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THE GREEN REVOLUTION: THE ROLE OF CIMMYT AND WHAT LIES AHEAD

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I wish to reflect upon some of the organizational hallmarks that have helped Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) play such an effective and catalytic role in agricultural development over the past 20 years. In doing this, some of the agricultural research methodologies and new institutional systems that CIMMYT has played an instrumental role in developing are of special significance. I also wish to reflect on what are likely to be significant developments in agricultural development in the years ahead and CIMMYT's role in this.

The Forerunner of CIMMYT, The Cooperative Mexican Agricultural Program

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 (CMAP), which was launched in 1943 as a joint undertaking between the Mexican Ministry of Agriculture and the Rockefeller Foundation. Those of us who were members of the research staff of the Mexican Government-Rockefeller Foundation Cooperative Agricultural Program (Oficina de Estudios Especiales) during 1943-60 are deeply obligated and 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 this group who merit special acknowledgment of outstanding support and guidance were: Ing. Marte R. Gomez, Ing. Gonzalez Gallardo, President Adolfo Lopez Mateos, Ing. Julian Rodriguez Adame of Mexico, and the "four horse-men" of the Rockefeller Foundation: Drs. E.C. Stakman, Paul Mangelsdorf, Richard Bradfield, and J.G. Harrar. Contrary to the general public's perception, the research objective of this pioneering program was much broader than the development of improved high-yielding disease resistant crop varieties. Over its 20-year lifespan in Mexico, this program developed improved maize and wheat production technologies appropriate to the conditions of farmers in Mexico as well as in many other developing countries. 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.

One of the most significant contributions made through this cooperative effort was to help build a national agricultural research system in Mexico. Training of local researchers, therefore, 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.S. and Ph.D degrees.

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

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Production Impacts In Mexico

Since the sixties, Mexico has continued to make research impacts in maize and wheat through its own 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 percent per annum and maize production at a 3.0 percent annual rate. Today, Mexico ranks 5th in maize production and 15th in wheat production in the world. National yields of maize have increased at a rate of 3.1 percent per annum since 1970-72, with the total area devoted to maize cultivation declining slightly. Growing deficits in domestic maize production have been caused primarily by the very strong demand for this cereal grain as a poultry and livestock feed. The current average national yield for Mexican wheat is approximately 4 tons per hectare, the highest in the developing world and only surpassed in the developed world by a few European countries. This is due largely to productivity gains. Mexico once again is self-sufficient in wheat production.

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, is the real challenge. 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 coast of Mexico. 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, Gibberella , Septoria, and to a complex of root-rot producing organism, especially Sclerotium rolfsii. 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 underexploited area and productivity of wheat sown during the summer rainy season at high elevations, especially on the central plateau. Research efforts during the late forties clearly established the biologic and economic feasibilities of production under these conditions. Since the harvest from the traditional winter production areas was adequate to meet demands until the late seventies, this production potential remained unexploited. Within the past 5 years, the area sown to summer wheat has increased rather dramatically. Expanded cooperative research by CIMMYT-INIA to broaden the spectrum of resistance to a number of foliar diseases, as well as for tolerance to high levels of soluble aluminum, is essential if the full potential of summer wheat production at high elevations is to be exploited. CIMMYT also has interest in development of such research for use in the Andean region.

Establishment of CIMMYT

The success of the cooperative program in Mexico led to the creation of INIA, now (INIFAP), as well as CIMMYT. Upon the request and insistence of the late President of Mexico, Adolfo Lopez Mateos, in 1964. INIA assumed the national mandate to produce research results for Mexican farmers. CIMMYT assumed an international mandate to support and complement the maize and wheat research work on national programs throughout the world, but with emphasis on the production problems of developing countries.

A Shared Legacy

In commenting on CIMMYT's contributions to raising maize and wheat productivity, I will treat the achievement 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, in large part, is modeled 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, at least in wheat, were achieved prior to the establishment of CIMMYT.

