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Mainstreams of CIMMYT Research: A Retrospective

Cimmyt 1966-1986

maize and wheat for the third world

Mainstreams of CIMMYT Research: A Retrospective

Steven A. Breth

Preface

The publication of this document commemorates CIMMYT's twenty years of service to Third World agriculture. Much has changed during the past two decades: scientific advances have opened up new horizons for research; the needs of the Center's clients (national crop improvement programs) have evolved as they have accumulated experience and expertise; and CIMMYT itself has changed in response to changing circumstances. Yet through it all, the Center has, at its core, remained essentially the same vital, dynamic institute that it was at its inception.

CIMMYT's maturity as an institution and its global impact belie its official age of 20 years. In a very real sense, the Center is much older. CIMMYT's origins can be traced back to 1943 and the Mexican Ministry of Agriculture Cooperative Agricultural Program/Rockefeller Foundation, which was initiated to improve Mexican agriculture. The Office of Special Studies (as the program was called within the Ministry) employed at its peak 21 non-Mexican agriculturalists and over 100 Mexican colleagues. This cooperative effort was very effective in helping to improve the country's agricultural sector and, by the mid-1950s, Mexico was approaching self-sufficiency in maize and wheat production.

The Mexico/Rockefeller joint venture gave credence to the idea that a small, dedicated group of researchers could influence the course of agricultural development. CIMMYT was itself a result of this collaborative effort, and the success of those earlier days enabled the newly formed Center to respond rapidly and effectively to the spectre of mass starvation in the Indian subcontinent during the late 1960s. Those crisis years gave rise to a sense of urgency among CIMMYT staff, reinforcing their commitment to the Center's mission and *modus operandi*.

Many accounts of those early days have been written. We asked ourselves, "Of what value would yet another account be, and really, what *should* one say in observing the twentieth anniversary of an institution as dynamic, yet as stable, as CIMMYT?" A consensus emerged that a conventional history was not needed; rather, a description of the "mainstreams of CIMMYT research" and the courses they followed over the past 20 years was deemed appropriate.

It was with great confidence that Steve Breth was asked to undertake this task. In Steve we found an individual who is arguably one of the most knowledgeable writers focusing on international agricultural research today. Steve has been associated with agricultural research since 1963, when he joined the USDA as an economist working on a study of agricultural development in West Africa. From 1965 to 1969 he served as an editor for the American Society of Agronomy, and from there moved to IRRI for a five-year stint as a writer/editor. In 1974 Steve joined CIMMYT in a similar capacity, leaving in 1977 to join the IADS communications group. He is now with the newly formed Winrock International Institute for Agricultural Development, and special thanks are due to Robert Havener, President of Winrock International, for giving Steve the time needed to write this publication.

With his unique background in mind, CIMMYT asked Steve to view the Center's development in light of the forces that shaped the direction of international agricultural research. In so doing, he provides a better understanding of the Center's character and its evolving role in the agricultural research community. This then was Steve's mandate and is the objective of this publication: to give the reader a sense of the Center, its evolving research agenda and priorities, and to place those distinguishing characteristics in a retrospective context.

Donald L. Winkelmann
Director General

Prologue: Preparing the Ground

An Invitation

The genesis of CIMMYT can be traced to an invitation extended during the Mexican presidential inauguration of 1940. That invitation, in fact, had many ramifications. It contributed much to the concept that the food production problems of poor countries are rooted in a lack of effective research rather than in the absence of ostensibly superior technology from affluent countries. And that ultimately led to the formation of the network of international agricultural research centers, of which CIMMYT is one, and the consortium of donors — the Consultative Group on International Agricultural Research (CGIAR) — that now funds them. Before focusing attention on CIMMYT, it is appropriate to review some 20 years of early history involving agricultural research in Mexico, which set the scene for CIMMYT.

At that inauguration, the Minister of Agriculture, Marte R. Gomez, asked US Vice President Henry Wallace to provide technical assistance in helping Mexico overcome its chronic food shortages. Wallace, a former US Secretary of Agriculture who had travelled widely in Mexico, was receptive. Since this was before the birth of foreign aid agencies, Wallace turned to the Rockefeller Foundation, which had experience in mounting international public health programs. The foundation agreed to help answer Mexico's request and in 1941 it sent a commission of three eminent agricultural scientists — E.C. Stakman, Richard Bradfield, and Paul C. Mangelsdorf — to survey Mexican conditions and make recommendations.

Office of Special Studies

Their report called for an attack on Mexican food production problems through a three-pronged approach: research, education, and extension. In 1943, the Rockefeller Foundation assembled a small team of researchers to help the Mexican government. To support efforts to raise output as quickly as possible, the government established an autonomous organization, the Office of Special Studies, within the Ministry of Agriculture.

CIMMYT comes into being, 1963. From left to right: Dr. J.G. Harrar, President of the Rockefeller Foundation; Lic. Adolfo López Mateos, then President of Mexico; Dr. Nicolás Sánchez Durón, then Director of INIA, and Ing. Julián Rodríguez Adame, then Secretary of Agriculture and Livestock.

The Office of Special Studies conducted research on a wide range of crops, including maize and wheat, and later on livestock. It established research plots and demonstrations in farmers' fields and developed extension methods. It employed recent university graduates as interns and helped them get fellowships for advanced training. At its peak, the Office of Special Studies had 21 US and 100 Mexican researchers.

During the 1950s the government of Mexico made a substantial commitment to agriculture and, by 1960, a broad range of research investigations were underway.

The experiment proved successful and, by the mid-1950s, Mexico was approaching self-sufficiency in maize and wheat. In maize, an expansion in area planted, better cultural practices, the selection of superior varieties from native strains, and the incorporation of disease resistance all contributed to the gains. Hybrids were produced and widely accepted by large-scale farmers, but hybrids remained beyond the reach of many small-scale farmers due to limited seed distribution systems and other factors.

In wheat, several major scientific achievements occurred during this period. Strong resistance to stem rust, a disease that was ravaging Mexican wheat-growing areas, was the first breeding goal. Impatient with the rate of progress, the breeders of the Office of Special Studies found two climatically different locations where they could grow, successively, two generations each year, and in that way halve the time necessary to produce a variety.

The two locations were not only climatically different, they differed in elevation by 2600 meters and in latitude by 10 degrees. Thus the advancing generations were exposed to, and could be selected against, differing spectrums of diseases and environmental problems.

Moreover, it was soon found that this shuttle breeding system permitted elimination of plants sensitive to daylength. The drawback of varieties whose flowering is controlled by daylength is that they cannot be successfully grown in areas or seasons that have a different daylength than the one in which they are developed. The daylength insensitive varieties that emerged from this system were thus more broadly adapted, as well as resistant to stem rust and certain other diseases.

Farmers who had begun using fertilizers on wheat, however, were next frustrated by the tendency of tall wheats to topple over when heavy doses were applied. The wheat breeders of the Office of Special Studies turned to sources of the Norin 10 dwarfing genes as a possible solution. Norin 10 was being tested in the U.S. for dwarfing winter wheats.

The first crosses with Mexican spring wheats were made in 1953. It was nine years later before a host of problems such as sterility and poor grain quality were surmounted sufficiently for Mexico to release its first semidwarf varieties. These varieties were not only more resistant to lodging, they had a new plant architecture that resulted in a greater proportion of the dry matter going into the grain. The result was a quantum leap in the yield potential of wheat that would give Mexican wheats international acclaim within a few years.

During the 1950s the government of Mexico made a substantial commitment to agriculture and, by 1960, a cadre of well-trained Mexican agricultural professionals had been developed, a graduate school of agriculture had been established to train new scientists and technicians, and a broad range of research investigations were under way. The government decided the time was right to form a national agricultural research program, INIA (Instituto Nacional de Investigaciones Agrícolas).

International Programs

The Office of Special Studies was closed in 1961. Several of the Rockefeller staff remained in Mexico as advisors to INIA and to extend the lessons learned in Mexico to other countries. The Office of Special Studies had engaged in some international work. A few young scientists from other Latin American countries had taken part in in-service training. And regional networks such as the Central American Corn Project had been established to exchange genetic materials and information.

After 1961, international wheat nurseries were formed that introduced wheat-producing countries throughout the world to Mexican wheats, and the first trainees from outside the Western Hemisphere were accepted.

A New Institute

In 1962, following a visit to the new International Rice Research Institute, President Adolfo Lopez Mateos suggested creating an international agricultural institution in Mexico with collaboration of the Rockefeller Foundation. An agreement was made, and in 1963 an International Maize and Wheat Improvement Center was established as a cooperative program of the Mexican Ministry of Agriculture and the Rockefeller Foundation. The center absorbed what had been the foundation's Inter-American Food Crop Improvement Program

It quickly became evident that the geographic scope of the new institution was too limited. It had insufficient resources to handle the large volume of urgent requests for training and germplasm coming from countries of Asia and Africa. As a result, the founding partners decided to rewrite the charter.

On April 12, 1966, under a new charter, CIMMYT was established as a nonprofit organization responsible to an internationally elected board of trustees. The Ford Foundation and the Rockefeller Foundation joined Mexico as the initial principal supporters of CIMMYT.

Evolution of an Institution

During the past two decades, the capacity of developing countries to address their agricultural problems has grown immensely. CIMMYT has contributed to that change and, as it has occurred, CIMMYT has changed in many ways, too. But through this period certain hallmarks of CIMMYT's activities have held constant

One hallmark is the large-scale production of diverse germplasm that national researchers can use directly, adapt, or manipulate, broadening the choices available to farmers. A second is training intended to enhance the competence and productivity of the specialists who are the heart of crop improvement work in developing countries. A third hallmark, which is closely related to both germplasm development and training, is the Center's participation in worldwide networks of maize and wheat scientists. A fourth is the development of procedural tools to help network scientists do their jobs more efficiently and with greater impact.

Finally, a fifth hallmark, which is less tangible, but no less important: a sense of thoroughgoing pragmatism in addressing the problems of hungry people. It is conveyed by CIMMYT people through training, by example, and through frequent meetings and discussions with agricultural leaders and government officials at all levels. The widespread assimilation of that attitude has motivated a generation of scientists and technicians to move from the desk to the field in order to confront and overcome the real problems farmers face.

In part through CIMMYT's work, two ideas that were commonplace in developing countries 20 years ago are now much less widely held: that small farmers are stubbornly resistant to new ideas and that researchers seldom produce anything useful.

The foundation of CIMMYT's strength has been its nonpolitical nature, its continuity of funding, and its stability of staffing. Global and regional political winds have shifted many times during the past 20 years, but the fraternity of agricultural scientists that works with CIMMYT has grown and become stronger. It is one of CIMMYT's most important roles to serve as an impartial clearinghouse for scientific information and genetic materials whose dissemination might otherwise be stymied by political rigidities or bureaucratic entanglements.

The sustained support for CIMMYT by donors large and small has established a climate in which meaningful long-term goals can reasonably be set. And stable staffing affords good prospects that the sequence of steps necessary to achieve those goals can be carried out. Although changes and shifts occur, CIMMYT staff members are in posts long enough to become thoroughly familiar with research issues, to acquire detailed knowledge about conditions affecting agriculture in various regions, and to build personal relationships with local scientists and other leaders. The freedom to take the long view is an advantage shared by few international and national organizations.

The Sixties: Campaigns Against Hunger

The year CIMMYT was founded, 1966, was a momentous one for starting an agricultural institution. In India the cereal harvest had fallen drastically short for the second year in a row. On a per capita basis, food production had plunged to the lowest level since the Second World War. Pakistan, too, would have a poor crop. The world saw the spectre of famine riding the plains of the Indian subcontinent.

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CIMMYT was able to make a significant impact immediately, benefiting from the momentum of two decades of work in Mexico. Eighteen thousand tons of seed of Mexican wheat varieties were shipped to India in 1966 as a follow-up on smaller seed imports a year earlier. For several years, Indian scientists had been assessing the adaptability of Mexican varieties to Indian conditions and determining which performed best. In Pakistan, where local tests of Mexican materials had also been done since 1961, 42,000 tons of seed were imported in 1967.

These imports provided significant short-term and long-term gains. In combination with appropriate fertilization and management practices worked out by local and CIMMYT scientists, the new varieties raised yields enormously in India and Pakistan when more favorable weather returned in 1967. And with such good results, farmers became eager for the further improved varieties local scientists had begun developing using Mexican varieties as a source of dwarfing and other desirable traits. In addition, progressive governmental officials began to institute the policy changes needed to enable farmers to find fertilizer, seed, and other inputs when needed. A number of other wheat-producing countries followed the pattern established in India and Pakistan.

As an international organization, CIMMYT in its early years continued some major undertakings begun in its predecessor Mexican program and formalized and expanded several others that had been minor initiatives. To the large-scale development of spring bread wheat were added full-fledged programs on durum wheat, triticale, and barley. And the principles of massive crossing and rapid advancement of generations were applied to them. High yield potential and broad adaptation were important goals in improving these crops, as they were for bread wheats. The search for resistance to the major diseases was intensified.

International testing enlarged enormously. The International Spring Wheat Yield Nursery, begun in 1963, was continued, but by 1970, yield nurseries were also being shipped for durums and triticales. New types of nurseries were created. Screening nurseries allowed the performance of advanced lines to be widely evaluated, particularly for disease resistance. The F_2 nurseries gave well-staffed national breeding programs the opportunity to make selections in broadly based segregating populations.

The Maize Program did pathbreaking work on identifying and developing a number of productive and broadly adapted populations, which were made available to national programs. Through its efforts, the germplasm available to maize breeders around the world was greatly broadened.

A protein quality laboratory was established to provide essential data for the Maize Program's investigations of high lysine, or opaque-2, maize. Within a few years, work on cereal chemistry was begun to provide milling and baking data for the wheat program.

