be satisfied with smaller hectarage. India and Indonesia are two outstanding examples in which rice production is tending to run ahead of demand.

The second factor in diversification will be the shift upward out of dependence on food grains and toward a greater dependence on livestock and livestock products as per capita incomes rise. This is mostly an income effect. An implication, of course, is that the demand for feed grains will increase in a parallel fashion. Thus, the commodities for which CIMMYT is responsible can be expected to be more important in the future.

Finally, although it may not be true for some individual countries, the global agricultural economy will face a serious labor adjustment problem in the aggregate as agricultural development proceeds. If individual countries participate in the international trading system, the demand they face for their agricultural output is relatively elastic. But for closed economies, and for the demand for agricultural output in the aggregate, demand tends to be price inelastic. Hence, improvements in production technology that shift the supply curve to the right will drive commodity prices down relatively more than the increase in output. It is this decline in price which drives labor, and to a certain extent other resources, out of the sector.

This is a diversification problem in the context of the larger economy, but is no less significant than that faced by individual commodity sectors. As noted above, it is one of the major policy challenges policymakers will face in the future if we continue to be successful in generating new production technology. The point I want to emphasize, however, is that the international community that helps to bring on the change in technology should be willing to support the research needed to facilitate this adjustment process. As noted, this involves diversification both within agriculture and out of agriculture to the nonfarm sector. To do anything less than facilitate this process is to sacrifice an important part of the gains to be had from new production technology.

The Challenge of Science and Technology Policies

The developing countries are increasing their support for agricultural research on a significant scale, and the CGIAR system and the donor community more generally are helping to make the national systems even more productive. Unfortunately, few developing countries have anything that would pass for a science and technology policy for agriculture. Although this topic could be a paper in its own right, I want to touch on just a few of the more important issues.

New production technology is the engine of growth for agriculture worldwide.

First, there is the issue of maintenance research.[7] Breeding programs that make plant materials more productive also make them more vulnerable to insects and diseases. This year's *Annual Report* for the CGIAR describes in dramatic fashion the efforts of IRRI to keep up with the mutations of bacteria and viruses affecting rice. I suspect the efforts of CIMMYT to keep up with the challenges of diseases affecting wheat is no less dramatic. What this means is that policymakers need to balance the demands for such things as applied research, basic research, strategic research, and maintenance research. Few of them have the analytical capacity to help make intelligent and informed choices on these issues. The Technical Advisory Committee (TAC) addresses these issues, of course, but it too lacks the analytical capability to do anything other than make informed judgements.

Second, there is the problem of environmental issues and sustainability. These problems have received little attention to date in the developing countries. Their solution, as in so many other cases, requires a contribution of an improved knowledge base and sound economic policies. The improved knowledge has to be generated by biological and physical scientists on the one hand, and by social scientists on the other hand.

Third, much of the discussion in earlier parts of my paper suggests that the international system is significantly underinvesting in economic and other social science research. There are 13 international centers, but only one of them is dedicated to policy research. Moreover, the *Annual Report* of the CGIAR will note that only 2% of the operational research budget of the system is for policy research. Yet my paper is a litany of problems associated with mobilizing the surplus for more general economic development, of raising per capita incomes in rural areas, of devising domestic policies that can be effective in the new configuration of the international economy, of the potential of policy reforms, of problems of diversification, and so on. Moreover, the point in each case is that dealing with these problems more effectively will increase the payoff from the agricultural research system as a whole and diminish the incentives to reduce agricultural research budgets.

Finally, there is the challenge of building an ever more ample scientific and technological community on the international scene. An international agricultural research system is emerging that is made up of research systems in the developing countries, the 13 centers of the CGIAR, other international centers, and the research institutions in the developed countries. Although the integration of these systems has grown rapidly in recent years, the cohesiveness of this integration is still quite fragile. Everybody has much to gain from helping to weld these various components into a truly robust system.

Concluding Comments

I would like to conclude by noting how complementary sound economic policy is to the new technology created by biological and physical scientists. New production technology is the engine of growth for agriculture worldwide. But without proper incentives it will not be adopted. Moreover, without proper economic policies, the increased output from that new technology will not contribute effectively to general economic growth, farmers will be made worse off in a relative sense rather than better off, development will not be sustainable because environmental problems will erode the national resource base, and people will go hungry in the midst of plenty because they do not have the wherewithal to buy the food that is available.

As this discussion should make clear, our challenges are great. Therefore, as we congratulate CIMMYT for its first 20 years, let us also lift up our eyes to the even greater challenges before us. And in the process, let us wish CIMMYT at least another 20 years of prosperity and productivity!

Notes

1. I draw here on my J.W. Fanning Lecture, "Promoting Development in a Changed International Economy," presented at the Georgia Center for Countinuing Education, University of Georgia, Athens, Georgia, USA, April 22, 1986.

2. Schuh, G.E. 1979. Floating exchange rates, international interdependence, and agricultural policy. *In* Rural Change: The Challenge for Agricultural Economists, G.L. Johnson and A.H. Maunder, eds. Proceedings of the Sixteenth International Conference of the Association of Agricultural Economists, Banff, Canada, September 3-12, 1979.

3. For a more detailed discussion, see Schuh, G.E. 1984. Third-country effects of exchange rate realignments: The cases of Brazil and Mexico. Presented at the Symposium on the World Food System, Harvard Business School, Cambridge, Massachussets, USA.

4. See The World Bank. 1986. Poverty and hunger: Issues and options for food security in developing countries. World Bank Policy Study, The World Bank, Washington, DC, USA.

5. For a fuller discussion, see Schuh, G.E. 1982. Out-migration, rural productivity, and the distribution of income. *In* Migration and the Labor Market in Developing Countries, R.H. Sabat, ed. Westview Press, Boulder, Colorado, USA. Pp. 161-190.

6. For an evaluation, see The World Bank. 1986. World Development Report, 1986. The World Bank, Washington, DC, USA.

7. Plucknett, D.I. and N.J.H. Smith. 1986. Sustaining agricultural yields: As productivity rises, maintenance research is needed to uphold the gains. Bioscience 36(1):40-45.

Discussion

W.P. Falcon
Food Research Institute, Stanford University, Stanford, California, USA

I, too, am honored to be on the program this morning, and having been a CIMMYT Trustee for the past six years, I take particular pride in CIMMYT's accomplishments. Lest you think this is an attempt by CIMMYT management to pack the program, I should also note that I'm a last-minute stand in for John Mellor.

I want to complement Ed Schuh on his paper. It is vintage Schuh, it is forward-looking, and it carries his trademarks, which are apparent to those who have read his earlier works:

- A focus on the importance of macropolicy,
- Importance of the gains from trade, and
- The high pay-off of investments in research on agricultural systems.

I find little to quarrel with, for the paper contains many gems, and the penultimate paragraph is the crowning jewel. I urge you to read it; indeed, I urge you to frame it. It is a wonderful statement about the world food problem and the complementarity between economic policy research and the biological side of agricultural production.

Economics is a dismal science; we never seem to be satisfied. However, I ask you to think back to CIMMYT's 10th anniversary. Think of what we would have been talking about then: shortages of grain. The prevailing view—although not Ed Schuh's—was rising real prices of grain. We would have been wringing our hands. Now can it be such that the world is getting worse when we have higher prices, and worse also when we get lower prices? I think Ed has been very good this morning in pointing out the great benefits that have accrued, and surely the problems of progress and plenty are to be preferred to those of shortages and starvation.

It is within this broad context of an economy-wide view that I think Ed has made a major contribution to this session. While I find that I am in general agreement with what he says, I nevertheless wish to quibble on four points, where I think his heart and his hope may have gotten in the way of his hard-headed judgement of what reality might be.

What are those four points? I have never underestimated the power of bankers (World or otherwise) but I really wonder whether debt service can drive either the developed or the developing countries toward trade liberalization. I hope you are right, Ed; I fear that you may not be. Certainly the forces of protectionism around the world—Uruguay meetings notwithstanding—have to be a major concern. I really do not think, however, that debt service alone will cause the liberalization that we need to take place.

Second of all, you make a wonderful plea for the gains from trade. It is so logical that one could hardly doubt that it would carry the day. But I'm impressed as I travel around the world by the forces of autarky, of looking in rather than out. I find that particularly true in Africa. Although there have been some improvements of late, I really worry about some of the sense—but, more important, a lot of the nonsense—that resides under the heading of self-sufficiency. Countries, and centers that serve those countries, do not seem to me to help themselves in trying to produce particular crops in places where they should not be grown. To spend five dollars to save one, supposedly in the interest of self-sufficiency, is not a good way out. I know that you agree with that as well, Ed; I just wish that more of the world agreed, too, and I fear you are a bit too sanguine on promoting the forces of trade and how that will help us in the years ahead.

Third, although I take seriously your comments about the fact that finances are now swamping the real trade aspects of our international relations, I am confused about the lags that are involved in response to exchange rate movements. I would have liked to have thought, for example, that in the case of the United States, the recent slide of the dollar would show up sooner rather than later. It has not. I don't doubt the long run effects of the exchange rate, which is, as you point out, the most significant price in the economy. I am more confused, however, about the short term response, and particularly the ways that certain policies, commodity and otherwise, can impede that.

And finally, I worry, on both strategic and tactical grounds, about the general situation in a number of middle income countries. In some sense, what made the whole world economy for agriculture tick from 1965 to 1982 was a series of countries (you can cite them—South Korea, Taiwan, Singapore, and Nigeria and Mexico before the oil crisis) which created the idea that with growth, and also with agricultural development, the better the countries did, the more they would import from other countries. There was a seeming paradox, which I think is correct for the 1970s, that those countries that did best in agriculture also imported the most. I worry about two things for the 1980s and the 1990s. Where is that new set of countries coming from to help drive the world food system, to put some buoyancy back into it? Because although surpluses are better than shortages, low commodity prices still cause a great deal of policy problems for countries around the world.

Where will those countries come from? What will be the driving forces? Those middle income countries were certainly the driving forces of the food economies of the 1980s. This is of more than strategic significance, it seems to me that it is of tactical significance for the centers. If we cannot make the case that those developing countries that do best also import best and become broader members of the world economic community, I predict the problems of funding increased amounts of agricultural research are going to get worse rather than better.

Surely the problems of progress and plenty are preferable to those of shortages and starvation.

I certainly hope that those countries come forward. I hope that the findings of the 1970s, namely, that those countries that did the best agriculturally also entered the world trade system in a most important way, will continue into the 1980s. I think that is what you are saying by implication. I wish I felt more strongly about where those countries are, and how that's going to work.

As we look ahead, there are three issues that I wish you had talked more about, and maybe in the discussion this will come up. With some important short term reservations, I accept your point for maize and wheat that the real price of grain is declining. What are policymakers to do about this? This is a terribly important issue. If we look ahead five years at investments in research, investments in irrigation, and investments in water conservation, for example, what ought we realistically to be planning for the price of wheat, maize, rice, and other commodities as we make those investment decisions? I don't believe that international prices are somehow God given, like the Holy Grail, yet in the medium term they do set the fundamental opportunity costs with which countries must deal. I wonder what you think about the years ahead, and whether you think that prices at the current level are the price that centers and countries ought to use as they assess investment opportunities in their particular commodities. I think that is a real issue.

Difficult as price levels are, it seems to me that, for governments, price instability is even more difficult. Here I think the critical question is: when do countries divorce themselves from world markets? And when do they go with world price movements? To say that one follows world prices is, I think, no help at all. I believe that for many countries to follow world prices immediately would be a very foolish act indeed, in view of the

If we cannot make the case that developing countries that do best also import best, and become broader members of the world economic community, I predict the problems of funding agricultural research are going to get worse rather than better.

instability and the level at which the developed countries are currently still pushing their adjustment problems on the developing countries. You made this point very elegantly this morning.

What are the ground rules for policy formation, or the use of international prices? It doesn't seem to me that the centers, the World Bank, the academic community, or anybody else has got their arms around that one in a proper way at the moment. We're living with some outdated theology on this point, and we need to take some new looks at it.

And finally, I thought you might have commented, Ed, a little bit more on the policy role of centers. You did by implication, I think. I apologize if I wander over into a delicate TAC issue, but it seems to me that given the litany of problems that you mention, the centers will have to do more, not less, policy research. I'm a wonderful fan of the International Food Policy Research Institute (IFPRI). I think they have done some particularly good work, especially on the consumption side. But I don't agree with the argument that since one center in the system does policy work, no other centers in the system have a rightful claim to do so.

The question then becomes: what is the proper niche for a center like CIMMYT, or the International Rice Research Institute (IRRI), or the other commodity-based centers in policy analysis? I have a vested interest. I should specify that at the outset. But let me suggest a couple of things. I suspect that food policy rather than agricultural policy is a more proper focus. By food policy, I mean a concern with production, consumption, marketing, and trade, all in the context of the macroenvironment. I do not think that countries will look to centers for advice on whether they should devalue. I don't think that's proper. I think they can rightly look to the centers for leadership and for insights into the increasing amount of substitution that goes on in the world, in production, diversification, and issues in consumption and the tradeoffs between different kinds of food commodities (much more important issues in an increasingly urbanized world). I think there has been ample demonstration that for particular staples and particular countries one could get one's arm around agricultural policy in important ways.

Finally, I note with substantial approval the work going on at CIMMYT on domestic resource cost analysis, trying to get a better handle on specific regions of the world where economies have a real advantage in producing particular kinds of crops. I think it is important to CIMMYT in terms of its policy orientation. It's also important to CIMMYT in terms of its own allocation of research resources.

I will stop, but I don't want to stop yet, Ed, because I want to go back to something you said. I mentioned the penultimate paragraph at the outset of this talk, and I want to read it again to close, which is the highest compliment that I can pay you.

New production technology is the engine of growth for agriculture worldwide. But without proper incentives it will not be adopted. Moreover, without proper economic policies, the increased output from that new technology will not contribute effectively to general economic growth, farmers will be made worse off in a relative sense rather than better off, development will not be sustainable because environmental problems will erode the national resource base, and people will go hungry in the midst of plenty because they do not have the wherewithal to buy the food that is available.

That, I believe, is a wonderful statement, and I think the focus that you've brought here.

The Role of Science and Technology in Maize and Wheat Production

M.H. Arnold
Cambridge, United Kingdom

Wheat and maize are two of the most important food crops in developing countries, ranked second and third after rice. The last two decades have seen spectacular increases in yield and production of wheat in these countries, particularly as a crop for the winter season, under rainfall in Mediterranean climates and irrigation in subtropical regions. Comparable increases in maize production have been less widespread, however, and the impact of new technology more sporadic (Anderson, 1986). A smaller proportion of maize is grown under irrigation and much of the crop is subjected to the uncontrollable variability of those environments that are characteristic of Third World countries in tropical regions. In the absence of irrigation, it is the more humid of these environments that offer the greatest scope for increased production but, because they are vulnerable to damage under poorly managed agriculture, they also give greatest cause for concern.

As we consider the role of science and technology in the production of maize and wheat, therefore, we must do so against a background of changing circumstances in developing countries and changing perceptions among scientists, policymakers, and the concerned public at large. Such considerations include the urgent need to arrest the abuse of fragile environments that arises from poor husbandry and results in soil degradation, erosion, and desertification. At the same time, we must continue to develop technologies that give improved and sustainable production systems with reduced unit costs.

In the continuing debate on how these problems should best be tackled, some have developed the view that what can be labelled "Green Revolution technology" is often inappropriate. It promotes the wide use of uniform varieties and the purchase of chemical inputs, beyond the means of most small farmers. In contrast, the development of "agroecological technology," would, according to this view, be more appropriate. It would embody the principles of traditional farming systems, emphasize diversity, the biological control of pests and diseases, and the recycling of nutrients through organic matter (Altieri and Anderson, 1986).

While no one could dispute the merit of the principles advocated in these philosophies, the reality is that the population explosion is upon us and we cannot escape from its implications or the urgency of finding solutions to the problems it poses. We need green revolutions and, while responding to valid criticisms, we should not permit the image of "Green Revolution technology" to become tarnished because some have promoted inappropriate technologies in its name. It is the role of science and technology to continue to contribute to green revolutions, but to do so in ways that are ecologically sound and take due account of the sociological, economic, and political circumstances.

While problems of the environment loom large in any consideration of the future, the contributions of improved varieties to increased and more stable production will remain of fundamental importance. The use of improved varieties continues to afford the farmer one of the most cost-effective innovations. Science has continually provided opportunities for accelerating progress in plant breeding and recent advances in biotechnology offer exciting possibilities for more rapid genotypic improvements in future.

These basic elements of all production systems, the environment, the genotype, and their complex interactions, provide a convenient framework within which to discuss the role of science and technology in the future production of maize and wheat in Third World countries.

The Environment

Foremost in any discussion of the environment in relation to crop production in tropical regions must be the availability of water and its management in relation to soil conservation and plant nutrition. This applies whether by "water" we mean rainfall or irrigation. Though similar principles apply in these respects to most tropical regions and to a wide range of crops, I shall illustrate them by reference to sub-Saharan Africa and its potential for increased maize production.

Up to the present, a far smaller proportion of arable land has been irrigated in Africa than in India (Eicher, 1986). This is especially true of sub-Saharan Africa, where the immediate scope for profitable irrigation schemes is limited. Nevertheless, following the Indian experience, we need to investigate the factors limiting the application of water on a small scale in Africa, where the tradition of irrigating the land is much less developed, whether from wells, bore holes, or ponds. In this respect, work at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) on the management of small watersheds and the collection of runoff in ponds, needs to be more thoroughly explored in Africa. The yield increases demonstrated from the application of small amounts of stored water at critical periods in the development of the sorghum crop (Krantz and Kampen, 1977), for example, is an approach that might well have application to maize production as well.

Other possibilities for the more effective use of available water include the greater use of Africa's extensive wetlands. Although time will be needed to solve the sociological problems of collective management for all such areas, the first essential is to conquer the serious human diseases (malaria, bilharzia, and river blindness) that so severely limit the possibilities for their intensive use at present.

Although the effective use of surface water, as well as the greater use of small scale irrigation, must contribute more to the future of African agiculture, expansion of production in the immediate future will have to depend primarily on the more efficient use of rainfall.

Science and technology must foster green revolutions in ways that are ecologically sound and take account of socioeconomic and political circumstances.

Patterns of Rainfall Distribution

Early work on the distribution and expectation of rainfall in tropical Africa (Manning, 1950) showed promise of providing both a framework for planning cropping sequences and for modifying crop maturation periods through plant breeding so that they fit more effectively the expected pattern of rainfall (Hutchinson, Manning, and Farbrother, 1958). Application of these principles to the low rainfall areas of Kenya, for example, led Dowker (1971) to breed early maturing maize populations. He estimated that the reliable period of rainfall was of only about 60 days' duration and that the crop must flower within this period in order to mature on the reserves of moisture in the soil. Although maize is less tolerant of drought than sorghum, Dowker postulated that what was primarily required was early maturity, irrespective of the type of crop. After trying a range of both maize and sorghum cultivars, he concluded that maize offered better prospects of providing the required degree of earliness than sorghum. Maize was also preferred to sorghum as a food crop by the local people and had the added advantage of being far less prone to bird damage. The Katumani composites he produced did much to improve the reliability of the food supply in large areas of Kenya (Harrison, 1970).

More precise knowledge of expected rainfall distribution can also provide a useful experimental tool. By varying sowing dates, it can be used, for example, to study the effects of water stress at different phases of plant growth. This procedure has been used in attempting to breed for drought tolerance in a range of crops, including triticale (Nachit, 1985). Although breeding for drought tolerance is difficult and complex and numerous other selection criteria have been used both in maize (Trapani and Gentinetta, 1984) and wheat (Austin, in press). Although numerous tests for drought tolerance have been advocated over the years, few have stood the test of time and progress in breeding has been sporadic at best. This is an important area of investigation, however, where science has a great deal more to contribute.

Although the general approach of estimating rainfall probability and potential evaporation has shown great promise for planning strategies in crop production in Africa (see review by Rijks, 1984), success has been frustrated partly through the vagaries of weather patterns and the difficulties of predicting them. Attempts to predict the persistence of a particular rainfall distribution in a given locality are confounded by such phenomena as the occurrence of significant, but irregular, periodicities in rainfall patterns (for a review of this and other aspects of climate, see Farmer and Wigley, 1985). All of these uncertainties serve to emphasize the dangers of short term experimentation, be it in cropping systems, agronomy, or crop improvement.

In spite of all the difficulties, this is an area where sustained scientific investigation could lead to results of universal applicability. The importance of defining agroecological zones, not only in terms of rainfall and evaporation, but also in terms of pests and diseases, is fundamental to planning applied research and is an important activity of international centers. CIMMYT is leading the way in the accumulation of data for the agroecological zoning of maize and wheat, but the methodology will take time to evolve. In particular, there is a need to link the analysis of biological data such as that on pests and diseases more closely with the meteorological approaches. It is not only the spatial distribution of ecological zones that is important, but also the fluctuations in weather patterns that determine variation in their boundaries with time.

Soil Fertility

The violence of the convection storms that characterize tropical rainfall make arable land particularly vulnerable to erosion. Methods of soil conservation, such as terracing and tie ridging, have been known and practiced in some areas of Africa for generations (Thornton and Rounce, 1936; Peat and Brown, 1960), but have never been widely adopted. Other methods, such as contour bunding, call for careful planning, collective action, and the will to maintain the bunds and waterways. Policies that result in suitable incentives for doing the work are not easy to devise and, in general, have not been forthcoming. Consequently, much will continue to depend on production technologies that afford protection to the soil and minimize runoff.

It is sometimes forgotten that well-grown crops themselves provide excellent ground cover, whereas poorly grown or widely spaced crops can seriously endanger the sustainability of production. A well grown maize crop is valuable in this respect, particularly when incorporated into cropping systems that involve a mosaic of crops maturing at different times. Areas of perennial cover, grass, trees, and shrubs are also extremely important. In the humid and semihumid tropics, the system of alley cropping developed at the International Institute of Tropical Agriculture (IITA) is based on sound principles and offers promising opportunities for maize production in these areas. More research is needed, however, to find ways of reducing labor requirements and increasing the benefits of growing alleys.

The production of well grown crops of maize is not always easy on tropical soils, however, and is dependent on maintaining adequate levels of nutrients in the root zone. With increasing cropping intensities arising from the rapidly increasing population, large areas of land have been subjected to soil mining (Ruthenberg, 1980) and degradation has become a serious problem. To restore and maintain adequate levels of plant nutrients in many of these highly weathered African soils has of itself become a difficult problem. The challenge to science and technology is to find ways of replenishing the nutrients and overcoming toxicities in ways that are economically viable and practically feasible (see review by LeMare, 1984). There is now a large amount of empirical data on the responses of maize to fertilizer on African soils, but greater understanding of the mechanisms of nutrient availability is required in order to work out the most economical ways of restoring and sustaining productivity on a range of different soil types. For example, increasing understanding of the part played by mycorrhizae in the uptake of phosphate by roots may facilitate the wider use of rock phosphate, which occurs naturally in many African countries. Compared with superphosphate, it has obvious economic advantages, provided uptake by plant roots can be ensured.

Genotypic Improvement

Tropical rainfed environments also call for special characteristics in varieties. Traditional varieties are tall and continuously exposed to the risk of lodging by the same convection storms that create the risk of soil erosion. The work pioneered at CIMMYT by Elmer Johnson to produce plant ideotypes with short, strong stems gave rise by 1983, after 17 cycles of recurrent selection, to material showing nearly a 50% reduction in height, improved grain-to-stover ratio, and an increased yield potential of about 2 t/ha, when grown at high population densities (CIMMYT, 1984). Combined with resistance to streak virus, developed at IITA, these populations and material derived from them show great promise for future maize production in many African countries.

Looking further ahead, however, we must consider the improvements that are likely to become available from developments in the biological sciences, particularly from those areas of achievement usually referred to as biotechnology. These developments will accelerate the process of producing new varieties and provide new opportunities for creating genetic variability, but they will not change, in any fundamental way, the requirements for success. In order to illustrate the types of contribution from science that are likely to influence the rate and future extent of genotypic improvement, we must first consider briefly the elements of a successful breeding program.

A plant breeding program can be likened to a factory. It starts with market research to define the product, looks for suitable raw materials and develops processes to convert those raw materials into products with customer appeal. In plant breeding, the main raw material is genetic variation and the factory processes are the systems of evaluation and selection that progressively tailor breeding material to the complex needs of the physical, biological, and socioeconomic environments. In Third World countries, the customer is usually the small farmer with severely limited access to purchased inputs, and the market research must include an understanding of the farming systems involved. It is this perspective of the whole breeding process that must be kept in mind when considering the future role of science and technology in genotypic improvement.

The terms "biotechnology" and "genetic engineering" have been used with widely different meanings. To some, they conjure up the notion that we are on the verge of an agricultural revolution, that we shall be able to create novel crop plants, or at least to change existing plants in ways that would be analogous to those in which electronic engineers continually improve and update computer hardware. At present, however, our attempts to engineer plants can be likened to those of an electronic engineer who attempts to modify a computer for which there is no circuit diagram. He or she might know how parts of it worked,

Although the term "biotechnology" conjures up the notion that we are on the verge of an agricultural revolution, present attempts to engineer plants can be likened to an electronic engineer's attempts to modify a computer for which there is no circuit diagram.

but would have no way of understanding how it is functionally integrated. There are far too many gaps in our knowledge of biochemistry and physiology to make it feasible to think in terms of planned and directed changes in all but the simplest of plant characteristics, at any rate for the foreseeable future. We are well short of being able to construct a circuit diagram for plants, and the challenge facing the international centers is to determine how much can be invested in areas such as molecular biology, without destroying that critical balance in the multidisciplinary approach which is so important for success.

In the broader sense, genetic engineering can be applied to all mechanisms of recombination and selection. Maize and wheat have advantages over many other crop plants in that they have both been subject to intensive genetical study from the earliest days. Moreover, wheat being a hexaploid can tolerate chromosome manipulation in ways that diploids cannot. The painstaking development of various aneuploid series, stemming from the pioneering work of E.R. Sears, together with the use of new techniques in biophysics, have provided powerful tools for both genetic analysis and the development of breeding methodology. Further studies will be possible when techniques currently being developed in biotechnology are ready for application.

Among the contributions to be expected from advances in molecular biology are those that will facilitate the investigation of limiting steps in metabolism, through the engineering of changes in genes, such as their structure, number of copies, or location in the genome. Through such means biochemists and physiologists will acquire a more precise understanding of the complex processes that determine crop performance, thus indicating the nature of directed genetic changes necessary for crop improvement. Knowledge built up in this way could lead, for example, to an understanding of the molecular basis of heterosis and so suggest directed changes that might result in improved performance of inbred lines. Possibilities for the application of molecular biology to crop improvement in general and to the wheat crop in particular have been reviewed by Austin *et al.* (1986).

Efficiency of Selection

Some of the most important contributions that science has already made to plant breeding, and will continue to make in the future, are concerned with more efficient techniques of selection. Logistical considerations mean that the breeder moves from very small to progressively larger quantities of seed. Types of evaluation that require large quantities of seed must be left to a relatively late stage in the process, by which time the cumulative cost of producing each selection retained in the program has increased proportionately. Any procedure that can identify unwanted material early in the selection sequence therefore adds greatly to the speed and efficiency of the whole selection process. A good example is provided by the evolution of techniques for selecting for bread-making quality in wheat.

The ultimate test will always lie in baking a loaf of bread. Originally, this was the only test available and, because it requires relatively large quantities of flour and is extremely time consuming to do on a large scale, it must be left to a late stage in the program, when most of the material found to be substandard for other characteristics has already been eliminated. More recently, the use of analysis by infrared reflectance, together with the development of small milling machines capable of producing samples of flour in 30 seconds from five grams of grain, mean that large numbers of samples can be analyzed rapidly for milling hardness, extraction rate and protein content. In a typical breeding program, some 15,000 samples may be tested in a single season in this way (Bingham, 1983). Moreover, greater understanding of the physical properties of the proteins involved has led to a sedimentation test that gives accurate predictions of bread making quality, thus greatly assisting selection for the combination of yield and quality.

Still greater efficiency in breeding for bread-making quality has now been achieved in some programs. Techniques in biochemistry and biophysics have enabled separation and identification of the proteins and their subunits that contribute to the visco-elastic properties of dough that are essential to make bread. Although quality is partly influenced by the total quantity of protein present in the endosperm, a feature largely determined by the environment, it is also dependent on the types of glutenin subunit in the total gluten. In particular, the degree of visco-elasticity is determined principally by the presence of glutenin subunits with high molecular weight. Electrophoretic techniques now permit the identification of the various protein subunits in a sample of endosperm taken from only one-third of a single grain. Those samples showing the presence of glutenin subunits with high molecular weight can be identified and, since the embryo is left intact, the grain can be sown to produce the next generation of plants (Payne, 1986).

This test has already proved useful for selection during single seed descent as well as in identifying parents for crosses. Moreover, studies on the wild diploid ancestors of wheat have revealed great diversity in endosperm storage proteins, many of which are not known in bread wheat. Among them are glutenin subunits with high molecular weight. These are being transferred to wheat and may well contribute further to improved bread making quality. Unfortunately, the technique for identifying protein subunits cannot yet be used as a simple screening procedure for large segregating populations, as it is too demanding in time and skill. It might well be possible in the future, however, to exploit the knowledge gained in several ways. With advances in laboratory technology, it might prove possible to develop the technique into a more rapid and automated one; with advances in molecular genetics, it might eventually be possible to increase the number of copies of the genes coding for those protein subunits required for better bread.

The technique of monitoring the presence of a protein subunit using electrophoresis is only one example of a range of techniques being developed in cytogenetics and molecular biology designed to assist the breeder in identifying the presence of a desirable gene. Isozymes have been widely used as markers in genetical experiments and they are potentially useful in plant breeding. In wheat, for example, isozyme markers have been used to monitor the presence of alien chromosomes, or segments of them, in breeders' material (Ainsworth and Gale, 1986). In general, however, it has proved difficult to find enzyme loci linked to the particular genes in which the breeder is interested.

More recently, attention has focused on the possibility of monitoring the presence of the segment of the chromosome on which the desirable gene resides, through its linkage to the cleavage sites attacked by specific restriction endonucleases (Law, 1986). In the rapidly evolving language of biotechnology, the differences among chromosomes in this respect are referred to as restriction fragment length polymorphisms (RFLPs). For example, in wheat, RFLPs for the ribosomal (r)RNA genes of the nucleolar organizer region of chromosome 1B and 6B have been used to monitor the presence of these chromosomes from different parents in the progenies derived from crosses among them (Snape *et al.*, 1985).

Various other techniques are also becoming available for the identification of genes or their products. After digesting isolated DNA with restriction enzymes, specific genes can be detected by hybridizing (probing) with cDNA obtained from the particular mRNA sequence. Moreover, the protein produced as the tertiary gene product can be identified using a range of techniques involving antibodies.

Any suitable techniques of this general type which could be developed for use on a large scale would offer extremely valuable opportunities to the breeder of the future. In breeding for resistance to pests and diseases, for example, the possibility of being able to detect the presence of resistance genes without having to challenge the host plant with the pest or parasite would greatly simplify selection procedures and afford new opportunities for combining multiple resistance genes into a single genotype. Useful techniques will not come quickly, however, nor without a great deal of sustained effort.

Genetic Variation

Another general area in which we may expect increasing contributions from the advancing frontiers of the biological sciences is that of new sources of genetic variation, the raw material of plant breeding. Wide crossing, protoplast fusion, somaclonal variation, and DNA transformation are all becoming available as tools for the plant breeder but, as yet, they are not generally available for all plant species. The Gramineae have generally proved to be difficult with respect to some of these techniques and both wheat and maize currently lack workable transformation systems. With several different approaches being vigorously pursued, however, success is almost certainly not far away (Flavell and Mathias, 1984). Once this and other bridges have been crossed, a wide range of new possibilities for gene transfer or modification could be contemplated, including, for example, the incorporation of novel forms of virus resistance (Baulcombe, 1986) or genes for herbicide resistance.

Although we must wait to exploit these developments in recombinant DNA technology, recent work on wide crossing is giving promising results. For example, the salt tolerant wild diploid grass, *Agropyron junceum*, has now been successfully crossed with wheat, using the variety Chinese Spring monosomic for chromosome 5B. Pairing between homoeologous chromosomes was observed in nullisomic 5B hybrids (i.e. those lacking the Ph gene that controls pairing) and evidence has now been obtained that the salt-tolerant character has been successfully incorporated into the wheat genome (Forster *et al.*, 1986).

The widest cross so far established is that between wheat and maize (Laurie and Bennett, 1986). Although zygotes have been cultured to the extent of several cell divisions, it seems unlikely that the amphiploid itself could ever develop into a successful plant, if for no other reason than the disparity in morphology and physiology of the C3 and C4 mechanisms for photosynthesis. Nevertheless, the successful union of the two genomes might permit incorporation into the wheat genome of useful segments of DNA. Of particular interest is the possibility of wheat acquiring transposable elements from maize, in which they are better understood than in any other crop species. Stemming from the discovery of their role in mutations by McClintock (1951) the molecular basis of their functioning is now being unravelled, offering new possibilities for DNA transformation and the location of structural genes (Flavell, 1984; Starlinger, 1985).

These few examples illustrate the many different ways in which it is becoming increasingly possible to generate genetic variation or to effect genetic change. But the induction of genetic change is only part of the problem. We need to know far more about the types of change to induce and the consequences of those changes for the effective functioning of the plant. To what extent might it be possible, for example, to exploit recombination between wheat and maize? Can we contemplate converting wheat into a tropical crop or making high-quality bread from maize flour? These questions and many like them present enormous challenges for future research by plant physiologists and biochemists. Only with appropriate answers will plant breeders be able to define their objectives and plan their programs so as to maximize the benefits of new techniques in biotechnology. Even then, they will adopt the new techniques only if they show clear advantages over established methods (for a fuller discussion of this point, see Bingham, 1984).

Yield Stability and Production Variation

If we are a long way from understanding the developmental and physiological processes of plant growth, we are even further from understanding the mechanisms whereby different varieties respond differently to different environments. However excellent laboratory tests might become, therefore, nothing will substitute for the evaluation of potential new varieties in farmers' fields over the whole production area, and for more than one season. An international center such as CIMMYT is in a unique position to orchestrate the wide evaluation of germplasm through regional and national networks. Recent developments in the analysis of large sets of variety trials, such as those on the CIMMYT wheat and maize data (Byth *et al.*, 1976; Westcott, in press) show promise of overcoming some of the limitations of former methods, based largely on linear regression.