CIMMYT's Research Contributions

Its staff--past and present--has played pioneering roles in the development of commodity-focused agricultural research in the Third World. Most significant among its achievements has been the development of high-yielding wheat and maize varieties with broad adaption and enhanced yield dependability and the development of the agronomic practices that permit these improved materials to express their high genetic yield potential. The greatest commercial benefits of this research have been achieved in wheat. But considerable impacts in maize 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. More recent efforts to develop germplasm with greater dependability of yield under environmental stress situations and CIMMYT's work in developing crop management research procedures are also significant activities.

Broad Adaptation

Until the fifties and still present to some extent, 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 are 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, this permitted a more effective screening program to build up a more durable resistance (broad spectrum) to stem rust as well as to other pathogens. With two breeding cycles every 12 months, a new variety could theoretically be produced in 4 years, rather than 8 years required with the conventional methods.

We used two locations in Mexico to accomplish this. The locations were separated from each other by 10 degrees of latitude (and with changing day lengths) and with differing temperatures because of a change in elevation of 2,600 meters. Segregating populations were shuttled, grown, and selected in these two very diverse environments. Some unexpected results soon became evident from this unorthodox breeding approach. Progenies from certain individual plant selections from a very few crosses were soon observed in F3 and F4 plants 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. Our aim was to try to identify individual plants that combined not only resistance to stem and leaf rust--which was the original objective--but also had broad adaptation and resistance to shattering and lodging.

By 1948, the Princess of Serendip 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, and 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. These varities with their day-length insensitivity and broad-based rust resistance were also later shown to be top yielders in many other production areas in developing countries. This made the tasks of seed production and distribution easier in the early years. With only a few varieties needed to serve commercial farmers--rather than a dozen or more that would have been necessary if narrowly adapted varieties would have been developed, the work of 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 should try to develop a single universal variety. This would be unwise from a genetic erosion and disease susceptibility standpoint as well as in terms of trying to optimize yield potential, especially in many problem soils. 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 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 U.S. 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 of 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 photoperiodism and those that control vernalization (temperatures), making it possible to isolate many different genotypic combinations.

Breakthrough in Genetic Yield Potential

Though successful in combining 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, lodging had become the major problem limiting yields, especially in Sonora Mexico. During 1952-53, we made a concerted, but unsuccessful, effort to find suitable sources of shorter and stronger straw varieties for use as parents in the breeding program. The entire world wheat collection of the USDA was screened for straw height and strength. I learned in late 1952 of Dr. Orville Vogel's preliminary successes of incorporating the dwarfing genes from Norin 10 into winter wheats from the late Dr. Burt Bayles, then senior wheat breeder for the USDA. I wrote Dr. Vogel and requested genetic materials containing Norin 10 dwarfing genes for use as parents in the Mexico spring wheat breeding program. In 1953, Dr. Vogel kindly sent me a few seeds from three different F2 selections from the cross Norin 10 x Baart and a few seeds from each of five superior F2 plants from the cross Norin 10 x Brevor.

Our first attempt to cross the Mexican materials to Vogel's materials was unsuccessful because the resulting F3 plant was used as the female parent, which was highly susceptible to all three rusts. The F3 plant was killed outright without producing viable F1 seed. Using the few remaining seeds, a second attempt was made in 1955 and was successful. In the F1 and F2 progeny derived from the superior Norin 10 x Brevor cross, 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 more obvious and worrysome was the high degree of male sterility, especially in the later tillers, which led to much promiscuous outcrossing. 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 in texture, 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.

Strong selection pressure was exerted to attempt to overcome these problems, and various types of crosses were made. By 1962, 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 to the partitioning of more of the total dry matter into grain production. The newly released semidwarf varieties had yields of 6-7 tons per hectare, compared with the 4-4.5 tons per hectare of the tall, improved Mexican genotypes that were used as parents. 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 sixties, more than 400 high-yielding semidwarf wheat varieties derived, at least in part, from crosses made at CIMMYT have been released in some 50 countries. These materials 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 twice as much as traditional varieties under more optimum fertilizer and moisture conditions.