A formal in-service training program was established for young scientists and the number of trainees handled annually was expanded. Training was offered in agronomy,

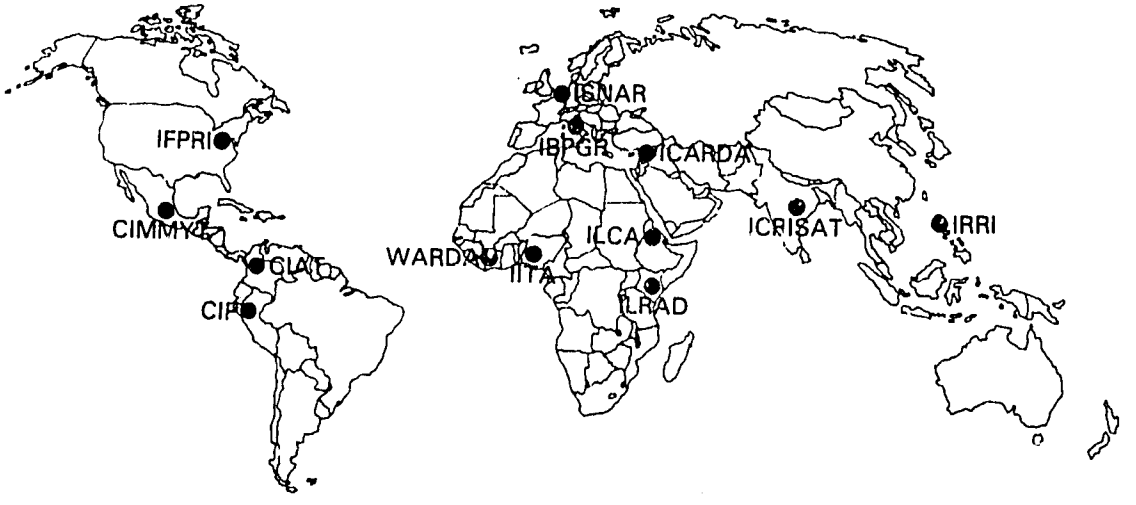
CIMMYT and the CGIAR

The remarkable early successes of CIMMYT and of IRRI, the International Rice Research Institute, gave impetus to the idea that more widespread and diversified efforts in international agricultural research were needed. The Rockefeller and Ford foundations, which initiated and funded both CIMMYT and IRRI, established two additional centers in the late 1960s: the International Institute of Tropical Agriculture, founded in 1967, and the Centro Internacional de Agricultura Tropical, initiated in 1968.

Shortly thereafter it became clear that the funds required to adequately support these four research centers could not long be supplied by the two donors alone. Moreover, there were emerging demands for new centers and it was clear that broader funding was essential. In response to this need the World Bank, the United Nations Food and Agriculture Organization (FAO), and the United Nations Development Programme (UNDP), along with 12 other donors, created in May of 1971 an innovative form of international association to support the budding research system.

The idea was to form a "Consultative Group on International Agricultural Research" (the CGIAR, or CG). The purpose of this new organization was to fund a network of international agricultural research centers, each with its own independent board of trustees, but each pursuing activities consistent with the System's mandate. An arresting manifestation of the success of this approach is the rapid increase in funds channeled through the CG, from an initial budget of US$ 9 million in 1971 to nearly US$ 200 million in 1986. At its inception the CG System comprised 15 donors and 4 centers; the System now has 40 donors supporting 13 centers and, as a recent study of its impact shows, the System has been a notably good investment for its donors.

It is to its credit that the CGIAR has avoided the bureaucratization that all too often accompanies the creation of such a system. Administrative overhead is minimal. The World Bank provides the CG's Chairman and the Executive Secretariat. The System is advised by a Technical Advisory Committee whose Secretariat is provided by the FAO and whose members are prominent agricultural scientists from around the world. The CG has no constitution, no by-laws, and as few "rules" as possible; commitments are verbal, and cooperation and concensus are the hallmarks of the organization.



plant pathology, experiment station management, and cereal chemistry, in addition to breeding. Opportunities for post-doctoral fellows to work in the Wheat or Maize Programs increased. The emphasis that CIMMYT gave to training and to continuing contact with former trainees reflected the conviction that, in most developing countries, the critical barrier to agricultural progress was the woefully thin ranks of adequately trained researchers.

To provide immediate assistance in strengthening national research programs, a number of CIMMYT staff members were assigned to important maize- or wheat-producing countries. By 1970, CIMMYT had nearly 20 scientists in developing countries outside Mexico; most were part of bilateral programs.

National crop research programs made impressive strides during the 1970s. The numbers of well-trained scientists grew and, in more and more countries, research programs abandoned the academic separation of disciplines and reorganized on multidisciplinary lines.

The drama of the early years was climaxed by the award of the 1970 Nobel Peace Prize to Norman E. Borlaug, director of CIMMYT's Wheat Program. The award recognized his tireless efforts to apply science to the eradication of hunger. He saw the award as being symbolic "of the vital role of agriculture and food production in a world that is hungry both for bread and for peace," and called himself "but one member of a vast team made up of many organizations, officials, thousands of scientists, and millions of farmers--mostly small and humble—who for many years have been fighting a quiet, oftentimes losing war on the food production front."

The Seventies: Rising Competence of National Programs

The beginning of the 1970s was marked by the inauguration of CIMMYT's headquarters, about 45 kilometers northeast of Mexico City. The 43 hectares of land forming the experimental farm had been procured by the government of Mexico and lent to CIMMYT.

Four substations were also acquired and developed in the early 1970s. These stations are situated at various elevations and provide significant agroecological contrasts to conditions at CIMMYT headquarters (2240 meters elevation) and the major wheat research site used by the Center, the CIANO station (39 meters elevation) in northwest Mexico (operated by the Ministry of Agriculture). The establishment of the present Toluca station (2650 meters elevation) provided the wheat program with a critical second cycle per year under environmental conditions quite different from those at CIANO. The opening of the Poza Rica station on the Veracruz coast was especially important for the Maize Program because it provides a site with the humid tropical conditions that characterize much of the developing world.

Regional programs—National crop research programs made impressive strides during the 1970s. The numbers of well-trained scientists grew and, in more and more countries, research programs abandoned the academic separation of disciplines and reorganized on multidisciplinary lines, often modeled on CIMMYT and other international agricultural research centers.

The burgeoning of national programs placed heavy demands on CIMMYT for consultation and advice on research planning and operations. The need could not be satisfied effectively by periodic visits of headquarters' staff, nor could personnel be posted to all countries asking for help. While maintaining bilateral arrangements with some countries, CIMMYT turned increasingly to regional programs as an efficient mechanism for making the assistance of outreach scientists available to many countries.

CIMMYT's regions are defined as groups of countries, usually contiguous, whose production environments and production problems are similar. CIMMYT provides staff members to regions that have a significant output of wheat or maize and that agree to exchange germplasm and scientific information in order to better utilize scarce research resources through cooperation.

By 1979 there were four regional maize programs, four regional wheat programs, and four regional economics programs. The

individuals in the maize and wheat regional programs tend to be specialists in crop improvement or production agronomy. The regional economists work closely with both maize and wheat regional scientists.

The duties of the regional staff are to work alongside national program scientists and help improve their research skills, to identify technical problems affecting the use of improved germplasm and to help find agronomic and economic solutions through on-farm research and other means; to help national programs assess their training needs; and to encourage and support national crop improvement and production activities.

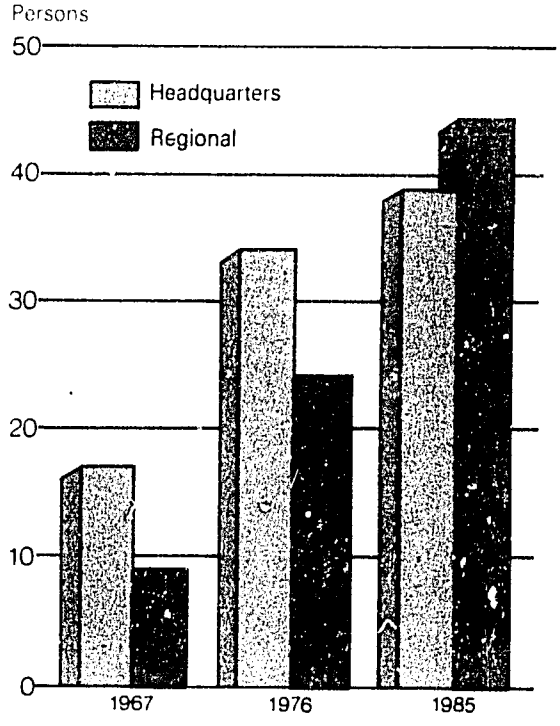
The regional scientists carry out these tasks by helping national scientists monitor the various international nurseries distributed by CIMMYT. They also help assemble and evaluate materials for regional trials, as well as work with national program materials. To foster the integration of production agronomy and on-farm tests into national research systems, the regional staff members help plan agronomic experiments. They also organize training courses, workshops, and traveling seminars for national scientists. Thus, working as a team, the regional scientists support the efforts of national researchers to improve farmers' productivity. Their intimate knowledge of local production constraints, such as insect and disease complexes or socioeconomic problems, also provides important information for conduct of research at CIMMYT itself.

Collaborative research—The 1970s marked the beginning of a large number of collaborative research projects. These projects are partnerships in which each partner has a partners are national programs in countries where a disease or agronomic problem is acute. Some are organizations in affluent countries that have special facilities or have developed advanced techniques.

Some examples of collaborative research include the investigation of three maize diseases: downy mildew in collaboration with Thailand and the Philippines; maize streak virus in collaboration with Tanzania, Zaire, and the International Institute of Tropical Agriculture; and corn stunt in collaboration with Nicaragua and El Salvador.

Another collaborative project involves improving spring and winter wheats through large-scale crossing of these two gene pools. In this project, primary partners include Oregon State University and the Turkish national program. CIMMYT takes responsibility for developing spring wheats from the progeny of the crosses, while Oregon State and Turkish scientists take responsibility for developing winter wheats.

Work on barley yellow dwarf, an elusive disease of cereal crops that is more widespread than commonly thought, involves multifaceted collaboration. With funding from Italy, CIMMYT is screening advanced lines. It also is helping several countries in Africa and South America that are testing germplasm and investigating the epidemiology of the disease. Four universities in Italy are working on identification techniques and screening for barley yellow dwarf in rice and maize. Rothamstead Experiment Station, UK, is also collaborating in developing identification techniques.

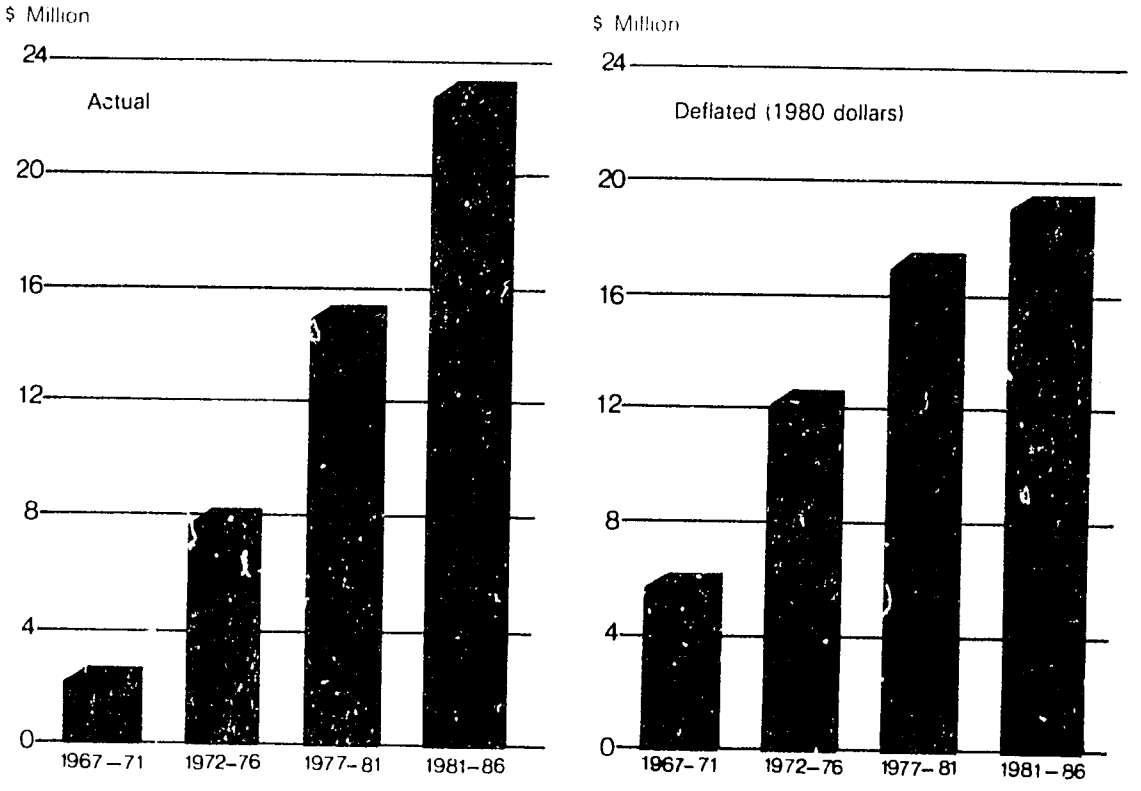


Senior scientists are increasingly placed in regional posts around the world

Most collaborative programs are more narrowly focused. To mention but a few: work with the University of Hohenheim on the development of fertile, short-strawed, high yielding rye inbreds for the triticale program; work with the Netherlands Institute of Phytopathological Research to develop computer programs for analysis of disease data; work with Colorado State University and CSIRO (Australia) on the use of tissue-culture techniques in screening wheat mutants for disease resistance and stress tolerance; work with North Carolina State University on resistance to case-knot nematode; and work with the University of Missouri on the investigation of aflatoxin in tropical maizes.

These collaborative arrangements provide basic and applied research results useful to the production-oriented research programs operated by CIMMYT and national programs. They also keep CIMMYT staff members abreast of new research developments and provide an opportunity for the exchange of ideas with scientists in technically advanced countries.

International testing expands—During the 1970s important changes took place in CIMMYT's research strategies as well. The Maize Program began to test improved populations internationally and acquired data on adaptability in different areas. In 1974 the Maize Program was reorganized to make international testing integral to the population improvement process. The new system was designed to more efficiently yield a wide array of materials suited for the multifarious conditions under which maize is grown around the world. International performance data became a vital input from the early stages of improvement. The system also served to give national researchers automatic access to a broad spectrum of germplasm in various stages of refinement. By 1979, maize scientists in 85 countries were taking part in the international testing program organized by CIMMYT.



CIMMYT's average annual budget during 5-year periods, actual and deflated (to indicate real purchasing power)

"The Green Revolution, Peace and Humanity"

The following are excerpts from Norman E. Borlaug's Nobel lecture, given on December 11, 1970.