It is increasingly possible to generate genetic variation or effect genetic change.

Nonetheless, the results of such analyses are difficult for breeders to take fully into account in the day-to-day decisions they have to make. This is a complex area where only sustained multidisciplinary effort is likely to produce improved methodology. There is a need for closer integration of the biometrical, agrometeorological, and physiological approaches, coupled with knowledge of the distribution of pests, diseases, and other limiting factors. The aim would be to develop improved methodologies, first for defining ecological boundaries for varietal adaptation, and second for breeding for increased stability of yield within those boundaries, so as not to contribute unnecessarily to the increased variability of production (in absolute terms) that is inevitable as yields increase (see Hazell and Anderson, in press). Particularly in rainfed environments, there is a need to strike an appropriate balance between the desire for wide adaptability and the need for specific adaptation. This is another challenge for science for which there will be no quick or easy solutions.

Harnessing Science to Production

All of the foregoing examples of new challenges for science and technology emphasize the complexity of the problems, the need for a multidisciplinary approach, and the importance of sustained effort. The contributions of outstanding individuals, working in relative isolation, are no longer sufficient. We have already moved to team approaches, but these must be reinforced through collaboration, not just among motivated individuals, but with the solid backing of institutions. Although it is the individuals who do the work, the institutions must provide the continuity that is so important for success. Of the many types of collaboration now being developed, I shall mention only a few.

Fundamental to success are the collaborative arrangements that have been developed between the international centers and national reasearch systems. These arrangements must be responsive to changing circumstances and strengthened when necessary. Of equal importance, however, is the continually evolving pattern of collaboration between international centers and advanced institutions throughout the world. Collaborative projects between CIMMYT and the Plant Breeding Institute (PBI), funded by the Overseas Development Administration (ODA), afford good examples. They currently include work related to wheat on dwarfing genes, alien gene transfer, and wide crossing. Such projects not only harness the scientific capability of an advanced institution to problems of crop production in developing countries, but they also serve to provide wider involvement of national scientists in problems of international importance.

This wider aim of involving more scientists in problems of developing countries is one that attracted the attention of the International Council of Scientific Unions (ICSU) and led in 1978 to the establishment of its special Commission for the Application of Science to Agriculture, Forestry, and Aquaculture (CASAFA). In collaboration with the international centers, universities, donors, and other organizations, CASAFA seeks to identify problems of widespread importance where science could make greater contributions. Of relevance in the present context is promotion by CASAFA of the need for more fundamental understanding of drought tolerance and the biochemistry of parasitic angiosperms. This latter knowledge may be crucial to finding control measures for striga, which is rapidly becoming a serious constraint to the production of maize and other crops in Africa.

It is in these and other ways that science and technology will contribute to the future green revolutions that will be essential for human well-being as well as for the preservation of the natural environment on which everything else depends. In marking its 20th anniversary, CIMMYT will carry with it the goodwill of all of those who have these interests at heart.

References

Ainsworth, C.C. and M.D. Gale. 1986. Enzyme structural genes and their exploitation in wheat genetics and breeding. *In* Enzymes and their Role in Cereal Technology, J.E. Kruger, C.E. Stanfer, and D.R. Lineback, eds. American Association of Cereal Chemists. (In press.)

Altieri, M.A. and M.K. Anderson. 1986. An ecological basis for the development of alternative agricultural systems for small farmers in the Third World. American Journal of Alternative Agriculture 1:30-38.

Anderson, J.R. 1986. International Agricultural Research Centers: Achievements and Potential. Consultative Group on International Agricultural Research, Washington, DC, USA.

Austin, R.B. Some crop characteristics of wheat and their influence on yield and water use. *In* Improving Winter Cereals for Moisture-Limiting Environments: An International Seminar, Capri, Italy, 27-31 October 1985. (In press.)

Austin R.B., R.B. Flavel, and H.J.B. Low. 1986. Molecular Biology and Crop Improvement: A Case Study of Wheat, Oil Seed Rape and Faba Beans. Cambridge University Press. 114 pp.

Baulcombe, D.C. 1986. The use of recombinant DNA techniques in the production of virus resistant plants. *In* Biotechnology and Crop Improvement and Protection, P.R. Day, ed. Monograph No.34, British Crop Protection Council, Thornton Heath, UK.

Bingham, J. 1983. Genetic constraints on progress in wheat breeding. *In* The Yield of Cereals, D.W. Wright, ed. Proceedings of an International Seminar held at Cambridge and Stoneleigh, June 5, 1983. Royal Society of England Monograph. Pp. 5-11.

Bingham, J. 1984. Achievements, prospects, and limitations of conventional plant breeding. *In* Genetic Manipulation of Plants and Its Application to Agriculture, P.J. Lea and G.R. Stewart, eds. Oxford University Press, Oxford, UK. Pp.1-17.

Byth, D.E., R.L. Eisemann, and I.H. de Lacey. 1980. Two-way pattern analysis of a large data set to evaluate genotypic adaptation. Heredity 37:215-230.

CIMMYT. 1984. Maize research. *In* CIMMYT Research Highlights 1983. CIMMYT, Mexico, DF. Pp. 35-57.

Dowker, B.D. 1971. Breeding maize for low rainfall areas of Kenya. I. The reliability of yield of early and late maturing maizes. Journal of Agricultural Science, Cambridge 76:523-530.

Eicher, C.K. 1986. Transforming African Agriculture. The Hunger Project, San Francisco, USA.

Farmer, G. and T.M.L. Wigley. 1985. Climatic trends for tropical Africa: A research report for the Overseas Development Administration. University of East Anglia, Norwich, UK.

Flavell, R.B. 1984. Transposable elements. Oxford Surveys of Plant Molecular and Cell Biology 1:207-210.

Flavell, R.B. and Mathias. 1984. Prospects for transforming monocot plants. Nature 307:108-109.

Forster, B.P., J. Gorham, and T.E. Miller. Salt tolerance of an amphiploid between *Triticum aestivum* and *Agropyron junceum*. (In press.)

Harrison, M.N. 1970. Maize improvement in East Africa. *In* Crop Improvement in East Africa, C.L.A. Leakey, ed. Commonwealth Agricultural Bureaux, Farnham Royal, UK. Pp. 21-59.

Hazell, P. and J.R. Anderson. Proceedings of the IFPRI/DSE Workshop on Sources of Increased Variability in Cereal Yields. (In press.)

Hutchinson, J.B., H.L. Manning, and H.G. Farbrother. 1958. Crop water requirement of cotton. Journal of Agricultural Science, Cambridge 51:177-188.

Krantz, B.A. and J. Kampen. 1977. Crop production systems in semi-arid zones. *In* Soil and Water Management for Crop Production: An Introduction to Regional Farming Systems, W. Thorne and M. Thorne, eds. AVI Publishing Co., West Port, Connecticut, USA.

Laurie, D.A. and M.D. Bennett. 1986. Wheat x maize hybridization. Canadian Journal of Genetics and Cytology 28:313-316.

Law, C.N. 1986. The need for a multidisciplinary approach to genetic manipulation in plant breeding. *In* Genetic Manipulation in Plant Breeding, C.J. Jensen, W. Odenbach, and O. Schneider, eds. Proceedings of the International Symposium Organized by Eucarpia, West Berlin, 8-13 September 1985. Walter de Gruyner, Berlin, West Germany. Pp. 867-882.

LeMare, P.H. 1984. Limitations imposed by nutrient supply in tropical African soils. *In* Advancing Agricultural Production in Africa, D.L. Hawkesworth, ed. Commonwealth Agricultural Bureaux, Farnham Royal, UK. Pp.357-361.

Manning, H.L. 1950. Confidence limits of expected monthly rainfall. Journal of Agricultural Science, Cambridge 40:169-176.

McClintock, B. 1951. Chromosome organization and genic expression. Cold Spring Harbor Symposium on Quantitative Biology 16:13-47.

Nachit, M.M. 1985. Use of planting dates to select stress tolerant and yield stable triticale genotypes for the rainfed Mediterranean environment. Rachis 3(1):37.

Payne, P.I. 1986. Varietal improvement in bread-making quality of wheat: contributions from biochemistry and genetics, and future prospects from molecular biology. *In* Biotechnology and Crop Improvement and Protection, P.R. Day, ed. BCPC Monograph No. 34. British Crop Protection Council, Thornton Heath, UK.

Peat, J.E. and K.J. Brown. 1960. Effects of management on increasing crop yields in the Lake Province of Tanganyika. East African Agricultural Journal 26:103-106.

Rijks, D. 1984. The zonal climates of Africa and biological resources (and the collection and analysis of primary data in the AGRHYMET Programme). *In* Advancing Agricultural Production in Africa, D.L. Hawksworth, ed. Commonwealth Agricultural Bureaux, Farnham Royal, UK. Pp.299-307.

Ruthenberg, H. 1980. Farming systems in the tropics. Third edition. Clarendon Press, Oxford, England.

Snape, J.W., R.B. Flavell, M. O'Dell, W.G. Hughes, and P.I. Payne. 1985. Intrachromosomal mapping of the nucleolar organiser region relative to three marker loci on chromosome 1B of wheat (*Triticum aestivum*). Theoretical and Applied Genetics 69:263-270.

Starlinger, P. 1985. Transposable elements in plants. Biol. Chem. Hoppe-Seyler 366:931-937.

Thornton, D. and N.V. Rounce. 1936. Ukara Island and the aricultural practices of the Wakara. Tanganyika Notes and Records 1:25-32.

Trapani, N. and E. Gentinetta. 1984. Screening of maize genotypes using drought tolerance tests. Maydica 24:89-100.

Westcott, B. A method of assessing the yield stability of crop genotypes. Journal of Agricultural Science, Cambridge. (In press.)

Discussion

D. Acker
United States Agency for International Development, Washington, DC, USA

On behalf of US Agency for International Development Assistant Administrator Nyle Brady, I express congratulations to CIMMYT and also sincere and deep regret that he could not be with you for this occasion.

To have a presentation on maize and wheat improvement by a cotton breeder and discussion by an animal scientist is perhaps an illustration of wide outcrossing.

Dr. Arnold has advanced much good food for thought. My contribution will be largely to underline certain points made and, for the purpose of causing continued attention to certain areas, asking a few questions.

Dr. Arnold's paper suggests to me the potential for a system of agroecological zones, each characterized by soil and climate traits and of much value to research workers in designing their programs and testing their efforts. Progress in this effort will depend on our collecting data on weather, disease and pest occurrence, and soil and crop genotype response, and fully utilizing future and past data. Current data handling technology makes this feasible.

It should be emphasized that productive agriculture is one of the best protectors of the environment. An excellent maize crop shelters the soil, diminishes erosion by wind and water, contributes organic matter and, because it can reduce total area required for maize, may result in marginal land remaining in grass.

Just as CIMMYT has played a key role in making triticale and high-lysine maize productive realities, the Center will also play a significant part in emerging and future advances, by virtue of its scientific position and the lasting nature of its motives and support.

The paper's cautionary but optimistic reference to genetic engineering reminds us that what we seek and what can be provided is additional genetic variability from which we can draw. As to where we use genetic engineering, tissue culture, or other components of what is called biotechnology (a term with perhaps too wide a use), I suggest that we should not be quick to draw rigid rules or policies. Not many years ago, university and research administrators ruled that no computing equipment could be purchased except for what was needed in a central computing facility. Those units that held a too-rigid policy too long failed to gain full advantage as mini-, micro-, and personal computing equipment, with linkages, developed. This may also be the case with equipment and techniques of genetic engineering.

Policies and guidelines are appropriate, but they should be elaborated with a wide view to developments, needs, and growing capabilities of component units and evolving national research systems.

Dr. Arnold's many examples illustrate that our development and selection tools are increasingly powerful and varied, and so there is potential to increasingly tailor genotypes to macro- or micro-agroecological zones. Will the precision of our devices be sufficient? Will the strength of the national agricultural systems be sufficient? Will the public or private investment be sufficient?

My commendation to Dr. Arnold for a thoughtful and thought-provoking paper, and my thanks for the privilege of participating in this discussion.

The Role of Germplasm Development in Increasing Maize Productivity

D. Duvick
Pioneer Hi-Bred International, Johnstown, Iowa, USA
Presented by W. Kuhn
Pioneer Hi-Bred International, Johnstown, Iowa, USA

I'd like to thank the Center for allowing me to be present on this auspicious occasion. It would be gratifying enough to celebrate CIMMYT's 20th year by noting the organization's many contributions to the agricultural development of Third World countries. But it is all the more appropriate that we are marking the event by looking ahead to a larger role for the center's training program. In my judgment, this activity is an essential complement to CIMMYT's research efforts and almost certainly will multiply the benefits of your efforts to improve germplasm.

The role of germplasm development in increasing maize productivity is greatly enhanced or diminished by social, political, cultural, or environmental considerations.

If you'll permit me, I'd like to pursue that thought a bit further since no element in this entire effort can be effective standing alone. The role of germplasm development in increasing maize productivity can be greatly enhanced or diminished by social, political, cultural, and environmental considerations. Dr. Schuh has already addressed the potential impact of national and international policies on Third World agricultural development. I don't want to preempt any of the distinguished speakers who are to follow me. But as a foundation for my topic, I'd like to trace a bit of recent history for you to illustrate the interdependence of these diverse factors.

Cultural/Social Interactions

The trend line for US maize yields has increased continually since 1930 in contrast to the 30 years or so previously when yields remained virtually unchanged (Duvick, 1984a). Numerous studies have shown that the largest single component of those increases has been genetic improvements in the seed planted by farmers. Other studies have shown that the rate of gain attributable to improved genetics has been fairly constant. Increases in on-farm yields, by contrast, have not been so orderly, due in large part to variations in the weather from year to year.

In the mid-1950s, maize yields in the US began a steep upward climb that corresponded with the increased use of synthetic nitrogen fertilizer. The two curves—yields and nitrogen consumption—are, in fact, almost identical for the next 15 years. But before we assume a one-to-one relationship between maize yields and nitrogen use, consider these additional points: plant populations during that same period almost doubled; chemical herbicides began to replace mechanical weed control; machinery and equipment became more precise and sophisticated; and farmers began planting their corn crops earlier in order to take fuller advantage of the growing season. Most important, a steady succession of new hybrids allowed farmers to exploit the potential of these management improvements. Each new generation of hybrids had greater stability and more yielding ability than the one before.

During that same period, other elements probably influenced the slope of that curve as well. Certainly there were economic incentives, for farmers as well as their suppliers, to produce more grain both per unit of land area and in total. There was also the perception that the United States had a certain moral responsibility to feed the rest of the world. These factors are more difficult to quantify but they must be taken into account in any comprehensive plan to effect positive changes in the agricultural development of Third World countries.

I won't attempt to address the attitudes and circumstances that can and will affect the degree to which improved germplasm can increase maize productivity outside the US; other speakers are much more knowledgeable on those subjects. But I ask you to remember, throughout this conference and when you return to your particular area of specialization, that we must employ a fully integrated systems approach to the opportunities for further agricultural development in the Third World if we are to be successful.

Expectations for the Contribution of Improved Germplasm to Higher Yields

For the moment, let's assume we can isolate germplasm from the other components of improved productivity and examine it separately. What is a reasonable expectation for the contribution this single element might make? One recent study of maize in Minnesota (Cardwell, 1982) showed that the move from open-pollinated varieties to modern hybrids accounted for 16% of the yield gains made since 1930. Other general breeding improvements added another 43%. This is somewhat less than the yield gains attributable to genetic improvements that were demonstrated in separate studies by Duvick (1984b) and Russell (1974). Since I am most comfortable with the methodology used in my studies, I would like to cite my results as an example of the potential available to us.

In trials conducted from 1978 through 1980 in Iowa on a series of 47 commercial hybrids released at intervals from 1934 to 1978 and one open-pollinated variety of 1930 vintage, the increase in yield provided by genetic improvements averaged 92 kg/ha per year. This is equivalent to 89% of the total yield gain in Iowa for the same period. A second experiment using sets of single-cross diallels showed a yield gain attributable to genetic improvements of 73 kg/ha per year or 71% of the total yield increase.

The Components of Improved Germplasm

The design of my own and other experiments (Austin *et al.*, 1980; Castleberry *et al.*, 1984; and Russell, 1984) has shown that the increased yield capacities of the newest hybrids and varieties, in relation to those of older cultivars, are exhibited not only when other inputs are optimal but also when fertility, pests, and environmental conditions are unfavorable. It's true that the yield advantage of modern hybrids is greatest when potentials are greatest and that the spread between the highest- and lowest-yielding genotypes grows smaller as fertility and other factors place greater limits on yield potential. But that should not be surprising if one realizes that no known genotype can make grain with zero inputs. The point is that the higher yields of the new hybrids and varieties are due to their improved resistance to environmental stresses and to disease and insect pests, rather than to simple "yield genes" that are expressed only under ideal growing conditions.

Given the fact that most new varieties and hybrids are tougher and more stable, under all environments, than older varieties, it's useful to examine the specific traits that provide this higher yield potential. Maize hybrids, in particular, have received a good deal of attention in this regard from several experimenters (Castleberry *et al.*, 1984; Duvick, 1984b; Meghji *et al.*, 1984; Russell, 1984).

The research results have consistently shown that the new hybrids are greatly improved in root strength, in resistance to stalk-rot fungi, in resistance to heat and drought, in ability to tolerate inadequate levels of nitrogen, in resistance to European corn borer (*Ostrinia nubilalis*), and in ability to withstand the deleterious consequences of dense planting rates. The sum of these genetic improvements, then, is what allows the new hybrids to yield better than older ones, under good conditions or bad.

Strategies for Germplasm Improvement

The genetic contribution to improvements in the productivity of maize in the US is thus well established. What may be of greater interest to this body, however, is the way it came about. For out of that, we may be able to develop a viable strategy for improving the productivity of maize in developing countries as well.

First, and most important in my judgment, is the fact that much of the available germplasm was highly characterized, especially as inbred lines with known performance in hybrids. Public institutions and private companies focused a good deal of their effort on examining breeding material for useful and potentially useful traits. The result was a source of elite germplasm that was truly elite. These catalogs of genetic information made germplasm improvement easier and more efficient than would have been possible otherwise.

I recognize that making selections out of diverse populations and synthesizing, improving, and then releasing intermediate varieties was perhaps the only way, initially, of serving the many national programs in the Third World. But with the increasing sophistication of some national programs and CIMMYT's new inbred development effort, a program to thoroughly characterize the Center's most promising genetic selections, especially in hybrid combination, would seem a wonderful opportunity to broaden the Center's influence on germplasm improvement.

If I were permitted to cite a single example from my own company's international research program, it would be that our most dramatic successes in maize germplasm improvement have come from the use of highly characterized material — whether from North American germplasm (often integrated into tropical or subtropical material) or, as in the case of our research program in Asia, from selections in locally adapted materials.

These results, I believe, suggest that a cooperative effort in this regard by CIMMYT and national program researchers could improve the rate of germplasm improvement exponentially. However, as Dr. Cantrell has pointed out in a previous discussion on this topic, using the most appropriate techniques can be almost as important as having the best available germplasm. So a program of this sort would also require a significant commitment to the development of improved research techniques within many national maize programs.

Nevertheless, I submit that such a joint effort might well provide the greatest possible return on the Center's resources.

Genetic Diversity a Key

Another element which has contributed to the success of germplasm improvement in North America and, again, one which may be strategically appropriate for developing countries, is a strong emphasis on genetic diversity. At the present time, US farmers plant several hundred differently named maize hybrids. Even allowing for those cases in which the same hybrid may have several different names or numbers, the diversity of maize germplasm is surprisingly broad, more than is usually supposed (Duvick, 1984c). (One must remember, however, that US farmers tend to concentrate maize plantings on a relatively small number of superior hybrids. Thus, the available diversity is not spread evenly around the country.)

In addition, there are tens of thousands of experimental varieties in various stages of testing. Behind those are numerous primary and secondary broad-based gene pools. Ultimately, of course, they all trace back to a rather small percentage of the total available number of landraces and wild relatives of maize. However, considerable outcrossing and introgression have taken place over the years, to introduce and adapt certain exotic materials to US growing conditions. This breeding effort has resulted in the introduction of significant amounts of genetic diversity to US maize. In many instances, the introgressed germplasm contained useful additional genes whose action was unknown or unsuspected until a new disease, insect, or environmental problem appeared.

For example, when a new virus complex appeared in the mid-south growing region of the US some 20 years ago, it was found that certain maize inbreds with a small amount of Caribbean parentage gave excellent resistance to the disease (Duvick, 1984c). The Caribbean germplasm was originally introduced to improve husk coverage and heat resistance of Midwest inbreds, to better adapt them to southern growing conditions. But the "hidden" genes proved to be of greater benefit than than those providing the characteristics originally sought.

The point, of course, is that broadening the diversity of germplasm used in national programs will provide some obvious benefits, but it may also have usefulness that we cannot anticipate.

Additionally, the US experience emphasizes the absolute necessity of strong, continuing plant breeding research—especially in the national programs—to provide broad-based sources of new genetically diverse hybrids and/or varieties at regular intervals. This provides for "genetic diversity in time," the essential but usually unrecognized basis for stability of performance in the face of disease and insect pests which are constantly changing.

Complementary Specialization

The last strategy for increasing the productivity of maize through germplasm improvement is somewhat more philosophical than instructional, but it is an area in which we have done only a moderately good job in the US. Perhaps you can learn from our mistakes. I'm speaking of the determination (and discipline) to specialize in what you do better than anyone else and, at the same time, to help structure a system in which the work of one group complements and supports the work of others. Typically, this is an evolutionary process in which an organization's expertise, its resources, and its people help define its role. Unfortunately, there may be a reluctance to focus the sum of one's resources on those activities that would contribute to the greatest good but which might not necessarily be of the greatest interest.

We are in the ironic position of being able to move genes from one species to another, while lacking the knowledge to determine which genes control or contribute to which traits.

In the US, for example, we are just now being made aware of the large gaps in our knowledge of basic biology and plant physiology. This "awakening," if you will, is the result of the rapid advances being made in biotechnology. We find ourselves in the somewhat ironic position of being able to move genes from one species to another but without the knowledge to determine which genes control or contribute to which traits.

There is little purpose in attempting to affix blame for this situation. But we should ask ourselves who should have been doing that basic research: our colleges and universities? The government? Or private industry? Maybe each thought the other was doing it. Or perhaps grant money was only available to fund other, more product-oriented research. The point is, it didn't get the emphasis it should have received. The price of that neglect will be a slowing in the rate of germplasm improvement.

The problem we are experiencing today might have been avoided by better communication and cooperation among the organizations whose ultimate responsibility is to bring improved hybrids and varieties to farmers. It would not have been an easy thing to accomplish because of the social and political considerations I alluded to earlier. But if we had known then what we know now, I suspect the most appropriate candidate—that is, the organization with the greatest expertise, the available resources, and the people to carry it out—would have assumed that role.

The consequences of genetic "isolationism" in the case of coffee are already evident: we cannot allow that to happen to the world's major food crops.

The Role of CIMMYT

These, then, are the possible strategies I see for optimizing the contribution of improved germplasm to the increased productivity of maize in the developing countries of the world. I recognize that even if you agreed completely with these suggestions, to implement them would involve a good deal more than simply constructing the necessary framework and establishing the programs. But I also know that we must move ahead, and I see a unique role for CIMMYT as a catalyst in that process. I will be brief in my summary of those opportunities and perhaps my recommendations will provide Dr. Sprague with the elements necessary for a lively discussion!

First, the germplasm resources maintained by CIMMYT can and, I believe, will be most widely used if they are adequately characterized. They will contribute not only improved performance traits but also greater genetic diversity when they are introgressed into locally adapted materials. In those national programs that are ready to utilize breeding material from the Center's new inbred development program, the impact would be even greater.

Second, CIMMYT can and, I feel, must continue to serve as a conduit for the free and unrestricted flow of germplasm between the developed and the developing countries. We have already begun to see the consequences of "genetic isolationism" in the case of coffee. We cannot allow that to happen to the world's major food crops.

Third, and finally, CIMMYT has a unique opportunity and ability to pull together and foster communication among the diverse national programs for maize in the developing countries, to help train their researchers and educate their producers, and to help remove or hurdle the political and social obstructions that will invariably be placed in the path of those who would move these programs forward.

It will be a major effort. It will require patience, perseverance, cooperation, and unity in the goals you set for yourselves. It will also require the support of the rest of the world's agricultural community. And if the attendance at this 20th anniversary celebration is any indication, you shall have it.

References

Austin, R.B., J. Bingham, R.D. Blackwell, L.T. Evans, M.A. Ford, C.L. Morgan, and M. Taylor. 1980. Genetic improvements in winter wheat yields since 1900 and associated physiological changes. Journal of Agricultural Science, Cambridge 94:675-680.

Cardwell, V.B. 1982. Fifty years of Minnesota corn production: Sources of yield increase. Agronomy Journal 74:984-990.

Castleberry, R.M., C.W. Crum, and C.F. Krull. 1984. Genetic yield improvement of US maize cultivars under varying fertility and climatic requirements. Crop Science 24:33-36.

Duvick, D.N. 1984a. Progress in conventional plant breeding. *In* Gene Manipulation in Plant Improvement, J.P. Gustafson, ed. Plenum Press, New York, USA. Pp. 17-31.

Duvick, D.N. 1984b. Genetic contributions to yield gains of US hybrid maize, 1930 to 1980. *In* Genetic Contributions to Yield Gains of Five Major Crop Plants, W.R. Fehr, ed. CSSA Special Publication Number 7, Crop Science Society of America, Madison, Wisconsin, USA. Pp. 15-47.

Duvick, D.N. 1984c. Genetic diversity in major farm crops on the farm and in reserve. Economic Botany 38:161-178.

Meghji, M.R., J.W. Dudley, R.J. Lambert, and G.F. Sprague. 1984. Inbreeding depression, inbred and hybrid grain yields, and other traits of maize genotypes representing three eras. Crop Science 24:545-549.

Russell, W.A. 1974. Comparative performance of maize hybrids representing different eras of maize breeding. *In* D. Wilkinson, ed., Proceedings of the 29th Annual Corn and Sorghum Research Conference, American Seed Trade Association, Washington, DC, USA. Pp. 81-101.

Russell, W.A. 1984. Agronomic performance of maize cultivars representing different eras of breeding. Maydica 29:375-390.

Discussion

E.W. Sprague, Hull, Georgia, USA

Dr. Duvick has covered many interesting and thought-provoking points in his paper. He begins by putting the role of germplasm in perspective amidst the various factors that affect the potential of crop yields. I am sure that all of us would agree that these factors necessitate a multidisciplinary approach to analyze and work on the broader issue of increased productivity. Of course, the relative importance of these factors may be questioned and could provide issues for a long debate.

Contribution of Improved Germplasm

I'm sure we would also agree that germplasm development is a major factor in the establishment of increased yields, and that all the many factors influencing yield make an integrated team approach necessary in any such plant improvement program. It would be interesting to hear more about the relative influence of root strength, stalk rot resistance, heat and drought tolerance, and various other factors on yield potential, yield stability, and adaptation.

Strategies for Improving Germplasm

With regard to strategies for germplasm improvement, I believe all plant breeders accept that characterizing the germplasm is essential to achieve any goal. CIMMYT has been characterizing and refining germplasm continuously as part of its responsibility. However, it might be argued that too severe a characterization too early in a large germplasm development program could result in the elimination of potentially very useful germplasm. Therefore it might be better that characterization for certain factors, such as for specific combining ability, should not be implemented until the later stages of an improvement program. As was noted, CIMMYT is involved in this stage of development. This point is certainly worthy of discussion. Furthermore, as part of a discussion on strategies for germplasm improvement, we must not forget that our highly productive materials must be produced in marketable quantities and be of good quality.

Genetic Diversity

I'm sure a great deal of discussion could be stimulated on the way in which genetic diversity could be most efficiently and effectively broadened and maintained. What is the relative desirability of the system of pools and populations versus inbreeding, cataloging, and storing inbreds, or a combination of each?

One new method of generating genetic diversity mentioned specifically in the paper is the movement of genes from one species to another, made possible by recent advances in biotechnology. With regard to our understanding of and ability to utilize such techniques, I would perhaps not be as hard on the US as Dr. Duvick has been. I would agree that an understanding of complementary research is necessary for an appropriate and timely implementation of different techniques, and it is true that someday we will probably employ many forms of the new advances in biotechnology to a great extent in the development of productive germplasm. Research to achieve this end is of importance. Nevertheless, I would suggest that such techniques are not — nor will be in the near future — the weakest part of our system of germplasm development.

Through its role of germplasm development and international testing of various materials, CIMMYT certainly is, in many cases, enhancing genetic diversity and reducing vulnerability to pests at the national, regional, and global levels.

Opportunities for Increasing the Yield Potential of Wheat

L.T. Evans
Commonwealth Scientific and Industrial Research Organisation, Division of Plant Industry, Canberra, Australia

Two and a half thousand years ago Socrates is reported to have said to Ischomachus, "I should like first to learn ... how I should cultivate land to obtain ... most wheat" (Xenophon, *The Oeconomicus*). So in giving me the title for this talk, CIMMYT is asking an old but still important question.

In times of surplus grain, as now, there are always many to argue that greater yield potential is the last thing we need. But when the surpluses disappear, as they always have done, greater yield potential becomes a favored goal again.

Then there are those who want to return to more environmentally innocent, low input systems rather than pursue ever higher yields. How the world would support more than one billion people with such systems and protect vulnerable marginal land is not clear.

There are also those who argue that raising the low and uncertain yields obtained in adverse environments is much more important than raising yield potentials still further. But even in developed countries with strong research organizations, we have made only slow progress in such environments, and while the world's population continues to grow we must raise yields where we can.

But high-input cropping is not competitive, say others. That is not the case for European wheat growing today, nor need it be so even when the distortions of the Common Agricultural Policy have gone their way, as Bingham *et al.* (1985) have argued. So, despite these and other cavils, CIMMYT has rightly taken the long view in highlighting greater yield potential at this anniversary.

Yield and Yield Potential

The yield of wheat crops is determined by many factors, environmental, genetic, and socioeconomic. Yield potential may be defined as the yield of a cultivar grown in environments to which it is adapted, when nutrients and water are nonlimiting and when pests, diseases, weeds, lodging, and other stresses are effectively controlled. There will be many wheat crops in which yield potential, by this definition, is only a minor limitation on yield. But as we come to rely increasingly on irrigated or high-input crops as a major stable component of global wheat production, so does the limitation of yield potential assume greater significance. Silvey's (1978) analysis, for example, indicates a sharp increase in the contribution by genetic yield potential to the rise in British wheat yields in recent years, and a similar conclusion can be drawn from the yields and yield potential of maize crops in the USA.

The tendency of people at each stage of our history to believe we have reached the limit has applied to wheat yields no less than to other parameters of advance. When Van Gogh painted his cornfield just one hundred years ago there were "experts" who thought yield could go no higher. Even Vavilov voiced a similar thought 50 years later when the highest wheat yield known to him was 3.5 t/ha, in England. Fifty years later still the average wheat yield in the United Kingdom was more than twice as high (7.6 t/ha in 1984) as that and the world record wheat yield stands at 15.65 t/ha, reached by John Potter of Tidworth, England in 1982. Yet both Jensen (1978) and Austin (1978) were pessimistic about further increases in yield potential, Austin's careful estimate being 11.4 to 12.9 t/ha for winter wheat in Britain. However, there is no sign yet of an approaching yield plateau in either the UK or USA, and the gains from hybrid wheat and other advances have yet to be exploited. Preliminary results with hybrid wheats, for example, indicate further potential yield gains of 10 to 25% (McRae, 1985; Gale *et al.*, 1986; Bingham, 1986). Before considering avenues for further improvement, we need a perspective view of the yield gains achieved so far.

The [illegible] stage of [illegible] to believe we have reached [illegible] applies to wheat yields no less [illegible] to other parameters of advance.

Greater Yield Potential and Better Agronomy

The definition of yield potential given above indicates how it can be estimated by trials in which the crops are amply watered, fertilized, supported, and protected. Protection from lodging, pests, and diseases is crucial to a fair assessment of the older cultivars. Without it their yield potential is underestimated and subsequent genetic advance is overestimated, as in several studies.

Our experiments with British winter wheat varieties (Austin *et al.*, 1980) indicated that yield potential had been raised by about 40% in the 70 years since Little Joss was released and that the rate of increase showed no signs of declining. These direct estimates can be compared with indirect estimates made by an analysis of winter wheat trials conducted by the National Institute of Agricultural Botany (NIAB). These have the advantage that cultivars are compared under the agronomic conditions for which they were bred, and the disadvantage that they may overestimate progress if the outgoing standard variety begins to fail in its resistance to disease. But the results were quite comparable with the more direct measurements of yield potential, giving only a slightly higher rate of advance, as may be seen in Figure 1.

Experiments by Fischer and Wall (1976) and Waddington *et al.* (1986) indicate a comparable rate of improvement in the yield potential of CIMMYT lines of bread wheat (Figure 1), and more spectacular

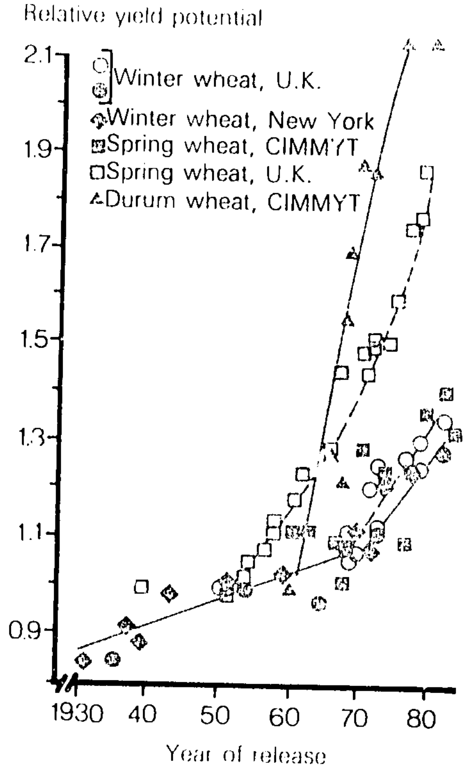


Figure 1. Changes in the relative yield potential of wheat cultivars in relation to the year of their release. 1950 releases assigned a value of 1.0 for all except the durums.