The area in which these semidwarf varieties have demonstrated superior yield performance is vast: 50 million hectares, half of the total wheat area in the developing world. Immense as it is, this wheat-producing area shares many common bonds in terms of varietal requirements. Rusts are the major disease problem, moisture is generally not a limiting factor, and intermediate-to-early maturity is the major growth-period requirements. The materials developed in Mexico had these characteristics. In addition, their day-length insensitivity and other agronomic characters made them adapted to a very broad range of production conditions. The current coverage probably delineates the boundaries of these major production environments. The fact that 50 million hectares have yet to be planted to improved varieties indicates that these production areas require different varieties than those produced to date. New gene pools and more specific selection criteria are likely to be needed for untouched problem soil areas. These areas primarily include acid soils with high levels of soluble aluminum, alkaline soils with high levels of sodium, and soils in marginal rainfall areas.

Development of High-Yielding Maize Materials

Local maize varieties in the tropics and subtropics suffered from a similar problem to traditional wheat types. They were leafy, grew too tall, and tended to lodge heavily when grown under improved agronomic conditions. Compared to U.S. 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 indexes of tropical and subtropical maize materials. The center's efforts to develop high-yielding open-pollinated maize varieties have also been a unique research contribution. These efforts led to the development of more grain-efficient, yield-dependable varieties whose seed could be saved by the farmer for planting the next season without significant loss of vigor.

A recurrent selection scheme, rather than the introduction of a dwarfing gene, has been the basis for repartitioning total dry matter weight toward greater grain production in maize. The results have been the same: the improved maizes have much higher genetic yield potential than 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 result of this work, new sources of genetic variability have been introduced into national maize improvement programs; germplasm, which can be readily used, is being used to improve locally developed materials. The maize germplasm developed through this improvement methodology has been a collaborative effort with national scientists throughout the developing world. The partnership has produced 1,000 experimental varieties, and some 150 varieties 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. The euphoria faded to frustration. This effort was discontinued by virtually all of the private sector maize seed companies, as well as government and university programs, as the discovery of unfavorable linkages associated with the opaque-2 gene became apparent.

The CIMMYT maize breeding program, with excellent close collaboration with the geneticist-breeders and biochemists, has gradually overcome the adverse linkages. 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 by CIMMYT. This work has shown that the adverse linkages between high levels of lysine-high tryptophane (opaque-2 gene) and low grain yield, soft grain texture, susceptibility to ear rots and insect damage can be, and have been, overcome. CIMMYT is now developing QPM hybrid maize varieties. OPM varieties are currently being grown commercially in Guatemala and China.

It appears that the development, acceptance, and use of QPM varieties are now at a position similar to that of the semidwarf wheat varieties 20 years ago in India, Pakistan, and the United States. Many noisy skeptics said that the wheat varieties would never be accepted. Nevertheless, look what has happened in the past 15 years! I predict QPM too will have "its day" in the years ahead.

The New Crop: Triticale

Triticale is an amphiploid "species" developed from crossing wheat and rye, employing either durum or bread varieties as the wheat parent. This new cereal crop, which promises to become an important food and feed grain crop in many areas of the world within the next decade, is currently grown in at least 10 different countries on a total of about 750,000 hectares.

CIMMYT inherited a small triticale research program from its predecessor organization. At that time, all triticales were tall, of late maturity, and highly sterile; the grain that was produced was badly shrivelled. CIMMYT established a large, broad-based breeding program to overcome these defects. Despite criticism of the program and prediction by some theoretical scientists that these defects--especially sterility and shrivelling of the grain--would never be overcome, one by one they have been, and triticale is now becoming a commercial crop in some countries. Triticale is far superior in grain yield to wheat in acid soils, especially in areas with high levels of soluble aluminum. In many areas with good soils (such as Sonora, Mexico), it yields are as much as or slightly more than the best bread wheat varieties. Triticale is currently being grown on commercial average in the Soviet Union, Poland, Australia, Spain, France, West Germany, Canada, the United States, Argentina, and Mexico, and it is used primarily as a feed grain. Triticale flour (unlike flour from durum wheat), when properly blended with flour from bread wheat and with the dough appropriately handled during fermentation, will produce good bread. In recent years, in certain seasons when environmental conditions are favorable for heavy infection with Karnal bunt, the level of grain infection on wheat bread varieties is 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 are either entirely free of Karnal bunt or only have a trace of bunt.