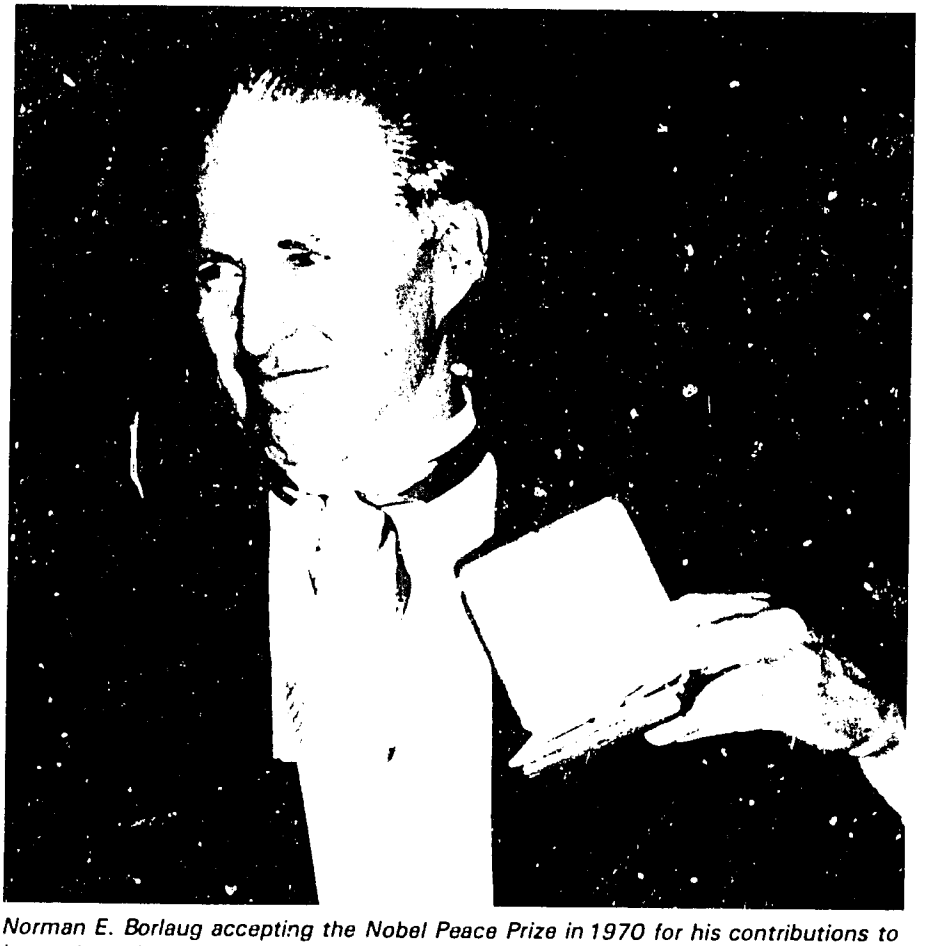
The food production brigade
"When the Nobel Peace Prize Committee designated me the recipient of the 1970 award for my contribution to The Green Revolution, they were in effect, I believe, selecting an individual to symbolize the vital role of agriculture and food production in a world that is hungry, both for bread and for peace. I am but one member of a vast team made up of many organizations, officials, thousands of scientists and millions of farmers—mostly small and humble—who for many years have been fighting a quiet, often-times losing war on the food production front."

The qualities of leadership
"Where are those leaders—where are the leaders who have the necessary scientific competence, the vision, the common sense, the social consciousness, the qualities of leadership and the persistent determination to convert the potential benefactions into real benefactions for mankind in general and for the hungry in particular?"

Meshing international and national programs
"The international centers were developed to supplement national agricultural research, production, and training programs, not to replace them. The centers are but one link in the worldwide network of organizations attacking basic food crop production problems on a worldwide, regional, national and local level. The backbone of this network is now and must continue to be the national programs. These must be given greater financial support and strengthened staff-wise to meet the challenge of rapidly expanding food needs for the future."

Quality of human life
"We must recognize the fact that adequate food is only the first requisite for life. For a decent and humane life we must also provide an opportunity for good education, remunerative employment, comfortable housing, good clothing and effective and compassionate medical care. Unless we can do this, man may degenerate sooner from environmental diseases than from hunger."

The future of mankind
"Since man is potentially a rational being, however, I am confident that within the next two decades he will recognize the self-destructive course he steers along the road of irresponsible population growth and will adjust the growth rate to levels which will permit a decent standard of living for all mankind. If man is wise enough to make this decision and if all nations abandon their idolatry of Ares, Mars and Thor, then Mankind itself should be the recipient of a Nobel Peace Prize, which is 'to be awarded to the person who has done most to promote brotherhood among the nations.' "



Norman E. Borlaug accepting the Nobel Peace Prize in 1970 for his contributions to improving wheat production in the developing world.

International testing of bread wheat, durum wheat, triticale, and barley continued to grow. By 1979, 38 different types of nurseries were distributed to national collaborators in 115 countries. The nurseries included materials for crossing and selection—both early and advanced generations—as well as released commercial varieties. The array of nurseries offered national improvement programs, large and small, appropriate germplasm for their scale of research work. The abundance of performance data from multilocation testing of the nursery entries gave breeders in national programs and at CIMMYT a strong basis for choosing parents for new crosses.

The economic dimension—Economics became CIMMYT's third major research program in the early 1970s. The first economics studies were aimed at uncovering the reasons why wheat and maize growers did or did not adopt new technology. The studies showed that it was possible to identify agroclimatic and socioeconomic conditions that critically influence patterns of adoption. Subsequent research focused on developing procedures for facilitating work between crop scientists and economists to improve understanding of the issues farmers consider important in decision making. As an outgrowth of this work, guidelines were framed that focus the development of new technology on the needs of farmers. These procedures are being used by an increasing number of national programs as the result of training programs and workshops organized by CIMMYT staff members.

Data processing—CIMMYT installed its first computer in the mid-1970s to support the Maize, Wheat, and Economics programs. Procedures were developed for analyzing and processing the growing volume of data from international maize and wheat trials. Computer programs were created to produce the fieldbooks, field tags, and seed packet labels used by the wheat program in each season. In addition, a variety of special statistical analyses were performed for economics research and other studies.

Training—With the completion, in 1970, of the dormitories and classrooms that made up part of its new headquarters' facilities, CIMMYT was able to step up its training program. In 1971 and 1972, the number of in-service trainees exceeded the total for the previous five years.

The addition of full-time training officers made possible the formalization of training as well as an expansion in the types of in-service courses offered. In the Maize Program, courses were offered in production research, maize improvement, and quality protein evaluation. In the Wheat Program, courses were available in breeding, pathology, production agronomy, and cereal technology. Other courses have since been created in such areas as planning and analysis of farmer surveys and experiment station management.

In-service training courses last three to seven months and most combine classroom work with fieldwork side-by-side with CIMMYT senior scientists. Generally the courses are designed to increase the motivation of young scientists within a multidisciplinary setting, to increase technical knowledge and skills, to impart the steps and principles involved in selecting research objectives and conducting field experiments, and to teach procedures for developing recommendations for farmers.

CIMMYT provides a variety of other training opportunities in addition to in-service training. Senior researchers from national programs may spend time at CIMMYT as visiting scientists becoming familiar with CIMMYT research programs. Postdoctoral fellows join the research programs for periods of one to two years; some have later been appointed to the CIMMYT staff. A few Ph.D. candidates are accepted each year to conduct their thesis research under the supervision of a CIMMYT staff member.

The Eighties: Extending the Gains

The most dramatic shift in CIMMYT's activities during the 1980s has been an increasing emphasis on improving the stability of yield, particularly in more marginal areas. The creation of germplasm with broad adaptability and high yield potential remains a principal goal. The maintenance of yield stability through stronger and broader resistance to insects and diseases continues to receive a large measure of research resources. But the research agenda increasingly includes attention to less-favored

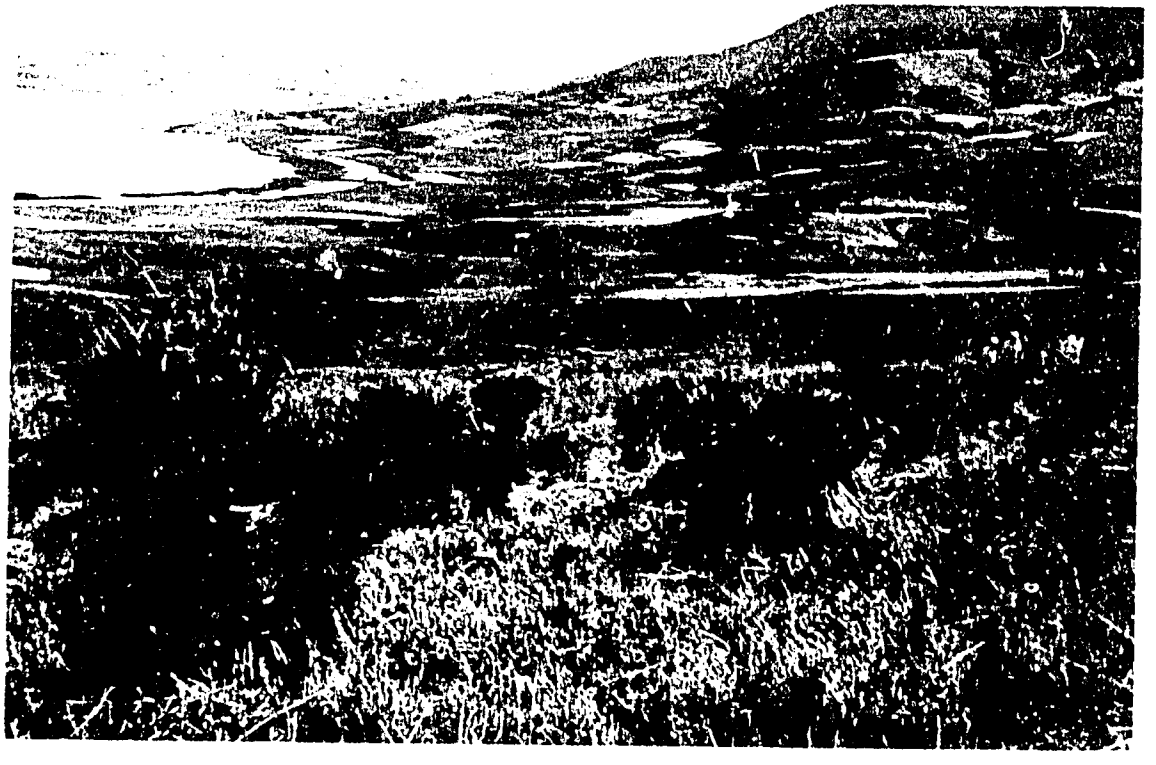
areas where the productivity revolution of the past 20 years has reached only a fraction of the farmers.

Marginal areas are characterized by such limiting factors as a high incidence of disease and/or insects, drought, acid soils, or excessive heat or cold. Some marginal areas suffer sharp annual fluctuations in cropping conditions—as, for example, those caused by irregular rainfall patterns—which discourage investment in technologies that enhance productivity. Other areas have persistently low yields because of inherent production barriers such as incidence of highly destructive diseases or infertile soil.

As part of its approach to marginal areas, CIMMYT is emphasizing the generation of germplasm that has greater yield dependability. One route involves applying conventional breeding procedures in search of genetic variation within a crop species for additional tolerance to specific environmental stresses such as drought or excessive cold or heat. Another is less conventional and involves finding in related genera strong sources of resistance to stresses that prevent productive crop growth (acute incidence of certain diseases or insects) and sources of tolerance to pernicious soil conditions (toxic levels of aluminum, strong acidity, or salinity), and to transfer them to otherwise productive varieties.

The most dramatic shift in CIMMYT's activities during the 1980s has been an increasing emphasis on improving the stability of yield, particularly in more marginal areas.

CIMMYT's research on wide crosses—the crossing of different crops, or of a crop and a wild species—has important implications for marginal areas. This work is going on both in maize, where the principal elements are maize and tripsacum (a wild relative of maize), and in wheat, where such wild relatives as *Agropyron*, *Elymus*, and *Aegilops* species are being utilized. Triticale, a crop created by wide crossing, has notable productivity in acid soils. The goal of most other wide crosses is to transfer useful but scarce genes into productive maize and wheat genotypes.



CIMMYT researchers are devoting more attention to less-favored environments, where many farmers have yet to benefit from improved agricultural technologies.

Maize hybrids—For some farmers who grow maize under more productive conditions, maize hybrids in combination with improved agronomic practices could give significant productivity increases. While CIMMYT will continue to focus on open-pollinated varieties, it has begun a hybrid development program in response to requests from some national maize programs. CIMMYT will generate breeding information about its pools and populations that will help scientists in making hybrids. Also, CIMMYT will undertake research and training in the development and production of nonconventional hybrids.

Expanded germplasm banks—To support the search for special characteristics needed in marginal areas, CIMMYT strengthened its germplasm banks in the 1980s by upgrading its storage facilities and creating new staff positions.

CIMMYT's maize germplasm bank traces from the extensive collections of the maize landraces (primitive varieties) made in Mexico, the Caribbean, and Guatemala by the Office of Special Studies in the 1940s. In later years, collections from Brazil, Bolivia, and Peru were added. The bank has the world's best collection of landraces from the Western Hemisphere—the center of origin for maize. But until recently, the main function of the bank was only to supply useful materials to the breeders in CIMMYT's Maize Program and in other programs that request seed. Now it has specifically taken on other responsibilities, including the long-term conservation of the Hemisphere's landraces.

The collection has about 12,500 entries, but perhaps 20% are duplicates or redundancies that will be culled in the future. Low-temperature storage facilities completed during 1985 will make it possible to more than double the lifetime of seed and thus cut the frequency of regeneration from once every 20 years to as infrequently as once every 100 years. Less frequent regeneration will reduce genetic drift—the change in genetic composition that occurs each time an accession is regenerated Duplicate samples are kept in other germplasm banks as well.

A computerized data management system is being developed for the bank. In preparation for that, data on the origins and various characters of the entries have been consolidated.

The bank also maintains wild relatives of maize—the various teosinte taxa and members of the genus Tripsacum. While these plants may possess genetic variation not found in maize, characterizing and classifying them is a long-term undertaking.

The CIMMYT wheat germplasm bank maintains germplasm of bread wheat, durum wheat, triticale, and barley that possesses desirable characteristics. The main function of the wheat bank remains the storage of materials developed by CIMMYT breeders, plus some new materials from other countries. These materials comprise a working collection that, prior to the 1980s, was available primarily to the Center's own breeders. In 1981, with the completion of new bank facilities and the hiring of a senior scientist to head the bank, CIMMYT began fulfilling requests from breeders outside the Center for germplasm having specific agronomic, disease-resistance, and quality characteristics.

The wheat bank started with about 20,000 unduplicated entries and grew to nearly 60,000 entries by 1985. These include bread wheats, durum wheats, triticales, barleys, and interspecific germplasm entries. The source of the material held by the bank is mainly the CIMMYT international screening and yield nurseries and the spring and winter crossing blocks.