Source: Austin *et al.* (1980) for winter wheats in the UK, National Institute of Agricultural Botany trials for both winter and spring wheat cultivars in the UK (Evans, 1980), Jensen (1978) for winter wheats in New York state, Waddington *et al.* (1986) for CIMMYT spring wheats, 1983-84 season, and Waddington *et al.* (1987) for CIMMYT durum wheats, 1983-84 season.

improvement is evident in the experiments with CIMMYT lines of durum wheat (Leihner and Ortiz, 1978; Waddington *et al*., 1987), as also in the NIAB trial results for British spring wheats. Relative increases have been more modest for wheat cultivars in New York State (Jensen, 1978) and Sweden (MacKey, 1979), but the absolute yield levels should also be taken into account in comparing these plant improvement programs, as is done in Figure 2, because the fastest rates of improvement in relative yield potential are for such crops as durum wheat at CIMMYT or spring wheat in the UK where the initial yield levels were lower.

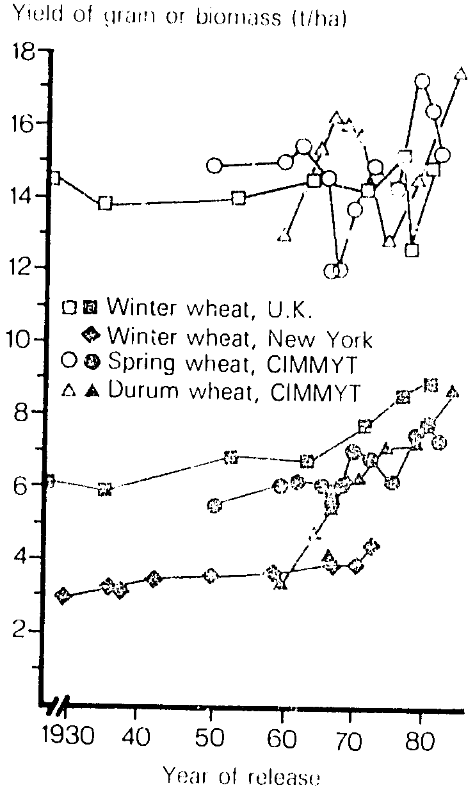


Figure 2. Changes in the yield per crop of grain (solid symbols) and above-ground biomass (open symbols, dry weight) with year of release for wheat cultivars grown without limitations by water, nutrients, lodging, or pests and diseases.

Source: Austin *et al.* (1980) for winter wheats, UK, Jensen (1978) for winter wheats, New York state, Waddington *et al.* (1986) for CIMMYT spring wheats, 1983-84 season, and Waddington *et al.* (1987) for CIMMYT durums, 1983-84 season.

Note that the absolute rate of increase in yield potential over the last 10 to 15 years has been similar for UK winter wheat and for CIMMYT spring wheats and durum wheats, and much greater for the bread wheats than in earlier years. By contrast, average yields in the UK and in the Yaqui Valley of Mexico have diverged substantially over the last 10 years, as shown in Figure 3. Comparison of Figures 2 and 3 indicates that whereas the gap between potential and average yield has narrowed in the UK, it has widened in the Yaqui Valley, presumably reflecting socioeconomic policies more favorable to the use of inputs and intensive agronomy in the UK than in the Yaqui Valley.

This comparison allows me to make the point that actual crop yields depend so much on the interaction between genotype and the level of agronomic support for the crop that it is not really meaningful to divide the credit for yield increases between breeders and agronomists as if their contributions were independent of one another. They are not, but before discussing this further, let us consider one more case, namely wheat in the USA. Figure 4 illustrates the substantial (2½-fold) rise in the average yield since the late 1940s. The beginning of the rise more or less coincided with the introduction of shorter cultivars, which have largely been replaced over the last 10 to 15 years by semidwarf varieties. As Dalrymple (1986) has shown, the rise in wheat yield has closely followed the curve for the proportion of area sown to short and semidwarf cultivars, but it follows just as closely the rise in the proportion of wheat crops to which fertilizers are applied, as may be seen from Figure 4.

Clearly, it is not easy to disentangle the contributions of breeding and agronomy to rising wheat yields. Nor should we try too hard to do so, beyond discerning where the major limitations lie, because it is their interaction which is crucial to further increases, not only of yield but also of yield potential.

That varietal improvement encourages the greater use of inputs and better agronomy is well known, and Figure 4 could be interpreted in that light. But it is equally true that advances in agronomy open up new opportunities for breeding. The best known example is the advent of cheaper nitrogenous fertilizers, which created a need for shorter cereals less prone to lodging, while the development of more effective herbicides made this change possible. Better herbicides and machinery for faster tillage also made more timely cultivation and changes in crop scheduling possible. As a result, winter wheat crops in the UK may now be sown a month or more earlier, opening up opportunities for increased yield, particularly after varieties have been bred to take advantage of this change (Bingham *et al.*, 1985).

But there is also a more subtle interdependence between plant breeding and agronomy which should be better understood, because it has important implications. As we shall see later, the

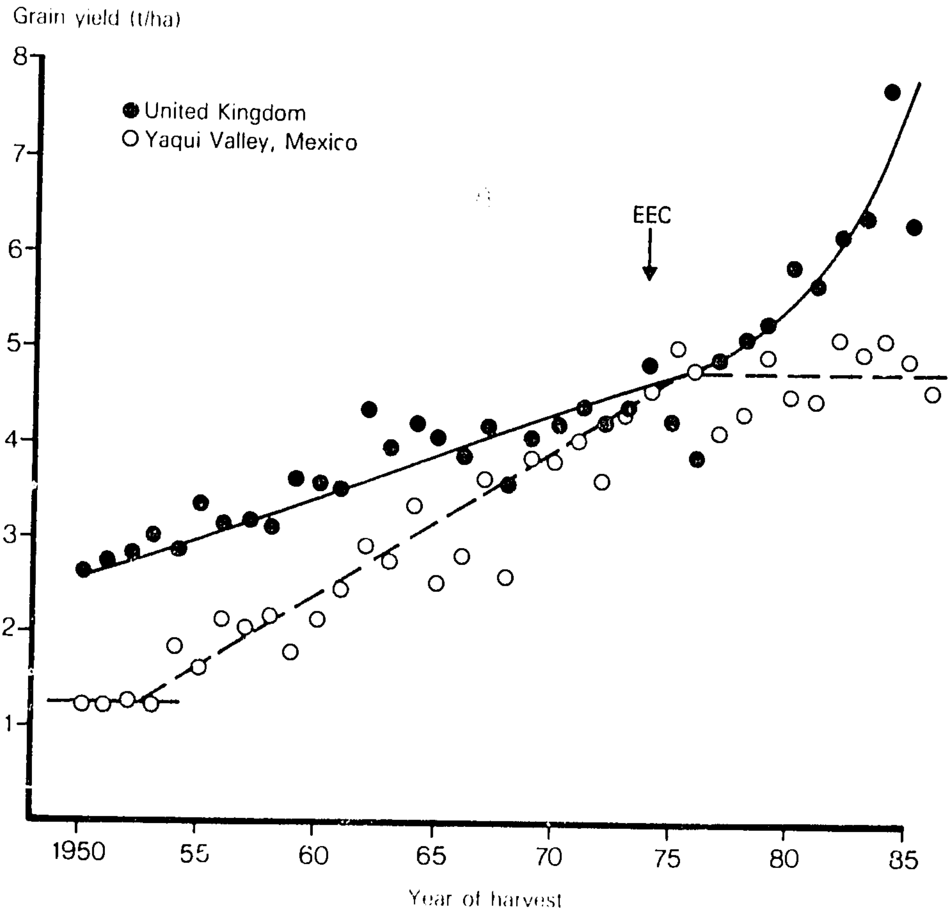


Figure 3. Wheat yields in the UK (solid symbols, FAO statistics) and Yaqui Valley, Mexico (open symbols, Secretaria de Agricultura y Ganaderia).

increase in the yield potential of wheat has been achieved without any increase in the rates of growth or photosynthesis, and without much change in biomass (e.g., Figure 2). Clearly it has had to come from changes in the allocation of that biomass among the various organs of the plant, as was first pointed out by van Dobben (1962). But reduced allocations for the growth of roots, stems, or leaves, or for reserves, are likely to reduce competitiveness with weeds, recovery from pests and diseases, and the ability to survive environmental and other stresses. However, as the agronomic control of these assaults on the wheat crop has improved and become more predictable, the plant breeder has been able to select cultivars with a reduced investment in stems, leaves, roots, and reserves, thereby freeing assimilates for greater investment in the grain, higher harvest index, and greater yield potential. That is one reason why plant breeders prefer to select under high input conditions, but it also explains why some improved cultivars may not perform well under adverse conditions, and why cross-overs in yield performance may be found.

Such interdependence also makes it important for centers like CIMMYT to maintain a proper balance and lively interaction between plant breeding and agronomy if further gains in yield potential are to be secured. The dictum "Not by bread alone" should be extended with "nor by breeding alone."

With that background let us turn to five areas of opportunity for increasing the yield potential of wheat, namely:

- Growth and photosynthesis;
- The timing of the reproductive cycle;
- Shifts in biomass allocation;
- Regulatory processes, and
- Environmental responses.

But in doing so we should remember that the yield of a crop is the integrated end product of many processes. There is no single key to increased yield potential,

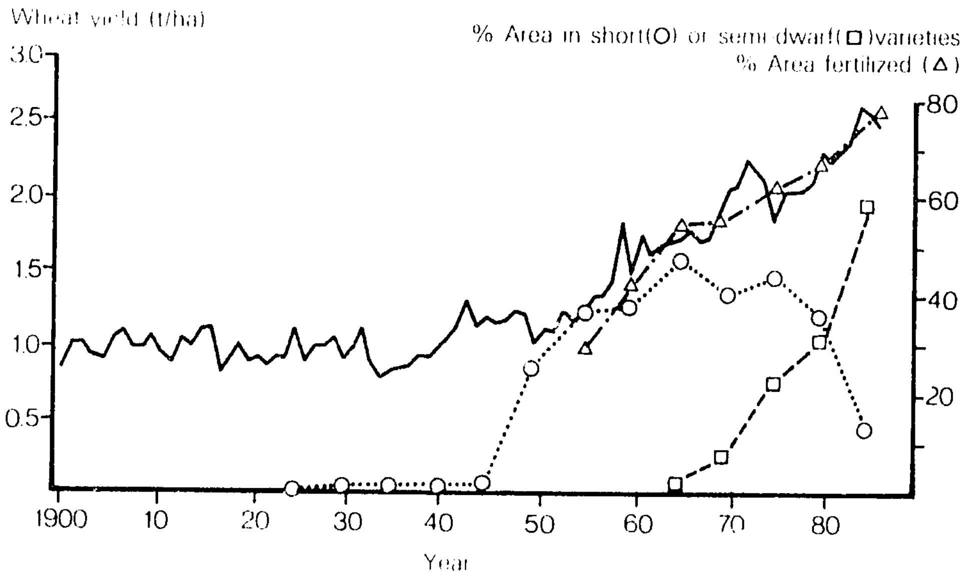


Figure 4. Wheat yields in the USA in relation to changes in the proportion of area under short or semidwarf cultivars.

Source: Adapted from Dalrymple (1986), with the addition of data on percentage wheat area fertilized from the five yearly US Census of Agriculture (Dalrymple, 1980).

no touchstone, and each characteristic interacts not only with the environment but also with the rest of the genome.

Growth and Photosynthesis

Plant breeders often find it hard to believe physiologists when they assert that growth rate has not, so far, been improved by selection, because their eyes may tell them otherwise. But a slightly earlier start after sowing or a larger embryo in the seed can result in substantially bigger plants at any one time, and periodic harvests are needed to decide the issue. Relative growth rates (RGR), the logarithmic rates of increase, must be compared on plants of the same size. When this has been done with wheat, the RGR values are remarkably similar whether wild or cultivated, diploid or hexaploid, tall or dwarf, or homozygous or hybrid lines are compared (Evans and Dunstone, 1970 and unpublished; Evans and Bush, 1987).

Crop growth rates (CGR) are very sensitive to irradiance (Fischer, 1985a) and there have been few comparisons across genotypes. The CGR is little affected by stature (Fischer *et al.*, 1981), but may be greater in cultivars with more inclined leaves (Green, 1987). Biomass at maturity has been more frequently measured. Austin *et al.* (1982) found no consistent difference in final biomass between the various genomes and ploidy levels in wheat, and comparisons of old and modern cultivars by van Dobben (1962), Austin *et al.* (1980), Deckerd *et al.* (1985), and Kulshrestha and Jain (1982) revealed no increase in biomass as yield potential has risen (e.g., Figure 2). Waddington *et al.* (1986) found that three of the highest yielding recent CIMMYT wheats had greater biomass and higher apparent rates of biomass accumulation, but these three cultivars also had the longest time to maturity and probably experienced higher average temperatures and a greater proportion of the life cycle with a closed canopy. The comparison of CIMMYT durum wheats of differing vintage also indicated greater biomass in some recent cultivars (Waddington *et al.*, 1987, cf. Figure 2), but in this case longer duration is not th explanation. However, these results are not necessarily in conflict with the conclusion that maximum growth rates have not been increased. It may simply be that there is more late growth, as seems to occur with the longer "stay green" of modern maize hybrids, with high biomass barleys, and with some wheats with lax leaves (Green, 1987).

Growth rate depends on the balance between gains from photosynthesis and losses from respiration. These latter can be a major fraction once the canopy has closed and we still know far too little about possible varietal differences in the efficiency and coupling of dark respiration. As for photosynthesis, there is no evidence in wheat to suggest there has been a rise in the maximum rate per unit leaf area. In fact, comparison of the wild diploids with the modern hexaploids indicates that this rate has fallen substantially in the course of domestication and improvement (Evans and Dunstone, 1970; Khan and Tsunoda, 1970; Austin *et al.*, 1982).

This apparent paradox is due to a frequently negative relation between leaf area and CO_2 exchange rate (CER). For a given amount of leaf weight and photosynthetic enzymes, the plant can have a larger area with a lower CER or vice versa. The former strategy is better in the early stages of crop growth and in sparse stands or weedy conditions, whereas the latter is more appropriate in dense stands. Selection among spaced plants for high yields often seems to result in larger leaves, which could account for the fall in CER even though the negative relation between leaf area and CER is not always strong (Rawson *et al.*, 1983).

The CER of wheat is comparable with that of other crop plants with the C_3 pathway of photosynthesis, such as rice, but is notably less than the maximum rates found in crops with the C_4 pathway, such as maize and millet, as illustrated in Figure 5. Higher RGR is associated with, but not necessarily due to, the higher CER, but the superior performance of the C_4 millet at higher temperatures is coupled with much poorer performance at cool temperatures. In fact wheat is remarkably well buffered to ' nperature in its growth and photosynthesis, and is as well adapted to its environmental niche as rice and millet are to theirs.

The most spectacular, but also remote, hope for improvement would be the finding or engineering of a more efficient form of the often rate-limiting photosynthetic enzyme, ribulose-1,5-bisphosphate carboxylase-oxygenase (rubisco). This constitutes · to a third of the proteins in wheat leaves, and may determine their photosynthetic rate (Evans, 1983). Such a key enzyme is bound to have been under strong selection pressure, both natural and artificia.. Some variation in its Km and specific activity has been found among wheats (Evans and Seemann, 1986). With alloplasmic lines, howeve., no difference was found between the nuclear genomes of wheat in their effect on the specific activity of rubisco through the small subunit, while the differences associated with the large subunit (high for B and S cytoplasms and low for A and D cytoplasms) were found only in vitro (Evans and Austin, 1986). The likelihood of genetic engineering giving rise to a significantly greater specific activity of rubisco is not high, but its potential impact is so great as to merit continuing effort.

The Timing of the Reproductive Cycle

The spread of wheat growing around the world has depended to a considerable degree on the ability of plant breeders to modify when the crop reaches such stages as inflorescence initiation, anthesis, and maturity in relation to local climatic conditions. Such modifications, by empirical selection against untimely reproductive development, led to close

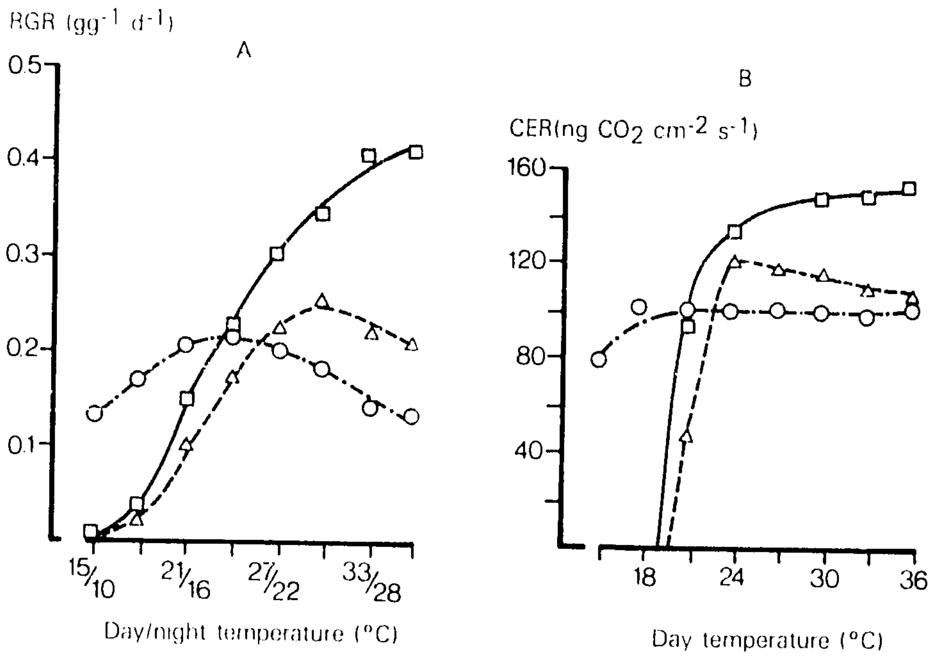


Figure 5. Relative growth rates (A) and photosynthetic rates (B) of wheat cv. Yaqui, rice cv. IR8, and the millet *Echinochloa frumentacea* as influenced by temperature.

Source: Evans and Bush (1985).

local adaptation. But international centers such as CIMMYT, breeding wheats for many different environments, had no option but to emphasize adaptability and, therefore, relative insensitivity to the seasonal signals by which close local adaptation is obtained. Although such emphasis may have involved some loss in local yield potential, this has probably been more than outweighed by the advantages of a wide-ranging and large scale crossing program that brings together genes with a favorable influence on general yield potential. The experiments of Waddington *et al.* (1986, 1987) suggest that these advantages are by no means exhausted, but there is also likely to be considerable scope for further increases in yield potential by selection for local adaptation.

For example, close matching of the crop life cycle with the length of the growing season, and in the timing of its major steps with the probable sequence of temperature, irradiance, daylength, and such stresses as drought or frost, as well as disease, is bound to be advantageous. The need to avoid frost injury of young inflorescences, drought stress at meiosis, or high temperatures during grain filling may require strong environmental controls on inflorescence initiation and development which have been selected out of adaptable varieties. Environmental stress may result in quite clearly defined optimum times for anthesis (e.g. Woodruff and Tonks, 1983), but even in the absence of such stresses there is likely to be an optimum balance between the main stages of the life cycle, which varies with the seasonal sequence of environmental conditions.

Consequently, as Syme (1968), Hunt (1979), Ford *et al.* (1981), Hoogendoorn (1985) and others have shown, there are pronounced regional differences in the relative magnitude of responses to vernalization and daylength in both spring and winter wheats (Davidson *et al.*, 1985). Many cultivars from high latitudes are sensitive to daylength, and many from middle latitudes to vernalization, while those from low latitudes tend to be insensitive to both factors. Major genes for both the vernalization and daylength responses are well known (Law and Scarth, 1984), but our understanding of the ways in which they influence yield potential is far from adequate. For example, why so many Australian cultivars have a significant response to vernalization, or why many winter wheats from Europe respond to short day vernalization, is still not clear.

Much may still be gained from further modifications of the controls on the reproductive cycle, as suggested by the findings of Waddington *et al.* (1987) on the significance of later anthesis for yield potential in durum wheats. My recent work with European winter wheats indicates that the control of inflorescence initiation by daylength may be quite separate and different from its control of inflorescence development, and genes from winter wheat may contribute to yield potential in spring wheats in various ways.

The reproductive cycle may also have to be modified as agronomic practices change. For example, faster land preparation now makes it possible for European winter wheat to be sown one month or so earlier, and the need to utilize the substantial amounts of residual nitrate in the soil before winter makes earlier sowing desirable on the grounds of [illegible] efficiency and environmental considerations (Bingham *et al.*, 1985). However, such a change is likely to require selection for delayed inflorescence initiation to ensure that it does not occur before winter.

Delayed inflorescence initiation may also be important for wheat at low latitudes. Hoogendoorn (1985) found low-latitude wheats to reach ear emergence rapidly owing not only to their insensitivity to vernalization and daylength but also to earliness per se. This latter characteristic has only recently begun to be studied in wheat, following its identification by Hunt (1979) and Ford *et al.* (1981). It is found in high latitude wheats where it is needed because of their short growing season, but it may be disadvantageous to yield potential in low-latitude wheats with little response to daylength or vernalization. When these are grown at warm temperatures, a nonseasonal factor that delays inflorescence initiation may be needed to replace the usual seasonal ones. When the International Rice Research Institute (IRRI) introduced daylength insensitivity along with semidwarf stature in rice, it so happened that this was compensated for by a quite prolonged juvenile or basic vegetative phase in IR8, contributing to its high yield potential. Low-latitude wheats might profit similarly because, as Fischer (1985b) has pointed out, it is the acceleration of development at higher temperatures that is central to low wheat yields in the tropics.

Shifts in Biomass Allocation

We have already seen that much of the past increase in the yield potential of wheat has come from a shift in the allocation of crop biomass, with selection for this made possible by improved agronomic support for the crop. There is no reason to suppose that this shift has already reached its limit in wheat. Indeed, Austin *et al.* (1980) estimate that the harvest index of wheat could reach 62%, thereby raising the yield potential by a further 25%, and this should be realizable by selection as agronomic practice advances.

The introduction of the reduced height genes Rht1 and Rht2, made possible by better weed control and made necessary by greater use of nitrogenous fertilizers, has probably had the greatest impact on wheat yields not only through reduced lodging but also through increased yield potential. It is not easy to document this assertion, however, because we still know too little about how these Rht genes influence yield in spite of their enormous impact on world food supplies.

The addition of the Rht1, 2, or 3 genes has no discernible effect on relative growth rate, but sometimes delays initial germination so that the more dw[illegible] plants appear to grow more slow[illegible]. The later formed leaves of the more extreme dwarfs are closer together, which could reduce the penetration of light into the crop canopy, and account for the slightly lower crop growth rate in the most extreme (Rht3) dwarf wheat examined by Fischer *et al.* (1981). In our work with isogenic lines of Yaqui 50 and CIANO 67, kindly provided by CIMMYT, stem weight was reduced in [illegible]roportion to stem height, releasing a substantial fraction of assimilates for investment in other organs such as tillers or in reserves. Neither in our experiments nor in those of Fischer and Stockman (1986) was the absolute level of soluble reserves in the stems greater in the shorter lines, although our findings differed on relative levels. But clearly most of the savings from reduced stem growth are invested immediately in other organs rather than reserved to support extra grain growth later on.

Even when major genes can be introduced into wheat by the techniques of molecular biology, prolonged observation and selection by skilled plant breeders will still be required to maximize the [illegible]ut of such genes on yield potential.

At this point there appears to be an interesting difference between winter and spring wheats in what they do with the savings. In winter wheats the rise in the rate of inflorescence growth balances the fall in stem growth (Brooking and Kirby, 1981), resulting in heavier ears at anthesis and proportionally more grains per ear at maturity, counterbalanced to some extent by a fall in kernel weight. The review by Gale and Youssefian (1985) indicates that this is the usual effect of the Rht genes in winter wheat, whereas in spring wheats (both durum and bread wheats) their effect is quite different, increasing the number of ears rather than the number of grains per ear, and being less consistently advantageous to yield. These results from comparisons between isogenic lines or groups of random lines of spring wheat that differ in their Rht allele are in sharp contrast to the results of comparisons by Fischer and Stockman (1986) of high-yielding spring wheat varieties with different Rht alleles, in which grains per ear increased far more than ears per plant. Adjustment of the genetic background clearly has a major effect on how the Rht genes influence yield potential.

Our experiments with the CIMMYT isogenic lines (Evans and Bush, 1987) underscore this point because the effect of the various Rht genes appears to differ between the Yaqui 50 and CIANO 67 lines in several respects, but particularly in relation to grain number, just as it does between winter and spring wheats. With the more extreme dwarfs in CIANO 67, grain number at maturity was much less than expected from ear weight at anthesis, especially in cooler conditions with the Rht3 gene. Yet under these conditions with April Bearded spring wheat the Rht3 gene increased grain number (Gale and Flintham, 1984) as it did also in British winter wheat hybrids heterozygous for only the Rht3 gene (Gale *et al.*, 1986).

However, the extent to which savings from stem growth promote ear growth also depends on environmental conditions. Under low irradiance or at high temperatures, the ears of both Yaqui 50 and CIANO 67 were heavier at anthesis to the extent that stems were lighter. But at cool temperatures or high irradiances, the ears of the taller lines were as heavy or heavier than those of the shorter ones. This suggests that use of the Rht genes in spring wheats may have their greatest impact on yield potential at lower latitudes. With the CIANO isogenic lines under intermediate conditions there was evidence of an optimum height for yield potential, which may make the more extreme Rht3 gene particularly valuable in the production of hybrids (Gale *et al.*, 1986).

It seems likely that further genetic adjustment may still be needed to convert all the potential savings from incorporation of the Rht genes into realizable yield potential, as with the CIMMYT durums when the Rht genes were first introduced (Leihner and Ortiz, 1978). Thus, the conclusion by Waddington *et al.* (1986, 1987) that recent increases in the yield potential of CIMMYT wheats are unlikely to derive from the Rht1 and Rht2 genes, and are not due to changed patterns of allocation, may need modification. This analysis also suggests that even when major genes can be introduced into wheat by the techniques of molecular biology, prolonged observation and selection by skilled plant breeders will still be required to maximize the impact of such genes on yield potential.

Regulatory Processes

Past increases in yield potential have involved changes in the operation of regulatory processes rather than in the efficiency of assimilatory ones. The shifts in allocation and the rise in harvest index have been due, in essence, to a reduction in the demands for assimilate by vegetative organs, thereby permitting greater investment in the young inflorescence. In turn this leads to the differentiation of more florets and the setting of more grains, and this in turn creates a stronger sink in the competition for assimilates (Cook and Evans, 1983). On this interpretation, the increase in grain number per ear or per square meter of crop has been the driving force for greater yield potential. Crop photosynthesis may not have been able to keep up, with the result that, initially at least, there may be a fall in kernel weight.

Among the CIMMYT durum wheats in the 1983-84 experiment, for example, grain number m^{-2} increased by 209%, and grain number per ear by 114%, from Tehuacan 60 to Carcomun "S", but kernel weight fell by 16% although both the rate of grain growth m^{-2} and the harvest index doubled (Waddington *et al.*, 1987). As Bingham (1986) points out, there are many genes of quite large effect available to increase grain number m^{-2}, but these may have little effect on yield unless coupled with additional capacity to fill the grains, as appears to be the case with hybrid wheats (Bingham, 1986; Gale *et al.*, 1986). However, we also know that in wheat the photosynthetic rate responds to increased demand by the grains and that high rates may be maintained for longer when the demand is greater (e.g., King *et al.*, 1967; Rawson *et al.*, 1976; Atsmon *et al.*, 1986). Thus selection for progressively higher grain number should make possible selection for faster or more prolonged photosynthesis during the grain growth stage, indirectly increasing crop biomass.

The duration of grain growth is not simply determined by the supply of assimilates but by genetic constitution acting through regulatory controls on grain size and on the time when lipid deposition in the chalazal zone puts an end to grain growth (Sofield *et al.*, 1977). However, the maximization of yield potential requires the duration of photosynthetic activity in the leaves to be synchronized with the duration of grain growth. If leaf senescence sets in too soon, grain growth is limited, but grain growth is also limited if leaf senesence sets in too late, with the result that the photosynthetic enzymes in the leaves are not remobilized and utilized in grain growth. These and many other regulatory processes are likely to be modified by selection as agronomic improvement makes this desirable, but growth regulators may increasingly be used as surrogates for selection, just as nitrogenous fertilizers have acted as surrogates for genetic improvement in the rate of photosynthesis.

Environmental Responses

Environmental conditions have profound effects on the yield of wheat, but this is not the occasion to review these, and I must confine myself to just one aspect of the influence of environment on yield potential. This concerns the balance between photosynthetic assimilation and the reproductive cycle. Even with spring wheats, cool temperatures slow down reproductive development relative to vegetative growth and photosynthesis, with the result that the rate of photosynthesis becomes less limiting to yield. Grain yield is less sensitive to irradiance at cool temperatures, and less responsive to CO_2 enrichment (Krenzer and Moss, 1975). At high temperatures, reproductive development is accelerated relative to assimilation, the rate of photosynthesis becomes more limiting, and yield more sensitive to irradiance and CO_2 level. Gifford (1977) has estimated that, under favorable conditions, wheat yields will rise by 0.25% per vpm rise in CO_2 concentration, but the higher temperatures likely to accompany the rise in atmospheric CO_2 levels will tend to cancel that out. Fischer and Maurer (1976) found grain yield to be quite sensitive to even small increases in temperature in the field.

There is no master key to increased yield potential. The significance of processes that limit it depends on both the external environment and the interna genetic milieu.

Thus, not only is yield potential highly dependent on environmental conditions, but so too are the processes that limit yield potential, and especially the balance between assimilation and grain growth. Yield potential is not an abstract entity, but the outcome of genomic, environmental, and agronomic interactions.

Conclusions

We can still envisage many possible avenues to greater yield potential in wheat, and there is no reason to suppose that it is near its limit. The models and calculations that suggest otherwise are too often constrained by our present understanding of the processes involved.

There is no master key to increased yield potential. Many processes may limit it, and these may be sequential, cooperative, competing, or conflicting. Their significance depends on both the external environment and the internal genetic milieu. Physiological and genetic analysis is needed to identify the opportunities for advance but empirical selection enlightened by such analysis remains the surest way forward.

Further increases in yield potential by plant breeding will be highly dependent on further innovations and advances in agronomic support for wheat crops. We may not foresee these but they are likely to continue to open up new opportunities for plant breeding progress. As Medawar (1972) puts it, "To deride the hope of progress is the ultimate fatuity, the last word in poverty of spirit and meanness of mind. There is no need to be dismayed by the fact that we cannot yet envisage a definitive solution of our problems."

Acknowledgements

I am grateful to Dr. R.A. Fischer for his vigorous comments on this manuscript, and to Drs. D.G. Dalrymple and M.D. Gale for permission to cite their unpublished manuscripts.

References

Atsmon, D., M.G. Bush, and L.T. Evans. 1986. Effects of environmental conditions on expression of the "Gigas" characters in wheat. Australian Journal of Plant Physiology 13:365-379.

Austin, R.B. 1978. Actual and potential yields of wheat and barley in the United Kingdom. ADAS Quarterly Review 29:76-87.

Austin, R.B. 1982. Crop characteristics and the potential yield of wheat. Journal of Agricultural Science, Cambridge 98:447-453.

Austin, R.B., J. Bingham, R.D. Blackwell, L.T. Evans, M.A. Ford, C.L. Morgan, and M. Taylor. 1980. Genetic improvements in winter wheat yields since 1900 and associated physiological changes. Journal of Agricultural Science, Cambridge 94:675-689.

Austin, R.B., C.L. Morgan, M.A. Ford, and S.G. Bhagwat. 1982. Flag leaf photosynthesis of *Triticum aestivum* and related diploid and tetraploid species. Annals of Botany 49:177-189.

Bingham, J. 1986. Adoption of new techniques in wheat breeding. New Zealand Plant Breeding Conference. (In press.)

Bingham, J., J.A. Blackman, and R.A. Newman. 1985. Wheat: A guide to varieties from the Plant Breeding Institute. National Seed Development Organization, Newton, Cambridge, England. 80 pp.

Brooking, I.R., and E.J.M. Kirby. 1981. Inter-relationships between stem and ear development in winter wheat. The effects of a Norin 10 dwarfing gene, Gai/Rht2. Journal of Agricultural Science, Cambridge 97:373-381.

Cook, M.G., and L.T. Evans. 1983. The roles of sink size and location in the partitioning of assimilates in wheat ears. Australian Journal of Plant Physiology 10:313-327.

Dalrymple, D.G. 1980. Development and spread of semi-dwarf varieties of wheat and rice in the United States. An international perspective. United States Department of Agriculture, Washington, DC, USA. 150 pp.

Dalrymple, D.G. 1986. Changes in wheat varieties and yields in the United States, 1919-1984. (Unpublished MS.)

Davidson, J.L., K.R. Christian, D.B. Jones, and P.M. Bremner. 1985. Responses of wheat to vernalization and photoperiod. Australian Journal of Agricultural Research 36:347-359.

Deckerd, E.L., R.H. Busch, and K.D. Kofoid. 1985. Physiological aspects of spring wheat improvement. *In* Exploitation of Physiological and Genetic Variability to Enhance Crop Productivity, J.E. Harper, L.E.

Schrader, and R.W. Howell, eds. American Society of Plant Physiology, Rockville, Maryland, USA. Pp.46-54.

Evans, J.R. 1983. Nitrogen and photosynthesis in the flag leaf of wheat (*Triticum aestivum* L.). Plant Physiology 72:297-302.

Evans, J.R. and R.B. Austin. 1986. The specific activity of ribulose-1, 5-bisphosphate carboxylase in relation to genotype in wheat. Planta 167:344-350.

Evans, J.R. and J.R. Seemann. 1984. Differences between wheat genotypes in specific activity of ribulose-1, 5-bisphosphate carboxylase and the relationship to photosynthesis. Plant Physiology 74:759-765.

Evans, L.T. 1980. Response to challenge: William Farrer and the making of wheats. Journal of the Australian Institute of Agricultural Science 46:3-13.