Crop Production Research

CIMMYT has had a tradition of being farmer-focused in its research approach. While the center is famous for its contributions in plant breeding, improved germplasm has been the only calling card for the center. While high yielding varieties have served as the catalyst for introducing higher-yielding agricultural technology, the contributions of fertilizer, irrigation, and improved agronomy were essential to the impacts that have been achieved on Third World food production. CIMMYT has played a significant role in advocating the development of a more suitable infrastructure for high-yield agriculture. As evidence in those countries (such as Turkey), where wheat production is most limited by agronomic and economic problems, the center has emphasized crop management research above crop improvement research. This comprehensive approach to agricultural research is fundamental to achieving progress.

CIMMYT has played a leading role in the development of more effective crop management research procedures in which economists and biological scientists work together. The procedures that have been developed place a major emphasis on onfarm experimentation because the production conditions of most research stations are not typical of the conditions faced by representative farmers. These methodologies have been adopted by many national research programs in the Third World and have greatly increased research effectiveness in the development of farm-level production recommendations.

CIMMYT's Institution Contributions

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

International Testing

In 1950, the first of four successive stem-rust epidemics struck U.S. and Canadian wheat crops. The greatest destruction happened in 1954 when 75 percent of the durum and 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 used commercially. A race similar to 15B was also spreading simultaneously in Latin America. The standard response to such an epidemic is the rapid testing of wheat lines to identify resistance to the new race of pathogen, then to multiply the seed of the resistant lines as soon as available, while also continuing crossing resistant lines to pyramid and broaden the genes for resistance. A race as virulent as 15B demanded the widest possible testing in the shortest possible time.

A disease 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 and E. C. Stakman, that are still benefiting global agriculture. In 1950, the USDA appealed to seven countries--Mexico, Colombia, Ecuador, Peru, Chile, Argentina, and Canada--to join the United States in testing 1,000 lines of wheat selected from the U.S. world wheat collection and some advance 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 1,000 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 being formed. Before the 1st International Stem Rust Nursey, many breeders were reluctant to release advanced lines from their breeding programs to fellow scientists for fear the 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.

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, the United States, Colombia, Chile, Argentina, and Brazil. The nursery was grown in Canada, the United States, Mexico, Guatemala, Colombia, Ecuador, Peru, Bolivia, Paraguay, Chile, Argentina, Brazil, and Uruguay. This nursery clearly established the broad adaptation of the Mexican varieties in contrast to the limited adaptation across latitudes of the long day-length varieties of Canada, the United States, and Argentina. Mexico was part of the training exercises for the FAO-RF sponsored North African/Near East/Middle East wheat in-service training program. The nursery included the important commercial varieties of the North African, Near Eastern, and Middle Eastern countries and Mexico, as well as the two long day-length varieties, Thatcher (Minnesota) and Selkirk (Canada), and a number of promising new semidwarf lines from Mexico. The Inter-American Spring Wheat Yield Nursery and the Near East Mexican Yield Nursery were combined in 1961 to form the International Spring Wheat Yield Nursery (ISWYN), which is still in existance today and whose data serve--for those wheat scientists who use it intelligently--as an invaluable guide for orienting their breeding programs.

CIMMYT's serves as the hub of the largest germplasm distribution and testing networks in the world today. CIMMYT sends over 1 million packets of experimental seed--carrying significant amounts of useful new genetic variability--to plant scientists in more than 120 countries each year. 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 of each year's international nursery are then compiled, published, and distributed among networks of maize and wheat scientists. CIMMYT's germplasm banks--some of the largest and best maintained in the world--supply thousands of seed samples upon requests to scientists throughout the world.

International testing ushered in a new willingness to share advanced generation unnamed lines, as well as early generation materials. This, in turn, accelerated the introduction of materials with genetic variability--the basis of progress in plant improvement--into national breeding programs. 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, providing acknowledgment of the source of material was given. These developments broke down psychological barriers that had tended to keep the efforts of plant breeders separate. Not only did international testing introduce new genetic variability into national breeding efforts, but it also provided individual breeders with an international system to simultaneously evaluate the adaptation and disease stability of their promising new materials in many different environments. I believe it fair to say that the advent of international testing, which led to an unexpected acceleration in plant breeding programs around the world, marked the beginning of the modern era in plant breeding.