The germplasm entries are each evaluated for about 40 characters related to morphology, agronomic performance, disease resistance, and grain quality. CIMMYT's facilities permit short-term and medium-term storage. For long-term storage duplicate sets of the entries are sent to germplasm banks located elsewhere. In 1985, national programs received samples of 2600 entries from the bank.

CIMMYT and México

CIMMYT has enjoyed two decades of cordial and fruitful relations with the government and people of Mexico. Creating the Center was a Mexican idea and the government has remained a steadfast supporter of CIMMYT's work. That support has been demonstrated though continuing financial contributions, though the provision of land for experiment stations, and through the excellent cooperation of such government agencies as the National Institute of Forestry, Agriculture, and Livestock Research (INIFAP, formerly INIA), and the National Plant Health and Quarantine Service (Sanidad Vegetal).

INIFAP scientists collaborate closely with their CIMMYT colleagues in the development and testing of germplasm, continuing a long-standing partnership in the effort to improve Mexico's agriculture. INIFAP serves as the official channel through which improved germplasm is named, increased, and released to Mexican farmers. Sanidad Vegetal greatly facilitates CIMMYT's international testing activities, supervising and streamlining the movement of massive amounts of experimental germplasm in and out of Mexico each year.

Over the past two decades, nearly all of the wheat varieties released by Mexico have been developed through a cooperative program with the government. Their statistics show that, during the last 20 years, these wheats have come to occupy more than 90% of Mexico's wheat-growing area. The next two decades, however, may well belong to maize. Mexico, the home of maize, is among the five largest developing-country producers of the crop. According to the government, Mexico currently has about one million hectares planted to improved varieties based at least partially on germplasm developed through the maize international testing network in which CIMMYT and Mexico play prominent roles. As even better varieties are developed via this network, Mexico is well positioned to ensure their effective utilization.

CIMMYT and Mexico's fruitful research relationships have been complemented by similarly productive cooperation in training. Since 1966 more than 100 professional agriculturalists have provided valuable help to CIMMYT as research assistants, simultaneously learning about the research process. Over 30 of these individuals went on for their Masters and/or Ph.D. degrees with financial support from, or arranged by, the Center, and eight of these returned to CIMMYT as postdoctoral fellows. As in other successful relationships, all parties gain handsomely from the process. As well, the Center has provided in-service training to over 60 young Mexican scientists.

Mexico's extremely diverse climate and landscape have contributed in no small part to the progress achieved to date. The Center works at five primary research stations and conducts specialized, problem-specific research at a number of other sites around the country. The ability to conduct experiments at locations as environmentally diverse as the irrigated desert of Sonora, the lush tropical lowlands of Veracruz, and the high plateau of Central Mexico has contributed greatly to the good performance and, hence, widespread adoption of CIMMYT-derived germplasm the world over.

The smooth operation of CIMMYT requires the collective effort of over 700 Mexican nationals at all levels, from laborers to senior scientists, at headquarters and the various research stations around the country, and in regional posts. The Center could not function without access to the experience, skills, and energies of Mexico's workforce. As well, of course, CIMMYT strives to be a good employer and a good neighbor.

Dr. J.A. Valencia (left), Director of CIANO, and Dr. N.E. Borlaug.

Training—In the 1980s, while continuing in-service training courses in Mexico, CIMMYT began to mount more courses abroad in collaboration with national program scientists. In 1985, for example, a number of in-country training courses were held, involving over 600 research workers. This change was made possible by the heavy involvement of regional scientists in training as well as by an increase in the size of training staff, which now comprises eight maize, wheat, economics, and experiment-station training officers plus a coordinator.

In the 1980s, while continuing in-service training in Mexico, CIMMYT initiated more courses abroad in collaboration with national program colleagues.

Many of the overseas courses have stressed on-farm research. In these courses, CIMMYT is using the call system, an innovative training procedure that brings course participants together for one to two weeks at key stages during the crop cycle. Each call focuses on certain aspects of the on-farm research process (conducting on-farm surveys to assess farmers' circumstances, analyzing those circumstances and planning trials, managing trials, analyzing experimental results, formulating recommendations) and the emphasis is placed on learning through doing. A call system course may concentrate only on certain skills or it may attempt to cover the entire range. In the latter case, the course might be spread over 18 months and would include at least five calls. During the periods between calls, the participants resume their normal job responsibilities.

Expanding activities in economics—In the 1980s the Economics Program continued to develop and teach procedures for on-farm research, while expanding its activities into other areas as well. Increasing attention is now given to the analysis of data related to the world maize and wheat economies. Analysis of production, consumption, and trade trends for these crops forms an important part of the Program's work. One of the major products of this interest is the publication, in alternate years, of Maize or Wheat "Facts and Trends." In addition to summarizing trends for the crop, the publication also adopts a particular theme for special focus. Recent themes have included the economics of maize seed production, wheat marketing and pricing issues for developing countries, feed and food uses of maize, and consumption and import trends for wheat.

Another activity initiated by the Economics Program is the development of a set of procedures that will be useful to decision makers concerned with the allocation of research resources among crops and regions. The techniques involve the estimation of the real costs of resources used in producing competing commodities. A blend of economic information with biological data is required for the analysis. The Program collaborates with national program colleagues in the development of case studies that are used in the development of a manual of procedures useful for national research program administrators.

In addition to continuing its work in on-farm research, the Economics Program also began to explore ways of using farm level data for assessing certain aspects of policy. Data generated by on-farm research are useful not only for deriving farmer recommendations, but also for assessing the adequacy of input delivery, credit arrangements, information systems, and markets. Work is underway to identify direct losses in production associated with inadequacies in the implementation of current policies. Cost-effective methods for undertaking such research are being developed and will form part of the Economics Program's training efforts.

CIMMYT and biotechnology—The 1980s have been heralded as the beginning of the age of biotechnology. Many universities and advanced laboratories are creating promising tools for biological research. CIMMYT, however, is not engaged in developing biotechnological techniques. But through its work on wide crosses, CIMMYT employs and refines new techniques as they prove useful.

For example, in crossing maize and tripsacum—a wild relative of maize—special crossing methods and techniques for saving a potentially useful embryo (embryo culture) are essential. Recent improvements in those techniques have raised production of hybrids from 1 in 1000 crosses a few years ago to 80 in 1000 crosses. The special pollination and

embryo culture techniques are used again when the maize-tripsacum hybrid is backcrossed to maize in attempting to transfer beneficial traits to maize from tripsacum.

CIMMYT also collaborates with laboratories that are developing biotechnological techniques. It brings to these partnerships a broad spectrum of germplasm and its exceptional facilities for incorporating new traits into commercially useful genotypes. An example of collaboration is CIMMYT's work with CSIRO in Australia on somaclonal variation. Such single-cell cultures may speed the introgression of traits that are not likely to be incorporated by sexual methods.

Thus, CIMMYT is in a position to take advantage of new tools as they are developed and to make the benefits quickly available to developing countries.

Reprise

CIMMYT is a service agency to national agricultural research programs in the developing world. Working together, CIMMYT and national programs have developed new germplasm and new techniques. But it is the local testing, evaluation, and adaptation by national programs that largely determines whether innovations will have an impact on many farmers. Throughout its history, CIMMYT has made the support and strengthening of national programs a fundamental tenet of its operational philosophy.

In the future, no less than in the past, this partnership is the key to helping the millions of farm families whose livelihoods depend on the production of maize or wheat.

Economics Program staff now develop procedures to facilitate national program research in three areas: technology generation, research resource allocation, and policy implementation.

A Global Maize Improvement System

The aim of CIMMYT's maize improvement research is to increase farmers' options for raising the productivity of the resources they commit to maize production. Since maize is grown in a wider array of environments than any other cereal crop, only local researchers and farmers are in a position to identify the precise combination of varietal attributes that are right for a locality.

CIMMYT participates in and promotes the international development of maize germplasm, producing intermediate rather than finished products suited more for broad agroclimatic zones than for particular ecological niches.

CIMMYT participates in and promotes the international development of maize germplasm. CIMMYT's breeding program yields intermediate rather than finished products. Generally they are suited for broad agroclimatic zones, or mega-environments, but perhaps are not fully adapted to a particular ecological niche. For that reason, they must undergo a degree of adaptive testing before release to farmers.

In CIMMYT's international maize testing program, national programs are influential in determining which maize materials will be improved and how. The system gives national programs a strong voice in the selection of genetic materials and it affords them the opportunity to extract germplasm at any stage for their own improvement programs or for possible release.

Conceptually, the system is like a funnel, with a large array of genetic diversity entering at one end and a small amount of refined and tested genetic materials emerging from the other end. The improvement process starts with the gene pools—groups of rather diverse germplasm that has been classified according to zone of adaptation, growth duration, and grain type and color. The number of pools has varied over the years, but currently there are 37. The pools are grown each year, with periodic additions from the germplasm bank and other sources. They undergo mild selection, but the aim is to retain the basic character of the pool as a mass reservoir of classified genetic variability.

The best fraction of each of these pools provides the basis for forming refined populations (32 such populations are currently in use). Each population is classified according to environmental adaptation and its important characteristics:

- climate: tropical or subtropical
- elevation: lowland or highland
- maturity: early, intermediate, or late
- grain color: yellow or white
- kernel type: flint, dent, floury, or QPM

Populations are subjected to strong selection pressure based on international testing. The International Progeny Testing Trials (IPTT) are conducted by national scientists around the world. One IPTT constitutes 250 full-sib families selected from one population. Each IPTT is grown at six locations, but the locations are usually different from population to population.

Based on data from those trials, CIMMYT scientists select the 50 to 60 best families from each population for within-family improvement, recombination, and regeneration of the population.

The data also indicate which families will be chosen to form experimental varieties. Some experimental varieties are formed from the 10 best-performing families of each IPTT at each location. Another experimental variety is formed from each population based on the 10 best families at all six locations in which the population was tested.

These varieties are advanced to the F_2 stage and sent to 30 to 50 cooperators around the world as Experimental Variety Trials. The top-performing varieties in those trials are further tested in the Elite Variety Trials, which are conducted at 60 to 80 locations.

Data from all three types of trials are made available to cooperating maize breeders throughout the world. They decide whether to use the germplasm in their own breeding work

or in testing for possible release as a variety. CIMMYT supplies small quantities of seed of selected materials to national programs that request it.

The international network has tested over 850 experimental varieties during the last decade. To judge the usefulness of this material, the Maize Program relies on two indicators. One is adoption of the germplasm by national breeding programs. So far, scientists in 43 of those programs have used the experimental varieties and other germplasm to develop and release nearly 150 varieties and hybrids. The second indicator of progress is systematic evaluation of the improved materials. In 1982-83, for example, multilocational variety trials were conducted to determine whether improvement of the populations was leading to better varieties. The results suggested that experimental varieties developed from more recent cycles of selection were higher yielding, earlier, and shorter than those from the original cycles. Moreover, stability analyses indicated that those varieties were better adapted to low-yielding environments and also performed better at high-yielding and medium sites.

A More Efficient Tropical Maize Plant

By 1970, modern varieties of wheat and rice had firmly established the advantages of short height for raising yield potential and responsiveness to good management. But most of the tropical maize strains used in the CIMMYT breeding program or that were in cultivation were over three meters tall. These strains had a harvest index of only 0.3, meaning that their grain made up only about a third of the total dry matter produced by the plant. In modern wheat and rice varieties, and in commercial maize varieties of the US corn belt, the harvest index was about 0.5.

The advantage of a shorter plant with a higher harvest index is that, when seeded at high density, it produces about the same amount of dry matter per hectare as a plant with a low harvest index, but the grain yield is much higher.

In the late 1960s, CIMMYT began a special project to test the benefits of shorter height in tropical maize. Breeders turned to recurrent selection to accumulate minor genes for

Tuxpeño Crema-1, a tropical maize population developed by Dr. E. Johnson, underwent selection for reduced plant height for some 21 cycles and, as a result, was significantly improved in grain yield efficiency.

shortness. They applied the breeding scheme in an attempt to progressively shorten Tuxpeno-1, one of CIMMYT's widely adapted, high yielding, tropical maize populations.

In each cycle of selection, at the time of pollination, only families shorter than the mean were chosen for recombination. Then, at harvest, the ears were placed at the base of each plant in the selected families so that the families could be visually evaluated for yield, lodging, and disease resistance. On those grounds, some of the selected families or plants were rejected. As the plant height decreased in successive cycles, the planting density was increased.

After 18 cycles, plant height had been cut almost in half, to 156 centimeters, the harvest index had improved to 0.47, and yield had risen by a third to 6.2 t/ha, an exceptional yield for the tropics. In addition, cycle 18 materials were earlier in maturity.

After 18 cycles of recurrent selection, the height of Tuxpeño had been cut almost in half, the harvest index had risen to 0.47, and yield had increased by a third to 6.2 t/ha, an exceptional yield for tropical maize.

Sources of improvement—Most of the yield improvement was related to the ability of short plants to withstand high density plantings without lodging and without an increase in barren plants. Lowering the height of the ear was largely responsible for the reduced lodging. A narrowing of the interval between pollen shed and silking accounted for a reduction in proportion of barren plants.

Comparisons of the original population with the shortened population in trials under less favorable conditions, including farmers' fields with low nitrogen use, showed that the yield gain was not limited to well-managed experiment stations. In fact, on a percentage basis, the yield advantage of the shortened population was even greater at the low-yielding sites, suggesting that the shortened population had gained general stress tolerance. The shorter Tuxpeño-1 (cycle 18) also made a good parent in the production of hybrids.

The study also showed that there is a limit to the amount of yield increase that can be derived from selection for reduced plant height. After the fifteenth cycle, there was little improvement in harvest index and grain yield. Based on this work, reduced plant height became a high priority breeding objective in CIMMYT's maize improvement program. Most of CIMMYT's maize populations now have generally acceptable plant height, a higher harvest index, less lodging, and greater responsiveness to fertilizer.

Drought Tolerance in Maize

Worldwide, maize is seldom grown under irrigation. In farmers' fields, the crop typically suffers several weeks without rain at some point during the growing season. Drought stress, however, is a danger not only when rains fail temporarily, but also when, in very hot weather, the plants transpire more water than they can draw from the soil, even if it is raining regularly.

In tropical Africa, fluctuations in maize output appear to be affected more by the timing and quantity of rainfall than by any other factor. Thus the availability of varieties with better drought tolerance could improve the stability of food supplies among small farmers.

Maize is particularly vulnerable to shortages of moisture at two stages. After seeding, if the germinating seeds are unable to extract sufficient water from the soil, poor stands will result. A second critical stage is the two-week period before and after flowering.