Evans, L.T. and M.G. Bush. 1985. Growth and development of channel millet (*Echinochloa turnerana*) in relation to its potential as a crop plant and compared with other *Echinochloa* millets, rice, and wheat. Field Crops Research 12:295-317.

Evans, L.T. and M.G. Bush. 1987. Growth and development in tall and dwarf isogenic lines of wheat. Field Crops Research. (In press.)

Evans, L.T. and R.L. Dunstone. 1970. Some physiological aspects of evolution in wheat. Australian Journal of Biological Science 23:725-741.

Fischer, R.A. 1985a. Number of kernels in wheat crops and the influence of solar radiation and temperature. Journal of Agricultural Science, Cambridge 105:447-461.

Fischer, R.A. 1985b. Physiological limitations to producing wheat in semi-tropical and tropical environments and possible selection criteria. *In* Wheats for More Tropical Environments, A Proceedings of the International Symposium. CIMMYT, Mexico. Pp.209-230.

Fischer, R.A., F. Bidinger, J.R. Syme, and P.C. Wall. 1981. Leaf photosynthesis, leaf permeability, crop growth, and yield of short spring wheat genotypes under irrigation. Crop Science 21:367-373.

Fischer, R.A. and O.R. Maurer. 1976. Crop temperature modification and yield potential in a dwarf spring wheat. Crop Science 16:855-859.

Fischer, R.A. and Y.M. Stockman. 1986. The cause of increased number of kernels in Norin-10 derived dwarf wheats. Australian Journal of Plant Physiology. (In press.)

Fischer, R.A. and P.C. Wall. 1976. Wheat breeding in Mexico and yield increases. Journal of the Australian Institute of Agricultural Science 42:139-148.

Ford, M.A., R.B. Austin, W.J. Angus, and G.C.M. Sage. 1981. Relationships between the responses of spring wheat genotypes to temperature and photoperiodic treatment and their performance in the field. Journal of Agricultural Science, Cambridge 96:623-634.

Gale, M.D. and J.E. Flintham. 1984. The effect of the Tom Thumb dwarfing gene on grain size and grain number in wheat (*Triticum aestivum*). *In* Semi-Dwarf Cereal Mutants and their Use in Cross-Breeding II. IAEA-TECDOC-307, International Atomic Energy Agency, Vienna, Austria. Pp. 63-69.

Gale, M.D., A.M. Salter, F.C. Curtis, and W.J. Angus. 1986. The exploitation of the Tom Thumb dwarfing gene, Rht3, in F_1 hybrid wheats. *In* Semi-Dwarf Cereal Mutants for Cross Breeding IV. International Atomic Energy Agency, Vienna, Austria. (In press.)

Gale, M.D. and S. Youssefian. 1985. Dwarfing genes in wheat. Progress in Plant Breeding, G.E. Russell, ed. 1:1-35.

Gifford, R.M. 1977. Growth pattern, carbon dioxide exchange and dry weight distribution in wheat growing under differing photosynthetic environments. Australian Journal of Plant Physiology 4:99-110.

Green, C.F. 1987. Genotypic influences on the growth of winter wheat in relation to absorbed solar radiation. Field Crops Research. (In press.)

Hoogendoorn, J. 1985. The physiology of variation in the time of ear emergence among wheat varieties from different regions of the world. Euphytica 34:559-571.

Hunt, L.A. 1979. Photoperiodic responses of winter wheats from different climatic regions. Zeitschrift für Pflanzenzüchtung 82:70-80.

Jensen, N.F. 1978. Limits to growth in world food production. Science 201:317-320.

Khan, M.A. and S. Tsunoda. 1970. Evolutionary trends in leaf photosynthesis and related leaf characters among cultivated wheat species and its wild relatives. Japanese Journal of Breeding 200:133-140.

King, R.W., I.F. Wardlaw, and L.T. Evans. 1967. Effect of assimilate utilization on photosynthetic rate in wheat. Planta 77:261-278.

Krenzer, E.G. and D.N. Moss. 1975. Carbon dioxide enrichment effects upon yield and yield components in wheat. Crop Science 15:71-74.

Kulshrestha, V.P. and H.K. Jain. 1982. Eighty years of wheat breeding in India: Past selection pressures and future prospects. Zeitschrift für Pflanzenzüchtung 89:19-30.

Law, C.N. and R. Scarth. 1984. Genetics and its potential for understanding the action of light. *In* Light and the Flowering Process, D. Vince-Prue, B. Thomas, and K.E. Cockshull, eds. Academic Press, New York, USA. Pp.193-209.

Leihner, D.E. and G.F. Ortiz. 1978. Improvement of durum wheat plant type, yield potential, and adaptation. Euphytica 27:785-799.

MacKey, J. 1979. Genetic potentials for improved yield. *In* Proceedings of the Workshop on Agricultural Potentiality Directed by Nutritional Needs, S. Rajki, ed. Akad. Kiado, Budapest, Hungary. Pp.121-143.

McRae, D.H. 1985. Advances in chemical hybridization. Plant Breeding Reviews 3:169-191.

Medawar, P.B. 1972. The Hope of Progress. Methuen, London, England. 133 pp.

Rawson, H.M., R.M. Gifford, and P.M. Bremner. 1976. Carbon dioxide exchange in relation to sink demand in wheat. Planta 132:19-23.

Rawson, H.M., J.H. Hindmarsh, R.A. Fischer, and Y.M. Stockman. 1983. Changes in leaf photosynthesis with plant ontogeny and relationships with yield per ear in wheat cultivars and 120 progeny. Australian Journal of Plant Physiology 10:503-514.

Silvey, V. 1978. The contribution of new varieties to increasing cereal yield in England and Wales. Journal of the National Institute of Agriculture and Botany 14:367-384.

Sofield, I., I.F. Wardlaw, L.T. Evans, and S.Y. Zee. 1977. Nitrogen, phosphorus and water contents during grain development and maturation in wheat. Australian Journal of Plant Physiology 4:799-810.

Syme, J.R. 1968. Ear emergence of Australian, Mexican and European wheats in relation to time of sowing and their response to vernalization and daylength. Australian Journal of Experimental Agriculture and Animal Husbandry 8:578-581.

van Dobben, W.H. 1962. Influence of temperature and light conditions on dry matter distribution, development rate, and yield in arable crops. Netherlands Journal of Agricultural Science 10:377-389.

Waddington, S.R., J.K. Ransom, M. Osmanzai, and D.A. Saunders. 1986. Improvement in the yield potential of bread wheats adapted to Northwest Mexico. Crop Science 26:698-703.

Waddington, S.R., M. Osmanzai, M. Yoshida, and J.K. Ransom. 1987. The yield potential of durum wheats released in Mexico between 1960 and 1984. Journal of Agricultural Science, Cambridge. (Submitted.)

Woodruff, D.R. and J. Tonks. 1983. Relationship between time of anthesis and grain yield of wheat genotypes with differing developmental patterns. Australian Journal of Agricultural Research 34:1-11.

Discussion

K.J. Frey
Iowa State University, Ames, Iowa, USA

My task today is to reiterate and elaborate on the highlights of Dr. Evans' paper and to incite you, the audience, to discuss the topic, "Opportunities for Increasing the Yield Potential of Wheat."

In the paper a tremendous amount of information has been summarized. And the information is the latest available - of the 53 papers cited, 44 were published in the past 10 years and two-thirds are from the 1980s.

Dr. Evans first emphasizes that "there is no sign yet of an approaching yield plateau in either the UK or USA." With this I agree completely. He goes on to say that "there are also those who argue that raising the low and uncertain yields obtained in adverse environments is much more important than raising yield potentials still further. But even in developed countries with strong research organizations, we have made only slow progress in such environments." I would like to take issue with this point to say that many examples can be given in which insertion of a gene(s) has permitted respectable crop production in an adverse environment. For example, when a gene for tolerance to excess aluminum in acid soils is placed in Brazilian Wheat Cultivars it becomes possible to produce wheat on a million or more hectares of acid soil in that country. A second example is from that Garden of Eden for crop production, called Iowa, where a gene for resistance to iron chlorosis, when placed in soybean cultivars with high yield potential, can double soybean yields on a quarter million hectares of alkaline soils. And according to a study by Johnson and his colleagues in Nebraska, sizable advances have been made in increasing yield potential of wheat cultivars for the adverse environment of the Great Plains of the USA. Actually the best argument for building high yield potential comes from the fact that such lines, when finely tuned with genes for resistance to biotic and abiotic factors and genes for regulation, generally will be the best lines to grow anywhere in the world.

To Dr. Evans' suggestion that "it is not easy to disentangle the contributions of breeding and agronomy to rising wheat yields," I say amen! (Such studies do, however, help young scientists get tenure and keep money flowing in to research institutions for plant breeding.) A study that illustrates this interaction well was published from the Maize Program at CIMMYT in *Crop Science* (1986). Mass selection was practiced for reduced plant height for 15 generations in a lowland tropical maize population called Tuxpeño Crema. Plant height was reduced one meter but in the process the architecture and physiology of Tuxpeño Crema maize was so changed that the optimum plant density was increased from 48,000 to 65,000 per hectare. Yes, cultivar and its optimum agronomy cannot be separated easily.

Dr. Evans says there are five areas of opportunity for increasing yield potential of wheat:

Growth and photosynthesis For either growth rate or photosynthetic rate, there is a dearth of genetic variation in cultivated cereals, including wheat. Dr. Evans proposes genetically engineering Rubisco, the rate limiting photosynthetic enzyme, to make it more efficient. At this point in our knowledge, to bet research money on the successful genetic engineering of Rubisco, in my opinion, is equivalent to betting an old farm horse will win a race among thoroughbreds. I would call your attention to several pieces of research on other species that *have* affected net photosynthesis and growth rate, however. Glenn Burton has increased forage yields of warm-season pasture grasses by 200% genetically by selection for biomass. David Wilson has increased biomass production of ryegrass 15% by selecting for reduced dark respiration in this species.

Research on oats and pearl millet has shown that even though genetic variation for growth rate does not exist within the domesticated gene pool, very significant increases in this trait occur from utilizing germplasm from weedy and wild relatives. For oats, which have been studied most, the increased growth rate is due to greater leaf area per culm and delayed leaf senescence, which ultimately increase seeds per panicle by 8%, seed weight by 12%, and grain yield by 25%. Introgression of genes from wild or weedy relatives has increased biomass of maize and seed yield of sorghum, barley, and peanuts also—presumably by increasing growth rate. I would recommend research in this area to wheat breeders.

Timing of the reproductive cycle
Probably I would lump this with the "regulatory processes" category. Nature, over millennia, has evolved many elegant genetic systems triggered by predictable environmental factors, primarily light, photoperiod, and temperature, that cause a species to be locally adapted. Only a few of these have been analyzed genetically, but on the basis of a few reports, it seems that these triggering mechanisms generally are simply inherited. If this turns out to be so, these traits can be added to cultivars at will. This is an area of intense importance, but does it contribute to yield potential of wheat in general or only to specific lines and for specific environments?

Shifts in biomass allocation—History shows that for most of our cereals grain yield increases from plant breeding have been due to increases in harvest index. Biomass has stayed remarkably constant. Whether breeders can go much above 50% and maintain vigorous plants I have some apprehension. But perhaps with new sources of germplasm cereal breeders will be able to push the harvest index higher. Certainly by reducing vegetative growth, some of the energy used for maintenance has been diverted to grain yield. Harvest index as a trait has high heritability and is easy to recover. I suspect its inheritance will be simple when the studies are conducted.

Regulatory processes—Dr. Evans makes the case for manipulating regulatory processes that determine seed size and number, duration of grain filling, and leaf senescence pattern by genetic means. The only plea I can make here is that we need an immense amount of research in this area.

Nature, over millennia, has evolved many elegant genetic systems that cause species to be locally adapted.

Environmental responses—Certain responses of cultivars to production environments are genetically controlled. Since the farmer has no control over temperature mean and ambience and photoperiod and little control over moisture amount and incidence (except in areas of irrigated agriculture), the breeder must develop cultivars to fit the environmental norm. Whether there are inviolate reactions of vegetative or reproductive growth of wheat to temperature, I would question. As Dr. Evans intimates, however, the increase in CO_2 in the world's atmosphere may have profound effects on the genotypes of crop plants we will need for the next century.

Dr. Evans' paper is lucid, thought provoking, and exhaustive of the wheat literature on his assigned subject. Points that I would question and additions I would make have been interspersed into my discussion of the paper.

I will, however, take a few seconds to present some philosophies and observations that I have developed during my four decades as a plant breeder.

While discussing the semidwarfing genes of wheat and their interaction with the genetic background, Dr. Evans said, "Adjustment of the genetic background clearly has a major effect on how the Rht genes influence yield potential." This is a way of saying that "few genes act in solitude." It follows that each species has evolved several genetic, and in turn physiologic, strategies to meet a given environmental imposition. Each strategy probably evolved in a different niche. If the breeder knows his germplasm well, he or she can choose between genetic alternatives, but generally this information is not available. It is my observation that whereas most plant breeding methods are systematically promulgated upon experimental data, most genes and genetic phenomena useful in plant breeding have been discovered serendipitously.

Germplasm is the key to a plant breeder's success. In the past four decades CIMMYT, and the Rockefeller Foundation program before it, have run the grand experiment that proves this point. Granted, CIMMYT has had astute scientists and [illegible] resources, but most of all it has made available and used the world's wheat germplasm. Any line that had merit anywhere in the world was introgressed into the CIMMYT wheat gene pool. These lines were used in single crosses and F_1s were crossed with other F_1s; segregates by the millions were observed and a few that excelled were saved. Yes, CIMMYT, your grand experiment has been a success—germplasm is the key.

Production Agronomy: Its Problems and Improvement

C. Charreau and G. Rouanet
Institute for Tropical Agricultural Research/
Center for International Cooperation in Agronomic Research
for Development, France

In comparison with the fast population growth, the total annual growth of agricultural production in developing countries during the last ten years was a little over 3% in Latin America and Asia, but only 1.4% in Africa. Despite the fact that years of unusual drought in Africa cannot be overlooked, the future is still gloomy. Although West Africa used to export one million tons of foodstuffs (particularly peanuts) at the beginning of the 1960s, it was not even self-sufficient during the 1970s. In 1983-84 imports of foodstuffs amounted to 1.5 million tons, but if this figure is extrapolated taking into account current trends, it may be translated into several tens of millions of tons in just 25 years.

The farm production situation, especially serious in some countries though not in all, constitutes a real challenge if we consider the unfavorable economic situation in those countries. Such factors as growing deterioration of the balance of payment, low domestic savings, weakness or deterioration of public equipment, excessive urbanization, and the growth of a less productive service sector that is privileged compared to the less populated rural sector, place on farmers—whose importance in relation to the total population is reduced—the burden of producing even more.

The Asian experience that gave birth to the Green Revolution in the 1970s clearly shows, as pointed out by Dr. Swaminathan, that agricultural progress assumes that several conditions are simultaneously fulfilled: progress may even be rapid if "an assembly of technologies, services, and government policies is developed and implemented in a coordinated manner." In a wide sense, plant and farm technique improvement cannot be considered independently of other components of agricultural intensification, such as the economic and political ones. This is true both for assessing the constraints of existing production systems and defining the priority guidelines of research, and for promoting the implementation and dissemination of more advanced techniques.

Within the context mentioned above, thinking about farm production problems in tropical areas is desirable at a time when some of us wonder if the main reasons production in certain countries has stagnated may be because of inadequate technological models, or because proposed models are not adapted to farmers' circumstances. It is particularly rewarding to have these types of exchanges at CIMMYT, an institution with a 20-year history of brilliant contributions to the improvement of maize and wheat in tropical areas.

Agricultural Constraints

General Constraints Linked to the Natural Environment

Whatever the production system, tropical agriculture faces a series of basic constraints linked to the natural environment. A brief summary of such constraints is presented here.

Soil-related constraints—Aside from the recent volcanic soil formations in highland areas and certain alluvial soils, most tropical soils have obvious limitations that vary with the situation and crops. For plant growth, these limitations include poor exchange capacity, major element (P_2O_5, K) deficiency, excessive acidity, low organic matter content and inadequate release of nitrogen, poor porosity, and high soil compaction impeding deep root development and water percolation. A large part of the surface water runs off, favoring erosion even in areas of low rainfall.

Studies conducted by the Institute for Tropical Agricultural Research (IRAT) in Sefa, Casamance, Senegal from 1965 to 1970 have shown that runoff and erosion, while limited under natural forest cover, increase dramatically when lands lie fallow, and even more so when they are first cropped (Table 1).

These general features may be further expanded: low moisture retention capacity of sandy soils in the Sudan-Sahelian zone, which makes climatic irregularities even more acute; and the frequently waterlogged, clayey soils in areas of excess rainfall. This is particularly detrimental to maize and most staple crops, with the exception of rice.

Constraints linked to climate and biological environment—These constraints include: limited solar radiation in forested areas that reduces the potential yields of crops requiring sunlight (e.g., maize); aggressive rainfall (runoff, erosion) even in low-rainfall areas; excess water in comparison to crop requirements in forests and sometimes in highland areas or savannas; rapid and aggressive weed infestation, more particularly in savanna zones, especially under intensive cultivation (with soil preparation and manuring); and pests (fungi, viruses, insects) in the field and after harvest, particularly in forested areas.

Agricultural Constraints Linked to Cultivation and Production Sytems

Agricultural constraints are conditioned by numerous factors of varying importance according to each region. Some examples follow.

Agricultural and ecological production framework—Most frequently, a crop is planted within a certain agricultural and ecological framework and on a precise date. Taking maize and wheat as examples, the following have been observed.

- Maize is planted in intertropical zones during the rainy season or out of season with irrigation, where there is only one rainy season (in Burkina Faso); in each short rainy season when rainfall distribution is bimodal (Congo, southern Cameroon); and at different elevations from low (forest or savanna) to more than 2000 meters (Rwanda, Andean zone).
- In the case of wheat, the range of situations in intertropical zones, though reduced, goes from sowing in cold dry seasons under irrigation (Sahel) to sowing at the end of the rainy season in highland areas (East Africa). There are intermediate situations in which irrigation has only a secondary role as a supplement to rainfall (Madagascar).

It is obvious that agricultural and ecological constraints, and their priority, vary widely according to each particular situation.

Type of farm and product destination—In contrast to industrial crops (rubber tree, sugar cane), many crops are cultivated in the tropics in farms that are well differentiated according to their size and technological

Table 1. Runoff, seepage, and soil erosion, Sefa, Senegal, 1965-70

Land type	Coefficient of Runoff (%)	Coefficient of Seepage (%)	Annual erosion (t/ha)
Forest	1.0	99.0	0.2
Fallows	16.6	83.4	4.9
Crops	21.2	78.8	7.3
Bare soil	39 5	60.5	21.3

food habits (growing consumption of imported wheat). As a result, local products lose part of their market share. In such cases, farmers become discouraged, which greatly affects the dynamics of production and intensification.

Constraints of rural life in tho tropics – Even in areas under integrated development projects, rural living conditions in the tropics are precarious or deteriorate due to the vagaries of climate or population growth. The traditional cultural environment is not replaced – as it is in temperate countries – by developments (electricity, highways, schools, health centers, stores, etc.) that help farmers to better manage their farms. Consequences are evident (aging of rural population, urban migration, etc.) and in certain regions they do not allow farmers to tackle agricultural problems and, much less, to implement solutions.

It would be illogical to think that future innovations may be implemented without farmers' active participation.

Technical Framework

General Remarks

Agronomists face the innovation dilemma – The following review of the complexity and diversity of agronomic conditions reflects the difficult task facing agronomists. They must look for answers to such worrisome questions as how to understand the farmer's real problems without overlooking their extreme diversity, on the one hand, and avoiding hasty generalizations that threaten to distort individual priorities, on the other. They must analyze constraints, so that the results reflect farmers' priorities as closely as possible (including major social and political factors) without the risk of making an inadequate diagnosis. When developing new experimental schemes, they must take into account certain general and economic constraints that condition their validity. They must guarantee that their analyses are truly objective and not distorted by their own concerns.

In the last 20 years, many agronomists, economists (particularly from CIMMYT and the Center for International Cooperation in Agronomic Research for Development, CIRAD), and specialists in human sciences have contributed numerous answers to these questions, and have proposed, often successfully, methodologies based on more rigorous methods. Nevertheless, agronomy is still an art as well as a science; its scientific arsenal and lucid analyses should not lack a certain empiricism in approaching producer problems, but should use intuition and experience in the global appreciation of different situations.

Inherited traditions – Until recently, technological changes were brought about by farmers themselves. It would be illogical to think that in the future innovations may be implemented without their active participation in the development of new technologies. Many "failures" of the last decades should be examined by professional researchers and developers from this point of view. Likewise, even today, combining research and innovation while restricting the role of farmers as mere doers must be avoided. As we will see later on, many technological innovations that never passed through the channels of research and development are being implemented through the spontaneous action of rural communities.

Rainfed agriculture in developing countries is based, even in 1985, on traditional technologies that are not yet going to disappear, despite their poor adaptation to the current and future situations.

- The principle of long fallow, which allows initial fertility to be recovered;
- Reasonable amounts of burning which allow plowing and make accumulated biomass available to plants;
- Use of organic fertilizer, especially manure;

- Farming or post-harvest tools made of wood (based on the rational use of the environment);
- Landscaping and erosion control techniques, similar to those observed in numerous regions of India and Africa, such as the Dogon region in Mali or the Mandara Mountains in Cameroon;
- Several traditional cropping techniques based upon rotation or crop association, and finally
- Agroforestry.

An example of such systems may illustrate our discussion: off-season cultivation of transplanted sorghum in the soils (vertisols) of northern Cameroon, where there is an amazing diversity of ecotypes, outstanding plant adaptability in a difficult environment; and the economical (in water and effort) techniques used, which seem very difficult to improve even today.

Nevertheless, most of the techniques described above, based on mere human forces working in a natural environment within a strictly self-sufficient scheme, cannot meet the challenge posed by rapidly growing food demands. But, far from being a holdover from the past, traditional techniques deserve all our attention when we are more and more considering low input technologies, when we attempt an efficient and diversified use of the environment, or when we want to give a new turn to the adoption of peasant farming techniques.

Different research products Certain innovations aim directly at improving production and productivity (better yield per hectare, better quality of products, fewer working hours, etc.). The extension target involves the producer (farmers, cooperatives, development projects) and, more often, the plot, the farm, the land, or the region. The research that supports these innovations generally stems from applied and adaptive research.

Other research efforts provide support (often thematic) by trying to understand phytophysiological mechanisms, soil fertility dynamics, and the biology of predators. Such breakthroughs often result in tools or methods that contribute to the emergence of new technologies; thus, research in this field is both strategic and relevant to basic research.

Lastly, there are other innovative methods and techniques which are useful in assessing situations and developing and following up innovations and production. These methods interest producers, developers, decision makers, and researchers. In the following pages, several research projects are reviewed.

Tools and Methods for Development Research

Diagnostic and follow-up tools At the *regional level*, several geographers and researchers have attempted to use cartographic methods to provide decision makers and developers with operational diagnostic and follow-up instruments. Climatological and pedological maps are accompanied by numerous examples of applied cartography: maps for evaluating constraints, potentiality maps, etc.

It would be useful to mention some tools used particularly at CIRAD within this context. Based on climatic and pedological concepts as well as on mapping techniques, *agroclimatic zoning* aims at dividing a region into homogeneous zones that show increasing potential for a certain crop. It is an interesting task for researchers, extension agents, as well as for national decision makers. The use of numerical images produced by satellites (Landsat; Spot, as of this year) has opened new perspectives.

Recently CIRAD has started an overall analysis of the Sahelian zone based on the concept of a multifaceted regional tool: the *mesoregion*. This is a new attempt to "subdivide" countries into a certain number of homogeneous regions, according to three major criteria: production systems, soil occupation rates, and annual rainfall.

This analysis has identified 11 mesoregions in the Sahelian zone which are independent of national boundaries. Two examples of how this tool is applied are (1) the effect of innovations within a country may be more easily extrapolated within zones of other countries belonging to the same mesoregion, and (2) within the same country, priority analysis may be done by mesoregion, thus contributing to a rational organization of research and development efforts.

There are many survey methods at the *plot and farm level* which allow us to obtain, analyze, and compare true or experimental data. These include classic methods for analyzing soils, roots, and leaves (foliar diagnosis) and agronomic surveys at the plot or farm level. Computer techniques help the researcher make better use of more data and quantify them more accurately.

As an example, we mention a recently developed method for analyzing water balance. Based on studies conducted by several institutions (the Food and Agricultural Organization (FAO), Overseas Agency for Scientific and Technological Research (ORSTOM), Interstate Commission for Water Studies (CIEH), Agricultural Hydrology and Meteorology (AGRHYMET), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), University of Texas), computer-aided systems for assessing water balances and methods for using these systems at the farm level have been designed. One example is the recent BIP software developed by CIRAD to simulate the water balance of rainfed crops in dry tropical regions, based on the estimate of the evaporative demand, water requirements of crops, and rainfall. This water balance also takes into account the main characteristics of soils and cropping systems (root depth).

Even though this tool can be perfected, it is already particularly useful in the following instances to:

- Explain yields obtained at an experiment station or through on-farm experiments and to evaluate plant and soil improvements;
- Predict possible yields based on rainfall hypotheses, agricultural and meteorological warnings, and irrigation management;
- Define species, varieties, or possible crop cycles; and
- Assess the need for designing supplementary irrigation equipment for a certain crop (climatic risk).

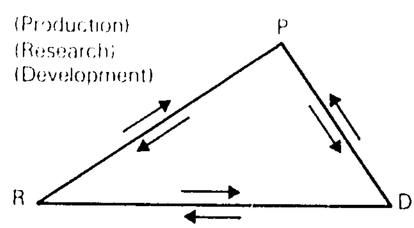
Methods of experimental development—In tropical agronomy, the following steps were applied, especially in Africa, until the 1960s: (1) research priorities were essentially defined by political authorities and researchers, (2) most research was performed at experiment stations and field observation sites to take into account pedoclimatic variations, and (3) research results were delivered only to official extension services or to those responsible for development projects, whose role was dual: to define and to adapt innovations by microregions and to promote the application of such results by farmers.

It would be erroneous to state that these methods—though quite varied—have not sometimes provided brilliant results. Nevertheless, the failures observed have prompted us to reconsider this approach and to make use of methodologies brought about by human sciences.

That is why during the 1970s we have witnessed former procedures, represented as

R --------→ E --------→ P
(Research) (Extension) (Production)

increasingly replaced by new approaches that further integrate the partners at the diagnostic and research planning levels, as well as at the implementation level:



All of the new approaches implemented since the 1970s aim at reconciling "upstream" research, traditionally favored by researchers, and "downstream" development research, closer to producer concerns. All of these methods consist of the following phases:

- A finalized farm diagnosis, sometimes of the main crop and sometimes of the farming systems to rank constraints encountered by producers;
- The establishment of a technical reference background to answer the problems mentioned above, based on on-farm experiments, or by readdressing the most fundamental research demands at central stations; and
- Follow-up evaluation of the adoption and development processes. Many projects undertaken by CIRAD in Africa or by CIMMYT in Central America illustrate these new methods.

State of Technical Knowledge

Plant material and agronomy Adapting plant material to the environment is a means of attempting to solve the constraints imposed by the latter. This is true when choosing one species over another, according to agricultural and climatic characteristics.

Within the same species, such as maize, this procedure has been in use for centuries, particularly through mass selection in order to obtain ecotypes that are both irreplaceable genetic material and often remarkable examples of plant adaptation to microenvironments or to technologies.

Over the last decades, genetic improvement has resulted in spectacular results in quantitative and qualitative efficiency of several varieties of wheat or maize, especially thanks to CIMMYT research, but also plant adaptation - via resistance - to environmental constraints such as severe endemic diseases (rusts, helminthosporium, viruses, etc.).

Ongoing efforts aim at strengthening insect resistance, particularly to borers (in the case of maize), or at developing varieties tolerant to the acidity of tropical soils.

Variety improvement is not a miracle solution to the cropping intensification expected in tropical areas.

Genetic breakthroughs sometimes help expand the ecological space: early-maturing maize varieties allow maize cultivation in areas where regular maize cannot grow, wheat or triticale varieties will become more adapted to intermediate altitudes, to higher rainfall levels, or to higher temperatures. Breakthroughs also allow the design of new cropping systems, such as yearly double cropping in short cycles (maize-cowpea or maize-cotton). But they also present new demands in cultural practices, thus contributing to change them: the need for increased fertilization to actually achieve the high yields that new varieties allow; the need for eliminating other agricultural constraints whenever possible: more weed control, supplementary irrigation, etc.

However, it would be a mistake to see variety improvement as a miracle solution to the cropping intensification expected in tropical areas: the current yield potential of both traditional and nontraditional varieties is much higher than the yields usually obtained by farmers, and seldom constitutes a major limiting factor. For example, the Green Revolution of the 1970s was first of all the result of better cultural practices in the regions in India equipped with irrigation networks. As Dr. Swaminathan points out, "It was not until later that high-yielding varieties (HYVs) were introduced."

On the other hand, there has been some controversy on the adequacy of HYVs in difficult agricultural environments. Some researchers – a decreasing number of them, it is true – insist that it is difficult to develop varieties that perform well in both favorable and unfavorable environments. Numerous studies conducted by CIMMYT, particularly on wheat, show that this ambitious objective is sometimes achieved, as observed in comparisons of yield performance across many years and sites in International Spring Wheat Yield Nursery (ISWYN) trials on varieties such as Nacozari or Veery "S".

This has not always been the case. For example, in the field trials performed by the Ivory Coast Textile Development Company (CIDT) in the southern Ivory Coast in 1975 the variety Tuxpeño 1 performed much better than the improved local variety (CJB), provided that the soil was sufficiently prepared (using tractors or draft animals) but its yield was lower when the soil was manually prepared in the traditional manner.

Nevertheless, it was pointed out in most cases that (1) optimum agricultural practices, where they may be implemented, increase the HYVs' superior performance over local varieties, (2) HYVs enhance the efficiency of other inputs (particularly nitrogen fertilizing) and profitability, and (3) even in difficult conditions it is possible to devise low-input cropping techniques that make it possible to optimize the use of improved varieties.

Water and soil In *arid* and *semiarid zones*, we have witnessed the often catastrophic impact of rainfall on bare soil or on cultivated soil. The high percentage of runoff deprives seeds of the water they need and damages the environment through erosion. Let us examine some examples of techniques implemented to correct this situation.

For plots or regions there are many *anti-erosion techniques* which unfortunately were not widely promoted. These include protection of zones subject to overgrazing and deforestation, public awareness of the problem of burning, techniques to combat wind erosion by planting windbreaks, and erosion control techniques, protecting catchments.

Though these techniques are well known, the major problem is their effective implementation. Many issues are still being studied by researchers with a view to proposing more efficient and economical solutions that will be easily undertaken by the people themselves. It is worthwhile to mention work performed by ICRISAT in India in ridging using "movable simulators" to study the reaction of the soil to the rain's aggressiveness in the field.

Techniques for *water storage in the plot* and *protection against runoff* are included in the general antierosion techniques described above. Methods range, according to the case, from contour cultivation with or without ridges, to grass benches or terraces. Though these well-known methods can be improved, they are not as widely implemented as they should be. As an example, a layout based on the leveling of terraces and the installation of drainage at the lower levels has provided average grain yield increases of 21% as compared to a simple system of contour terraces at ICRISAT.

Other techniques, which also have been insufficiently implemented, have proven their usefulness in limiting runoff and evaporation by storing water in the soil. These include (1) subsoiling or tillage, which increases permeability and storage capacity, (2) hoeing, which restores permeability reduced by compacting or rain splash, (3) end-of-season plowing, which in certain cases allows carrying over part of the water from the previous cycle to the following one, (4) mulching with crop residues in case of zero tillage, and (5) tied ridging.

For example, trials carried out at Kamboinse, Burkina Faso show that the effect of ridging combined with tied ridging may allow, in certain positions along the toposequence, the doubling of yields in a maize crop.

Numerous *water management* studies deserve our attention: we will again use the example of water balances to show their possible uses: (1) agricultural warning: foreseeing deficits, (2) substantial savings in the amount of water coming into irrigated areas, thus avoiding the many inconveniences derived from poorly controlled irrigation and allowing an expansion of irrigated surface, and (3) where water resources are scarce, the possibility of supplementary irrigation to reduce the serious risks of a drought and its related detrimental effects during the growing season.

To illustrate the point, in 1984 in an experiment sponsored by CIRAD in Lossa, Niger, the timely supply of 80 mm of water to a sorghum crop made it possible to harvest 6000 kg of grain per hectare, compared to only 600 kg/ha in nonirrigated fields.

In *humid savannas* and *forest zones*, where rainfall exceeds evaporation and transpiration most of the year, the dangers of using techniques common in temperate areas are well demonstrated. An estimated two million hectares[1] per year are currently deforested in tropical areas, under conditions that expose soils to major erosion. Selective deforestation methods avoid the brutal uprooting of stumps and use of heavy machinery, thus minimizing such risks. The soils are well developed, of fragile structure, and remain stable as long as the natural plant cover protects them.

Land clearing, particularly for annual plants, results in the exposure of soils to the aggression of rain. On the other hand, tillage, when it is practiced with motorized equipment, has a compaction effect that reduces permeability and increases surface runoff and erosion.

Lastly, the activation of mineralization mechanisms after sowing causes the rapid depletion of organic matter and often, due to the crops themselves and to certain mineral fertilizers, higher soil acidity.

That is why many methods based on limited tillage and mulching have been developed, particularly at the International Institute of Tropical Agriculture (IITA), which successfully attempt to solve the major problem of permanent cultivation of annual plants in humid zones.

In the humid savannas and forest zones, the danger of using techniques common in temperate areas is well demonstrated.

In other cases, as in Gabon or in central Brazil, with heavily mechanized agriculture, effective solutions are sought through terraces allowing total absorption. Reducing cultural practices to a minimum can avoid compacting of soils by promoting the use of moldboard plows, rather than disk plows, or by covering the soil with straw (waste maize stems) after harvest until soybean planting begins.

In humid zones, intercropping is a traditional answer to the risk of soil erosion, as is alley cropping. Numerous projects and models have been implemented over the past few years; we will give some examples in this section of the paper.