Training and Leadership Development

CIMMYT's has always placed a very high priority on its training and leadership development efforts in support of collaborating national institutions. The center currently counts some 4,000 researchers from 120 countries as alumni of its in-service training courses at headquarters and outside Mexico, and its fellowship program for visiting scientists, graduate students, and pre- and post-doctoral 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 at CIMMYT has been on actual physical performance of research tasks. A tutorial form of instruction has been emphasized in which in-service trainees and visiting scientists work alongside the CIMMYT staff in the field and in the laboratory. This approach has had a positive motivational effect on trainees and research fellows.

CIMMYT's Research Environment

The center has largely been unfettered by restrictive bureaucratic and political constraints, adequately funded, and supported by an excellent infrastructured of experiment stations, laboratories, and information and administrative services. It has also enjoyed excellent ties to and collaboration with the Mexican INIA/CIANO Wheat Research Program and the support of the Sonora farmers' patronato organization, which supports wheat research. This environment has permitted scientists to focus their energies on the research agenda at hand and has resulted in high levels of motivation and commitment among the staff. As such, CIMMYT has helped to establish a fraternity of maize and wheat scientists and a standard of excellence for thousands of researchers from around the world. CIMMYT's achievements have also helped to give the agricultural research profession greater credibility in political circles in the Third World.

Development of Scientific Information Networks

CIMMYT has always given major emphasis in its program activities to the maintenance of close working relationship with national program scientists. This has involved frequent travel by CIMMYT headquarters staff to the research plots of national collaborators, providing training and visiting scientist fellowships for scientists from developing countries to come to Mexico, providing assistance in obtaining funds for graduate studies to pursue master's and doctorate degrees and the provision of published scientific information, generally on a cost-free basis. In an earlier day, much of the staff travel to collaborating countries was done by the staff based in Mexico. In particular, CIMMYT's directing staff traveled widely each year, visiting with research collaborators, administrators, and policymakers in many countries. As the number of countries with which CIMMYT had research relationships grew from 60 to more than 120, new institutional mechanisms were necessary to handle these interorganization relationships more effectively. The development of the regional program concept has been a major component of the current institutional strategy. Half of CIMMYT's scientific staff is now posted in regional programs. Much of their activity is similar to what staff traveling 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 research problems and opportunities, the linkages with national programs have been enhanced.

Contributions to Increased Food Availability and Agricultural Productivity

CIMMYT's research efforts have been ongoing for 20 years and, if the predecessor period is included, for more than 40 years. What has been the impact? The center's contributions to increased agricultural productivity are intertwined with the efforts of many scientists, production specialists, extension workers, policymakers, and farmers. In germplasm development, the staff has worked in a partnership role with national research programs. 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, farm-level impacts are the consequences of many other components besides improved varieties. Increased use of fertilizers, irrigation, improved agronomy, plant protection, and greater policy incentives all have played major roles in the productivity advances that have been made.

The Green Revolution

CIMMYT was born in the midst of, and was largely a consequence of, a world food production crisis--centered in Asia during the early to midsixties. With countries lacking foreign exchange to purchase food imports, dire predictions were being made that without perpetual food aid, countries in the region faced continuing, and probably worsening, famines. Political leaders, many with their back 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. Over-ruling the counsel of some local researchers, India and Pakistan's national leaders took calculated risks and after 4 years of widespread onfarm testing decided to embark on a major production program to introduce the new seed-fertilizer technologies as quickly as possible. Once farmers saw the yields of the new wheats (and improved agronomic practices) on demonstration plots on their own farms, they became the major spokesmen for increased adoption. The spread of these new wheats and rices is unparalleled in the history of agriculture, except perhaps for the spread of hybrid maize in temperature-zone countries during the forties, fifties, and sixties. In less than 20 years, half of the Third World's wheat and rice area has come to be planted with these modern genotypes.

Many initial reporters chose to depict the new wheat and rice technologies as a wholesale technological transfer of high-yield, temperature-zone farming systems to peasant farmers in the Third World. In reality, however, this was not the case. More accurately, the term "green revolution" should be used to identify the beginning of a new era for agricultural research and development--which continues today--in which modern principles of genetics/plant breeding, agronomy, plant pathology, entomology, and economies have been applied to develop indigenous technologies appropriate to the conditions of Third World farmers.