Indirect indicators—Breeding for tolerance to drought is complicated because direct indicators such as root morphology or osmotic adjustment are too time-consuming to use in selecting plants. Instead, CIMMYT maize scientists, starting in 1976, tested indirect measures as criteria for improving drought tolerance. For this research, Tuxpeño-1, a productive maize population from the CIMMYT improvement program, was selected because of its good performance at rainfed sites. It was grown with normal irrigation and under two

levels of drought stress created by limiting irrigation. Cutting off irrigation three weeks after the seedlings emerged was considered severe stress. Ending irrigation two weeks before silking was considered moderate stress.

The researchers created a drought-resistant synthetic variety under a recurrent selection scheme using five indicators of stress. These were leaf and stem elongation rate, the interval between anthesis (pollen shed) and silking, leaf death score, canopy temperature, and grain yield. Taken together, these indicators provide indirect information on rooting depth and intensity, ability to adjust osmotic activity to periods of insufficient water, and general tolerance to stress.

After six cycles of recurrent selection the synthetic variety yielded 2.0 t/ha under severe drought stress, 24 percent more than the original population. Under moderate drought stress it yielded 3.2 t/ha, 29 percent more than the original population. And with normal irrigation, it yielded 6.6 t/ha, 10 percent more than the original population.

The chief reason for the greater yields in the drought-resistant population when grown under drought stress was a higher number of kernels per plant, rather than an increased weight per kernel.

In a parallel experiment, researchers compared selection under the five indicators with selections based on yield alone and found the indicators to be significantly better. In particular, simple selection under severe drought produced a variety that performed poorly under normal irrigation, suggesting that responsiveness to well-watered conditions can easily be lost.

General tolerance to stress. The experiments also showed that in the drought-tolerant variety, general stress tolerance was an important factor, along with the ability to find more water and to continue metabolic activity under stress. For breeders who lack the resources to apply all the indicators used by CIMMYT, selection in high density plantings would raise general stress tolerance and thereby improve drought tolerance.

Most of the improvement in drought tolerance occurred during the first three cycles of improvement. Shrinking gains after that suggest that the variability for the traits under selection had become a limiting factor, a hypothesis now under investigation.

Based on the indicators tested in this series of experiments, four elite populations with good agronomic type and high yield potential have been chosen for recurrent selection to improve drought tolerance. This work is just beginning. In addition, a germplasm pool consisting of entries that possess drought-tolerance properties is being formed. This pool will serve as a source of germplasm for drought-tolerance breeding at CIMMYT and for national programs.

CIMMYT physiologist Dr. G. Edmeades measures the canopy temperature of maize under moisture stress.

Protein Quality of Maize

Plant breeding has sometimes been likened to putting a butterfly in a jar without losing the butterflies already captured inside. The development of quality protein maize has tested the ingenuity and perseverance of maize breeders with some exceedingly small and skittish genetic butterflies.

Deficiencies--The discovery of the mutant gene opaque-2 in the 1960s raised hopes among maize breeders around the world that the quality of maize protein could be vastly improved.

Although compared to other cereals maize has a moderately high protein content, the protein is short of two essential amino acids, lysine and tryptophan. Due to those deficiencies, humans and animals other than ruminants can use only about half the protein in maize, unless their diets contain other sources of lysine and tryptophan. Maize carrying the opaque-2 gene has higher levels of lysine and tryptophan, which permit animals to metabolize more of the protein. More recently several other genes have been found that have an effect similar to that of opaque-2.

In 1970 CIMMYT began introducing the opaque-2 gene into a wide range of germplasm and some of the products were tested internationally. It soon became evident that serious liabilities were associated with the opaque-2 gene. The so-called high-lysine maize had soft, chalky kernels instead of the hard, translucent grains preferred by most maize growers. In addition, low dry matter accumulation in the kernels depressed yields, and the grain dried slowly and was vulnerable to ear rots and attacks of storage insects.

Although many programs phased out high-lysine work, CIMMYT felt that by making use of its large germplasm resources and the international testing network, acceptable varieties with high-lysine content in the grain might be achieved. CIMMYT scientists had already found a few modifier genes that could improve kernel hardness and appearance, but some of these genes simultaneously lowered lysine and tryptophan content. Consequently, the CIMMYT protein laboratory played a vital role in the improvement process by devising rapid screening methods to identify materials that had nearly normal kernel texture and retained protein quality.

Quality protein maize germplasm is of interest to national program researchers in a number of developing countries.

Modifier genes—In seeking to separate the high-lysine gene from the deleterious effects of associated genes, CIMMYT breeders set out to accomplish a feat often discussed, but rarely attempted, i.e., that of changing a major trait by accumulating many small modifier genes. And through diligence and care, they succeeded. By the mid-1970s, protein quality had been improved substantially and CIMMYT decided to make a concentrated effort to improve the germplasm's yield, grain type, and other characteristics. The central idea was that, to be successful, high-lysine maize had to be comparable to improved normal maize in every other respect.

Two significant actions were taken. First a wide range of normal maize genotypes differing in maturity, adaptation, and grain texture and color were converted to high-lysine, hard endosperm maize—quality protein maize (QPM), as it came to be called. Second, QPM gene pools were developed and improved.

The critical step in converting the normal genotypes to QPM was to devise a method for accumulating modifier genes. Each modifier gene has only an incremental effect in converting opaque kernels to crystalline form. The genes must be piled up in order to make an impact. But modifier genes that reduce lysine and tryptophan content have to be culled out. Through repeated selection, chemical analyses, and recombination, remarkable improvements in the appearance and texture of the kernels were achieved.

Various techniques were developed to overcome other deficiencies. For example, in selecting and breeding for hard kernels, there is a tendency for the kernels to become smaller. Spaces between kernel rows are symptomatic of this problem, so breeders selected against open spaces in order to boost yields.

Numerous trials were also conducted to be sure that the kernel modification was stable under different growing conditions, a question not yet fully answered.

The establishment of QPM pools is patterned after CIMMYT's work with normal materials. The pools provide a large array of genetic modifiers and new gene combinations. At the same time, through crossing and moderate selection pressure, the quality of the materials has been upgraded in several ways: plants are shorter, ears are lower, maturity earlier, and kernel appearance is improved—all while retaining better protein quality and yield.

By the 1980s, a wide range of QPM germplasm had been developed and many of the shortcomings associated with the opaque-2 gene had been substantially reduced. At this point the breeders regrouped all the QPM material to reduce its total volume and to facilitate further refinement and wider testing. Seven lowland tropical and six subtropical QPM gene pools were formed, distinguished by maturity, grain color, and kernel type (dent or flint), and the improvement process was continued.

Plant breeding has sometimes been likened to putting a butterfly in a jar without losing the butterflies already captured inside. The development of quality protein maize has tested the ingenuity and perseverance of maize breeders with some exceedingly small and skittish genetic butterflies.

QPM varieties—Additionally, six tropical and four subtropical populations were formed. Families generated from these populations have been evaluated at six locations around the world in CIMMYT's international progeny testing trials. Data from these trials have been employed to form experimental QPM varieties, which also are undergoing international testing.

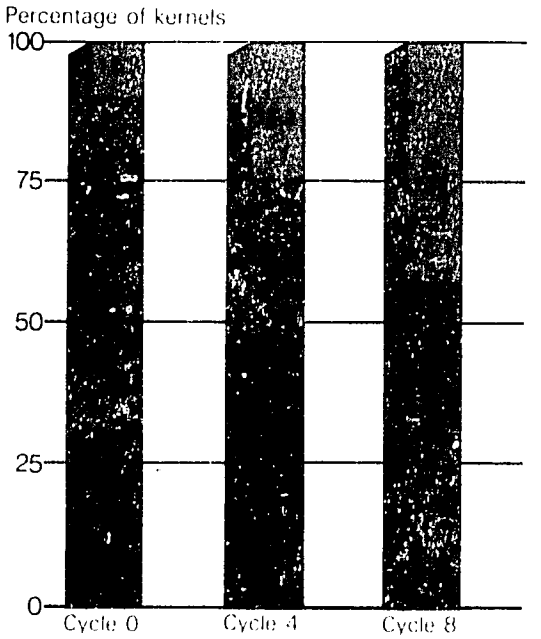
These changes have improved the data available for refining QPM germplasm, they have involved national programs more closely in improving the germplasm, and they have given national programs easy access to the best QPM materials.

Low yields have been a major weakness of QPM, but in recent international trials, several QPM experimental varieties have equalled the normal check. Good results have been obtained in other trials as well. Nutricta, a QPM variety released in Guatemala, has yielded as much as some of the best experimental varieties and hybrids.

The normal appearance of kernels is now stable at the ear level, but within-ear variability still exists. Further modification should reduce the variability.

Considerable progress has been made in decreasing the incidence of ear rots, largely because kernels are harder and dry faster. Nevertheless, under severe conditions, ear rots cause somewhat more damage to QPM materials than to normal maizes.

Commercial interest—National programs in a number of countries are showing strong interest in the new QPM germplasm. Several materials are being grown on a small scale by farmers in southern Mexico. In Guatemala, Nutricta was released and, from the same population, researchers have developed new experimental varieties that may be even better. Paraguay has released a QPM population as Nutri Guanari V-241. Swine feeding trials are under way in such countries as Argentina and Mexico. Private seed companies in some South American countries are using QPM in the development of hybrids. Senegal is in the final stage of testing a QPM material prior to release. China is multiplying seed of one experimental variety for release to farmers under the name Tuxpeño 102. The Chinese are also developing QPM inbred lines for use in the production of hybrids.



Improving kernel appearance in quality protein maize during eight cycles of selection (1-5 Scale: 1 = normal appearance; 5 = totally opaque)

The outlook for QPM is affected by shifting views on human nutrition. There is now less concern about a protein crisis than existed 15 years ago and more stress on overcoming calorie deficits. Nevertheless there are clearly important groups of people that are vulnerable to protein deficiency—pregnant women and children under the age of five. There may be a special role for QPM in parts of Africa where diets are dominated by low protein root crops and where costs of traditional protein sources are soaring. Ironically, under these conditions mothers and young children may have even less access to protein sources than other household members.

CIMMYT takes the conservative view that QPM has potential as an element in programs to combat malnutrition. As an improved source of protein in a crop that is widely grown, it has an advantage over new and unfamiliar high-protein crops that might be introduced as part of campaigns to enhance human and animal nutrition.

Beyond that, through the process of developing QPM to its present status, CIMMYT breeders have done pioneering work in demonstrating how many modifier genes, each with a tiny impact, can be accumulated to induce major changes in the characteristics of a plant.

Insect and Disease Resistance

From its inception the Maize Improvement Program has given a prominent place to the development of resistance to major diseases and insect pests in developing countries. Substantial progress has been achieved in the work on diseases by means of a three-pronged approach: (1) routine selection at experiment stations in Mexico for resistance to ear and stalk rots and to leaf blights and rusts; (2) further selection against those and other diseases by national scientists evaluating IPTTs; and (3) special projects conducted in cooperation with various national and international institutions to develop resistance to diseases for which selection cannot be done efficiently in Mexico.

Though much smaller gains have been made in the work on insects, the groundwork has been laid for more rapid development and delivery of insect-resistant germplasm in the future to cooperators in national programs. The search for resistance depends heavily on being able to

reliably distinguish between resistant and susceptible plants. Developing insect resistance is a difficult undertaking for that reason—natural infestations of insects tend to be variable and unpredictable. This is particularly true for the members of the moth families that constitute the major pests of maize worldwide.

From its inception the Maize Improvement Program has given a prominent place to the development of resistance to major diseases and insect pests in developing countries.

Laboratory methods. In 1975 CIMMYT started a laboratory for mass rearing maize stem borers, corn earworm, and fall armyworm. Techniques used in temperate climates had to be adjusted to fit the biological characteristics of tropical insect strains. In addition, the output had to be large enough to service the immense volume of materials contained in the CIMMYT maize pools and the population improvement program.

There are several essentials for improving insect resistance through artificial infestation. First, a colony must be established that contains insects that are as voracious as their wild cousins. Second, it must be possible to produce enough of the insects at the right time for infestation. Third, germplasm must have sufficient genetic variability for resistance. Fourth, there must be an efficient means for infesting plants with equal numbers of insects. Fifth, to classify the insect damage, a rating scale must be developed. Finally, there must be an effective breeding scheme to raise the level of resistance.

To ensure that insect colonies are representative of the wild population, CIMMYT rejuvenates them every 6 to 10 generations (about 1 year), depending on the species. Wild insects are collected and raised in isolation for one generation to ensure that they are not diseased or bearing parasites. Then the wild stock replaces the laboratory population or is crossed with it.

The diets have to be formulated specifically for each type of insect. For earworm and armyworm, the diet is mainly soybean meal, maize meal, and brewer's yeast. Maize borers are fed a prepared formula mixed with maize cob grits, brewer's yeast, and wheat germ. All three types of insects get vitamins and antibiotics, and CIMMYT has found that including ground maize tassels in the diets helps the colonies thrive.

Rearing facilities are tailored to the biology of each insect type to encourage growth and multiplication. Proper facilities avert such problems as cannabilism and make it easy to collect the eggs or the larvae. Fall armyworm moths, for example, were originally kept in small cages, but they left their eggs attached to the supports or frames, which made them difficult to collect. Substituting paper bags for the cages was an improvement. The egg masses then could be collected by cutting up the bags. Now waxed paper bags are used, and the egg masses can easily be scraped off with a spatula.

Insect rearing facilities are tailored to the biology of each insect type to encourage growth and multiplication.

The pupae of corn earworm presented a different problem. The pupae tend to burrow below the surface of the semisolid diet on which they are raised. So that the pupae do not have to be extracted one by one, scientists have designed a polystyrene cell unit that can be split into two layers. When the layers are separated, the diet mass and the pupation cells are split in half and the pupae can be dumped out.

Artificial infestation—Since the refinement of the mass-rearing methods, scientists have used artificial infestation for improving the efficiency of selection for resistance to one species or another in selected pools and populations.

In the past infestation was done with egg masses, until CIMMYT developed the "bazooka" technique for infesting maize with larvae. The bazooka is a cylindrical dispenser calibrated to place a uniform dose of maize cob grits mixed with larvae in each plant. The quantity of grits allows the scientists to control the number of larvae applied to each plant.

Compared with infestation with egg masses, use of the bazooka is faster, it gives more uniform infestation, and the insects are less frequently destroyed by predators, resulting in fewer "escape" plants.

Recently, CIMMYT has taken several steps to increase the flow of resistant material to national programs. In 1983 experimental varieties were formed to concentrate resistance in good agronomic backgrounds. The varieties are based on progenies showing the best levels of resistance in artificially infested nurseries. Preliminary trials of these experimental varieties are under way.