Maintaining mineral and organic fertility. To correct deficiencies and maintain and improve fertility without agricultural risks is the challenge to innovations in this field. The increasing price of inputs forces us to resort, as much as possible, to the agrosystem's own resources or to regional sources for improving fertility.

Many surveys on mineral balances undertaken in intertropical zones have shown that the maintenance of soil fertility in arid and semiarid zones is largely conditioned by the improvement of organic and nitrogen levels, sometimes by correcting the poor phosphate and potassium reserves, and lastly by replacing calcium and magnesium losses.

In humid tropical zones, soil acidity and phosphate deficiency are additional constraints in ferralitic soils and in the above-mentioned soils. Land clearing and tillage accelerate the mineralization processes and soon alter the organic and nitrogen levels.

During the last two decades, the steps followed in *fertilization* have been (1) evaluation of growth requirements and the amount of minerals removed by the plants, depending, obviously, on actual yields and type of removal (just the grains or the whole plant); (2) evaluation (in pots or in the field) of deficiencies and their importance, which encouraged the idea of an initial massive fertilization during the 1960's; (3) evaluation of maintenance fertilizer applications to restore the chemical fertility of soils under crop rotation, based on the amount of nutrients removed and leached; and (4) developing a fertilization pattern that can be disseminated easily is a more complex task.

Economic and financial factors must be taken into account; some fertilizers and means of improving fertility are true investments in view of their medium term action.

The most economic formulas, as well as those which are more available and easier for farmers to apply, must be sought. The most efficient methods and times of application must be specified. A fertilizer cannot be assessed except as it interacts with other yield, crop, and rotation factors (type of soil preparation, operations during cultivation).

To draw up viable recommendations, the process described above must follow an iterative approach that may combine experiment station research with on-farm trials. In any case, the methods to be disseminated are worth diversifying, according to the needs of different microregions and groups of farmers, and perfecting in on-farm trials.

Several studies for developing techniques aimed at improving and maintaining soil fertility in low input systems have been conducted in the past few years. They provide evidence of the benefits to be expected (e.g., in tropical maize cultivation) from composting crop residues (possibly in association with low nitrogen fertilizer applications), from using natural local reserves of phosphate (rock phosphates), from a close association between maize cropping and animal husbandry, and from the use of farmyard manure.

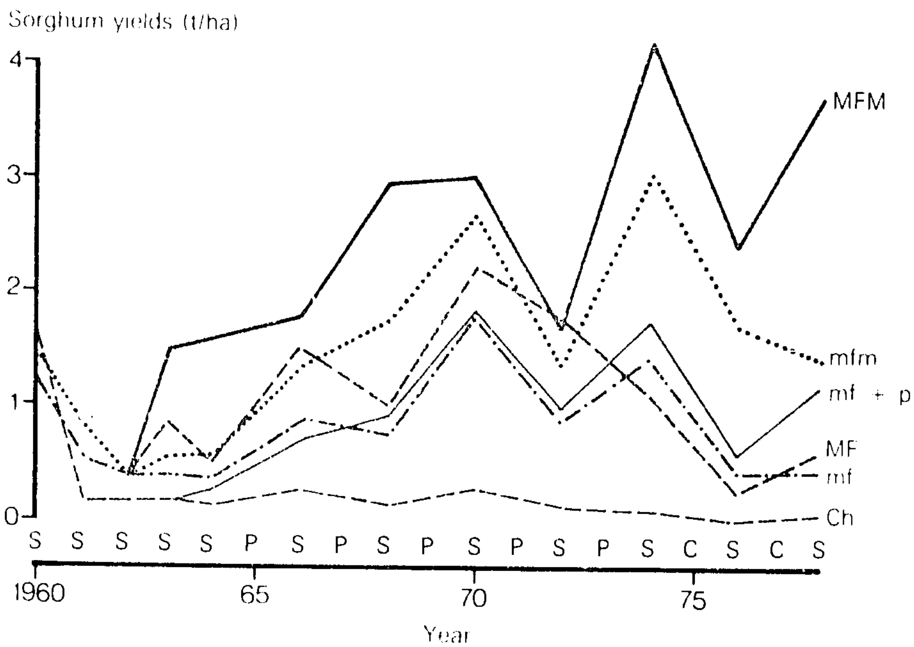
Trials conducted for five years in Sefa, Senegal by the Savanna Institute (IDESSA), IRAT, and African Industries and Forests (IFA) on maize legume rotation have shown that even in dry years (1981 and 1984) yields of 1.7 t/ha were obtained without applying urea and urea performance could be markedly increased by localizing its application in the form of supergranules. The use of maize straw compost without applying urea increases grain yields by an average of 900 to 1400 kg/ha with the addition of 0.5 to 1 t/ha of compost and 900 to 2000 kg/ha with the addition of 2 to 3.5 t/ha compost. With the application of 100 kg/ha of urea at the time of ridging, on a field to which 1.5 to 3 t/ha of compost have been added, yields of 3 t/ha are possible.

For many years, various institutions have conducted agricultural evaluations in West Africa of rock phosphates as partial substitutes of imported superphosphates. For example, the study on Matam phosphates in Senegal points to the advantage of their use in maize-cotton rotation on leached ferruginous soils in which they are partially dissolved due to the physico-chemical properties of these soils

Another example: results obtained by IRAT and FAO at Maradi, Niger, have confirmed that the addition of 70 units of P_2O_5 (local rock phosphate + imported soluble phosphate) allows a restoration of chemical fertility of ferruginous soils whose production potential in heavily populated zones has been substantially reduced in the last decades.

The utilization of farming systems aimed at gradual intensification that links mineral and organic fertilizers to cultural practices adapted to farmers' technological know-how has a dramatic effect on the average growth of yields, as demonstrated by results obtained at Saria, Burkina Faso (Figure 1).

In critical rainfall areas, balanced application of fertilizers (including potash fertilizers) in association with the crop residues returned to the soil makes it possible to have more stable production (lower inter annual variability of yields) as shown in a trial conducted at Bambey, Senegal. Likewise, farmyard manure applications make it possible to optimize profit from investments for liming on the degraded soils north of the peanut-growing area in Senegal.



sorghum (S), peanuts (P), or cowpea (C)

MFM = high fertilizer application and manure
mfm = low mineral fertilizer application and manure
mf + p = low fertilizer application plus plowing in crop residues and green manure
MF = high mineral fertilizer application
mf = low mineral fertilizer application
Ch = check without fertilizer

Figure 1. Fertility maintenance trial, Saria, Burkina Faso, sorghum-legume rotation.

Techniques and cropping systems During the past 20 years, the technical background of tropical agronomy has been enriched. There are few ecological situations in intertropical zones for which some technical improvements cannot be proposed, no matter the type of cropping systems or groups of farmers to whom they are directed, even if the range of techniques available, particularly tools and other inputs (seeds, pesticides) is very rudimentary compared to those available for farmers of industrialized countries in temperate regions.

Instead of making a tedious inventory, we include some examples of this vast range according to major technical topics, two in semiarid zones and two in humid zones. On closer examination, most of them are the products of traditional tropical agriculture, but have become the object of important scientific experimentation during the last decades.

Semiarid zone The technical background proposed for this zone often aims at suggesting a permanent cropping system, based on crop rotation with or without fallows, on the use of organic and mineral fertilizers and tillage intensification, supported by the agriculture animal husbandry association and, above all, if land extension allows it, on the mechanization of cropping techniques (animal traction, intermediate mechanization).

Many surveys conducted in Asia, Brazil, and West Africa on the *choice of crop sequences* have studied the most desirable rotations from the biological standpoint in various situations (elimination of pests linked to a crop, use of the residual effects of symbiotic nitrogen fixation by legumes, better weed control by alternating crops, reduction of phytotoxic substance accumulation, etc.) and from the economic standpoint (spreading of risks and tasks within the rotation scheme).

In general, the following may be pointed out: (1) suitability of rotations that involve alternating cereals and legumes, and (2) the disadvantages that result when the same crop is repeated on the same soil or when using the following crop rotations: sorghum-maize, rice-maize, or maize-sorghum.

In those regions where yearly double cropping is possible, rainfed rice and short cycle maize are preferable the first season, annual cotton and legumes are most convenient the second season. "Relay" crop systems are proposed, particularly in manual cultivation for lower rainfall regions, so that without discontinuing the cereal crop (maize), a legume is intercropped before maize flowering.

The development of techniques adapted to *animal traction* in semiarid zones was the result of the efforts of several organizations, in particular CIRAD in West Africa and ICRISAT in India. Such techniques focus on soil preparation (plows, seeders, ridgers), weed control, and transportation. The introduction of seeders and their development has been a contributing factor to the progress in peanut cultivation, and has started to become popular with maize. There is no harvested material being studied for animal traction, save for peanuts harvested in Senegal. In each case, extension efforts aimed at spreading the use of animal traction involve whole regions (i.e., the peanut zone in Senegal) or microzones (i.e., water management in Niger). Animal traction allows farmers to increase cropping area and to reduce delays when sowing and weeding.

Humid zone Many times we have seen the difficulties brought about by tillage, especially by mechanical tilling in the humid tropics. Several studies, particularly during the last decade, have examined cropping systems based on *minimum tillage*.

The practice of zero tillage has found some formulas in several tropical countries (Ivory Coast, Nigeria, Mexico, Brazil) for crops such as maize and rainfed rice. *Zero tillage* techniques allow the quick and economical cultivation of clay soils that are difficult to work on, as in Southeast Asia (wheat).

Zero tillage, in areas where some defects are corrected by multiyear rotations with some degree of soil preparation, has brought about the rapid use of herbicides (particularly total herbicides for pre-seeding), and the development of manual or portable tools to be used in unprepared soils and over mulching (seeders, fertilizer dispensers).

In several regions of humid tropical zones, the *association of crops* under forest cover is the heritage of various traditions. Such associations, which may also include perennial commercial crops like coffee, were the object of many surveys that took into account the following advantages:

- Better cover and protection of soil;
- Improved productivity as a result of the complementary requirements of several crops (sunlight, soil profile, and nutrients); and
- Sometimes reduced pest pressure.

In the highlands of western Cameroon, maize intercropped with soybean can produce yields that are 50% higher than those of the two species grown as a sole crop on an equivalent surface. This "over yield" is lower when maize is intercropped with beans. Working times are the same as for a single crop though they are reduced for weeding, which is often a peak period.

In *alley cropping systems* such as those implemented by IITA crops are permanently rotated within rows framed by bushes (often legumes that are regularly trimmed and used partly as mulch for annual species grown within the rows; the rest may be used as fuel, as support stakes, or as forage). Another characteristic of these widely diversified cropping systems is the continued transfer of symbiotic nitrogen fixed by perennial legumes, which benefits annual crops (maize, tubers, and cowpea). Most alley cropping systems proposed by IITA involve the perennial legumes *Leucaena leucocephala* or *Gliricidia sepium*.

Adopting New Technologies

Supply and Demand

Both theme-specific research and development research need to link supply to demand for innovation; in this approach researchers must be able to perceive the whole complex demand of farmers for innovations, to rank constraints, and to reason out the agricultural, technical, economic, and institutional consequences. This approach results in a better determination of targets and research programs.

Certain technologies do not imply deep changes in production systems or new investments. Such is the case in the substitution of local varieties by improved local varieties. But most of the time, new technologies involve changes in which researchers and developers must clearly evaluate all consequences.

The introduction of fertilizer within an autarkic system presupposes the existence of a market for harvest surpluses, the assumption of financial risks, and the creation of farming credits. The introduction of seeders or herbicides may eliminate working time constraints and implies increased farm size, with all the consequences that it entails. Frequently, an isolated technology may not be effective without other technologies (fertilization and improved variety, for example).

In short, it is evident that new technologies do not have inherent virtues, that their applicability is always relative and that their implementation assumes that they will be inserted into consistent farming systems acceptable both to producers and to their environment.

Whatever the technology and its "intrinsic applicability," it cannot be implemented if it is not accepted by producers. Their attitude definitely depends on the way certain conditions are met. These conditions act as a filter, and it is worthwhile to recall them:

- Previous knowledge of the technologies themselves (this is rarely the case, due to language, education, and information barriers);
- Ability to master technologies, posing the problem of training in new techniques (e.g. mechanization);
- Existence of effective logistic means that farmers may count on as support (actual input availability, credit possibilities, etc.);
- Guaranteed organized markets for production surpluses (not very frequent for food crops); and
- Reasonable financial risks linked to the adoption of technologies, particularly in a bad year (insurance and equalization).

Whatever the technology and its "intrinsic applicability," it cannot be implemented if it is not accepted by producers.

At any given time, the technical production system chosen by farmers reflects their socioeconomic environment. There are many examples: in Senegal, the evolution of cropping systems within "experimental units," the rapid rise and decline of maize according to the evolution of fertilizer prices and marketing costs. Also in Senegal (the Terres Neuves project), towards the end of the 1970s, we witnessed a modification of the rotation initially proposed by agronomists, in favor of the best-priced (peanuts) and best-developed commercial crop, as well as the most appreciated subsistence crop (sorghum).

Some Positive Features of the Balance

We cite the remarkable technological successes achieved in tropical agriculture with the oil palm, just to mention a commercial plant, and with cotton, particularly in semiarid Africa. Among food crops, the advances in wheat and rice production during the 1970s were spectacular and gave rise to such terms as "Green Revolution."

We do not want to extend ourselves, since the institution that is hosting this event was one of the major architects of this achievement; we will simply call to mind that, in 1984, 45 million hectares in developing countries were planted to wheat varieties derived from CIMMYT research. The ability of such varieties to perform adequately in difficult environments is, beyond any doubt, one of the reasons for their success, as is their response to intensive farming practices, particularly to mineral fertilization - as demonstrated by CIMMYT's outstanding work in Argentina.

Nevertheless, numerous authors (many economists), who have done a provisional balance of the last 40 years of research in tropical farm production, are somewhat pessimistic. On the contrary, certain agronomists think that technological breakthroughs and the impact of available results - even in the short term - have not been fully appreciated. In support of this thesis, it may be useful to provide examples of experiences that have proven that important advances are not just goals, but concrete facts.

A retrospective evaluation of three large rural development projects financed by the World Bank in northern Nigeria (Gusao, Funtua, and Gombe) has shown average production growth rates of more than 5% a year for the major cereal crops (millet, sorghum, and maize). For sorghum and maize, results are particularly spectacular: selected local sorghum varieties have yielded 1400 kg/ha, and maize varieties 2 t/ha. In general, yields obtained in fields cultivated according to recommended methods and practices doubled the yields in traditional plots.

The "Mali Sud" project in Mali and the "Ouest Volta" project in Burkina Faso, both sponsored by the CDFT (a French company for the development of textile fibers), are two examples of the development potential of cotton projects in regions where annual rainfall exceeds 900 mm.

In 1979-80, four years after the inception of the projects, cotton production has attained the record figure of 65,000 tons (40% increase) for the "Ouest Volta" project and 142,000 tons for "Mali Sud" (22% increase) in three years. Average yields, very high for nonirrigated cotton cultivation, exceed 1 t/ha, i.e., double the mean registered for sub-Saharan Africa.

Regarding project results on food crops, free marketing makes it difficult to evaluate production, but we estimate that millet and sorghum production in the project area will increase by 25% a year during the first four years of the "Ouest Volta" project. For "Mali Sud," we consider that average millet and sorghum yields, in rotation with cotton for the 120,000 ha of the project, will exceed by 40% yields obtained using traditional methods. In the case of maize, introduced and popularized in southern Mali, results have been unexpected: more than 24,000 ha have produced mean yields of about 2 t/ha.

For the two examples mentioned above, we observe that (1) important advances were achieved both in industrial (cotton) and food crops and (2) intensification of cereal crops was not possible without sufficient logistic organization (marketing, inputs, intensive technical supervision).

In general terms, we confirm that the development of food crops and their intensification are not hindered by a lack of superior plant material or sophisticated technology packages, but by situations in which there is no effective logistic organization, indispensable for production growth.

Other specific examples show that such rapid progress may be achieved through simple innovations. These include the fast replacement in Senegal during the 1960s of *sanyo* by improved local varieties of *souna* with a better response to fertilizers; the development of maize production in the 1970s in the Sine Saloum, thanks to research on this crop with regard to varieties, fertilization, and animal traction; the rapid development of maize north of Adamaoua in Cameroon toward the end of the 1970s when SODECOTON, a well-established company with important logistic means, was put in charge of promoting this crop. Also, there was the interesting study conducted in the high basins of Burkina Faso by the North Mossi Regional Development Organization (ORD) in 1984. It has proven that farmers used to very intensive practices in cotton crops do not hesitate to plant a whole field to maize, traditionally limited to house gardens. The technical level of these new maize crops rotated with cotton or white sorghum has quickly attained a high level of intensification (use of manure, urea, improved seed, and animal traction) and yields (2.4 to 4.7 t/ha) are two to four times the national average yield.

Weaknesses of Research and Development Systems

Deficiencies linked to the general social, economic, and political environment. Throughout our discussion, we have made evident how the implementation of innovations depends on constraints linked to the economic, social, and political environment. The following facts should be underlined:

- The problem of inaccessibility of unused (enclosed) agricultural lands;
- Low input levels on production sites and poor harvesting and storage facilities;
- Lack of technical training among farmers, added to the low educational level and, sometimes, language barriers;

- Poor farmer and professional organizations;
- Unattractive rural environments, which encourage urban migration, the lack, in many rural areas, of social services (hospitals, schools, etc.);
- Delays in land reform measures that would foster modernized agriculture, and
- Poor incentives (prices, credits, etc.), particularly in relation to food crops.

Deficiences in farm technology research *Research means are insufficient in relation to research demands.* Such insufficiency is especially dramatic if we take into account

- The wide range of situations and the importance of farming problems in the tropics,
- That research undertaken to date is recent when compared to that of other climatic zones, particularly the temperate regions,
- The lack in some regions of nongovernmental (commercial) research on cereals, unlike the situation in the temperate zones (mechanization, seeds, pesticides);
- The deficiencies that are starting to emerge in several basic research projects that are vital to future progress, and
- Lastly, poor research undertaken on traditional production systems and on their short and medium term improvement

Research inefficiency is observed, especially in the separation among different research fields theme-specific research with insufficient interconnections does not promote the implementation of general technologies; much basic research is not granted priority by those responsible for development, and it is evident that there are some missing links, especially in the cereal sector, in relation to post-harvest and product processing techniques

Researchers often lack credibility. Developers do not trust results obtained at pilot stations and they question the researchers' ability to analyze technical problems of development.

Implementation deficiencies Besides the general problems that hinder the implementation of innovations, it should be noted that innovations are often not well known. Many authors have correctly pointed out the slowness of the technology dissemination process. Several successful experiences or improvements that should be widely adopted by producers are not made known to the rural populations that might be interested in implementing them

On the other hand, the growing number of technical seminars and conferences that bring together national and international experts does not really contribute to improving the situation: their recommendations and conclusions very rarely reach the people responsible for agricultural advance. Besides, they are written in a style and language well beyond the understanding of rural populations. Lastly, many research products (small tools, adapted formula fertilizers, certified seeds) are not available to farmers.

Innovations proposed are often not adequate for farmers. We may quote several cases of supposedly superior varieties that do not suit the consumers' taste. Surveys undertaken in 1981 in Burkina Faso by ICRISAT have clearly proven that the supposed superiority of improved sorghum varieties was not demonstrated when they were used by farmers. In southern Mali, new varieties of shorter cycle maize were abandoned when farmers realized that they were less resistant than traditional varieties to drought periods during the cropping season.

Finally, technologies are poorly implemented. Frequently, we have noted that outstanding technologies, such as the use of herbicides on maize, lose a large part of their value and effectiveness when dosage, application time, or even the type of product are not properly chosen World Bank experts often explain, a posteriori, that expected yields for certain development projects were not achieved largely because neither the types, nor the dosage, nor the recommended application techniques had been complied with adequately

Several attempts at intermediate mechanization in Africa failed despite optimistic forecasts because farm sizes were too small to achieve a certain profitability margin, because of farmers' deficient technological know how, or the lack of inputs required by mechanization

Conclusions on Research and Development Strategies

General Conclusions

Research and implementation of new technologies cannot be conceived apart from a general strategy, under some basic principles

- If necessary, modify or adapt the legal regimes of land tenure,
- Improve general conditions of rural life (health, roads, education, etc) and begin farming potentially productive zones;
- Develop policies to aid producers (product pricing, input supply, credit, etc);
- Increase the producers' ability to play an active role, not only in producing, but also in marketing their products, purchasing inputs, or managing rural land,
- Develop and integrate upstream (inputs) and downstream industries (food processing), and
- Organize and maintain medium and long-term efforts aimed at protecting and restoring the natural environment and at preserving natural resources.

The implementation of such strategies assumes close coordination and a continuum of efforts in each state, but also at a regional level. It also assumes coordinating donors' efforts and, therefore, a harmonic distribution of foreign aid, which is no easy task.

Consequences for Research on New Technologies

Increasing overall research efforts We have reviewed the numerous reasons that favor an intensification of research efforts Concerning the ecosystem, there is still an important effort to be implemented in order to have a better knowledge of the fundamental mechanisms of the ecosystem and to define the most appropiate methods for protecting and making adequate use of the environment at the farm and regional levels Concerning agriculture, a distinction can be made between short- and medium term research

Short term research must be based on the farmers' real problems, in order to eliminate constraints using the results obtained Several simple techniques, which do not require great investments or an optimum technical environment, could be implemented and diversified within the a research and development framework involving researchers, developers, and producers

Long term research, which is vital to the future, requires a better knowledge of the environment and the physiological mechanisms that condition plants' adaptation to their environment and to the most productive systems It shall also aim at devising the most efficient agronomical techniques, widely diversified and adapted to the major systems and ecologies It shall seek stable systems and low-cost inputs oriented to intensive and continuous crops. It shall aim at diversifying products and finding new technologies for processing such products.

Increasing research effectiveness and cohesion—Effectiveness and cohesion are two major elements to be taken into account, involving the following:

- An effort to break the barrier and to confer responsibility on research workers. The emergence out of disciplines—tight isolation and involvement of researchers working on a given crop in other specialities closely connected to their personal focus, together with a product-related or system-related approach in an ecological zone—is an excellent way to encourage specialists to work together in a multidisciplinary team.

- Better organization of world research efforts. Making a restrospective analysis of the CGIAR, we can clearly appreciate its importance and beneficial role, and its efforts to define and implement a world strategy for agricultural research based on a balanced representation of institutions, each having a well defined mandate. The recent development of many single-theme networks enlisting the participation of several partners (international institutes, bilateral aid organizations, national research centers, etc.) constitutes a useful initiative to improve research effectiveness.

Increasing efforts to disseminate technology—Researchers and, in general, all potential innovators, should promote the rapid, easy, and efficient dissemination, in rural areas, of proven techniques and experiences.

Conclusions on the Implementation of Existing Techniques

The World Bank's[2] analysis of the reinforcement of the research and development system clearly shows the need for "solidarity" among the parties involved, in order to reduce risks of inconsistency and to increase the effectiveness of world efforts. A continuous effort is required to increase awareness of the interdependence of each partner's work in achieving the final goal. This is the only way to provide linkage between research and development strategies on one hand, and the response to the legitimate demands of Third World producers on the other.

Along this line of thought, the following is essential for all those concerned with technology implementation:

- To devote attention to the study of farmers' problems, starting with the less privileged, and whenever necessary to encourage researchers and specialists to solve, on a priority basis, the technical problems found;
- To inform farmers about proposed solutions and their adoption;
- To organize the logistics (inputs, marketing) involved in the adoption of new technologies;
- To encourage a progressive take-over of producers in the management of such logistics; and
- To stimulate the development of the upstream and downstream activities involved in the increase of crop production.

Notes

[1] According to the Farming Systems Program, International Institute of Tropical Agriculture (IITA).

[2] World Bank. 1983. Report No. 4684.

Discussion

A. Turrent F.
National Institute of Forestry, Agriculture, and Livestock Research, Mexico

The purpose of my comments is to enrich the Latin American perspective of this excellent paper.

Dichotomy is a very typical characteristic of the Latin American farming sector. One finds a very modern, capital-intensive, efficient, and market-oriented farming subsector contrasted with a subsector that is typically labor intensive and primarily aimed at the survival of its human resource, and that uses modern inputs on a very limited basis. A few examples of the first case are the Yaqui Valley in Mexico, the Cauca Valley in Colombia, and the coastal region of Peru. Wheat is grown in Mexico in this kind of setting and yields surpass 4.5 t/ha in more than one million hectares that are almost totally mechanized. Practically all services to farming are abundantly provided here. It can reasonably be said that here the barriers to higher yields have to do exclusively with solar radiation and with temperature regimes. These barriers can be removed only through genetic breakthroughs, rather than through better agronomic practices of production. Unfortunately, the high-quality land and water resources necessary to this success story are provided through large-scale irrigation and are limited, and so is the relative size of this subsector, which in Mexico accounts for less than 10% of nearly three million farming units.

The traditional farming sector of Latin America constitutes the largest proportion of its farming units. It is normally associated with limited services to production and marginal soils, and is dominated by traditional farming technologies. However, there are working relationships between the two subsectors, frequently through the labor market, that expose the traditional subsector to the use of modern inputs. In this way, pesticides and fertilizers are becoming the rule more than the exception in the traditional subsector. However, productivities of land, especially of labor, remain low and certainly could be increased. It can be said that there is an enormous potential for food production in this traditional subsector, but that the rules for developing the same are not well understood yet. It is obvious, though, that agronomy, in conjunction with other necessary disciplines, has yet to make its best contributions.

Maize is grown in Mexico almost exclusively within the traditional subsector, with yields that average 1.8 t/ha, over an area of 7.5 million hectares, and using about 50 man-days of labor per hectare.

In dealing with the question of how poorly adapted traditional technologies are to the current and future situation of less-developed countries, there are a number of facts relevant to the case of Latin America that I would like to discuss.

Traditional Farming Systems in Latin America

First, it must be said that Latin American technologies originated from an almost five-century old process in which native American and Indo-European know-how and resources were fused. This process has produced both families of technologies that characterize the market oriented and the traditional subsectors. In speaking of traditional technologies, two major types must be recognized: (1) slash-and-burn cultivation and (2) sedentary farming. The slash-and-burn type had been autarkic until recently, but demographic pressure on the land is shortening the previously used 16- to 20 year fallow period. This has brought two new challenges to the traditional producer: weeds and lower soil fertility. In the case of Mexico, where about five million hectares continue to be managed under this system, and more specifically in the Yucatan Peninsula where fallow periods are as short as four years, farmers are already using both fertilizers and herbicides in the second year of cultivation. The system is evolving out of autarky.

Many examples of nonautarkic, intelligent, and even elegant solutions to ecological barriers may be found in Latin America.

The sedentary type of farming in Latin America has variants that range from very advanced to poorly developed, within a traditional context. Examples of the better types of the former variant are the crops and dairy under confinement traditional mode of the high plateau of Mexico and the potato-maize-beans system of Rionegro, Colombia. In the first example, one can observe the native American agriculture (maize, beans, pumpkin, tejocote and capulin fruits, turkeys) and the European legacy (alfalfa, apples, pears, plums, holstein dairy cattle, hogs, sheep, hens, horses) combined by a technology binding all together, where modern inputs are commonplace. There certainly is room for advancement in this model, but the researcher must comprehend the prerequisites of the system, one of them being that mere agronomy does not provide all of the ground for improvement.

Refining Traditional Technologies

Many examples of nonautarkic, intelligent, and even elegant solutions to ecological barriers may be found in Latin America; by all means, one of them is the intercropping of maize with castor beans (*Ricinus*), developed by traditional farmers of the Oaxaca Valley of Mexico. This cropping system allows for year-round use of deep, medium- to heavy-textured soils, under a climate characterized by 600 mm total rainfall, that amounts to about one-third of the total evaporative demand. The producer harvests maize grain for home consumption and castor beans for the market, maize stover and castor bean foliage for feeding draft cattle, and also firewood. The soils receive moderate amounts of chemical fertilizers on a yearly basis and about five tons of manure per hectare, every three to five years. There is lots of room for improvement in this system, especially in the area of labor saving technology and of genetic improvement of castor bean ecotypes that could produce more foliage and denser wood. The model, which combines annual and perennial crops, is certainly useful for the intensification of land use with alternative perennial components, such as *Leucaena*, *Gliricidia*, *Cajanus*, and *Cactus* spp., etc.

These traditional farming systems tend to have in common an intensive use of the land in terms of time; they also frequently provide solutions for topographically marginal land, although, as a rule, limited concern is given to protection of the soil against erosion.

We researchers in Latin America have only recently begun to develop the tools to penetrate into this astonishing world of traditional know-how and to study the principles involved in developing alternative models suitable to different situations. I do not believe, though, that we will discard the rich set of principles of this traditional technology, when we will soon have to face the frightful world of the turn of the century, when probably all marginal land will have to be put into production.

I would maintain that to improve the role of agronomy in the development of the traditional subsector of Latin America a lot more effort should go into studying directly with producers the different patterns of technology adoption. This information should become an important tool for technology refinement. The prerequisites for a new technology should be examined, and practical rather than normative solutions should be adopted by researchers. In this context, I consider that the effort made by Latin American national programs on this subject is particularly insufficient. Evaluation methods, like those developed in the Puebla Project, should become widely used.

In dealing with specifications for improved maize varieties, I propose that weight should be given to quality of the consumed product, very much in the manner that it is considered with wheat. The quality concept in the case of maize has traditionally been equated with its nutritive value by the scientific community: total protein, the amino acid balance, the quality of starch, etc., are the basic criteria of quality. This seems to be a legacy of the 17th century European experience, when the Pellagra syndrome affected populations that consumed maize grain. It must have been then that Europeans decided that maize was adequate for animal feed, but inadequate for human consumption. Today, maize is used in the more developed countries primarily as animal feed and also as raw material for industry, and only marginally for human food (e.g. sweet corn). In Mexico and Central America, maize grain is widely used as human food, and the alkaline processing involved in making tortillas releases enough niacinogen that it prevents the Pellagra syndrome. The high yielding maize varieties of the midwestern United States are excellent for hog-ration formulation, but terribly poor for making tortillas, as my countrymen have learned in the last decade.

We must also realize that, compared to that of other cereals, maize stover is excellent as a fodder and that a short plant is not always convenient for animal and plant husbandry in integrated farming.

The authors' excellent coverage of the topic of soil protection must be commended. I can add very little to it in the Latin American context, except perhaps to urge that the implementation of soil protection techniques must be intimately associated with improved production and labor-saving technologies. Operational considerations and efforts in farmer education become central to the adoption of the new soil protection technology. Structural changes in the farm unit to introduce animal husbandry will create the need to produce green forage and at the same time produce manure for the soil. This will in turn provide opportunities for land use that better corresponds to the land's capacity.

I submit that the use of pesticides in traditional farming, particularly in what has been called "conservation tillage," should be considered more as a "necessary evil" than a "miracle solution" in solving problems such as soil erosion, labor shortages, inefficient use of water, etc.

Experience in Latin America reveals that traditional farmers seldom observe minimal protective measures and are primary targets of carcinogenic, teratogenic, and mutagenic long-term effects of many pesticides. We have observed boys drinking water from Paraquat containers. This herbicide is a deadly poison when accidentally ingested. In the Ejido Juan Jacobo Torres, Veracruz, Mexico, farmers have adopted Paraquat technology so well that they even follow the rule of washing and boiling the Paraquat container in detergent and then using it as a convenient receptacle to carry drinking water to the fields. Another example is the use of Lindane in maize and dry beans for post-harvest protection. Farmers have discovered that this insecticide is an inexpensive and widely available method for preserving their grain for long periods. Even though normally somebody in the family can read, they choose to ignore the warning of the manufacturer that the product should only be used for planting seed and not for grain protection. When questioned about this danger, they frequently argue that they have been using the same product for almost 10 years and nobody has ever gotten sick from it.

Conclusion

I would like to make a final comment on the weaknesses of research and development systems. This comment is directed more toward the national than the international context. It is traditional that the central research systems of Latin American countries have very poor relationships, if any, with the national university systems. This situation frequently stems from the dogma that the institutes' business is to conduct research, whereas that of the universities is to teach.

This dogma has prevented the well-known interactions that take place between the two groups in the more developed countries and that have contributed so much to the advancement of science and of productivity. The state-level university could deal very efficiently with local, specific problems, whereas a central research system could concentrate on problems of regional and national scope. This would concomitantly improve the quality of education through practice, and at the same time make government funding more effective.

We Latin American scientists should not let present university problems, such as student strikes and lack of human and material resources, prevent the development of a long-term fruitful relationship. At the same time, the international scientific community and donors should address the problem of how to balance the investment in short-term solutions that tend to perpetuate the need for foreign assistance, with the investment in institutional development that will decrease dependence on foreign assistance.

Human Resources Development: Transfer of Technology

M. Catley-Carlson
Canadian International Development Agency, Hull, Canada

There is at least one wish that is common to people of all nations, ideologies, and ages—for there to be more food, enough for all the hungry people in our world. At times this has seemed an impossible dream. As recently as a dozen years ago at the World Food Conference, most of us didn't believe the world could grow enough food for all its people.

Well, surprise! In 1986 we can say that impossible dream actually seems to have come true. We can now see that during the third quarter of our century world food production outraced global population growth. The plow was quicker than the stork—for a while, at least. True, we still have as many hungry people, maybe more—but we now know, and are acting on the fact, that their hunger is mainly a function of poverty, not of food scarcity. You have heard during the past two days some of the details of how increases in food production were accomplished, from some of the miracle-makers themselves, and you have heard some thoughts about what we must do next to revive the stalled increase in food per capita, to trigger Phase Two of the Green Revolution.

This 20th Anniversary of CIMMYT is an ideal time to reflect on how the miracle came about, and to pay tribute to the people and the institutions who made it happen. In fact, we should be saying a small prayer of thanks every day, because it is frightening to think what shape our world would be in if we *hadn't* had these giant steps forward in agricultural productivity. Unquestionably, we have been spared a great deal of turmoil, suffering, and horror.