The really important attribute of the new green revolution technologies was that they were yield-increasing, cost-reducing, land-augmenting technologies. It was the introduction of this new technology, combined with adequate policy incentives that led to significant productivity gains. The combination of the new varieties and higher yielding production technology has allowed all farmers to increase total farm output through higher yield levels and through the possibility for increasing cropping intensity. Coupled with stimulatory economic policies, farmers had incentives to produce surplus production for commercial sale. Not only did these innovations lead to increased 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 sources of employment. Consumers were the major beneficiaries, especially the urban and rural poor, whose diets rest heavily on cereals. Because per capita production has increased in rice, wheat, and maize, the rate of increase in food prices has been considerably dampened. This has permitted improved nutrition and helped improve the welfare of millions of low-income people.

Today, the significance of agriculture as the engine for overall economic development in the Third World has been convincingly proven. In the words of economist John Mellor, "the research breakthrough symbolized by the new cereal varieties offered an opportunity to turn away from defeatist agricultural development policies directed toward the race to keep food supplies in balance with population growth and famine relief and to turn toward a positive role for agriculture, which places it at the leading edge of the total development process."

Productivity Improvements in Maize and Wheat

Increased investments in agricultural research and rural development have helped to more than double maize production and to more than triple wheat production over the past 20 years in the Third World countries. Slightly less than half of the growth in maize production and 65 percent of the growth in wheat production have been due to higher yield levels. Third World production of both crops has increased more rapidly than population over the past two decades. Since 1961-65, per capita production has increased by 30 percent in maize and by 70 percent in wheat. Virtually all of this increased per capita production of maize have been destined for livestock and poultry feed. Direct-food maize (as percentage of total calories) remained constant at 8 percent. Increased per capita production of wheat caused the major increase in the importance of this grain in human diets in developing countries. Wheat accounted for 16 percent of total calories in human diets during 1961-65 and for 26 percent in 1981-84. These growth rates reflect impressive changes in productivity, especially given the dire predictions of increasing food deficits that dominated the agricultural press only a decade earlier.

When these Third World production indicators are disaggregated into regional statistics, it becomes evident that progress in agricultural development has been uneven across regions. The performance of China has obviously been spectacular, with per annum growth rates of 7 percent in wheat and 5.8 percent in maize over this 20-year period. Strong growth rates also have been registered in the developing market economies of Asia. Wheat and maize production has outpaced population in most of Latin America, except in the Andean countries. The growth rates in Mexico, Central American, and the southern cone countries of South America have been strong. Imports in Latin America have been on the rise, a consequence of rising incomes and growing demand for meat and livestock products. Middle East wheat production has barely kept pace with population growth, while per capita maize consumption has declined. In North Africa, the growth in wheat production has been sluggish, although maize yields have increased at a rate of 2.3 percent per annum. West Africa has had very low growth rates in yields and in production of both maize and wheat. Only in southern and parts of eastern Africa have maize and wheat yields and production increased near the rate of population growth.

It is interesting to note that those developing countries with the best growth rates in agricultural production also have the strongest rates of overall economic growth. With often rapidly rising per capita incomes, these developing countries have also purchased more agricultural imports to help satisfy very strong domestic growth rates in demand for livestock and poultry products.

Critics of the Green Revolution

Despite the tremendous production gains achieved in a very short time--which helped to starve off famine situations of gigantic proportions, the green revolution technologies have been the subject of intense controversy since their introduction.

Will Durant, the historian, once commented that "man's capacity for fretting is endless, no matter how many difficulties we surmount, how many ideals we realize, there is a stealthy pleasure in rejecting mankind or the universe as worthy of our approval." This phenomenon is quite representative of the attitude of many green revolution critics. These critics were utopian intellectuals speaking from privileged positions in ivory towers who had never personally been hungry or ever lived and worked with people living in abject poverty. They seemed to convey the impression that science and technology, if properly organized, could correct all of the social ills and inequities that had accumulated from the time of Adam and Eve up to the present, and thus remove this nasty task from the shoulders of political leaders.