Multiple resistance—A second step involves the formation of multiple resistance pools. Several sets of the International Lepidoptera Resistance Trials organized by Mississippi State University (USA) were grown in Mexico in 1984 and artificially infested with stem borers and armyworms. Some of the entries showed higher levels of resistance than had been found in any of CIMMYT's maize populations. Their yields, however, were low and their agronomic characteristics poor.

Prompted by these results, CIMMYT solicited seed of maize reported to be resistant to any of the genera or species of borers found anywhere in the world. The lines, synthetics, hybrids, and varieties sent by maize researchers are being recombined to form the multiple borer resistance pool. After mild selection for resistance and agronomic traits, some of the progeny are showing good resistance to borers and armyworms, as well.

The improvement of this pool will continue through recurrent selection. International testing of the most resistant families has begun at nine locations, using standardized levels of infestation. At each location, the cooperators will select and cross the families that perform best against each locally present insect and return the seed to Mexico for further recombination and testing.

While the multiple-borer resistance pool promises to serve as a strong source of diverse resistance to various borers, it may not serve as a direct source of selections that will perform well in tropical maize-growing environments, where other insects predominate.

As a result, CIMMYT established the multiple-insect resistance tropical pool. This pool includes some materials from the maize borer resistance pool but mainly contains the most resistant selections from CIMMYT's tropical populations and pools. The latter materials have undergone up to 18 cycles of selection in tropical environments and have good levels of resistance to tropical diseases and excellent yield and agronomic performance. Within this pool, selections are being made for resistance to borers and fall armyworms. When progeny are extracted from the pool in a few years, they should combine high yield potential with resistance to insects and diseases.

Several other areas of research are being explored as well, such as testing and making selections from certain Caribbean races of maize believed to have good insect resistance, and screening progeny of wide crosses between maize and tripsacum. But regardless of which of these avenues ultimately proves most fruitful, they all depend heavily on the care and feeding and on-time delivery of millions of insects

A Global Wheat Improvement System

CIMMYT wheat germplasm is developed to meet five minimum criteria: high yield potential, broad adaptation, and resistance to the three principal wheat diseases—stem rust, leaf rust, and stripe rust. In addition, attention is being given to improving resistance to the "minor" diseases of wheat, such as those caused by *Septoria*, *Helminthosporium*, and *Fusarium* species.

The accretion of these characteristics in CIMMYT-developed germplasm is a direct result of the multilocational breeding and testing that undergirds the Wheat Improvement Program.

Wheat yield potential received a mammoth boost from the introduction of dwarfing genes in the late 1950s. The dwarfing genes changed the way the plant apportioned carbohydrates among its vegetative and reproductive parts. The grain of productive tall varieties constitutes only 25 to 35% of the total weight of the plant. In dwarf varieties, the grain is usually 40 to 50% of the total weight. In other words, dwarfing improves the efficiency with which the plants use sunlight, water, and nutrients, the essential inputs for growth.

In addition, shortening the plant (and increasing its straw strength) multiplied the response to high fertility. When fertilized heavily, tall varieties produce somewhat more grain, but are likely to fall over, reducing the actual harvest to such an extent that the yields of less well-fertilized plants often are higher. The short, strong stems of dwarf varieties resist lodging; that and other features bred into dwarf varieties make them highly efficient users of inputs the farmers apply.

More recently the introduction of winter-wheat genes into spring wheats through spring × winter crossing has raised the yield potential again.

Adaptation—The bedrock of the broad adaptation of CIMMYT materials is insensitivity to daylength. In many varieties, flowering is triggered by the onset of days of a certain length. While there are some biological advantages in certain regions in daylength sensitivity, it is usually futile to plant such varieties outside of the normal growing season or at a location nearer to, or farther from, the equator. In either case, differences in daylength will make flowering occur too early, too late, or, if daylength never reaches the critical duration, not at all.

CIMMYT scientists strive to develop high-yielding, broadly adapted, and disease-resistant germplasm for a range of environments in the Third World.

CIMMYT's practice of producing two generations a year at different locations eliminates daylength-sensitive germplasm. From November to May, breeding and selection takes place in northern Mexico at 27.5° N latitude. The crop develops as days are getting longer. From May to November, lines are grown near Mexico City at 18.5° N latitude and the crop develops as the days are getting shorter. Only materials that perform well at both locations, that is, that are insensitive to daylength, are selected.

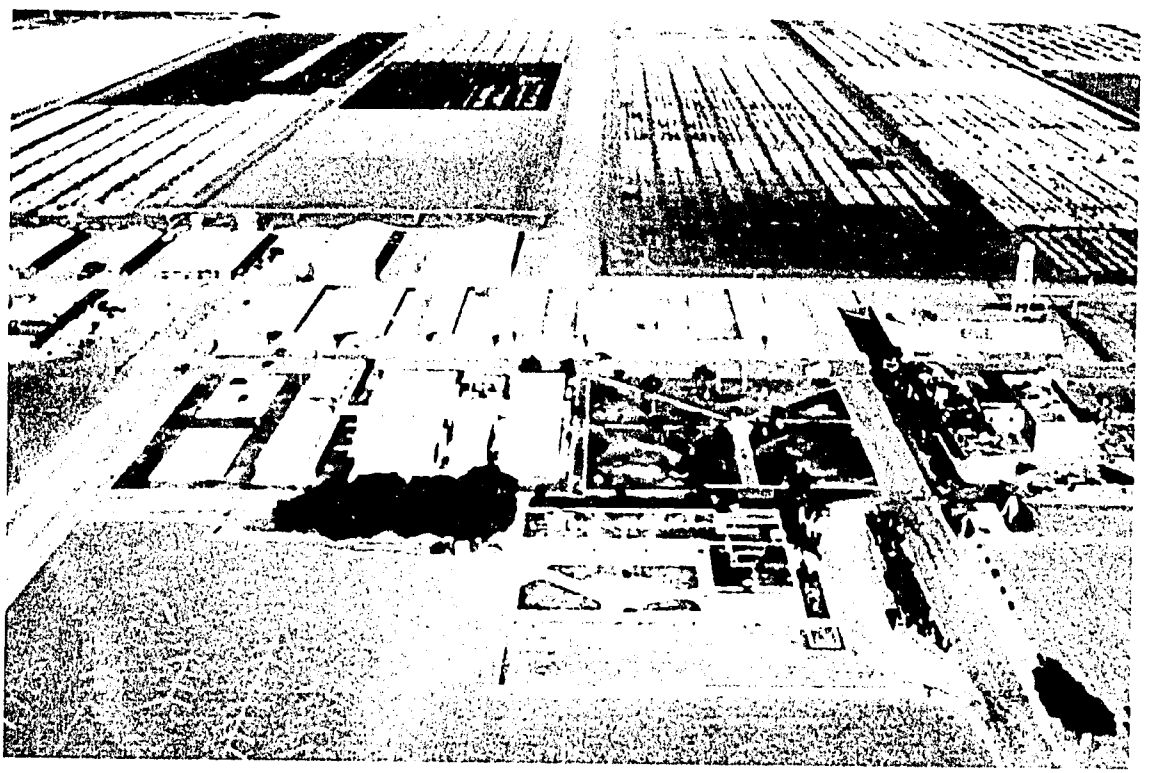
The movement of germplasm from one location to another during the breeding process broadens adaptation in other ways, too. The winter breeding site is near sea level (39 m) in an irrigated desert. The summer site has high rainfall and is at 2650 meters elevation. Consequently, selection of lines takes place in contrasting climatic conditions and in the presence of quite different complexes of diseases and insects.

The international nurseries are an added and demanding proving ground. Performance at hundreds of locations around the world provides the ultimate test of adaptability.

Rust resistance—The requirement of resistance to the three principal rusts contributes to the broad adaptation of CIMMYT germplasm. Rusts are fungi that parasitize wheat and other crops. They are formidable enemies of wheat and, because of their ability to mutate and attack previously resistant varieties, the job of breeding for resistance is literally endless.

Strong resistance to stem rust in Mexican wheats was established in the 1950s and CIMMYT breeders have broadened the genetic base of resistance though crossing with a wide range of sources. Multilocation testing has demonstrated that the resistance is sustained around the world.

Work on leaf rust resistance began later than that on stem rust, but significant advances were made by the 1970s. Although the general level of resistance in CIMMYT germplasm is sufficient for most locations around the world, it is not stable in Mexico and a few other spots with exceptionally virulent strains called races.



From November to May, wheat breeding and selection are done at Mexico's Agricultural Research Center of the Northwest (CIANO) near Ciudad Obregon, Sonora.

Screening for stripe rust resistance is done in the Andean region of South America, in the highlands of East Africa, and in Mexico, locations where a broad spectrum of stripe rust races are found. Data from the screening is used to guide subsequent crosses to enhance resistance. Materials with broad resistance to stripe rust started to become available in the 1980s.

Other features—Breeding for special features takes place as an overlay on the foundation of high yield potential, broad adaptation, and resistance to the major rusts. Breeding for resistance to such diseases as septoria, helminthosporium, and scab is under way in subsets of CIMMYT germplasm. Since these diseases are not ubiquitous and are important only in certain regions, no attempt is made to incorporate such resistance in all germplasm. To do so would unnecessarily slow the process. CIMMYT takes a similar approach in work on drought tolerance, heat tolerance, and tolerance to high levels of aluminum.

Yield stability—Statisticians have investigated the yield stability of various groups of varieties in different environments using results from 15 years of the International Spring Wheat Yield Nurseries. These are replicated trials that have been conducted annually since 1963 at about a hundred locations in 60 to 70 countries and that involve 50 advanced lines and varieties.

For the stability analysis, the locations were classified according to the mean yield of all varieties in all trials. Thus locations where the mean yield was 1 t/ha were characterized as 1 t/ha environments, locations that averaged 2 t/ha were characterized as 2 t/ha environments and so on. The most productive environment had a mean yield of 9 t/ha.

The varieties were grouped into genotypes: a) CIMMYT developed materials released directly by national crop improvement programs; b) those resulting from a cross made by CIMMYT but with at least one further selection made by a national program; c) locally bred varieties involving CIMMYT germplasm; and d) locally bred varieties without CIMMYT germplasm.

Stability was considered to have four facets. A variety or group of varieties has acceptable yield stability if its mean yield is significantly higher than the average yield at all sites; if its responsiveness to better environments is greater than the mean of all varieties; if the trend in yield from environment to environment is consistent; and if the yield in the poorest environment equals or exceeds the mean of all varieties.

CIMMYT wheat germplasm is developed to meet five minimum criteria: high yield potential, broad adaptation, and resistance to the three principal wheat diseases—stem rust, leaf rust, and stripe rust.

The analyses showed that group A—CIMMYT-developed materials released directly by national programs—had higher average yields than the other groups, more responsiveness to better environments, and in poor environments, yields no worse than average. In consistency, Group A was slightly exceeded by Group B. But closer analysis showed that that ranking may be misleading. In certain locations that are disease "hot spots," the strong disease resistance of certain genotypes in group A, caused them to yield well above the average for the group. Statistically that registered as yield instability, but from a practical viewpoint, it is an asset, not a liability.

The study did not find evidence to support the idea that some varieties with modest yield potential may perform better under poor conditions than varieties that have high yield potential. All the ISWYN varieties yielded about the same under poor conditions. In areas where low yields are caused by low levels of inputs, particularly water, the expression of yield is severely restricted for all varieties regardless of inherent yield potential. Moreover, the stability that some observers attribute to locally developed varieties is more a result of their poor performance in high-yielding environments than of superior performance in poor environments.

Thus through a dynamic system of wheat improvement, which rests on broad-based crossing and multilocational testing, CIMMYT and its collaborators generate a stream of steadily improved materials of value to large regions of the wheat-growing world.

Spring x Winter Wheats

The notion of crossing spring wheats with winter wheats—two large but separate gene pools—has been a powerful lure for many plant breeders

In nature, the genes of these two groups seldom intermix because outcrossing is uncommon in a self-pollinated crop, because winter and spring wheats are usually grown in climatically different regions, and because, even if plantings of spring and winter wheats are in proximity to one another, they normally flower at different times. As a result, wheats with the spring growth habit and wheats with the winter growth habit have travelled separate evolutionary paths, with guidance from farmers, and, in this century, from plant breeders.

Plant breeders have long recognized the special strengths of spring- and winter-habit wheats that might be usefully combined. Progeny of spring x winter crosses are now consistently among the best entries in international trials.

Special strengths—Plant breeders have long recognized that each group has special strengths that might be usefully combined with those of the other group. For example, winter wheats tend to have better drought tolerance; spring wheats tend to have better milling and baking quality. Moreover, the genes for these desirable traits could be found in already productive varieties—varieties with good genetic backgrounds. Thus when crosses were made, the progeny would bear a fair number of acceptable characters, and subsequent breeding and selection to eliminate undesirable traits would take less time.

In greenhouses, spring and winter wheats can be made to flower at the same time, primarily by manipulating temperature to vernalize the winter wheats. (Winter wheats require a period of cold temperatures to induce flowering.) Through this process a number of commercially important wheat varieties have been created. In fact, Norin 10 x Brevor, the original source of dwarfing in Mexican varieties, was a spring x winter cross.

A unique site—But greenhouse work is costly and the number of crosses that can be made annually is limited. CIMMYT has been able to shatter that limitation because of the special climate at one of its Mexican research sites.

In the 1970s CIMMYT began to look at large-scale spring x winter crossing as a means to strengthen the drought tolerance of spring wheats as well as their resistance to stripe rust, septoria, and root diseases. It found a partner in Oregon State University (USA), which was interested in developing winter wheats with greater stem and leaf rust resistance, higher yield, and better milling and baking quality—all of which are readily found in good spring wheats. In addition to shoring up weaknesses in the two gene pools, intercrossing offered the opportunity to enlarge the spectrum of genes for other desirable characters available to breeders.

The key was the Toluca, Mexico, station. Although the location is within the tropics, its elevation (2650 meters) ensures that periods with temperatures low enough to vernalize winter wheat occur from December through February. At Toluca, winter wheats are planted in November and spring-wheats are planted on several successive dates starting in January. In May both groups are flowering and breeders can make extensive crosses.

To accelerate the pace of breeding, spring x winter crossing also takes place at the CIANO station in Northwest Mexico, the site of CIMMYT's principal spring-wheat breeding activities. There, potted winter-wheat seedlings are grown in cold chambers to vernalize them. They are then transplanted outdoors and grown under electric lamps to extend the daylength and hasten flowering.