In a way, what the Green Revolution has achieved is that it has bought time for us. It has given us a couple of precious decades to get our global house in order—to find a way to balance our limited resources with our growing numbers—before the lingering truth of that vile but venerable equation, constructed by Malthus almost two centuries ago, reasserts itself in scenes of famine and chaos. Are we using that gift of time wisely? I leave it to your judgment. The big questions now are, I think:

- How do we sustain the recent increases in agricultural production, both ecologically and economically?
- How do we keep this kind of agricultural progress going, now that the best opportunities, the easiest advances, have been taken advantage of, and absorbed into the system?
- How do we spread the Green Revolution to the countries and the classes of people who have been bypassed, but who need it most?
- And, when the priesthood of agricultural science actually does come up with the real goods, the breakthroughs and miracles, how can we forge better links between labs and life, how can we get the results out of the test tubes and into the buckets and shovels?

The topic for this session is "Human Resource Development: Transfer of Technology." We must know something about it—after all, each of us *is* a human resource. But the rest is very problematical—there are as many ideas here today of what "development" means as the number of people present in the room. And our ideas are likely almost as divergent about what "technology" signifies, and about how you should, can, or can't "transfer" it. One thing I'm sure of is that we won't reach unanimous agreement, but diversity of views at least allows us to learn from one another.

Planting the Seeds of Progress

Human resources and technology transfer is an area of overlap, where the activities of CIMMYT, and of the Consultative Group on International Agricultural Research (CGIAR) as a whole, coincide with the concerns of the Canadian International Development Agency (CIDA) and of all the other institutions represented here. I approach this question, naturally, from the viewpoint of a donor government and a funding agency.

Knowledge has no impact, is almost pointless, unless it is passed along through training to enter into the affairs of the world.

What are we putting into CIMMYT and the rest of the international network of agricultural research centers? Quite a bit—about 15 million of the Canadian taxpayers' hard earned dollars, making Canada, I believe, the second largest national contributor to the centers' core programs. For good measure, we are also the leading sponsor of projects that are funded bilaterally by a donor country, but executed by the CGIAR and its members.

What are we getting for our money? Good value. I have no doubts about that. The Green Revolution itself, and the centers' vital role in the process, in so many countries, is an obvious and overwhelming justification for the relatively modest amounts of funding the CGIAR receives. There is really no question that the Canadian public, insofar as it is aware of the centers, is more than willing to see aid dollars put into their work, and fully agrees with this kind of long term investment in self-reliance.

We also see the CGIAR as one of the important agents in the broad advance of Third World scientific and agricultural knowledge. Canadians as a whole recognize that the imbalance becomes downright scandalous when less than 5% of the world's research and development is focused on the needs of three-quarters of humanity. We believe that the best way to correct the imbalance is to contribute to the improvement of national capabilities in research and development throughout the developing world. That's why the Parliament of Canada created the International Development Research Centre (IDRC), and continues to fund its efforts to sponsor research in, by, and for the developing countries. And that's also one of the reasons why Canada has been one of the major donors to the CGIAR.

To get more specific, another result we see when our aid dollars are invested here is the training activities carried out by CIMMYT and the rest of the CGIAR network. "Training is everything," said Mark Twain, and while he wasn't thinking of agricultural research, he was quite right. Knowledge has no impact, is almost pointless, unless it is passed along through training efforts so it can enter into the affairs of the world.

I understand that, over its 20 years, CIMMYT has provided a great diversity of training opportunities for more than 4000 people from close to 100 countries—most of the training practical in orientation, and most of the trainees young but already with significant work experience in their fields. Further, I believe that more than half of these were "in-service" trainees already working at the middle levels of national agricultural services in such countries as Algeria, Bangladesh, Pakistan, Peru, Tanzania, and Turkey. That is a record you can be ...not satisfied with, because there's still too much to be done... but proud of. It represents, we can all appreciate, an important step in building the absolutely essential foundations of the national agricultural knowledge systems that *must* be created in all parts of the Third World if we are to face the global food problem head-on, and win the war on hunger, permanently.

I think we all realize how important the training opportunities offered by CIMMYT have been, both in spreading the Green Revolution and in planting the seeds of future progress around the globe. That is why we are so happy about the inauguration of the new training facility, with all the promise it holds.

It has been evident for at least the past 10 years that the effectiveness of international agricultural research centers depends very directly upon the ability of developing countries to absorb and adapt scientific knowledge and technology. And that ability, in turn, grows only if stronger national agricultural research systems develop within the Third World. And the partnership between international and national centers can be fully effective only when they work closely together on such vital issues as identifying priorities, setting the research agenda, and determining training needs. In all of this, the key term is a full and complete *partnership*.

There is one more thought I would like to put forward for your consideration, while we're talking about training and partnership. It seems to me that the time is ripe to try some different approaches and draw on some relatively new resources. I'm thinking particularly of the now quite substantial numbers of well trained people—quite a few of them trained by CIMMYT—who are at work and in place in some of the more advanced and sophisticated Third World countries—the Indias, the Brazils. I think it would make a lot of sense for such people to be adding a new dimension to partnership by working with and helping to train their counterparts in the less fortunate developing countries. After all, there are an awful lot of local needs out there in the Third World, and CIMMYT can't train everybody, and maybe those who have already benefited have an obligation to help others through some form of South-South partnership and cooperation. I would be very interested in your thoughts on whether this has any potential, and how it might work in practical terms.

So, to sum up, from the viewpoint of a donor, Canada is extremely pleased to have had some supporting role in CIMMYT's first 20 years of success and achievement—but less than confident that we now have all the answers to the global food question, or that we are doing all that needs to be done, or even that we are necessarily headed toward a happy outcome.

Toward the Year 2000

If we try to look forward, we can see light up ahead, but we can't tell whether it's a new day dawning, or a locomotive racing toward us. One way to get our bearings, to come to a realistic appreciation of our present situation, is to cast our minds ahead—say, to the year 2000, the end of the century, the end of the second millenium—and ask ourselves, "Where do we want to be in the year 2000? And what do we have to do to get there?"

The answer is, of course, "We want to have a well-fed world." We want to have enough food, so equitably shared, that no human born on earth will be prevented by malnutrition from developing, physically and mentally, to the full potential of his or her genetic inheritance.

We already know that this means making food available to the half-billion to one billion people who, this very day, will not eat enough to sustain their strength fully. And we can foresee that, on top of this, it also means raising enough food to provide for the extra one billion plus people who will be added to the world's population by the year 2000. We also know, already, a few details: that 90% of these new people will be born in the Third World and, by the year 2000, half the population of the developing countries will live in cities, as the result of a massive demographic shift without precedent in human history.

We know, too, that the extra food we need must come essentially from your work, from qualitative progress as a result of agricultural research. We can't meet new needs in the way it was done through most of our history—by putting new land under the plow. We've taken that approach as far as it will go, and beyond. Prime agricultural land is being lost every year—to inappropriate agricultural policies and farming practices, to the spread of cities and villages, to factories and roads and parking lots, and to housing for the growing billions.

We want to have enough food, so equitably shared, that no-one will be prevented by malnutrition from developing, physically and mentally, to his or her full potential.

And the new land being tilled is increasingly marginal, which means lower productivity, erosion, desertification, and environmental decline. As people scramble to grow crops and raise herds in the foothills of the Himalayas, or where tropical forests recently stood in Latin America, or in semiarid African bushland, we are losing ground—about six million hectares a year is turning into desert and we are losing perhaps twice that area each year from our remaining forest. In total, about one-third of the world's people now live in countries where cropland area is shrinking. The only possible solution is that we must farm smarter on the good land, and reap bigger harvests from improved crops.

This is exactly the mandate of CIMMYT and the CGIAR—to show us how to produce those harvests and crops. But the world is not a laboratory, where conditions can be controlled and results reproduced time after time. The world is, rather, a wonderfully complex puzzle-house, where it's a long jump indeed from cause to effect, and the expected result of an intervention can be blocked or changed by more factors than anyone could count—by factors psychological, cultural, political, motivational, financial, climatic, and on and on.

So agricultural research on Third World crops is certainly essential. Those who work for CIMMYT or the CGIAR, the other research centers, or elsewhere in a national or international research organization, are in a sense the hinge on which we can swing open the door to a future without hunger. But there's more to getting through that door than knowing the hinge works.

Elements of Agricultural Change

To get where we want to be, to live in a well-fed world by the year 2000, we need to tackle a whole lot of other crucial questions beside research. We need good answers to a host of problems that are chiefly social and political in nature.

For instance, land use, as I already suggested, is of urgent importance. After the lesson of Africa's crisis over the past two years, I don't think it's overstating the truth to say that land use presents us with a global emergency. But there's another closely related dimension of that problem in the question of land distribution.

As population grows, the amount of cropland per person shrinks. Smallholdings are divided among the farmer's children, each receiving a plot too small to maintain a family—or are passed to the oldest son, leaving the others as landless laborers, likely migrants to the swelling urban slums, *favelas* and *bidonvilles*. And land ownership tends to trickle up as the larger landholders, able to afford the new technology, use their profits to buy out those whose plots are too small and who cannot afford irrigation and fertilizers for the new high-yielding varieties.

In many places, land reform is badly needed to maintain some degree of employment equity and social stability. But history shows how difficult land reform is to carry out, despite the benefits it has brought to, for instance, Korea and Taiwan. Those who already have the most land are normally those with the most political power and influence. Since the landless are almost always unorganized and without a political voice, it is very difficult indeed to see a political solution to this dilemma, except in isolated and extraordinary cases—sometimes in the context of aid projects.

Yet another crucial question, on top of land use and land ownership, is agricultural credit. Again, those who have are those most likely to get. The large landowner, prospeıous and plugged into his society, has access to its credit system and can invest in the new technology far more easily than the small-scale, marginal farmer. And if it's tough for the small-scale farmer, the credit crunch is absolutely ferocious for Third World women. Essentially, they are automatically shut out of the system. And yet, they *need* credit, and can put it to good use—as shown by the success of one of the rare initiatives in this area, Women's World Banking. Up to last year, this pioneering organization had helped 20 banks around the world provide 1000 loans to women, mainly in developing countries. Number of defaults? Zero. I'm happy to say that, as part of Canada's special effort to help Africa recover from its crisis, we are providing CA$ 3 million to help Women's World Banking increase its impact there. But so much more needs to be done.

Extension is another aspect that is especially relevant to the work of CIMMYT and the other CGIAR centers. Unless new knowledge is spread to the smallest farmers, it will not yield maximum benefits, and it may only add further to a growing gulf between rural rich and poor. But extension services have mostly been spotty at best in their performance, and are often understaffed, ramshackle, and ineffective. As a matter of urgency, we need efficient systems that are well enough organized and funded to reach the furthest village and the smallest field. There is not much point in investing in knowledge, and then failing to make it known—we should be putting as much money and effort into spreading the message as we are putting into discovering what the message is.

Community development is one more key to greater food production. By improving education, or health, or the local water supply, or training local leaders, community development efforts can remove some of the barriers and handicaps holding rural people back from what they *could accomplish*. Investments in what seem to be unrelated fields can actually boost productivity, as documented by a World Bank study showing that a farmer with just four years of basic education produces 8% more than a farmer without that schooling, even where agricultural inputs are not available. Just as there are negative linkages between sectors—a sick farmer is an unproductive farmer—there are positive connections, too. So efforts such as Canada's Africa 2000 initiative, which aims at having 2000 village-level, grassroots development projects under way by the end of next year, with broad participation by Canadian voluntary agencies and community groups, as well as African nongovernmental organizations and village councils, are also part of the push for a well-fed world.

I will mention just one more of these seemingly nonagricultural factors that in reality are decisively important to agricultural progress. If you set out to change a society, to foster social and economic progress, and you systematically ignore half the people in that society, you just leave them out of your plans, it doesn't take brilliant analysis to reveal that you are setting yourself up for failure. And yet, that's exactly what development planners did for decades—with some honorable exceptions, mainly among the voluntary agencies.

Projects and programs were designed, carried out, and evaluated, when indeed there was any evaluation, as if only men populated the world — as if women were *objects* of development. This was, to be charitable, less than astute, when women were, in the reality of daily life, not only the front line troops in the war against disease, ignorance, and malnutrition, within the family, but also a large part of the agricultural work force — so much so that it is quite realistic to say that in Africa "farmer" is a feminine noun. There were all too many cases of extension services providing training to the men for agricultural work that is done by the women — an error so basic it would be funny, but for the tragic waste.

If you set out to change a society, to foster social and economic progress, and you systematically ignore half the people in that society, you are setting yourself up for failure.

We've come some distance in recent years, partly because of the United Nations Decade for Women and the international conferences connected with it, and the flow of information, ideas, and data it helped generate. In CIDA we've moved ahead rather quickly in the past two or three years in regard to taking women into account as a decisive part of development efforts. We've moved, in fact, from a state of enhanced awareness and readiness, to a point where the role of women, as agents and beneficiaries, is analyzed as an integral part of the planning of every project and to the point where Women in Development, the WID factor, is a real element in the project officer's job description, subject to the same standard of accountability as any other major factor. I hope that many other development agencies and organizations are, like CIDA, fast approaching the stage at which they have difficulty taking seriously anyone who claims to understand development but still overlooks the key role of women.

Why have I talked about all these elements of agricultural progress — land use and land reform, credit, extension, community development, the role of women — when they are not primary concerns for CIMMYT and the CGIAR? Because they should be at least very active concerns, both for the organizations and for the people involved in them, whether staff or trainees.

Shaping Future Research

So, what would I change in the way we go about research and development for the next 20 years?

First, let's get permanently beyond the stage of "It's not my responsibility to make sure it *actually* works." Chernobyl and Challenger have shown again the folly of relying on systems that don't take into account human frailty and foibles. This advice that I'm handing out so freely cuts in all directions, of course, and applies to government aid agencies just as much as it does to agricultural research centers. It came, for instance, as a horrifying shock to aid administrators and policymakers to realize that, if there had not been so much food aid, Africa's food crisis might not have happened. Realizing this is only the start of, we can hope, greater wisdom.

I would suggest that a key consideration in *your* thinking should be that the technologies and farming systems flowing out of your work should promote increases in agricultural production that are sustainable over the long term, ecologically and economically, culturally and socially. I don't mean that, on top of research mandates, I expect you to go out and solve all those other problems. What I *do* expect is that you will be fully alert to all the factors that shape the actual results when your research is put to use — partly so that increased insight will give you more influence over that process, and partly so that you can in fact work deliberately and consciously to build, from your end, the linkages that are needed between agricultural research and the most humble peasant in the smallest field. It takes two to make a linkage.

Second, we *all* need to spend more time listening to the people who are supposed to be the object of all our development efforts. We need to establish in our timetables *real time* to go into the villages and the fields and see what is really happening. Maybe for every hundred hours spent in the lecture hall or the laboratory, three *real* hours should be spent in a peasant's hut or a remote maize patch. After all, in the wise words of Yogi Berra, "You can observe an awful lot just by watching." And even more can be learned by dialogue, by asking the right questions to the people whose voices are seldom heard, and whose lives and futures are most at stake... whether things are getting better or worse, what needs are the most pressing, and what help would be the most useful.

CIMMYT now has a 20-year record of important contributions to human well-being, to the war on hunger. If I were to prescribe an agenda for its next 20 years, I would say: first, give us more of what you have already given us, research that enables us to grow more food through better crops and methods; second, give the developing countries even more help in their effort to strengthen their own national systems of agricultural research; and third, help us build all those linkages that are needed between your research and the Third World farmer, by way of all those other required elements. And, for good measure, let's get on with bringing the Green Revolution to Africa.

And if this seems a lot to ask, remember...you have already helped one agricultural miracle to happen. All we want now is another—a well-fed world by the year 2000.

Discussion

G.T. Castillo
University of the Philippines, Los Baños, Philippines

After listening to the President of the Canadian International Development Agency (CIDA) this morning, those of us from the Third World can be confident that at least part of international development assistance is in the hands of someone who understands development defined in the most humane way.

My vision of human resources development involves the improvement of human capacity and capability to take advantage of what the world has to offer so that a person is not in a state of perpetual disadvantage.

Let me kick off the discussion by saying that in the Consultative Group on International Agricultural Research (CGIAR) system there are two popular concepts with which I am not very comfortable: (1) *comparative advantage* and (2) *technology transfer*. Perhaps it is naiveté that gives me the discomfort, but nevertheless I wonder how much of the inequality in our respective societies and in the world at large has been justified wittingly or unwittingly in the name of comparative advantage. Isn't comparative advantage something that can be acquired, given the opportunity and the wherewithal? My vision of human resource development involves the improvement of human capacity and capability to take advantage of what the world has to offer so that a person is not in a state of perpetual disadvantage. In the process he improves his comparative advantage.

As Soedjatmoko of the United Nations University puts it:

Today the world is witnessing a widening of the gap between those with ready access to information and those lacking in such an access. The development process is essentially a learning process. Development succeeds when a society as a whole and at all levels learns to make optimal use of its resources through the application of science and technology to improve the daily lives of its citizens in ways that are consonant with their basic values and aspirations.

Yona Friedman, a well-known independent architect, says that "An essential prerequisite for a country's economic progress is to increase the national store of applicable knowledge. Such an increase means the increase of the average level of knowledge rather than boosting the sophisticated knowledge of a small part of the population."

As I dream of what might be possible, my admiration turns to the plant breeders (they are my favorite people) perhaps because they can play God in a way that I cannot. Their horizons are limitless when they think of potentials. Why couldn't we look at human resource development in the same way?

The technology transfer model that conjures an image of a one-way transfer from international centers, to national agricultural research systems, to extension, to the farmer, is neither a very accurate representation of reality nor a very attractive model for international center-national program collaboration. The Third World environment for agricultural research and for farming is not exactly the same as it was 20 years ago. From what little I understand, *even germplasm* is internationally contributed—with much of it coming from developing country sources of diversity. And no matter how weak a national research system might be, it is not a vacuum. Furthermore, when farmers adopt new technologies, they almost never adopt them the way they have been introduced. They always make adaptations to suit their particular circumstances, and that's why these technologies work.

Yesterday, someone showed a slide that portrayed the international *centers* at the center, with national programs revolving around them. My perception of the world is slightly different. As Margaret Catley Carlson said, "Less than 5% of the world's research and development is focused on the needs of three quarters of humanity." How about putting three quarters of humanity in the center of the universe, with the international centers focusing their activities on it?

In many ways we have done most of the easy things. As we move from the favorable to the more unfavorable production environments, and from the better-endowed farmers to those who are more resource poor, achieving a good fit between experiment station and actual farm conditions becomes more and more problematic. Furthermore, the single commodity farm gives way to a farming systems scenario with a combination of crops, livestock, and multipurpose trees, including off-farm and non-farm sources of income. As a matter of fact, the farmer who grows only corn, wheat, or rice is relatively rare even under favorable growing conditions. Moreover, even a single crop such as corn can have multiple uses such as human food, animal feed, and fuel. To what extent do the relevant international agricultural research centers (IARCs) get together to deal with the real-life farming systems scenario, rather than each one approaching only their particular component of the total small farm, so that CIMMYT comes with corn, wheat, or triticale; IRRI comes with rice; CIP comes with potato; and so on. The real world does not adjust to specific center commodity mandates!

In addition to all these complexities, we are simultaneously concerned with issues not only of productivity but also of equity, employment, sustainability, and stability.

As stated in *A Common Ground for Maize Research: Regional Cooperation in the Middle East and North Africa*, CIMMYT Today No. 17, "The most adept manipulation of maize germplasm is no guarantee that the resulting varieties or hybrids will be adopted by farmers and make a noticeable difference in their production and income."

This realization is gradually giving way to approaches that bring the research closer to actual farm conditions to "better understand the problems and needs of farmers and serve as an instrument for developing technology that meets those needs." As one scientist who is doing on-farm research expressed, "'You have to become as careful an observer as the farmers are, which isn't easy when you consider that their knowledge of the maize crop is incredible. I grew up in this region and once prided myself on knowing it well. But through our on-farm research project, I'm learning how much I didn't know and am getting a chance to remedy my ignorance.'"

It has also been argued that "part of the value of on-farm work is that it brings the farmers' wisdom and experience into the process of technology development."

Although this beautiful training facility is admirable, I worry a little bit that trainees will spend too much time inside and not enough time outside. Coming from a developing country, even with an agriculture degree, is no assurance that someone has been sufficiently exposed to farms, farmers, and farming. Studies in the Philippines, for example, found that the majority of farm management technicians and pest control officers in two provinces have had no direct experience in rice farming.

The current vocabulary empahsizes: on-farm, farming systems, farmer participation, joint activities between those who develop and those who disseminate new agricultural technology, etc. They key word is *relevance*. If what we are doing is not relevant, it does not matter how rigorously we do it.

Coming from a developing country, even with an agriculture degree, is no assurance that someone has been sufficiently exposed to farms, farmers, and farming.

These developments have far-reaching implications for human resource development strategies from the farmer, to the researcher, to the extension worker, to the policymaker. The cultivation of a scientific spirit among farmers, the development of a farmer-orientation among scientists, and the enthronement of an understanding and a heart in the right place among policymakers make up the challenge for the next decade.

The Green Revolution literature is replete with positive and negative accounts of its impact on growth, equity, and employment, but hardly anyone mentions that technological changes have ushered in a new era of science-based agriculture in a way that has led farmers to novel ways of thinking about and managing the farm. It might have been a Green Revolution in farmer's fields, sometimes with a checkered performance, but much more positive, profound, and lasting in its significance is the "science intrusion" into farmers' heads. This intrusion, in creative combination with old practices and accumulated wisdom, enables farmers to apply the new technology.

To illustrate, one of the first studies done soon after the release of the first IR variety found that farmers who grew both the new and the old varieties treated them differently. To the former they gave a great deal of tender loving care; the latter, they left pretty much to God. Another more interesting illustration of the desire to keep up with what is new is reflected in the case of a farmer who, when asked what variety he was using, replied, "IR20." But when queried, "Why are you using IR20? Don't you have brown plant hopper here?", the reply was, "Brown plant hopper? What's that? I'd like to have it, too."

One experienced extension worker also observed that farmers who have been exposed to and have adopted new technologies get bored in farmers' classes if the subject matter is too elementary. He therefore believes that we should now be interacting with farmers at "Level III" instead of "Level I." Farmers are not only interested in the what and how; they want to know why.

What we are hoping for now is a complementary process of "farmer-instrusion" into scientists' heads so that their research would meet the needs of resource-poor farmers, many of whom are women, whether they are tillers, co-managers of the farm, sole managers, decision-makers on matters that relate directly or indirectly to the farm, or users of technology and its by-products.

Research reports available to us from India, Bangladesh, the Philippines, and Nepal indicate that the majority of women studied who are involved in farming activities are eager to participate in agriculture-related training, despite their busy lives. They believe they can still find the time to do so. As one Filipino farm wife put it, "Learning about new agricultural technology is more interesting than doing housework." What is so wrong about defining women as members of the human race eligible for human resource development?

Strengthening National Agricultural Research Programs

P.R.N. Chigaru
Department of Research and Specialist Services,
Ministry of Lands, Agriculture and Rural Resettlement, Harare, Zimbabwe

In addressing this topic, I have assumed that I am expected to give my perceptions, as a leader of a developing country national agricultural research system, about how the international agricultural research centers, as a whole, might more effectively pursue their stated goals of strengthening the national agricultural research programs of developing countries. I must confess from the outset, however, that I feel constrained in this task because I believe that I have nothing new to offer on this subject since it has formed the topic of debate in many a seminar, workshop, or conference and quite a number of articles and even books have been written about it

The latest efforts I am aware of in this regard include the report on the discussions of an ad hoc group which took place at Bellagio, Italy, in January 1986, where future strategies for the Consultative Group on International Agricultural Research (CGIAR) in the light of the Technical Advisory Committee (TAC) Priorities Study and the CGIAR Impact Study were considered. In these discussions, the need for refinements in the approach by the CGIAR to determining research priorities for the system was alluded to.

In February 1986, I also took part in the deliberations of the international agricultural research centers (IARCs) on farming systems research at a workshop held at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). One of the preoccupations of that workshop concerned the need for IARCs to evolve a common strategy on how to assist national research groups in the field of on-farm or systems research. The Special Program for African Agricultural Research (SPAAR) Working Group for Preparation of Guidelines for National Agricultural Research Strategies in Sub-Saharan Africa has also produced a draft document dated June 1986 on Guidelines for Strengthening National Agricultural Research Systems in Sub-Saharan Africa. I understand that a final draft of this document will be presented at the SPAAR in October.

Central to any discussion of the subject of strengthening national agricultural research programs are two fundamental aspects. First, it is recognized that national research programs or systems are the clients of the international research centers and their donors. Second, the targets of the research programs and projects of the centers, and indeed of the national research programs themselves, are the farmers, in any given country. Consequently, the research activities of the center are supposed to complement those of national research groups.

In this scenario, each IARC is viewed as possessing comparative advantages through its ability to assemble experienced international scientists at key locations around the world, and in moving information, technology, germ plasm, and other materials across international boundaries. By contrast, the comparative advantage of national research groups should be in their ability to undertake the adaptive research essential to generating recommendations that fit into given local and specific farming situations. Stated in this simplistic fashion, however, the relationship between international centers and national research programs would appear to be one that should be reproducible by every center in every developing country

Unfortunately, in real life, the situation is more complex. There are two main reasons why this is the case. On the one hand, the activities of the centers and the approaches that they have adopted vary greatly because of the diverse nature of the centers themselves and the mandates that have been thrust upon them by the system. The centers are heterogeneous groups working on different commodities and problems and, in many instances, they may serve different regions of the world. On the other hand, the national research programs also exhibit extreme diversity due to differences in the stage of economic development of each country, its population size and density, its stock of human capital and natural resources, and the availability of technology. In addition, there is also serious heterogeneity in agricultural conditions, political systems, and ideologies, all of which have direct or indirect influence on agricultural development generally and on agricultural research in particular.

It is clear therefore that it would be a vacuous exercise to attempt to generalize on a world scale on how national agricultural research programs should be strengthened. Personally, I have little first-hand experience of agricultural development in Asia and Latin America and of the agricultural research systems that have evolved in these regions.

It is therefore unwise for me to attempt to give informed judgments on how these systems might be strengthened. My reading of the literature, however, particularly the CGIAR Impact Study, persuades me to believe that agricultural research systems in these two regions are relatively more advanced than those in sub-Saharan Africa. They appear to have grown rapidly over the past two decades and are increasingly making effective contributions to agricultural development in these two regions. By contrast, sub-Saharan Africa remains the only major region of the world where food production per capita is declining. It is also the only region where population growth is outpacing the rate of production. Indeed, between 1970 and 1984, food production in Africa grew at roughly half the population growth rate of about 3.2% per year. For these reasons, therefore, and the obvious fact that I am an African, I hope you will accept that I have felt compelled to devote the rest of this paper to examining agricultural research in Africa and how this might be strengthened by the international research centers and the donors.

Nevertheless, despite what I have stated above, I am sure that there are certain problems facing African research programs that also occur in both Asia and Latin America. By the same token, there are a number of lessons that African research administrators and their scientists could learn from these two regions and vice versa. Although Africa looks to the centers for assistance in improving its national research programs, it can also profit from studying the situations in countries such as India and Brazil not only for the purpose of gaining insight into how such countries have treaded the path of agricultural research and development but also in order to avoid any pitfalls that these countries may have encountered.

In the next section of this paper, some of the challenges facing African agriculture are highlighted, including the manner in which past efforts have attempted to address these problems. The core of the paper is the third section, in which the main issues that need to be examined in the process of strengthening national agricultural research programs are discussed. I conclude by making suggestions about the approach that CGIAR centers and the international community should adopt in their quest to help Africa overcome its agricultural problems. In discussing these issues I have drawn freely from the background information and progress reports of the SPAAR program.

The Core Problems

Good harvests during 1985 and 1986 have dramatically changed the short-term food outlook of most African countries. But beneath this welcome turn of events are four long-term problems:

- The race between food production and population;
- Lack of jobs in the rural areas;
- Pervasive poverty, malnutrition, and food insecurity; and
- Agricultural diversification and rural industrialization.

These problems are described in detail by Eicher and his colleagues (1986) in a number of articles written on sub-Saharan Africa generally and the Southern African region in particular. The current population growth rates in Africa range from 2.5 to 4.1% and imply a population doubling time of 15 to 25 years. This rapid population growth rate is increasing the pressure on food supplies and the natural resource base. In many states population and income growth will generate food needs requiring food output to grow at 4 to 5% per year. Unfortunately, however, the historical record shows that only a few countries have sustained 3 to 4% annual growth rates of food production for a decade or more. As a result, therefore, there is a stark need for African countries to develop strategies that would enable them to expand food production efficiently.

The other core problems mentioned above all derive from this important problem of population growth being higher than food production. There is also the point that about 70% of African people live in the rural areas because of the inability of the industrial, urban, and service sectors to generate adequate jobs. About a quarter of the people were estimated by the Food and Agricultural Organization (FAO) to be hungry and malnourished in 1985. Hunger and malnutrition in rural areas are caused primarily by one or more of the following:

- Lack of access to land for families to produce adequate food;
- Low productivity of family labor on subsistence farms;
- Drought-induced instability of food production; and
- Poverty prevents families from purchasing adequate food on a timely basis.

With respect to diversification and rural industrialization, it is noted that many African countries have the potential of meeting the grain needs of their people for the foreseeable future. Diversification away from cereals is, however, desirable and an inevitable long-term process. There is a need for substantial investment in agricultural research in order to lay the foundation for gradual diversification away from grain. This research investment should be broadly allocated to food crops supported by the centers, those not supported by the centers (e.g., fruits and vegetables), and to cash crops, fisheries, etc. Increased emphasis on soil fertility problems, soil and water management including irrigation, forestry, climatology, and so forth is also needed.

There is a stark need for African countries to develop strategies that would enable them to expand food production efficiently.

Strengthening African Research System Capacity

National Research Strategies

It is recognized that every country in Africa needs some research capacity. The smaller countries need the ability to test and adapt varieties and other technologies from regional or international programs, and the larger countries need a full-fledged research system. The major problem at the present time, however, is that most African research systems, where they exist, are in decline and produce fewer useful results than in the past. Indeed, there are cases where the national research systems often form a bottleneck in the continuum between basic research and the adaptation and application of new technology at the farm level.

The question of the optimum size of a national research system and the level of funding that it requires is therefore a difficult one to answer. Many African national research systems absorb a higher proportion of agricultural gross domestic product (GDP) than their more efficient Asian counterparts. Most are considerably larger in terms of trained personnel and physical resources than they were 20 years ago. Yet in the meantime their effectiveness has, with few exceptions, declined. A large part of the problem derives from misdirected growth and growth impossible for the national programs to sustain. Such issues cannot be solved by merely pushing more financial resources at these systems. Strategy, quality of research, management capacity, and financial sustainability must be paramount.

With the tremendous resource contraints facing many African countries, prioritization of research requirements within the framework of a national agricultural research strategy is crucial. Such a strategy must not be developed in isolation but should fit into an agreed national agricultural development strategy. It should be accepted that most countries cannot afford "optimum" programs. Strong efforts therefore need to be made to decide which research interventions have to be conducted with existing capabilities, which research requirements can be "imported," and which requirements have to be put off to a later date. This decision-making process is often painful, the more so because donors are often able to offer assistance for certain research interventions. The temptation to accept such assistance is great but sustainability in both manpower and financial terms should be the guiding principles.

It follows therefore that, in framing agricultural research strategies, which most African countries have not done, the issues of sustainability and absorptive capacity are of absolute importance. Absorptive capacity includes the issue of administrative capacity. Where national administrative capacity is judged to be weak, national research structures and programs should be kept small and highly focused. Sustainability is closely related to scale. There are institutional pressures, particularly from donors and the centers, to make projects larger. These are particularly strong where the unbalanced growth of particular components in the research system has created disproportionalities. One easy way to correct this is to make everything else grow to catch up. This solution, however, carries a real danger of creating an unsustainably large system.

Financial Organization and Management Aspects

Finanical organization and management aspects are often underrated in their impact on agricultural research because research managers and planners are primarily technical specialists. Yet finance is one of the most important criteria of the size and effectiveness of research programs. Funds need to be provided on a sustained basis to be used in the most cost-effective manner. To achieve this, a careful analysis has to be made of all sources and applications of funds.

African research systems therefore need a steady growth of funding from national sources for agricultural research. At the present time, too many countries take the easy way out by using donor assistance to augment shortfalls in national research funds. While this is acceptable in the short term, care must be taken in order to ensure that such "easy" funds do not lead to the distortion of national priorities. Donor funding of research components should always be preceded by a careful assessment of whether it fits into the agricultural research strategy, and how it affects the whole national agricultural service.

One of the pitfalls of donor funding to date has been its usual short time horizon. It is pleasing to note, however, that the international donor community as a whole has now recognized that it will take 10 to 20 years or even more for some African national research systems to be developed in order to make them efficient and effective.

On the question of fund allocation to research, the following issues have to be addressed:

- Balancing national and donor funds;
- Balancing allocations to basic, applied, and adaptive research;
- Balancing allocations to research and research support services; and
- Balancing staff costs with research expenditures.

With respect to the last point, an analysis of most African research systems since independence reveals a seemingly in-built mechanism that, in the course of time, the percentage of salaries in the total budget increases while that of the nonsalary components decreases. This is not an easy problem to overcome because governments would find great difficulty in reducing staff and each general salary increase for government employment has to be absorbed. An analysis of this situation is overdue, however, and most developing countries would benefit from guidelines on optimum action for salaries compared to other expenses.

General Impact of International and Regional Research

Most African scientists recognize the important role played by the international research centers in Africa. Their involvement is becoming increasingly manifest. The centers, however, are not always able to respond positively to requests from some countries or to participate in certain research projects or components funded by donors. There are a number of reasons why this is the case:

- Centers do not see their role as that of providing counsultancy services or being sources of technical assistance;
- The mandates of the centers are often not clearly understood or are misintepreted, so that more is expected of them than they can deliver; and
- Almost all the centers suffer financial and manpower constraints that hinder them from fulfilling their mandates fully. The International Livestock Centre for Africa (ILCA) and International Institute of Tropical Agriculture (IITA), for example, have ambitious continent-wide mandates but without extra resources they are unable to cater fully to the agroecological diversity of the African continent within the limits of the budget available to them.