In the initial years, two major lines of criticism were leveled against the green revolution. On one side were the population doomsdayers who said that it was already too late in the over-populated 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 it sinking. Moreover, they viewed international technical assistance efforts in agriculture as only encouraging more population growth, which, as a result, would lead to a disaster of greater proportions later.

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

Another major line of green revolution criticism argued that the introduction of the new seed-fertilizer technology would only lead to worsening in the distribution of income and wealth, unless redistribution in the means of production occurred first. Critics in this school labeled the high-yielding wheat and rice technologies as being only suited to the rich landowners who could afford the seed, fertilizer, and irrigation needed to obtain maximum yield potential. It was true that the new technologies increased production costs per unit of cultivated area. What seems to be ignored in this equation, however, is the fact that the new technologies increased output proportionally more than the cost of the new inputs. Green revolution technologies have also been accused of accelerating labor displacement in rural areas because they encouraged mechanization. While this is also 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 very positive.

The spectacular success of the new wheat and rice seed-fertilizer technologies, no doubt, overshadowed many underlying social and economic problems related to income distribution in the Third World. Development efforts to correct serious inequalities in land tenure and to redistribute more equitably national means of production were probably set back. But, it is now well documented that small farmers--with only relatively brief lag times--adopted the new seed-fertilizer technologies about as rapidly as large farmers. Given their ability to take risks, larger farmers were the first to test the new technologies since they could afford to gamble more. While both groups have benefitted equally in proportional terms, obviously those with more resources received greater benefits in an absolute sense. I personally am not interested in distributing poverty more equitably. Instead, my approach is that we must increase production of food and at the same time strive for more equitable distribution. In countries where resource distribution is highly skewed and unequal, their long-term economic growths are not likely to be sustained without political and economic measures to redress such imbalances. It is a problem, however, that science and technology are not well equipped to handle. Plant species are apolitical creatures. They cannot to 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.

In more recent years, some members of the environmental movement have also become green revolution critics. The thrust of their criticisms has a distinct antitechnology bias, combined often with an idealized view of peasant farming as a harmony between man and nature. Arguments in this view often imagine conspirational relationships between scientists and agricultural chemical and machinery companies. They accuse us of trying to get Third World farmers "hooked" on energy-intensive production technologies that are not economically nor environmentally sustainable. Greater use of chemical fertilizers, pesticides, herbicides, pump irrigation systems, and farm machinery is inherently bad for the Third World according to them. 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.

It is my belief that agricultural chemicals are absolutely necessary to produce the food that is necessary to feed today's population of 5 billion, which is currently increasing at the rate of 82 million per year. Lest I be misunderstood, agricultural chemicals and fertilizers are like medicines, they are absolutely necessary to produce the food and fiber required by our world population, but they should be used with proper caution. There is no way that the world can turnback to the "good old days" of the early thirties when few agricultural chemicals and little chemical fertilizer were used. There are 5 billion people requiring food today, compared with only 2 billion in 1930. Without increased productivity, how would we provide the necessary food for the 3 billion people that have been added to the world population in the last half century?

This group of critics 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 a more enjoyable, pleasant, and longer life than any previous generation. In 1900, the life expectancy at time of birth in the United States was 46 years for man and 48 years for women. By 1940, life expectancy for the total population at time of birth had increased to 60.8 and 65.2 years for men and women, respectively. By 1982, life expectancy at birth for the total population reached 70.8 years for men and 78.2 for women, and it continues to increase. The truth for these elitist critics seems to be that life has become so enjoyable that they would like to extend it indefinitely, while enjoying the vigor, enthusiasm, and health of youth. This unrealistic utopian philosophy prevails because those promoting it have forgotten the basic fact that all that are born into this world must sooner or later die and give way for the next generation.

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 leave land out of food crop cultivation for green manure crop rotations to help organically restore soil fertility. Fortunately, soil fertility can be effective and safely restored through 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 cultivating practices.

There are some organic gardening enthusiasts who 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 percent nitrogen on a dry weight basis) that would be needed to produce the 65 million metric tons of chemical nitrogen used today would be about 4.4 billion tons--quite a dung heap and quite an aroma--were it available. This volume of organic materials is equal to twice the world's animal production, with all the additional grain and pasture feeding implications that such an increase would imply. Even now, there are many areas of the world where over-grazing is already causing serious erosion problems.