The research partnership—In all, over a thousand crosses a year are made and seed from the first generation progeny are divided with Oregon State University. CIMMYT breeders use the seed in subsequent crosses with the aim of producing spring-habit wheats. From this point, the progeny undergo the same rigorous testing and screening procedure as conventional spring wheats. At Oregon State University, breeders use the seed similarly in developing better winter-habit wheats. The national wheat program of Turkey is also involved in exploiting germplasm for winter wheat.

Almost as soon as advanced lines became available from CIMMYT's first spring x winter crosses, exceptional performance was evident. Now, progeny of spring x winter wheats are consistently among the best entries in the International Spring Wheat Yield Nurseries conducted annually at over 100 locations worldwide.

Veery 'S'—Crosses of high yielding Mexican spring wheats with certain winter wheats from the USSR and USA have been particularly noteworthy. One of these, a line called Veery 'S' has produced average yields 5 to 10% higher than other widely adapted, high-yielding varieties in several years of trials. From their Soviet winter-wheat progenitor (Kavkaz), the Veery lines have gained better resistance to powdery mildew and stripe rust as well as additional resistance to septoria leaf blotch and leaf rust. They also appear to be more tolerant of early season cold, late season heat, and drought. Consequently they perform well in a wide range of diverse environments

Mexico began to release varieties from the Veery 'S' line in the 1980s. They now cover 80% of the nation's wheat area. Selections made from Veery lines have been released in over a dozen other countries as well and more are coming. To date, over 3 million hectares of Veery-derived varieties are under cultivation.

Breeding for Disease Resistance in Bread Wheats

A leading aim of CIMMYT's bread wheat breeding program is to develop genetic resistance to the important wheat diseases. Because the major rusts—leaf rust, stem rust, and stripe rust—are by far the most destructive wheat diseases worldwide, resistance to them is a prerequisite for CIMMYT lines promoted to advanced stages. In addition, CIMMYT breeders incorporate resistance to other diseases that are regionally important into suitable germplasm.

The rusts—In the struggle against rusts, the battle is never over. These parasitic fungi can readily mutate into new virulent races, and they are capable of explosive multiplication, causing an epidemic. A variety that has been resistant to the prevailing races in an area may become susceptible almost overnight when a new virulent race suddenly appears. In many areas, a new variety can be expected to last no more than five years before a new race arises to which it is not resistant.

The best weapon against these insidious adversaries is broad-based breeding to accumulate multiple genes for resistance, intensive exposure to the rusts through inoculation, and multilocation testing to expose weaknesses in the resistance genes.

Crossing with a wide range of sources continues in order to broaden the base of resistance. In international tests, CIMMYT germplasm has demonstrated resistance to stem rust at locations around the world. In Northwest Mexico, the nation's major wheat-producing area, there has been no threat of a stem rust epidemic for 25 years.

Moreover there are indications that stable resistance to stem rust may be possible. Yaqui 50, a tall Mexican bread wheat, is one of several varieties whose resistance to stem rust has endured for over three decades. CIMMYT regularly uses such varieties in crossing for resistance.

In the 1960s, leaf rust, which had been a minor disease in Mexico, began to be troublesome. Efforts to incorporate resistance from various sources were begun and within a

Over several years of trials, selected Veery lines have produced average yields 5 to 10% higher than other widely adapted, high-yielding varieties.

decade considerable progress was made. In most areas of the world, CIMMYT materials are resistant to leaf rust. Ironically, the resistance is not stable in Mexico. A severe epidemic struck Northwest Mexico in the late 1970s. However, through periodic changes to new varieties, leaf rust has been held in check until now.

A bright omen in the search for stable resistance to leaf rust is the discovery of the "slow rusting" characteristic of certain lines. When leaf rust attacks these lines, the usual lesions occur, but their onset is delayed. By harvest the intensity of the attack is still mild and the effect on yield is minimal. A vigorous program to identify sources of this trait and to transfer it into productive varieties is under way.

Development of strong resistance to stripe rust is less well advanced than work on the other major rusts. Screening for resistance was begun at one of CIMMYT's high elevation stations in Mexico where stripe rust is endemic. But international multilocation testing revealed that the race spectrum at that location is narrow. As a result, the resistance genes in the materials were ineffective against races prevailing at numerous other locations.

In the mid-1970s CIMMYT began screening lines in the Andean region of South America, an area with severe stripe-rust incidence. Screening was also initiated in the highlands of East Africa. By employing data from these trials in making crosses, a broad genetic base for stripe-rust resistance is pervading newer CIMMYT materials. But the level of resistance still has considerable room for improvement.

Multilocation testing—Success in breeding for resistance is heavily dependent on international testing. The international nursery system permits the exposure of materials to a wide range of virulence. Performance data returned from cooperators are used to calculate the average coefficients of infection for various diseases in numerous locations. For rusts, a line that shows a consistently low coefficient at diverse locations is presumed to carry multiple genes for resistance. Lines with low

Starting in the mid-1970s, CIMMYT began screening lines for stripe rust resistance in the Andean region of South America, where a broad spectrum of stripe rust races is found.

coefficients for rusts or other diseases are used in simple and three-way crosses to pyramid the resistance genes. The segregating progeny are then exposed to all possible diseases in the field, to cull out those that do not have broad resistance. When germplasm combines broad-based disease resistance with a productive background, it is returned as advanced lines to national programs for retesting, further selection, or possible release.

Other diseases—*Septoria* spp., a fungus, is an example of a wheat disease complex that is of regional importance. In the 1960s and early 1970s, CIMMYT germplasm grown in North Africa and the Middle East often performed poorly because it lacked resistance to septoria diseases. Subsequently, CIMMYT began collecting sources of resistance to intercross with lines possessing high yield potential. Screening of the progeny for septoria resistance was done cooperatively with several national programs in the Mediterranean region. An acceptable level of septoria resistance has now been achieved in some CIMMYT germplasm suitable for regions where *Septoria* spp. are prevalent.

Several diseases are serious limitations to the productivity of wheat in tropical climates that are now considered marginal for wheat. Sources of resistance to helminthosporium leaf blight are being crossed with the best CIMMYT germplasm and tested at a warm, humid site on the eastern coast of Mexico. At this site, helminthosporium diseases are so severe that the only survivors are lines with strong resistance.

Resistance to such diseases as septoria and helminthosporium leaf blight is not incorporated into the full range of CIMMYT germplasm. Doing so would dilute the resources available for resolving more pervasive breeding problems. Instead the development of resistance is centered on the segment of CIMMYT germplasm appropriate for areas where the disease prevails, such as Bangladesh, Nepal, eastern India, Brazil, Paraguay and the countries of East Africa. Other countries that would profit from better fusarium resistance include China, East Africa, Brazil, Argentina, Uruguay, and Paraguay.

By superimposing resistance to diseases of regional importance on germplasm that has high yield potential and resistance to the major diseases, CIMMYT and its collaborating national programs expand the production options of poor farmers who populate marginal areas of the world.

Success in breeding for disease resistance is heavily dependent on international testing, which permits the exposure of materials to a wide range of virulence.

Durum Wheats

Compared to bread wheat, durum wheat has received less attention from breeders. At CIMMYT, intensive improvement of durum wheat has been under way for little more than a decade.

Although durums cover only 10% of the world's wheat area, they are of local importance in North Africa and the Middle East, Italy, Ethiopia, India, the Andean Zone of South America, Canada, the USA, and the USSR. The grain has special properties desirable for making noodles and other pasta products. Durums are also favored for producing certain types of unleavened bread and such homemade products as couscous, bulgur, and chapatis.

Dwarfing—When bread wheat strains bearing the Norin-10 dwarfing genes arrived in Mexico in the late 1950s, crosses were made with durums as well as with other bread wheats. Durum yields increased remarkably. Subsequent breeding and selection has lifted the yield potential of durum wheat to such an extent that under optimum conditions their yields exceed those of bread wheats.

While work to raise the yield potential of durums continues at CIMMYT, efforts to enlarge the genetic base of improved lines and to widen their adaptation have been given increasing emphasis in recent years.

Unreliable rainfall is characteristic of many durum-growing areas and CIMMYT is undertaking cooperative research with the International Center for Agricultural Research in Dry Areas (ICARDA) to improve drought

tolerance. In addition, spring and winter durums are being crossed with the intent of transferring the latter's drought tolerance to the spring-habit germplasm pool. Breeding for earlier maturity is another promising avenue: early maturing varieties would have less risk of being damaged by late-season epidemics, drought, or frost.

While work to raise the yield potential of durums continues at CIMMYT, efforts to enlarge the genetic base of improved lines and to widen their adaptation have been given increasing emphasis in recent years.

Advanced durum wheats in CIMMYT's breeding program have high and stable levels of resistance to stripe rust. To strengthen resistance to stem rust, CIMMYT ships genetic materials to cooperating national research institutions in Ethiopia where the presence of highly virulent races of stem rust provides excellent conditions for screening. They are then returned to CIMMYT for incorporation into lines for other parts of the world affected by stem rust. Better resistance to septoria, fusarium, and helminthosporium diseases is still needed.

Progress has also been made in producing lines with solid stems, which provide resistance to the attack of sawflies, a serious pest of wheat in certain countries of North Africa and the Middle East.

Export quality—Massive testing by the CIMMYT milling and baking laboratory facilitated the development of new durum lines that combine high yield potential with grain that has the size, weight, pigment, and protein content required for making pasta and other semolina products. High quality grain is essential for countries that hope to enter the lucrative durum export trade.

Through the international nurseries, CIMMYT germplasm reaches national programs. Durum varieties derived from CIMMYT materials are being grown widely in the Mediterranean basin, in Pakistan, India, Ethiopia, Kenya, Mexico, and in South America.

Triticale

Triticale has come a long way from its origin as a laboratory curiosity. The first successful crosses of wheat and rye, to create what is now called triticale, were made in the late 1800s. But development of triticale as a crop didn't start until the 1950s.

CIMMYT began working with triticales in the late 1960s. Triticale strains at that time were low yielding and had a narrow range of adaptation. Typical triticales were tall, late maturing, and photoperiod-sensitive, that is, the onset of flowering was affected by day length. In addition, they were partially sterile, so a large proportion of spikelets never formed grains; the grains that did form tended to be shrivelled.

Narrow genetic base—As a man-made crop, triticale lacked the eons of evolutionary time necessary to become genetically diverse. The narrowness of the germplasm base made it vulnerable to diseases and other problems.

The broad spectrum of varieties employed in CIMMYT's durum and bread wheat breeding programs afforded an opportunity to expand the genetic base of triticales. Working with the University of Manitoba (Canada), CIMMYT began an extensive-crossing program between short, photoperiod-insensitive Mexican wheats and Canadian triticales. The progeny were moved back and forth, in successive seasons, between two disparate locations in Mexico. As in CIMMYT's wheat improvement program, this procedure accelerated progress by allowing two generations to be grown each year. In addition, it exposed plants to different climatic conditions and disease complexes, and photoperiod-sensitive plants could be quickly eliminated. These triticales, however, yielded only about half as much as the best wheat varieties.

Breeders' luck—The single greatest advance in the history of triticale was a serendipitous event. In 1968, breeders found, among the third generation progeny of one of their crosses, a few plants that stood out. They were apparently the result of a spontaneous outcross, that is, a plant two generations earlier had been fertilized by pollen from an unknown bread wheat rather than being self-pollinated.

This line, called Armadillo, was photoperiod-insensitive, had one dwarfing gene, better yield, and much higher fertility. Its strong features were readily transmitted in crosses with other triticales and it also crossed well with bread wheats, durums, and rye. By the late 1970s large numbers of triticales had Armadillo in their pedigrees.

The single greatest advance in the history of triticale was a serendipitous event, a spontaneous outcross with an unknown bread wheat.

The early triticales, however, had weak stems, which resulted in a tendency to lodge, particularly when grown under heavy doses of fertilizer. Numerous crosses were made with stiff-strawed bread wheats to overcome this deficiency.

Shrivelled grain—Crosses were also made to produce plumper grain, and large-scale laboratory testing provided the information to make selections. Test weights, one measure of plumpness, have improved in some materials from 68 kg/hl to as high as 76 kg/hl, a level comparable to that of bread wheat. Although substantial gains have been made, shrivelled grain still preoccupies triticale breeders. Lines that have high test weights under optimum growing conditions often have lower test weights under poor conditions. But lines with good test weights under suboptimal conditions generally retain them when grown in better conditions. CIMMYT's high-elevation summer nursery sites provide suboptimal conditions that allow selection for stable, high test weights.

International triticale trials were established in 1969. The trials provide data on triticale's adaptation to a wide range of conditions. They also give breeders at CIMMYT and elsewhere ready access to triticale germplasm. Since 1973, the yields of the best triticales have equalled the yields of the bread wheats.

The combination of rye and wheat germplasm gives triticale better adaptation to difficult conditions than wheat. Recent analyses have shown that the best triticales are distinctly superior to bread wheats in certain dryland conditions, tropical highlands, and acid soils. But triticales have no significant yield advantage over wheat in irrigated subtropical conditions or Mediterranean climates.

CIMMYT has in recent years accentuated the expansion of the germplasm base. Crosses between bread wheat and rye and between durum and rye are made to create new primary triticales. Tissue-culture techniques have been improved to raise the proportion of primary crosses that succeed. Crosses are also being made between winter triticales and spring triticales, two gene pools that have quite different features.

Target areas—Triticale currently covers some 750,000 hectares in 30 countries, with the largest areas currently found in developed countries. In favored production environments, even when the yields are equal, triticales cannot compete with high-yielding wheats because the lower milling rates of triticale cause it to sell at a discount. In harsher environments, the superior yields of current triticales should more than compensate for a lower price. There are about 3 million hectares where wheat, barley, or rye is now grown that could be advantageously sown to triticale. In addition, another 15 million hectares that do not now support small grains could be sown to triticale. These are the zones in which current research is focused.

Triticale (right) tends to perform much better than bread wheat (left) when both are grown in adverse soils, such as in this highly acidic plot.

CIMMYT's Approach to On-Farm Research

CIMMYT's role in on-farm research is one of providing research procedures and training. The Center's Economics, Maize, and Wheat Programs are all involved in developing and providing these procedures and training. The development of technologies for use by farmers is the role of national agricultural research programs.

CIMMYT's work in on-farm research stems from its studies on the spread of new maize and wheat varieties and new management practices, which showed that adoption takes place unevenly. As a result of differences in agroecological and socioeconomic circumstances, even neighboring farmers in a locality may have quite different adoption patterns. Simply stated, adoption follows if the recommendations fit.

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Development of Procedures

With this premise as background, CIMMYT set out to develop procedures that would help national agricultural research programs efficiently generate appropriate recommendations. Four essential elements were identified.