An important issue to consider therefore is whether the centers can increase their effectiveness and coverage of Africa's agroecological zones and improve their ability to support national research systems through the establishment of regional subcenters. This is a topical subject within the CGIAR at present. The International Crops Research Institute for the Semi-Arid Tropics has taken the lead in this regard by setting up regional programs in the Sahel and in Southern Africa. CIMMYT has decentralized its regional activities on on-farm research in Eastern and Southern Africa and has embarked on joint maize research for the middle-altitude areas in Southern Africa. The International Livestock Centre for Africa has proposals for setting up regional centers in francophone West Africa and in Southern Africa. These regional centers are likely to give a better view of problems related to the different agroecological zones of Africa and provide focal points around which networks can be established. These efforts deserve encouragement. The establishment of the regional subcenters should, however, be preceded by careful planning, a clear perception of priorities linked to the availability of funds and an examination of the comparative advantages of the international centers in relation to the national systems.

It is generally agreed that CGIAR-type centers function best within clear and narrow mandates. The question must be asked whether more centers are needed to support national research efforts throughout Africa to exploit all opportunities for increasing food production and farm incomes. Two clear gaps appear to exist. The first is in the field of such cash/export crops as tea, coffee, or cotton. The second is in some "factor" areas like soil fertility or land and water management.

Two approaches are suggested to fill these gaps. First, the creation of new narrow-mandated centers along CGIAR lines with research facilities should not be treated with disdain. Second, the creation of specialist networks with a small, high-quality staff, documentation facilities, publication programs, and "de-bottlenecking funds" for seminars and local research efforts merits consideration. The SPAAR Program should give high priority to identifying such gaps and existing regional institutions or networks that could be built up to fill the gaps.

In connection with the latter point, regional organizations such as the Southern African Centre for Cooperation in Agricultural Research (SACCAR) need to be encouraged. This organization was started at the initiative of the nine states of the Southern Africa Development Coordination Conference (SADCC) and has its headquarters in Botswana. Its director is a senior scientist/educator from the region and all the directors of agricultural research in the nine countries, including two deans of university agricultural faculties and two directors of agricultural extension services, are members of its board of trustees. The major function of SACCAR, which has a small secretariat, is to further cooperation among agricultural researchers in the SADCC through seminars, workshops, meetings, exchange of publications, small research grants, and travel grants for researchers to visit other scientists in the region.

Conclusion

In the preceding parts of this paper, I have attempted to highlight what I consider to be the main issues concerned with strengthening agricultural research programs in Africa. There are, however, a lot of other issues that I have not touched upon. Nevertheless I believe that the most important issue is the development of a national agricultural research strategy that is linked to a national agricultural development plan. If such a strategy is formulated in a realistic fashion, taking into account the totality of the problems that face the agricultural sector as a whole, then all other smaller aspects that affect the development of an efficient agricultural research system would necessarily fall into place. In particular I am referring to the need to develop an appropriate policy framework that would allow a given research system to have the following:

- Sound human capital development and personnel management, including manpower training and incentives for retaining this manpower; and
- Strong linkages with extension services, training institutions, and other bodies concerned with the development of the agricultural and rural sectors.

In this connection, it is pleasing to note that international research centers and the donor community are paying more attention to these complementary activities of extension, information dissemination, and strengthening local agricultural faculties at the universities and links between these faculties and agricultural research systems. There is no point in building a research capacity that is nonfunctional because it lacks such links.

Bibliography

Chigaru, P.R.N. and M. Avila. 1986. Farming systems research experience in Eastern and Southern Africa. Paper presented at the IARCs Workshop on Farming Systems Research, ICRISAT, Hyderabad, India.

Eicher, C.K. 1986. Food security research priorities in sub-Saharan Africa. Keynote address at the OAU/STRC/SAFGRAD International Drought Symposium held in Nairobi, Kenya, May, 1986.

SPAAR Working Group for Preparation of Guidelines for National Agricultural Research Strategies in Sub-Saharan Africa. 1986. Draft document on guidelines for strengthening national agricultural research in sub-Saharan Africa.

Issues for Institution Building

Let me begin by asking: what are the key questions we need to look at in our institution-building effort? What does it take to make a successful research system? What are the needs of NARS?

As Shahid Husain put it on Monday, it takes four basic ingredients:

- A concept—a clearly defined goal and strategy;
- Money—the resources to address that goal;
- People—the scientific capacity to conduct the programs; and
- Management—the institutional capacity to organize the system, to develop a coherent program, and to effectively utilize available resources in pursuit of that goal.

All four are important. They are interrelated and any one can constitute a serious constraint. Their relative importance tends to change over time.

In the younger research systems, particularly in Africa, all four tend to be in short supply. What complicates things even further is that the growth and evolution of NARS is generally unbalanced. For example, through massive training efforts by the IARCs and other organizations the scientific manpower base is developing rather well in some countries. In Africa, even the share of Ph.D.s in total staff has in some cases reached levels comparable to those in Asia and Latin America. Admittedly, the scientists are younger and less experienced.

The main difficulty, however, arises from the lack of necessary operating funds. They are not growing proportionately. Although the flow of donor funds is impressive in some cases, it tends to be directed at capital investments. And, as Philip points out, in the absence of operating funds, even good scientists cannot do productive work. This, combined with a generally low level of management capacity, accounts—among other things—for the relatively low productivity of many African research systems.

A number of the more mature systems, in Latin America for example, are presently facing similar problems with similar effects. They have built up over time a solid scientific basis, a sound institutional structure, budgetary support from national sources, as well as management capacity. The problems they are now facing are financial: instability of support from national sources and serious fluctuations in funding.

I need not elaborate on the effects of this situation. They are:

- A serious distortion in the systems' resource mix, with the share of operating funds declining in some cases to levels as low as 5% of total resources;
- The resulting decrease in the systems' overall productivity; and finally
- A serious danger for the systems' scientific manpower base. With the best people leaving for more productive job opportunities elsewhere, the system faces degradation or even disintegration.

An Action Agenda

This introduction brings me to the action agenda for the strengthening of NARS that I suggested for discussion by this audience. Philip has given us the elements. The questions I would like to ask are these:

- Do we agree with the issues he raises?
- What about the relative importance of the resulting tasks?
- What could and should we in the CGIAR system contribute beyond our present activities in support of NARS?

- Should we rethink and reorganize our approach to working with NARS in order to better meet their needs?

My questions obviously go beyond CIMMYT to address the CGIAR system as a whole. CIMMYT is one important actor in this area. And, as Don Winkelmann has told us, CIMMYT stresses partnership with NARS in all its programs.

Before summarizing for you the main elements of this agenda, let me remind you of four important trends that we need to keep in mind in this discussion. They were flagged in Philip's paper and also came up during the discussions in this seminar:

- Changing patterns in demand for technology. The NARS need to reorient their programs to address the problems of tomorrow. They will be different. Ed Schuh and others have told us why
- The increasing diversity of NARS needs and potentials, both among regions and within regions. We shall have to face up to that. The rich get richer and the poor get poorer.
- Commonalities of certain issues and problems. Particularly in the areas of research policy, organization, and management, problems tend to be similar among many countries.
- Flows of resources to NARS. We need to be aware of substantial resources flowing to NARS. Philip rightly highlighted the issues of absorptive capacity and long-term sustainability of NARS from national resources once the flow of aid is over.

Turning to the agenda now, let us first look at the action requirements of NARS. They are the key participants in the evolving global partnership. Their needs, potentials, and problems largely determine the Centers' response.

Having listened to Philip's presentation, I have noted seven key items:

- Building national commitment to agricultural research;
- Developing national research strategies;
- Determining the size and orientation of NARS;
- Building up the scientific manpower base;
- Setting research priorities;
- Increasing the productivity of research systems; and
- Building linkages and enhancing scientific collaboration.

I will provide a brief comment on each.

Building national commitment to agricultural research is, in my view, the key to long-term success.

Building national commitment to agricultural research is, in my view, the key to long-term success. In many countries this commitment is weak. The role of agricultural research and its potential contribution to development and progress are not recognized, resulting in low political support in terms of funding, excessive reliance on external funding, and the use of easy money with all its consequences. This means buying time and postponing the hard decisions that many of the Asian countries took long ago in their times of crisis. The IARCs can help in addressing these problems. CIMMYT has played a pioneering role in this area with its research policy seminar program.

The development of national research strategies is closely related to building national commitment to agricultural research. As Philip explained to us, such strategies are a key factor for success. They provide a rational framework to guide the build-up of research capacities; they determine the main thrust of programs; they guide the use of scarce resources; and they provide a framework for channeling external resources to areas of high national priority. They help to avoid the dangers of distortions that Philip so eloquently explained (the easy money issue).

In determining the size and orientation of NARS, long-term viability of research systems is an important concern. Philip made it clear that the build-up of research capacities must be guided by a realistic assessment of what is feasible and what can be sustained from national resources. All too often we see over-ambitious plans for station development and staff training that cannot be maintained in the long run. Similarly, realism is needed when deciding what a system or a program can do. We must recognize the limits. Many of the smaller systems will have to concentrate on adaptive research and on the import of technology. Collectively, we can help in this respect and provide the advice needed by NARS.

I need not stress the crucial importance of building and continuously upgrading the scientific manpower basis of NARS. While the Centers can make and have made important contributions to the three items mentioned above, this is the area where their impact is strongest. And, looking ahead, we have heard a lot at this seminar about CIMMYT's plans to deal with the evolving needs of its partners.

The need for clearly defined research priorities to guide the allocation of scarce resources is obvious, yet this is a weakness in most NARS. This makes them vulnerable to external influences and distortions in their programs. Also, most NARS are not well equipped for the much-needed interaction with the policy sector. They need to build up their own capacities in economic and policy analysis. This is the basis for a two-way flow of information: informing the policy sector of alternative technology options and translating national development priorities into relevant research programs. This will lead to better choices. Again, this is an area in which CIMMYT has made important contributions and presumably will continue to do so. I tend to agree with the plea made by Ed Schuh for more attention to this issue in the broader sense.

Increasing the productivity of research systems is another important area. The key to research productivity is good science. For good science to yield results, we need the proper setting. We need organization and management. Most of us agree, I think (otherwise I would not be here, representing ISNAR), that much can and should be done to strengthen the organizational and management capacities of NARS. In practical terms this means:

- Adjusting the organizational structures of NARS to fit the countries' circumstances,
- Better planning and programming to increase the quality and relevance of research programs, and
- More effective utilization and management of the CGIAR system's resources: staff, funds, and stations.

This is another area to which most centers contribute, CIMMYT prominently in station management. We at ISNAR concentrate our program on these issues.

Building linkages and enhancing scientific collaboration have clear benefits. We practice collaboration, yet there is scope for improvement, particularly regarding collaboration on a horizontal basis among NARS. Philip mentioned two means of achieving this: collaborative research networks and subregional ventures such as the South African Centre for Cooperation in Agricultural Research (SACCAR). I tend to think that both mechanisms can contribute substantially to building up national capacities. They provide a means whereby the stronger NARS can effectively assist the weaker ones, while at the same time gaining in the process. Through its involvement in CONOSUR (now PROCISUR, the Cooperative Agricultural Research Program of the Southern Cone) and other networks, CIMMYT has considerable experience in this area. Undoubtedly we in the CGIAR will wish to contribute further to promoting such ventures.

Let us now focus on the centers and their relationships with NARS. The centers are making important contributions in all seven areas I mentioned. In more general terms, their contributions are germplasm, research procedures, collaborative research, technical assistance, training, policy analysis, and institution building (in the narrow sense). Taken together, these contributions are widely acknowledged as useful for strengthening national capacities. Centers approach their collaboration with NARS on a partnership basis.

Future Needs and Demands

Looking ahead at future needs and demands, I personally think that NARS are gearing up to the challenges facing them. Let me give you two examples.

The first is the evolution of the Centers' training programs. By decentralizing training in the downstream areas of the research process, Centers respond to the massive needs of weaker NARS. At the same time they continue to cater for the needs of the more advanced systems that require training in the upstream areas, close to the cutting edge of science.

The second example is the move towards a more integrated system. The Centers, formerly a loose federation of individual institutions, are moving closer together, are joining their forces, and are aiming at a common response to NARS' needs. This is best illustrated by a recent center initiative to establish a working group to study ways and means for more effectively responding to the pressing needs of NARS in sub-Saharan Africa. This is clearly in line with one of the suggestions in Philip's paper.

I would like to make a final comment regarding NARS expectations from donors regarding their contribution to institution building. Philip flagged a number of issues related to this subject. My understanding is that there *is* progress:

The Centers are moving closer together, are joining their forces, and are aiming at a common response to NARS' needs.

- The need for long-term support to institution building is being recognized and donors are gradually adopting a longer term perspective,
- The issue of donor influence on national priorities will gradually be solved as countries move to long-term planning and establish a coherent research strategy;
- The pressing need for operating funds is not yet solved, but increasingly recognized by donors: there is some progress; and finally
- The question of donor coordination is receiving much attention these days. Relevant examples are the Special Program for African Agricultural Research (SPAAR) initiative as well as donor consortia at the national level.

In closing, let me pay tribute to CIMMYT for its progressive approach to strengthening national programs. CIMMYT has all along stressed the concepts of partnership and complementarity based on comparative advantage. It has been close to national programs and farmers, as demonstrated by its on-farm research program. I know we still have a long way to go. But I am confident that CIMMYT will continue to be among the leaders in our joint effort of assisting NARS in building their national capacities. We, at ISNAR, are proud to be associated with that process.

CIMMYT Research: Extending the Gains

D.L. Winkelmann
International Maize and Wheat Improvement Center, El Batan, Mexico

Many ideas have been discussed during the past two days. Before talking about their implications for CIMMYT, I want to review briefly some enduring aspects of our history and to comment on some of the changes that have occurred during the past 20 years. The two combine to make today's CIMMYT both the same and yet different from the CIMMYT of 1966. I will then go on to talk about how we see the near future, incorporating many of the ideas of the workshop. I add that in 1987 and in conjunction with an External Program Review, we will formulate a five year plan. It is in that effort that the discussions of the workshop will have their greatest influence.

The ethos of today's CIMMYT remains very much what it was at our inception.

A Look to the Past

Hallmarks

As CIMMYT emerged from a joint Rockefeller Foundation/Mexican research effort, our staff in 1966 was made up of practiced veterans. That staff has grown larger and its composition and deployment have changed. Even so, certain things have stayed very much as they were in the earliest days. These are the hallmarks by which the Center is known.

First, and most important, the ethos of today's CIMMYT remains very much what it was at our inception. Its essential elements are an emphasis on field work, on the importance of direct researcher involvement, on a pragmatism based on the needs of farmers, and on the benefits and obligations of an open association with a worldwide network of practitioners sharing the same principles. As at its beginning, CIMMYT's operations still rest on these ideas.

Second, throughout our history we have played our role in concert with national programs. Those programs are the Center's clients. We see ourselves as agents for complementing their work, thereby facilitating their efforts to serve their own clients, the farmers. We do that by providing national programs with germplasm, training, research procedures, counsel, and information.

Third, the Center is recognized and treated as being above politics. Over the years it has always responded to the needs of national programs without the limitations that might have been imposed by its individual donors. National programs have long recognized that stance and have no reservations about sharing through CIMMYT or about CIMMYT's willingness to share with them. This evenhandedness is a continuing CIMMYT hallmark and the resulting trust is one of CIMMYT's most valued assets.

Fourth, like others in the Consultative Group on International Agricultural Research (CGIAR) system, we see the clear advantages in the long horizons and sharp focus of our research. The two combine to bring patience and care in the pursuit of well-defined research themes. That blend contributes notably to CIMMYT's success, as it did to the successes of our predecessors.

Finally, our evolution continues to be conditioned by a commitment to multidisciplinary research. We see great advantage in the combining of disciplines, practice it ourselves, and advocate it for national programs.

These, then, are the characteristics that make today's CIMMYT like the CIMMYT of 1966.

Impacts

You will all know of CIMMYT's substantial contributions through germplasm - some 70 million hectares are currently cultivated with varieties related to CIMMYT and its predecessor's efforts. You may not be as aware of our other contributions to developing country agriculture. Some 4000 national program researchers work more effectively thanks to the impressions and skills acquired through training sponsored by CIMMYT. And they are able to draw on an expanding array of research techniques and procedures fashioned through CIMMYT's accumulating experiences in research and training. The training and the procedures notably enhance national program efforts.

While hectares of land, trained researchers, new methods, and productive partnerships reflect much of the impact of decades of effort, there is more. Also important, albeit even more difficult to measure, is an influence on spirit and on attitude. An awareness of the potential impact of agricultural research now shapes the attitudes of those concerned with economic development and its policy. Having seen the potential through such research, these decision makers are ever more open to arguments for investment in agriculture - in its supporting infrastructure, in rationalizing its policy, and in fortifying its research. And this positive stance enhances the possibility of change within the sector.

New Views

Over time our perception of the process of agricultural research and the sector's development has evolved. In an earlier day, conventional wisdom saw agriculture as a source of resources which could be drawn away to more productive pursuits elsewhere. Today's view is that agriculture itself can cause widening circles of growth within the rural and the urban communities of developing countries. With higher productivity from new technologies, incomes increase to those who hold the land, labor, and capital of agriculture. Higher incomes favor added spending, which induces still more spending by its recipients. Agriculture initiates these rounds of growth. This perception, with its emphasis on resource productivity, has implications for the allocation of research resources, implications still being explored by today's research managers. Our Economics Program will further our understanding of these relationships.

Over the years changes have occurred in the nature of CIMMYT's partnerships with national programs, bringing ever more prominence to their role. In germplasm development more segregating materials are distributed than in an earlier day, and more resources are committed to joint ventures focused on particular problems; examples include cooperative research with Brazil to develop aluminum tolerant wheats and with Thai researchers for downy mildew-resistant maizes. In husbandry the balance has swung away from the direct pursuit of technologies for specific areas towards expanded training for national program practitioners so they might more effectively forge new technolgies for farmers.

CIMMYT is giving new attention to its own priorities. Some of this has led to more precise understanding of the relative demands for the various classes of maize and wheat. This point was raised by Dr. Arnold and by Dr. Borlaug in their papers and is implicit in one of the challenges signaled by Chairman Husain. Both crop programs are well along in delineating major environments, so called "mega-environments," and in estimating the relative size of each. This effort will give CIMMYT a clearer sense of the needs of its clients, hence of its own priorities.

And ever more energy goes to strengthening the capacities of national programs through training in research techniques, in problem identification, and in priority setting. These were, of course, concerns in an earlier day but emphasis has grown through the years, especially with the advent of CIMMYT's regional programs in the mid 1970s and their expansion through the last decade.

What all of this says is that CIMMYT is an institution that combines constancy in its hallmarks with fluidity in its activities as circumstance and accumulating experience point the way to new opportunities. We remain an up-to-date institution with enduring traditions.

The Future

And what of the future? What will be the themes of tomorrow? Consider first several of the circumstances that will shape our environment.

Growing strength in national programs presents the CGIAR system with new opportunities through recombining resources and tasks

Tomorrow's Environment

First, we recognize the importance for our work of the current emphasis on productivity. We also recognize that growing international trade in agricultural commodities has implications for the orientation of national program research, hence for our undertakings as well. We see the importance and the difficulty in identifying comparative advantage in today's open economies. These points were raised in the paper by Dr. Schuh. We see growing strength in some national programs and recognize that this presents the CGIAR system with new opportunities through recombining resources and tasks. We foresee that new science will bring new opportunities to complement conventional approaches. We can hope that national policies will favor increasing investment in well directed research, through judgement based more on biology and resource endowments, and ever less on whim or misapprehension. Finally, we understand that if desired rates of economic development occur, an ever higher proportion of our products will be destined for livestock feed with strong implications for the demand for maize and wheat.

Having said this, what about the direction of CIMMYT's work? What aspects of our research portfolio will show the most change? My own sense of evolving balances in our research agenda suggests changes in working relationships, germplasm, new science, enhancing human capacities, and our work for Africa.

Working Relationships

CIMMYT has a wide range of working relationships with national programs, with institutions, with development assistance agencies, and with individuals. It seems likely that current forms will continue into the future, with more emphasis on some, less on others. Some new relationships with new formats will also be developed. I want to talk about three formats that might well gain added prominence in the next decade.

The first of these is exemplified by an association now working on barley yellow dwarf virus (BYDV). While BYDV can have dramatic effects on yields, its impacts are usually small, but widespread and regular. The virus was identified in 1951 but little concerted work was done before the 1970s.

A worldwide conference on BYDV held here in 1980 helped to shape an international network of researchers concerned with various aspects of the disease, ranging from interest in the virus and resistance mechanisms through breeding and on to germplasm evaluation. Funding for the network has come from several donors, with the Italian Government bearing the bulk of the current costs. A CIMMYT staff member serves as a liaison person among the researchers and brings results to bear through our own spring bread wheat program and the barley breeding program of the International Center for Agricultural Research in the Dry Areas (ICARDA). What is appealing about this network is its wide range of scientific competencies, the way in which results are transmitted, the participation of researchers from developing and developed countries — each contributing according to particular advantage — and its close connections to active breeding programs. We expect to see more such networks in the future, bringing the elements of the global scientific community together around a particular problem and with strong connections to practicing plant breeders.

In the planning stages is a similar form of networking — similar in the sense that scientists from several countries are involved and their efforts are focused on a particular problem, albeit one less extensive in its geographical sway. One application could focus on the problems — such as weeds, fertility, soil structure and tilth, and salinity — inherent in sustaining yield increases in the ever more intensively used lands under rice-wheat rotations from Pakistan through to Bangladesh. In this application the focus is beyond agronomy and technology generation; it will look through science at the underlying relationships on which sustainable yields must be based. Such networks might plan joint research, partition problems according to competencies, share data and analysis, and ensure the professional and technical quality of the research itself.

A third format would see some of the activities currently in the hands of CIMMYT transferred to well-established national programs. Much of this has already happened, of course; the adaptive and applied agronomy of technology generation is now largely in the hands of national programs and a growing proportion of CIMMYT's nurseries, especially in wheat, are made up of varieties developed by national programs. Still, there is the possibility that other activities could be shifted to national programs. Some, for example, point to training and make the case that training for the professionals of a given region could be offered by that region's more advanced national programs. CIMMYT's role here might be in providing training materials and in supporting the teaching staff. Other examples will occur to many of you. CIMMYT will be looking further into this format, exploring with national programs and the CGIAR the feasibility and the desirability of such devolutions.

CIMMYT, indeed the international agricultural research centers (IARCs), play a critical, and I would guess an underestimated, role in many networks. That role rests on the perceptions that the Centers are not only efficient but are truly evenhanded in the distribution of materials and ideas. That conviction is essential to effective networks. It is also essential to ensuring the CGIAR system's continuing productivity.

New Science

We are all aware of the startling developments in science as molecular biologists, biochemists, and others have brought their discoveries to bear on issues in plant improvement. CIMMYT has moved in deliberate ways to take advantage of these developments and has established consulting and professional relationships with leaders in these and related fields.

We have done so because, like others, we are impressed with the advantages latent in the new techniques and feel it is only prudent to take steps to assure access to unfolding developments. One such step is to add a molecular biologist to our staff and, over time, to bring into play the physical and organizational infrastructure necessary to support the activities we envision.

Our thinking about the extent to which CIMMYT should invest in new science is shaped by three considerations. First, we see ourselves applying the techniques others develop; we are more tool users than tool makers; second, we must ensure that CIMMYT is able to employ new findings in the practice of plant breeding as these become applicable; third, we recognize that, beyond

CIMMYT's own requirements, national programs look to us to assure their access to the new techniques for application to their work.

We recognize that, beyond CIMMYT's own requirements, national programs look to us to assure their access to new biotechnological techniques.

Our current collaborative work using the new tools of plant breeding focuses on tissue culture, concentrating on finding new ways to maintain and multiply the hybrids emerging from our wide cross programs; on callus work to induce chromosonal breakages; and electrophoresis to identify the extent of gene transfer occurring through intergeneric and interspecific crosses. The work currently underway is aimed at bringing traits out of wild relatives into maize and wheat. Our special concerns are selected disease and stress conditions. These efforts conform well with the optimism of Professor Frey.

As we see it, one other major new technology appears to be applicable to CIMMYT's work, the use of gene probes. These could be used to screen large amounts of material in the laboratory, reducing the need for large field experiments; for diagnosis, such as in ascertaining the presence of a virus; and to assess the success of efforts to transfer alien genetic material. And perhaps, just perhaps, we could become the repository for such probes or clones as they are developed, both by ourselves and by others around the world.

While much has been promised by those who pursue the applications of new science to plant breeding, there are grounds for caution. For example, although genes can now be transferred and spliced, those in maize and wheat have not yet been mapped for function. Moreover, regeneration is still more an art form than a science. Until these challenges are met, the techniques related to splicing have limited applications for CIMMYT.

There is much to suggest that we make haste slowly. Even so, I am impressed by the commitment that major private plant breeding companies are making in this field, with some reporting as much as 10 to 15% of their research resources devoted to biotechnology. And, too, we are mindful of Thomas Huxley's observation that "a customary fate of new truth is to begin as heresy and end as superstition."

As the chorus claims, it is a fast-breaking field. We must organize so as to ensure that we know which developments are relevant to our needs and can move quickly to incorporate them. This will require not only expertise in the field of biotechnology and a recognition of the practicalities of conventional plant breeding but, as well, sufficient sympathy and familiarity that an augmented supply of science finds a responsive demand. The steps that we are taking are designed to serve those ends. Like Dr. Evans we see a continuing central role for conventional breeding and, to the extent desirable, we want to augment its efficiency through relevant new tools.

Germplasm

As in the past, germplasm will remain CIMMYT's major product. Our work in germplasm development has tended to favor the better environments of developing countries. This is most true for wheat, where much of the attention of the past has been on well-watered areas. That emphasis, by the way, was quite appropriate given that some two-thirds of the developing world's spring wheat is grown in such environments. Most tropical maize, on the other hand, is grown in the presence of significant environmental threats, with the well-watered areas suffering the menace of disease and insects while the drier areas encounter the dramatic effects of drought. Overall progress in bread wheats, durum wheats, maize, and triticales has ranged from remarkable to extraordinary. And what about the future?

In deciding the emphasis of the future we must recognize the importance of the favored environments while, consistent with the 1986 Technical Advisory Committee (TAC) Priorities Paper, we cater more to the needs of the more difficult environments. In deciding on the relative importance of each we must integrate the differing effects on economic development of new technologies, enhanced productivity, and increased income flows, along with the probability of achieving results.

As we view research on wheat for well-watered areas, emphasis will be placed on maintaining the gains achieved. More generally, and other things being equal, greater attention will be given to materials for more difficult environments. In this judgement we are more like Dr. Frey than Dr. Evans. Even if the probable gains were less in the poorer environments, a concern for the poorest, coupled with the perception that they tend to occupy the most difficult environments, would still be cause to focus on these areas. I add that we cannot yet say much about the final effects, after added rounds of spending, of given productivity changes in the two environments. Evidence on the relative size of such parameters must rate a high priority for economists.

Major efforts are now underway on materials that can accommodate drought stress. Work in the maize program was initiated several years ago, then put aside, and is now again receiving a major emphasis. Interestingly, this research tends to show that maize selected under both drought stress and well-watered conditions tends to perform much better under drought stress and somewhat better in well-watered circumstances than does maize selected only under well-watered conditions. Work on spring bread wheat, on durum wheat, and on triticale is also well along and we expect good results given the resources being committed.

It should be noted that there is not complete agreement on the most expeditious way to approach the drought stress issue for small grains. To the extent that disagreement can serve as a source for hypotheses, we expect our efforts to sharpen understanding of the preferred way to undertake such work as well as to develop improved genetic materials. Soil problems in several important maize and small grain environments severely limit productivity. Work undertaken in close collaboration with Brazilian wheat specialists is well along for bread wheats that can tolerate otherwise toxic levels of aluminum. Similar work, focusing on maize and involving several Latin American programs, is being launched.

Work is underway on wheat for more tropical environments and good progress, indeed surprising progress, has been made. One aspect of that work involves resistance to diseases that, while common to such environments, are less commonly encountered in traditional wheat producing areas. Also, and with probable beneficial impacts for selected areas already producing wheats, work is underway that will result in more late heat tolerance for wheats.

For both maize and wheat there is an expanded effort on earliness. This characteristic offers two advantages. The first is to permit escape from diseases or heat or drought. The second, and one becoming ever more widely recognized, is that earliness enables more intensive cropping, implying more options for farmers.

In reaching for these goals--earliness, tolerance for heat and drought, accommodation to problem soils, and new classes of disease resistance--CIMMYT breeders frequently work directly with concerned national programs. Those relationships will be enlarged and fortified as this class of work expands.

In assessing these lines of work, we are convinced that, via the farm level, we can come to know more about issues of importance in priority setting and policy making and are investing, especially through the Economics Program, in acquiring the needed understanding. Combining these insights with those from a more global perspective should help us and our national program colleagues to have a clearer sense of priorities.

We are convinced that, via the farm level, we can come to know more about critical issues in priority setting and policy making.

Also with respect to germplasm, we have greatly augmented our capacities to serve as curators of selected portions of the world's germplasm of maize, durum and spring bread wheats, and triticales. Again, as in so many cases, fulfilling our responsibilities in this area will involve us in collaboration with several national programs, especially in Latin America for maize germplasm. A substantial portion of the desired materials is in storage and we are developing the associated data. After periods of anxiety and, I think, no little confusion, it is satisfying to report that machinery will soon be in place to satisfy a well defined portion of the world community's needs.

Professional Training

CIMMYT and its predecessors have invested heavily in supporting the efforts of National Agricultural Research Systems (NARS), with a primary part of this effort expended in augmenting human capital through various kinds of training and consulting. As a measure of this, a recent survey of wheat program staff suggests that as much as 45% of their total effort can be ascribed to these activities. The marvelous new facility we just inaugurated is itself a testimony to our commitment. We will continue that emphasis in the future but will redirect some of the energies.

Before reviewing potential new allocations in training, there are components whose continuance should be reaffirmed. I refer here especially to the in service training programs in plant breeding. There is a clear advantage in offering that training here in Mexico as in the past. An important element in that judgement is simply that current levels of participation are close to those required in order to meet the demands of developing countries. This is not to suggest that we will fully satisfy those demands; replacements due to retirement and career changes will ensure a continuing need for such training. On balance, however, our annual capacity approximates the average annual needs of our client countries. And the evidence argues forcefully that these Mexico based programs are both effective and efficient in supplying such training.

We must, however, find ways to multiply the energies we are investing in training on agronomy and technology generation. The demand for these skills in developing countries is enormous compared with the training capacities of the IARCs. We have moved in this direction through an expansion in our in country training efforts. In time we hope to see more of this training in the hands of national programs themselves, or being offered on a regional basis under the auspices of the more mature national programs. If this occurs, CIMMYT would supply course structures, training materials, counseling on conducting the training and, at times, staff to participate in such programs. Even so, in service training in production agronomy would go forward in Mexico, perhaps at a modestly reduced scale, to serve as a vehicle through which NARS training capacities could be developed, new materials formulated, and new concepts pursued. An enduring characteristic of this work is the representative farmer at the center of the effort.

As in the past, efforts in training will rely heavily on learning by doing. However, given new developments in instructional materials and a clearer understanding of their potential role, we are moving to develop more such materials. In this case we ourselves are learning by doing as we discover the applications of supporting materials to reinforce the lessons of the crossing block, the breeders' plots, and the fixing of priorities for production trials.

We have long had a program for visiting scientists in which we welcome colleagues from NARS to work alongside our staff, at times in pursuit of particular research themes and at times more to familiarize themselves with specific methods or materials. This too will continue. Beyond this, we are adding the opportunity for participants to refurbish research skills. Our plan is that participants will remain here for four to six months, most of them with data from projects undertaken at home. We will provide the opportunity to analyze data, to pursue related research through the library, and to write research reports. This will meet a need forcefully expressed by many of our colleagues that results are not available to peers because researchers do not have the time to analyze and write, and that certain research skills atrophy because of that same constraint. Interest in this program is widespread and we have had extraordinary financial support from donors and from the private sector. Our new facility will play a crucial role in this undertaking.

Finally, we see a growing need for new specialized courses focused on a single or on closely related themes, like that offered in pathology and funded by the Dutch. These would be designed and developed in Mexico, based on the experience of network colleagues and our own staff, and made portable so that they, too, could be offered on a regional or national basis.

Our work in training has done much for human capital formation in agricultural research. What is too little appreciated is what it can do for CIMMYT itself. First, we have the opportunity to learn from the accumulated field experiences of participants in those programs. Beyond that, and largely unrecognized, training staff, with their own periodic involvement in research and continuing close connection to the research of others, are a vehicle through which CIMMYT's experience is synthesized, impressions formed, and procedures are formulated and improved. These procedures, in turn, are basic to the development of training programs. It is in training, then, that CIMMYT-wide experience can be gathered, integrated, and then framed in concrete terms.

CIMMYT training staff are a vehicle through which our experience is synthesized, impressions are formed, and procedures formulated and improved.

Work for Africa

Already sharply increased through special projects with the United States Agency for International Development (USAID) and the Canadian International Development Agency (CIDA), activities related to sub-Saharan Africa will receive an increasing proportion of our energies over the next decade. Our commitments there will surely be larger than implied by the areas of maize and wheat — some 18% and 6% of developing country maize and wheat — or even by the proportions of populations dependent on the two crops. They will be small, however, when measured in terms of the need for support and in terms of potential impact.

This work will be representative of the full range of products that CIMMYT delivers to national programs. A considerable part of the effort will be in germplasm development. Given the urgency of the food and income problem, we have moved our work on intermediate altitude maize to Africa, are now planning to strengthen our forces working on germplasm for the humid and subhumid tropics, and are contemplating a shift to bolster efforts related to maize's capacity to accommodate drought. In doing this we expect substantial cooperation with the International Institute of Tropical Agriculture (IITA), with France's Institute for Tropical Agricultural Research (IRAT), with the newly formed Special Program for African Agricultural Research (SPAAR), and with other teams being deputed to the region by donors to the CGIAR.

We have faith that African farmers will move to take up appropriate new technologies. Recent evidence from Ghana, where CIMMYT staff have worked with the national program through a bilateral project funded by CIDA, supports that faith. In a survey of maize farmers, high rates of adoption of improved varieties introduced from the international maize network, of nitrogen fertilizer, and of new seeding patterns were strongly evident in selected areas. There will be more evaluation of the Ghana experience in the near future and of other such activities in time.