There is another group of critics that insists that foreign technical assistance programs spawning "green revolutions" are destroying the markets for food-exporting nations. This is a gross over-simplication of facts. In the first place, poor nations and poor people are poor customers. For examples, the food-deficit hungry nations of Africa are today largely agrarian subsistence economies in which 80-85 percent of the total population are poor subsistence farmers without 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 produce to sell, and with which they can begin to buy other products and, in the process, join the money economics which will, in time, result in increased trade. Recent trade data for U.S. agricultural products confirm this fact. These data indicate that Third World nations with strong growth rates in their domestic agricultural sectors also have strong overall economic growth. It is also these nations that have increased their imports of U.S. products, not the poor, stagnant developing countries.

The growth that has occurred in human population numbers during this century makes it impossible--even if we wanted--for us to turnback the clock and use the less-intensive production practices that were dominant only a century ago, when world population was under 2 billion and large expanses of land were available for increased food production. In a world of 5 billion, in which bringing new agricultural lands into production has become increasingly more difficult and costly, we have no choice but to increase land intensification on existing farmlands. Such intensification can have adverse environmental consequences, but it doesn't have to. Rather that advocating that we go back to earlier production systems, the solutions lie in using our scientific knowledge to develop technologies that can increase productivity as well as ensure sustainability of production.

CIMMYT's Organization Hallmarks

CIMMYT's primary purpose is to help speed the process of developing improved maize and wheat technologies in the Third World. While the center's principal contacts are national program researchers, developing country food producers and consumers are the target to whom our collective work is directed. Even though national programs carry the primary responsibility for developing and extending improved production technologies to their farmers, CIMMYT also must share accountability. The achievement of wheat and maize productivity impacts on farmers' fields; therefore, it must be the ultimate measure of the value of the center's work--as well as that of the CGIAR system. CIMMYT cannot afford--nor can national program collaborators--to rest on past laurels and achievements. We owe the societies that support which depend upon us for a good return on their investment. Our assigned task is in the final sense to alleviate hunger and human misery--which we must never forget.

I believe that the most efficient 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 more comfortable to stand and work in the shade of the tree of your own discipline, even though the forest is made up of the shadows of trees of many disciplines. What is needed instead are venturesome scientists who are comfortable and willing to integrate across the shadows or scientific disciplines cast by all the trees in the forest, and, thereby, produce a technology capable of increasing the overall sustainable productivity of the "forest." Integration of scientific disciplines 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. This requires a research approach that recognizes and appreciates the need to have teams of scientists with different and complementary professional skills, and that attempts to be sensitive to the broad range of factors affecting productivity.

The development of a modern economy based on the application of science and technology depends on large numbers of educated people and on institutions (both private and government) through which the knowledge, experience, and energy of people can be effectively mobilized. CIMMYT's commitment to training must continue to be steadfast. In the development of new research leaders, we should not forget that the actual physical performance of a task is the best ways to gain mastery over it. And without truly understanding a research task, one is less qualified to guide others in its performance.

Our friend and colleague, T. W. Shultz, 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, and that is that research, while a necessary condition, 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.

I must caution here that I am concerned about CIMMYT moving away from a production orientation in its research organization. While I accept that the center 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 efforts. Ways to maintain contact with the producer are essential to keep program priorities on track and in maintaining the practical orientation of the center. Moreover, it mitigates the erosive effects of the dangerous institutional viruses of affluency and over-sophistication.

And to the CIMMYT staff and their families. I would like to end my presentation with this thought. The destiny of a scientist, briefly stated, is to learn about, to discover, and to communicate. Excellence of each of these elements is essential to the success of science. The profession we have chosen is not for the faint-hearted; it demands involvement; it cannot be delegated very far. While CIMMYT's new training, conference, and information building, named in my honor, can increase the effectiveness of the center's work, it is only a means and not an end in itself. We must judge our worth, not by the facilities that we have or budgetary resources, by what we have contributed to the improvement of agricultural productivity in environmentally sustainable ways in the Third World. I can think of few causes more noble. May God bless and speed you in this vitally important work.