Training efforts in Africa will also be fortified. It is our hope that a significant portion of the training required, most notably that related to production agronomy, will be undertaken within African programs. As Dr. Thomas Odhiambo has said "The vital question ...is the development of locale-specific technologies that permit continuous crop production over many years." Training in production agronomy will be critical to this effort. Kenya is already moving towards developing a national training capacity and we expect that other national programs will adopt similar strategies in the near future. CIMMYT can support such ventures through the preparation of related training materials and through working with national program training staff. Efforts are underway and we expect to see more resources committed to such work over the next three years. With respect to CIMMYT's training activities, it is interesting to note that the number and proportion of trainees from sub-Saharan Africa increased over each of CIMMYT's quinqennials. Moreover, the proportion of trainees in breeding has declined while the number in agronomy has increased.

In our view there is considerable scope for working with national programs in planning and assessing the directions of their work on maize and wheat. This kind of counseling could contribute much to the efficiency with which notably scarce national resources are used. In reflecting on priority setting within national research programs, there are many cases in which it is relevant to ask if too many or too few resources are devoted to maize or wheat research. Such decisions, of course, are properly in the hands of national program leadership; even so, we can provide pertinent information. In collaboration with such newly emerging entities as SPAAR, CIMMYT staff will also be good sources of information about high priority potential investments for donors in the activities of national programs.

Finally, we see ourselves as more actively engaged in direct collaboration with other IARCs whose mandates include work for Africa. One potential form of such collaboration is in research on technology generation involving several IARCs and relevant national programs. While we believe that others could do this job, there are two considerations that argue for our active participation. The first is the overwhelming urgency of the need for improved technologies appropriate to the circumstances of African farmers. The second is that African support for research in Africa would be substantially fortified by examples of successful applied or adaptive research.

Sustaining Momentum

By any standard of measurement the CGIAR system must be regarded as a marvelously successful venture. The recently concluded CGIAR Impact Study gives ample evidence of this. One welcome result of the study is that it should quiet apprehensions about the distribution of the benefits from IARC research. The evidence shows widespread benefits, especially to poor consumers, and that should be a comfort to those who were concerned about benefit flows. This is not, of course, to suggest that all is well on the income distribution front, but rather that the earlier, more strident critics seem to have been well off the mark.

But how can CIMMYT and the CGIAR best maintain the momentum that has contributed so substantially to agriculture in developing countries? The earlier discussion makes the case that the spirit of innovation must hold sway, not just over research itself, but also over efforts to contribute to new forms and structures in collaboration, in product, in training, and in procedures.

Sustaining momentum relates not only to support for the IARCs but to bolstering support for the national programs of developing countries. During CIMMYT's short 20 years we have seen that support oscillate, first for one institution and then another. We know that constancy strongly influences the utility of research and that on-again, off-again support seldom leads to acceptable payoffs. We also know that sustained support will probably only come after national decision makers are convinced that they cannot do without agricultural research, that their constituents will challenge their judgement if support is inadequate. And we know as well that those convictions can only come if national programs can give clear evidence that an investment in their work is an investment with high payoffs.

CIMMYT, too, must maintain its energies, and do so in the context of ever more subtlety in our understanding of the potential offered through research. The convictions of an earlier day were maintained by rallying cries that gripped the imagination — "Food for hungry bellies." Today's shibboleths sound faint and pedantic by comparison. We must also, even with the increasing emphasis on new science, maintain the luster of more conventional forms of research, forms that will surely provide the gains of the next decade and more. And finally, in the face of apparent abundance, we must gather the energies to add choice to the lives of the desperately poor.

In the face of apparent abundance, we must gather the energies to add choice to the lives of the desperately poor.

Surely these are formidable challenges, but this is not at all to suggest that this is the end; to paraphrase Winston Churchill, it is not even the beginning of the end. But it may well be the end of the beginning, in the sense that the circumstances of our next two decades will differ markedly from those of the last two. With the experience, the energy, the wit, and the innovative spirit of our staff, I have no doubt that we will reach new highs, with an expanding array of viable options to national programs and, through them, to farmers.

Gatherings like this — gatherings in which we pay high honor to our past and remind ourselves of how we came to be as we are — are essential to maintaining our momentum. Just as surely, guiding that momentum depends upon such workshops as this, where we tap the deliberate reflections of the knowledgeable.

Our opportunities are at hand; I know that you share my confidence in their realization.

Discussion

G. Camus
Technical Advisory Committee, Consultative Group on International Agricultural Research, Washington, DC, USA

Let me add my word of congratulations to CIMMYT on behalf of the Technical Advisory Committee (TAC) and also my personal best wishes as a former trustee and therefore an *ex-officio* member of the extended CIMMYT family. CIMMYT has reached yet another milestone. As all of you are aware, I have had the privilege to be closely associated with CIMMYT for about 10 years as a member of the Board of Trustees and I would like to say that it was a pleasant and most memorable experience. It is with pride that I take part in your deliberations today.

I would like to express my appreciation to the organizers for the opportunity of sharing with all of you the views of TAC on the future of CIMMYT and the challenges that lie ahead in a fast-changing world. During this celebration, the outstanding success and impact of CIMMYT's past efforts have once again been unanimously recognized. We all are convinced that striving for excellence has always been CIMMYT's philosophy, and is the basis for the Center's unique achievements. This is an admirable philosophy for us to have if we are to meet the forbidding challenges of tomorrow's world.

During this symposium we have had three very interesting and productive days, and the success of this meeting has been in no small measure due to those of you who have participated actively in the discussions. Let me mention in passing, Mr. Chairman, that this symposium has also provided a wonderful opportunity for an interactive process between selected centers, donors, National Agricultural Research Systems (NARS), TAC members and the scientific community, the Board of Trustees, and the management of CIMMYT. We in TAC welcome such interactions as part of the necessary continuing dialogue between the various participants in the global research system.

A Look at the Past

Before commenting on the Director General's presentation, let me turn briefly back, once more, to the past. CIMMYT and its founders, as well as the pioneers who made its establishment possible 20 years ago, have indeed a lot to be proud of.

On Monday we heard CIMMYT's achievements expressed very eloquently by one of the fathers of the Green Revolution, Dr. Norman Borlaug. The Green Revolution itself was discussed by Dr. M.S. Swaminathan, a person who was highly instrumental in translating some of the international research efforts and breakthroughs by CIMMYT and the International Rice Research Institute (IRRI) into a practical reality at the national level. We are all aware of CIMMYT's good record of interaction with national systems in developing countries and the Green Revolution provides a good example of this cooperation, which has, as mentioned by Dr. Winkelmann, adapted itself to new circumstances and evolved over the years.

The Impact Study conducted by the Consultative Group on International Agricultural Research (CGIAR) in 1983 conservatively estimated that 47 million hectares in the developing world were planted to semidwarf wheat and six million to maize derived from CIMMYT germplasm. These impressive figures speak for themselves. So do the 4000 or more former trainees from 95 countries who consider themselves a part of CIMMYT's extended family.

The Challenge Ahead

Such a record of past performance by CIMMYT augurs well for the future. We learned from the Director General's presentation that CIMMYT is fully aware of the series of challenges that lie ahead of it and that the Center has already taken, or is prepared to take, the necessary steps to respond to them as efficiently as in the past. We all recognize that the tasks ahead are very demanding and difficult, but they are also challenging and full of promise.

Given that CIMMYT and TAC are in agreement, I will limit myself only to a few topics of general importance for CIMMYT and the system as a whole, and not deal with such matters as, for instance, CIMMYT's approach to new science. We in TAC can only be in full agreement with the Center on its constructive and pragmatic approach. Let me endorse in particular the comments of Dr. Arnold and Dr. Winkelmann about the potential of new molecular biology tools like DNA probes and in particular RLFP (restriction length fragment polymorphism). In the short term, I believe these tools can represent important additions, and I stress additions, to the impressive array of breeding techniques currently used by CIMMYT plant breeders.

In the same vein, we can only welcome the Center's increasing involvement in Africa in cooperation with other organizations. Close cooperation between international agricultural research centers and national research systems on well defined action programs is undoubtedly essential to solving the present African crisis. I am not going to comment on such technical aspects of research trends as the relative demand for different classes of wheat and maize, or on the importance of the work, which we broadly endorse, to develop materials that can accommodate a series of stresses encountered when crops are grown outside their traditional or more favorable environments. Let me add quickly, however, that the discussion does not have to be restricted to those topics I have mentioned and that everyone, of course, will be free to raise any questions.

Close cooperation between IARCs and NARS is undoubtedly essential to solving the present African crisis.

Meeting Increasing Demands

My first point concerns the increasing amount and diversity of calls on CIMMYT's capacity and relatively limited resources. Those calls are both external and internal.

One external call involves the NARS. While some NARS, which also have evolved over the last 20 years, are now quite capable of taking a greater share of responsibility in international efforts, many others unfortunately are still lagging behind. These NARS lack the minimum effective capacity to conduct even adaptive research, despite global intensive training efforts. Such NARS need help, one way or another.

We have heard of CIMMYT's plans to cope with this particular problem. These plans include increased training efforts with emphasis on specialized courses, decentralization and emphasis on the preparation of training materials, help in priority setting, more segregating material provided than in the earlier days, networking, and innovative views on increased sharing of responsibilites with NARS ready to take their place as equal partners in the global research system. However, this will take time and resources.

With regard to the last point, I welcome the International Fund for Agricultural Development (IFAD) initiative, cosponsored by the Swedish Agency for Research Cooperation with Developing Countries (SAREC), the International Development Research Centre (IDRC), the Ministry for Economic Cooperation

(BMZ), and the Rockefeller Foundation, which will allow some of the more advanced developing country NARS to share their views with CIMMYT and IRRI at a meeting in early 1987 on the possibility of expanding their role in the global research system. It is TAC's conviction that the process of sharing responsibilities with NARS ought to be encouraged and accelerated where feasible.

The recent international seminar on priority topics and mechanisms for cooperation in agricultural research in Latin America and the Caribbean held at the International Center for Tropical Agriculture (CIAT) in August this year provided an indication of the views of NARS on research cooperation and the role of the IARCs. This issue is also being discussed in the CGIAR Task Force on sub-Saharan African research strategies, although here we are understandably dealing with relatively weaker NARS.

Now, internally, the pressure on resources is no less. In addition to the obvious need for "maintenance" research, as underlined by the Director General, we have the compounding effect of increased activities on germplasm development, on strategic research, and the need to keep abreast of various aspects of the new science, which are all prerequisites for the Center if it is to remain in the forefront of technology generation. CIMMYT is obviously conscious of all these needs, which are compounded by the increasing diversity and in fact the present weakness of most of the NARS.

Meeting Long-term Objectives

Thus, whatever cooperation and partnership develop, the global load will remain heavy in the near future. This raises a series of issues for CIMMYT, in particular one on which TAC expressed a strong view when it considered the report of the Second External Program Review of CIMMYT in 1982. The Committee then considered that disciplinary research at CIMMYT headquarters needed strengthening to ensure that the long-term objectives of the Center would be met. I am pleased to recognize that substantial progress has been achieved by the Center in this regard. One example is the establishment of work on seed health. The Green Revolution would not have happened had it not been for the ability of CIMMYT to exchange germplasm freely and safely with 100 or more countries. The establishment of work on seed health demonstrates CIMMYT's high priority for this concern and the Center's willingness to generate new knowledge to try and ensure that scientific principles will shape the guidelines for future exchange of germplasm. This distinguished group may wish to contribute to the debate on this matter or on other areas of disciplinary research that should receive more attention in the future.

Based on what you have heard in the last two days and keeping in mind CIMMYT's comparative advantage, the amount of research carried out elsewhere, the limited resources available, and the increasing need for decentralizing breeding activities, you might wish to give some thought to the appropriate balance between on-campus and off-campus activities. Approximately 40% of CIMMYT's senior staff are now based outside Mexico, and this has been a deliberate shift over the last decade. The Center's positive steps to implement the highland maize program in Ecuador, and the recent establishment of a joint program with IITA to establish a midaltitude maize-breeding program in Harare, are more recent moves in the same direction, and are fully endorsed by TAC. In the wheat program, some of the breeding and agronomy for nontraditional wheat areas are not being conducted in Mexico, but in Paraguay and Thailand. These moves have already been made, but what about the future? What should be the balance of these activities in the next 10 years—and what would be the respective nature of activities conducted on and off campus?—that is an important question which I shall pose, but refrain from answering.

A second issue closely linked to the preceding considerations is the consequence of the global funding context. Increasing demands are being made on CIMMYT in a climate where the total resources available to the CGIAR are either static or increasing only at a very slow pace. Let me remind you that the CGIAR represents a very small part, perhaps 1 to 3%, of global resources in agricultural research. However, as demonstrated by the past, the CGIAR system has played a fundamental part in generating technology that has led to quantum increases in productivity of the global system. The key words I consider to be particularly important in this context are comparative advantage and priority setting.

In the recently completed TAC review of CGIAR priorities and future strategies, both wheat and maize were singled out as commodities that will require special consideration in the future with respect to the relative level of resources devoted to each commodity by the CGIAR.

Let me now come to a sensitive issue, one on which emotions have tended to run high at times. This relates to TAC's proposal for a relative reduction in the resources allocated to wheat in the CGIAR. In the short to medium term, 5 to 10 years, the relative allocation for wheat is proposed to decrease slightly and then remain at about that level. This must not be construed to imply that productivity research on this crop will become less important in the future. It is simply anticipated that present expenses could be cut down slightly through increased partnership and sharing of responsibility with all components of the global system, both in the developing and the developed countries. For example, at the recent European Research Directors Conference in Bad Hornburg, we heard of the significant collaborative research network that CIMMYT is helping to create on barley yellow dwarf virus (BYDV). This already involves eight centers of excellence in Europe, North America, and Australia and will involve almost the same number of links with developing countries in Asia, Africa, and Latin America.

CIMMYT is taking the lead in this network, which allows the global scientific community to use limited resources in the most efficient way by jointly identifying priorities, assigning tasks according to comparative advantages, achieving critical mass, and sharing in the analysis and interpretation of new knowledge. Let me stress that many of the activities in the network are funded through mechanisms external to the CGIAR and therefore are additive to the CGIAR system.

Wheat and maize have been singled out as commodities that will require special consideration in the future with respect to the relative level of resources devoted to each commodity by the CGIAR.

In general, in the wheat program, TAC believes that whereas work should continue on the more favored environments, more emphasis should be placed on marginal lands. This may also provide an opportunity to further explore the potential of triticale for the next five years or so, after which an assessment of progress and constraints should be made. My own personal feeling is that triticale may enjoy higher adoption rates if we place more emphasis on triticale as feed, rather than food. I will not comment on barley because CIMMYT has already transferred responsibility for this crop to the International Center for Agricultural Research in the Dry Areas (ICARDA), in line with the TAC/CGIAR recommendations.

Concurrently, CIMMYT will be expected to allocate more resources to maize, particularly for African conditions where the needs are specific and urgent, consolidate its germplasm enhancement activities, and do more evaluation of wheat and maize genetic resources. The sustainability of production systems involving these two commodities and its implications for research and technology development will no doubt have to be addressed. Research on the common factors of production for maize and wheat, which also will require increased attention, may be at least partially addressed by forging more and better collaborative links with non-CGIAR centers, such as the International Fertilize. Development Center (IFDC) and the International Irrigation Management Institute (IIMI).

This means that, within the limitations of the future available resource base, not only must the various relationships with the Center's partners evolve, the research must also evolve to tackle the more difficult environments, and adjust as the capacity of NARS improves. Equally, the internal priorities among the various programs will need to change gradually, without drastic steps that could endanger the spectacular results so far achieved.

CIMMYT is faced with a series of choices involving internal reallocation of resources that need to be articulated in the context of a future strategy in a long term plan. This long-term plan will be the critical document examined by the External Program Review Panel when CIMMYT undergoes its third TAC review in the second half of 1987.

Germplasm Conservation

I have probably taken too long already, but I would appreciate being permitted to briefly touch upon one last point: germplasm collection and conservation.

CIMMYT plays a major role as conservator and supplier of basic wheat and maize germplasm for developing countries. Like its commodity-oriented sister institutions, it participates in the global genetic resource efforts of the CGIAR system, which represent in fact about 50% of the conservation efforts made in the less developed world.

The TAC is pleased to note the increased efforts of CIMMYT in germplasm conservation and particularly the close working relationships with the International Board for Plant Genetic Resources (IBPGR). Indeed, the IBPGR has actually provided finacial support to implement some of the activities that have been jointly discussed and agreed upon with CIMMYT. This is a good example of inter-center cooperation, and one that may serve as a good model for the future.

During its recent meeting in Cali, Colombia, TAC briefly considered the possibility of launching a study across the system in collaboration with the Centers and the IBPGR. The study would assess current efforts, needs for improvement, and ways in which the Centers could participate with other partners in a much-needed research program related to conservation, storage, and evaluation of the Centers' mandate crops. The matter will be discussed with Center Directors at our next meeting in October and probably taken up through some mechanism we will decide upon jointly. In the meantime, the Director General of CIMMYT might want to comment briefly on the adequacy of the Center's present facilities—greatly improved over the last years—and on how far he feels that CIMMYT should or could undertake research in this additional field.

Conclusion

My apologies again for being so long, but, as you have noted, I needed some extra time to underline TAC's strong support and appreciation of CIMMYT's programs and achievements over the past two decades, and to stress my conviction that CIMMYT shall successfully meet the challenges ahead of it.

Organizations Cited in the Text

AGRHYMET: Agricultural Hydrology and Meteorology

BMZ: Bundesministerium für Wirtschaftliche Zusammenarbeit (Ministry for Economic Cooperation)

CASAFA: Commission for the Application of Science to Agriculture, Forestry, and Aquaculture

CGIAR: Consultative Group on International Agricultural Research

CIAT: Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture)

CIDA: Canadian International Development Agency

CIDT: Compagnie Ivorienne pour le Développement des Textiles (Ivory Coast Textile Development Company)

CIEH: Comité Inter États des Études Hydrauliques (Interstate Commission for Water Studies)

CIMMYT: Centro Internacional de Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center)

CIRAD: Centre de Coopération Interntionale en Recherche Agronomique pour le Développement (Center for International Cooperation in Agronomic Research for Development)

CSIRO: Commonwealth Scientific and Industrial Research Organisation

DRSS: Department of Research and Specialist Services

EMBRAPA: Empresa Brasileira de Pesquisa Agropecuaria (Brazilian Agency for Agricultural Research)

FAO: Food and Agricultural Organization

FECOTRIGO: Federação das Cooperativas Brasileiras de Trigo e Soja (Federation of Brazilian Wheat and Soya Cooperatives)

HYVP: High-Yielding Varieties Program

IADP: Intensive Agricultural District Program

IARC: International agricultural research center

IBPGR: International Board for Plant Genetic Resources

IBSREM: International Board for Soil Resources Management

ICAR: Indian Council of Agricultural Research

ICARDA: International Center for Agricultural Research in the Dry Areas

ICRISAT: International Crops Research Institute for the Semi-Arid Tropics

ICSU: International Council of Scientific Unions

IDESSA: Institut des Savanes (Savanna Institute)

IDRC: International Development Research Centre

IFA: Industries et Forêts Africaines (African Industries and Forests)

IFAD: International [illegible] for Agricultural Development

IFDC: International F[illegible]zer Development Center

IFPRI: International Food Policy Research Institute

IIMI: International Irrigation Management Institute

IITA: International Institute of Tropical Agriculture

ILCA: International Livestock Centre for Africa

IMF: International Monetary Fund

INIA: Instituto Nacional de Investigaciones Agrícolas (National Institute for Agricultural Research)

INIFAP: Instituto Nacional de Investigaciones Forestales, Agrícolas, y Pecuarias (National Institute of Forestry, Agriculture, and Livestock Research)

IRAT: Institut de Recherches Agronomiques Tropicales et des Cultures Vivières (Institute for Tropical Agricultural Research)

IRRI: International Rice Research Institute

ISNAR: International Service for National Agricultural Research

NARS: National agricultural research systems

NIAB: National Institute of Agricultural Botany

OCEPAR: Organização das Cooperativas do Estado do Paraná (Organization of Cooperatives of the State of Parana)

ODA: Overseas Development Administration

ORD: Organisme Régional de Développement du Nord Mossi (North Mossi Regional Development Organization)
OSS: Office of Special Studies
PBI: Plant Breeding Institute
PROCISUR: Programa Cooperativo de Investigación Agrícola del Cono Sur (Cooperative Agricultural Research Program of the Southern Cone)
SACCAR: Southern African Centre for Cooperation in Agricultural Research
SADCC: Southern Africa Development Coordination Conference
SAREC: Swedish Agency for Research Cooperation with Developing Countries
SPAAR: Special Program for African Agricultural Research
TAC: Technical Advisory Committee
UNCTAD: United Nations Conference on Trade and Development
USDA: United States Department of Agriculture

List of Contributors

D. Acker
Director, Food and Agriculture
United States Agency for International Development
Department of State
Washington, DC, USA

M.H. Arnold
Consultant
4 Shelford Road, Whittlesford
Cambridge CB2 4PG, England

N.E. Borlaug
Consultant
International Maize and Wheat Improvement Center
Lisboa 27, Apdo. Postal 6-641
06600 Mexico, DF, Mexico

G. Camus
Chairman
Technical Advisory Committee (TAC)
c/o World Bank
66 Avenue d'Iena
Paris 75016, France

G.T. Castillo
Professor of Rural Sociology
University of the Philippines at Los Baños
Los Baños, Laguna 3720, Philippines

M. Catley-Carlson
President
Canadian International Development Agency
200 Promenade du Portage
Hull, Quebec, Canada K1A 0G4

C. Charreau
Director
Institute for Tropical Agricultural Research (IRAT)/Center for International Cooperation in Agronomic Research for Development (CIRAD)
45 Bis, Avenue de la Belle Gabrielle
94736 Nogent-sur-Marne, France

P.R.N. Chigaru
Director
Department of Research and Specialist Services
Ministry of Lands, Agriculture, and Rural Resettlement
Harare, Zimbabwe

D. Duvick
Senior Vice-President
Pioneer Hi-Bred International, Inc.
7301 Northwest 62nd Ave., P.O. Box 85
Johnston, Iowa, USA 50131

L.T. Evans
Chief Research Scientist
Division of Plant Industry
Commonwealth Scientific and Industrial Research Organization
P.O. Box 1600
Canberra City ACT 2601, Australia

W.P. Falcon
Director
Food Research Institute
Stanford University
Stanford, California, USA 94305

K.J. Frey
Professor of Plant Breeding
Department of Agronomy
Iowa State University
Ames, Iowa, USA 50011

S.S. Husain
Chairman
Consultative Group on International Agricultural Research
World Bank
1818 H St., NW
Washington, DC, USA 20433

G. Rouanet
Chief of Maize, Wheat, and Barley Programs
IRAT/CIRAD
45 Bis, Avenue de la Belle Gabrielle
94736 Nogent-sur-Marne, France

G.E. Schuh
Director, Agriculture and Rural Development
The World Bank
1818 H St., NW
Washington, DC, USA 20433

E.W. Sprague
Consultant
127 Beck Rd., RFD No. 1
Hull, Georgia, USA 30646

M.S. Swaminathan
Director General
International Rice Research Institute
P.O. Box 933, Manila, Philippines

A. Turrent F.
Director
National Institute of Forestry, Agriculture, and Livestock Research
Insurgentes Sur 694
Mexico, DF, Mexico

A. von der Osten
Director General
International Service for National Agricultural Research
P.O. Box 93375
2509 AJ The Hague, Netherlands

D.L. Winkelmann
Director General
International Maize and Wheat Improvement Center
Lisboa 27, Apdo. Postal 6-641
06600 Mexico, DF, Mexico

List of Participants[1]

Dr. Duane Acker
Director, Food and Agriculture
United States Agency for International Development
Department of State
Washington, DC, USA 20523

Dr. Hassan Al-Ahmad
Director of Agricultural Research
Ministry of Agriculture and Agrarian Reform
Damascus, Syria

Dr. Michael Arnold
Consultant
4 Shelford Road
Whittlesford
Cambridge CB2 4PG UK

Dr. Mansur Ahmed Bajwa
Director General
Ayub Agriculture Research Institute
Faisalabad, Pakistan

Dr. Manuel Barradas
Director
Experimental Station
Elvas, Portugal

Dr. Christian H. Bonte-Friedheim
Assistant Director General
Agricultural Department
Food and Agricultural Organization
Via delle Terme di Caracalla
00100 Rome, Italy

Prof. Aureliano Brandolini
Istituto Agronomico per L'Oltremare
Via A. Cocchi, Affari Esteri
50131 Florence, Italy

Dr. Guy Camus
Chairman
Technical Advisory Committee
c/o World Bank
66 Avenue d'Iena
Paris 75016, France

Dr. Gelia T. Castillo
Professor of Rural Sociology
University of the Philippines at Los Baños
Los Baños, Laguna 3720, Philippines

Ms. Margaret Catley-Carlson
President
Canadian International Development Agency
200 Promenade du Portage
Hull, Quebec, K1A 0G4 Canada

Dr. Chris Chapman
Representative
International Board of Plant Genetic Resources
c/o IBPGR Liaison Office for North America
1001 22nd St. NW No. 300
Washington, DC, USA 64255

Dr. Claude Charreau
Director
Institut de Recherches Agronomiques Tropicales
45 bis Avenue de la Belle Gabrielle
94130 Nogent-sur-Marne, France

Dr. Phillip Chigaru
Director
Department of Research and Specialist Services
Ministry of Lands, Agriculture, and Rural Resettlement
Harare, Zimbabwe

Dr. Ramon Claveran Alonso
Vocal Secetario de Investigaciones Agrícolas
Instituto Nacional de Investigaciones Forestales, Agrícolas, y Pecuarias
Insurgentes Sur 694, Piso 9
Col. del Valle
Mexico, DF, Mexico

[1] In addition to those listed here, CIMMYT headquarters and outreach staff also attended the symposium.

Dr. Harlan Davis
Subdirector General
Instituto Interamericano de Ciencias
Agrícolas
Apdo. Postal 55
2200 Coronado
San José, Costa Rica

Prof. Peter Rodney Day
Director
Plant Breeding Institute
Maris Lane
Trumpington
Cambridge CB2 2LQ UK

Dr. Lloyd T. Evans
Chief Research Scientist
Division of Plant Industry
Commonwealth Scientific and Industrial
Research Organisation
P.O. Box 1600
Canberra City ACT 2601, Australia

Dr. Walter P. Falcon
Director
Food Research Institute
Stanford University
Stanford, CA USA 94305

Dr. Curtis Farrar
Executive Secretary
Consultative Group on International
Agricultural Research
World Bank
1818 H Street NW
Washington, DC, USA 20433

Mr. Carlos Fernandez
Assistant Secretary
Ministry of Agriculture Special Projects
Office
Diliman, Quezon City, Philippines

Dip. Rodolfo Fierro Marquez
President
PIAEBAC
Centro Civico
Apdo. Postal No. 1-67
Mexicali, B.C., Mexico

Dr. Kenneth J. Frey
Professor of Plant Breeding
Department of Agronomy
Iowa State University
Ames, IA, USA, 50011

Mr. Chaudhry Abdul Ghafoor
Ministry of Agriculture
Punjab Province
Lahore, Pakistan

Dr. Ahmed A. Goueli
Governor
Damiett Province
4 Medan El Talaba
Agouza, Giza, Egypt

Mr. Haldore Hanson
Former Director General
CIMMYT
Lisboa 27
06600, Mexico, DF, Mexico

Dr. Lowell Hardin
Department of Agricultural Economics
Purdue University
West Lafayette, IN, USA 47907

Mr. Robert D. Havener
President
Winrock International
Route 3
Morrilton, AR, USA 72110

Mr. Shahid Husain
Chairman
Consultative Group on International
Agricultural Research
World Bank
1818 H Street NW
Washington, DC, USA 20433

Mr. Adam S. Ibrahim
PNDC Under Secretary
Ministry of Agriculture
P.O. Box M37
Accra, Ghana

Dr. Phaitoon Ingkasuwan
Professor
Rector's Office
Kasetsart University
Bangkok 10900, Thailand

Dr. H.K. Jain
Senior Research Fellow
International Service for National
Agricultural Research
Oranje Buiten Singel 6, 2511 VE
The Hague, Netherlands 33746

Dr. Leobardo Jimenez
Director
Colegio de Postgraduados
Texcoco Highway
Montecillos, Edo. Mex., Mexico

Dr. Elmer C. Johnson
International Plant Research Institute
830 Branston Street
San Carlos, CA, USA 94070

Dr. Adeyemi Joshua
Director
National Seed Service
University of Ibadan Post Office
P.M.B. 9
Ibadan, Nigeria

Dr. William Kuhn
Assistant Director, Corn Breeding
Pioneer Hi-Bred International, Inc.
7301 Northwest 62nd Ave.
P.O. Box 85
Johnston, IA, USA 50131

Dr. Douglas R. Laing
Deputy Director General
Centro Internacional de Agricultura
Tropical
Apartado Aereo 6713
Cali, Colombia

Ing. Pablo Larrea
Director General
Instituto Nacional de Investigaciones
Agropecuarias
Apdo. 2600
Quito, Ecuador

Mr. Alejandro Lopez
PIAEBAC
Coahuila 350 Norte
Ciudad Obregon, Sonora, Mexico

Ing. Emilio Madrid C.
Executive President
Instituto Nacional de Investigaciones
Agrícolas
Fidel Oteiza 1956, Piso 12
Santiago, Chile

Dr. Antoine Mathelier
Secretary of State
Ministère de l'Agriculture des Ressources
Naturelles et du Développement Rural
Damien, Port-au-Prince, Haiti

Mr. William A.C. Mathiescn
Consultant
13 Sydney House
Woodstock Road
Bedford Park, London W4 1DP, England

Ing. Alexis Matute Vargas
Instituto Hondureño del Cafe
Tegucigalpa, Honduras

Mr. Stephen E. McGaughey
Chief
Forestry & Fishery Section
Inter-American Development Bank
808 17th St. NW
Washington, DC, USA 20577

Dr John J. McKelvey, Jr.
Chairman of the Board of Trustees, IITA
RR 1, BOX 144A
Richfield Springs, NY, USA 13439

Dr. James R. McWilliam
Director
ACIAR
P.O.Box 1571
Canberra, A.C.T. 2601, Australia

Dr. Joseph M. Menyonga
International Coordinator
Organization of African Unity
Semi-Arid Food Grain Research and
Development
B.P. 1783
Ouagadougou, Burkina Faso

Dr. John Monyo
Executive Secretary
Technical Advisory Committee
Food and Agricultural Organization
Via delle Terme di Caracalla
00100 Rome, Italy

Dr. Jesus Moreno
Dir. Tecnico Rel. Cientificas
National Institute for Agricultural
Research
Calle Jose Abascal 56
Madrid 28003, Spain

Dr. Stachys N. Muturi
Director of Agriculture
Ministry of Agriculture
Kilimo House
P.O. Box 30028
Nairobi, Kenya

Ing. Luis Pampliega
Director General
Ministry of Agriculture
Paraguay

Lic. Eduardo Pesqueira Olea
Secretary
Secretario de Agricultura y Recursos Hidraulicos
Av. Insurgentes Sur 476, 13o. Piso
Mexico 06700, DF, Mexico

Dr. Zhuang Qiao-sheng
Institute of Crop Breeding and Cultivation
Chinese Academy of Agricultural Sciences
Beijing, People's Republic of China

Dr. M.V. Rao
Special Secretary to the Government of India
Krishi Bhawan
New Delhi 110001, India

Mr. Timothy Rothermel
Director
Division for Global & Interregional Program
United Nations Development Programme
One United Nations Plaza
New York, NY, USA 10017

Dr. Ernesto Samayoa
Sub-Director of Research, Northern Zone
CIANO-INIFAP
Apdo. Postal 515
Cd. Obregon, Sonora, Mexico

Dr. Da Sansan
Program Leader
Cereal National Program Station
Farako
BP 910
Bobo Dioulasso, Burkina Faso

Dr. Yookti Sarikaphuti
Director General
Department of Agriculture
Bangkhen, Bangkok 10900, Thailand

Dr. G. Edward Schuh
Director
Agriculture and Rural Development
The World Bank
1818 H Street, NW
Washington, DC, USA 20433

Dr. D.S. Sidhu
Professor and Head, Economics
Punjab Agricultural University
Ludhiana, Punjab, India

Dr. Ernest Sprague
Consultant
127 Beck Road RFD No. 1
Hull, GA, USA 30646

Dr. Jitendra P. Srivastava
Leader, Cereal Improvement
International Center for Agricultural Research in the Dry Areas
P.O. Box 5466
Aleppo, Syria

Dr. M.S. Swaminathan
Director General
International Rice Research Institute
P.O. Box 933
Manila, Philippines

Dr. Leslie Swindale
Director General
International Crops Research Institute for the Semi-Arid Tropics
Patancheru, Andhra Pradesh 502-324
India

Dr. Marco Antonio Turrent Fernandez
Director
National Institute of Forestry, Agriculture, and Livestock Research
Insurgentes Sur 694 - 10o. Piso
Mexico, DF, Mexico

Dr. Guy Vallaeys
Advisor to the Director General
Centre de Coopération Interntionale en Recherche Agronomique pour le Développement
45 bis Ave. de la Belle Gabrielle
94130 Nogent-Sur-Marne, France

Mr. Jose Ever Vargas Sanchez
Instituto Colombiano Agropecuario
Apartado Aereo 233
Palmira, Colombia

Dr. Manuel Villa Issa
Undersecretary
Promocion y Desarrollo Agropec. For.
SARH
Insurgentes Sur 476
Mexico, DF, Mexico

Dr. Alexander Von Der Osten
Director General
International Service for National
Agricultural Research
P.O. Box 93375
2509 AJ The Hague
Netherlands 33746

Dr. Edwin Wellhausen
Former Director General, CIMMYT
5400-A Via Carrizo
Laguna Hills, CA, USA 92653

Dr. Rolf Wilhelm
Deputy Director
Federal Department of Foreign Affairs
Bern, Switzerland

Dr. Hikoyuki Yamaguchi
Professor
University of Tokyo
Wakaba-cho 1-20-10, Chofu 183
Tokyo, Japan

Ing. Oscar Zazueta M.
Administrador Gral. Semillas
CAADES
Juan Carrasco 787 Nte.
8000 Culiacan, Sinaloa, Mexico

Dr. Frank Zillinsky
Consultant
1385 McMahon Ave.
Gloucester, Ontario KIT IC2 Canada