First, the farmers for whom the recommendation is derived must be carefully targeted. The delineation of recommendation domains—groups of farmers whose circumstances are similar enough that they will be eligible for the same recommendation—facilitates this process.

Second, the importance of interactions, biological and economic, must be recognized. Farmers make decisions in complex environments. Some of the sources of complexity are: the possibility of growing several crops a year, or sometimes simultaneously; the risks presented by uncertain climate and unreliable markets; the multiple objectives of the farm family, which often consumes much of its production and which may also derive income from off-farm work; the heavy dependence on family labor; and the heterogeneity of the land and labor used for production.

Third, such a complex system requires the joined perspectives of biological and social scientists in the research process. And fourth, to be reliable, much of the research should be carried out on the farms of representative farmers.

Adapting the Strategy

In order for a research strategy to be practical for national programs it must fit their means. That is, it must be one that national research programs can implement, despite their limitations of staff, equipment, and funds. Also, given the intense competition for scarce research funds in developing countries, the strategy must yield results soon, even if long-term results are potentially greater. Finally, the strategy must be compatible with the tendency of farmers to adopt new technology incrementally.

As a result, CIMMYT concentrates on a class of systems-based research that treats one, or sometimes two, enterprises (for example, wheat or a maize-bean intercrop) as variables. But the approach recognizes that competitive and complementary relationships with other activities exist and it ensures that these relationships are reflected in the design of technologies for the enterprise under investigation. In addition, CIMMYT stresses the value of restricting consideration to a few high priority components. These limitations make the strategy feasible for most national research programs, they encourage emphasis on near-term results, and they are consonant with farmer adoption behavior.

A Sequential Approach

The on-farm research procedures developed by CIMMYT are flexible enough to encourage adjustment and refinements as local situations dictate, but they are formulated so that researchers with little experience have firm guidelines that they can follow. The procedures involve a sequential approach to data collection. A rapid overview of the farming system guides further data collection on a smaller number of variables. This information is in turn translated into research priorities, which form the basis for on-farm experimentation. From an assessment of the experimental

results, recommendations are formulated. Biological and social scientists collaborate throughout the process.

Diagnosis is both the first stage of on-farm research and a continuing activity throughout the research process. Initially, researchers review existing data and informally survey farmers, merchants, and others about practices and problems. A formal survey may be carried out as well, if resources permit. The information from the initial diagnosis is used to develop a list of priority problems and to identify potential solutions that conform with farmers' needs. These form the basis for the first year's experimentation.

Planning is done before each season's on-farm experiments are installed. Information from diagnosis and previous experiments is used to determine which problems are the most important and that they are sufficiently defined so that alternative solutions can be proposed. After screening proposed solutions for their likely profitability, riskiness, compatibility with existing farming systems, etc., the most promising form the experimental variables from which a set of on-farm experiments is designed.

During planning, the concept of recommendation domains is used to sharpen the research focus: it facilitates estimating the number and type of farmers that share a problem and that are likely to benefit from a particular solution and it helps in the specification of the characteristics of representative fields where trials should be conducted.

Experimentation is the central part of the on-farm research process. The on-farm experiments address a few experimental variables and leave all nonexperimental variables at the farmers' level. Hence, it is vitally important to have determined the management practices of representative farmers before experiments begin. Various types of experiments are conducted, but generally there is a progression from experiments designed to characterize and define problems, to experiments that test solutions to well-defined problems, to verification trials that may be used as demonstrations as well. In this progression, the degree of farmer management, the number of sites, and the size of individual plots all tend to increase.

The assessment of on-farm experiments involves a review of the agronomic responses observed throughout the cycle, a statistical analysis of the results, and an economic analysis.

Finally, recommendations are formulated with the objective of providing farmers with the most useful information possible in the context of scarce research resources.

Other Information

An equally important product of this process is the information that can be provided to decision makers about the effects of policies at the local level and to scientists concerned with setting priorities for longer term research. The involvement of extension workers in the entire process gives them first-hand knowledge of the technology as it develops and it affords the researchers the valuable insights of the extension workers.

Interest in on-farm research is rising rapidly in developing countries. Through demonstrations and training courses, CIMMYT has helped national research programs in 20 countries integrate on-farm research procedures into the technology generation process.

CIMMYT economist Juan Carlos Martínez (left) discusses the progress of an on-farm trial with a farmer. Such interaction is an important part of the research process.

CIMMYT and World Agriculture

CIMMYT works on maize and wheat, two crops that together constitute over 40% of the cereal output of the developing world. Its ultimate goal is to provide farmers with more productive options. New varieties, if genuinely better, are relatively simple for farmers to adopt—their worth can readily be judged, they can be tried in small quantities, they are inexpensive, and, if superior and accompanied by an agronomic package that permits them to express their genetic potential, they pay off quickly. The adoption of a superior variety often creates an incentive for farmers to employ more intensive cultural practices, with profound effects on incomes and food supplies.

Alumni of CIMMYT training courses make up an increasing proportion of the research staffs of national programs.

The creation of new varieties of wheat and maize results from a partnership between CIMMYT and national programs. CIMMYT provides a broad array of germplasm in various stages of development. It is made accessible through the international testing networks. National programs evaluate the germplasm against local diseases, insects, and stresses, and use it in any way they see fit. The international testing networks also serve to provide national programs with multilocation data on promising germplasm they have under improvement. Which experimental lines or varieties to name and release to farmers is a decision made by national programs in each country. Thus, CIMMYT's role is not only to promote the development of superior germplasm but to strengthen the capabilities of national programs to improve germplasm and thereby provide farmers with a stream of useful varieties.

The creation of new varieties of wheat and maize results from a partnership between CIMMYT and national programs.

Through its wheat program, CIMMYT has had an extraordinary impact—the ancestry of half the wheat grown in the developing world, as well as important segments of wheat germplasm in developed countries, can be traced to CIMMYT developed materials. Maize germplasm from CIMMYT has had a less widespread effect, but there are signs that its day is coming.

Maize Germplasm

The cultivation of maize takes place in innumerable ways throughout the developing world. It is a crop that is grown in tropical,

subtropical, and temperate areas. Although it is an important food crop, nearly half the total harvest in developing countries is destined to be fed to livestock.

And it is, for many growers, a secondary or subsistence crop, rather than a primary food crop. Thus, diffusion of superior maize varieties is more complicated than that of crops grown by farmers in less heterogeneous environments and with less diverse economic objectives.

Over 70 countries participate in the international maize improvement network, which, in the last decade, has developed and tested over 850 experimental varieties.

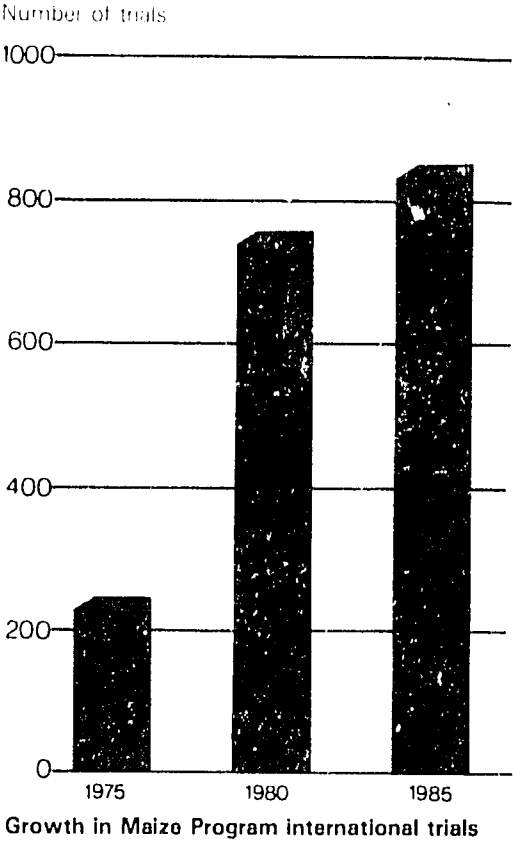
Over 70 countries participate in the international maize improvement network, which, in the last decade, has developed and tested over 850 experimental varieties. During this period, a large share of the national maize programs in developing countries have reorganized to follow the population improvement system used by CIMMYT. Those changes allow the programs to make better use of the diverse and steadily improving germplasm exchanged through the international testing network. Alumni of CIMMYT training courses make up an increasing proportion of the research staffs of national programs. Since 1971, CIMMYT has had nearly 900 maize trainees from 74 countries.

Nearly every maize breeding program in the developing world is using superior materials developed by CIMMYT to improve local varieties. Forty-three national programs have released 147 varieties and hybrids from materials in the international testing network.

In Brazil, for example, 12 such varieties have been released. Most have been chosen for their high levels of disease resistance. Ten varieties and three hybrids from CIMMYT materials have been released in Guatemala and are grown on some 40% of the country's maize area. In Costa Rica 10 to 15% of the maize area is planted to varieties selected from CIMMYT materials. In Nigeria, a variety resting on CIMMYT materials is one of two recently released improved varieties that together cover one million hectares.

Evidence of change in West African maize-growing areas comes from a recent sample survey of 10 Ghanian villages representative of the region. Among these farmers, who typically cultivate about two hectares of maize, four-fifths were planting at least part of their fields to improved varieties derived from CIMMYT germplasm. More than half were using these varieties on the majority of their fields.

Overall, CIMMYT estimated in 1983 that about 5 million hectares of maize varieties based on CIMMYT germplasm were being grown in the developing world. About half of that was in Mexico, about 1 million hectares were in Asia, and 0.5 million each in Africa, South America, and Central America.

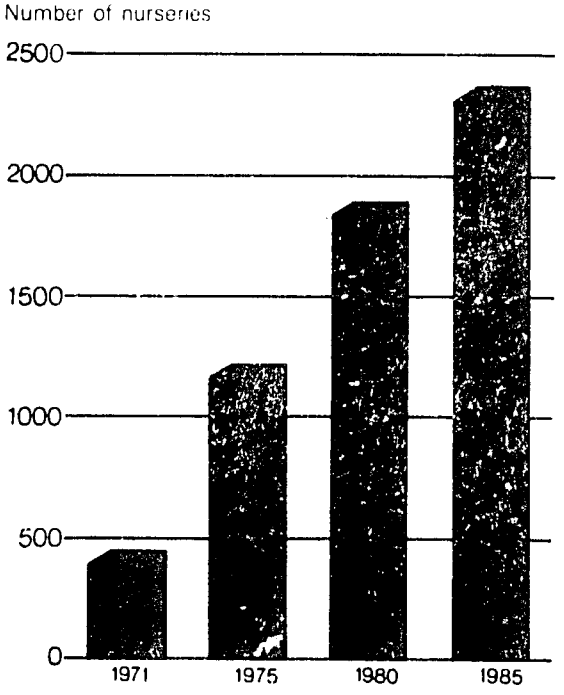


Growth in Maize Program international trials

Wheat Germplasm

The international spread of semidwarf wheats is one of the momentous events of agricultural history. The wheats bearing the Norin 10 dwarfing gene began moving out of Mexico in international nurseries in the 1960s. National programs recognized their worth and began releasing varieties so rapidly (in many cases importing large quantities of seed to speed the process) that by 1970, one out of every eight hectares of wheat in the developing world was planted to varieties bearing germplasm developed by CIMMYT or its predecessor organization. For certain countries, the conversion was even more dramatic. India, Nepal, and Pakistan had 40 to 50% of their wheat in modern varieties by 1970, and Mexico had 90%.

The international spread of semidwarf wheats is one of the momentous events of agricultural history. Over 400 modern varieties have been released by national programs and semidwarf wheats now cover over 50 million hectares in the developing world.



Growth in Wheat Program International nurseries (including bread wheat, durum wheat, triticale, barley, and special nurseries)

The diffusion of modern wheat varieties has proceeded unabated in the years since. The international testing program has made available germplasm with better yield potential, better yield stability, stronger disease resistance. The capabilities of national wheat scientists have grown in more and more countries. Over 400 modern varieties have been released by national programs. As a result, semidwarf wheats now cover over 50 million hectares in the developing world.

In Asia, excluding China, and in Latin America, 80% of the wheat land is in modern wheats. In sub-Saharan Africa the proportion is 50% and in North Africa and the Middle East, 30%. The adoption of modern varieties was delayed in China, but is now taking place at a rapid pace. The country now has some 15 to 18 million hectares in locally developed modern wheats (exceeding, for example, the whole of Latin America), but that represents only about one half of the wheat area of the country.

The effects of the wheat revolution have been profound in many countries. India and Bangladesh provide two examples. India's national average wheat yield is 1.8 t/ha, more than double what it was in the early 1960s.

In Bangladesh, the advent of modern wheats, in combination with faster maturing modern rice varieties, have given farmers sufficient time to grow a crop of wheat in the winter season. Bangladesh now plants 500,000 hectares of wheat, virtually 100% of which is in modern varieties. Compared with the early 1960s, the yield has more than tripled, the area of wheat has grown by a factor of 9, and production is 30 times greater.

CIMMYT wheat germplasm is making an important contribution to food production outside the developing world as well. In the US, nearly all the wheat planted in California, Arizona, New Mexico, and southern Texas, as well as half the wheat in Kansas, carries CIMMYT germplasm. Several new varieties in Australia and New Zealand also have a CIMMYT lineage. In all, about 10 million hectares of spring bread wheat in industrial countries carry CIMMYT germplasm in their pedigrees.

Finally, the most recent assessment of the impact of modern varieties, a study by the CGIAR, said that, conservatively estimated, the average yield increase from improved wheats in the developing world is 500 kilograms per hectare. Thus, those varieties have raised food production by about 25 million tons a year, or enough to provide the average annual grain consumption for 250 million people.

Hallmarks Revisited

These remarkable impacts on world agriculture have been attributed by many people to factors that are too numerous to summarize effectively here. It is perhaps more appropriate to revisit the hallmarks that have characterized CIMMYT as an institution, on the premise that what is "old" about the Center is as important as what is "new."

CIMMYT remains at heart a plant breeding institute, engaged in the many varied research activities required for the large-scale production of genetically diverse germplasm. Third World national program researchers can either use this material directly in their programs or manipulate it in such ways as to broaden the productive choices available to farmers. This joint effort is augmented by economics research, which serves to provide better information for decision making, both by CIMMYT scientists and by their national program colleagues. In addition, the Center assists national programs in various ways to develop improved agronomic procedures of practical benefit to researchers and, eventually, to farmers.

Dr. Sufi M. Ahmed (left) and a farmer reviewing the farmer's field in Bangladesh. Wheat yields in this heavily populated country have more than tripled and production is 30 times greater than during the early 1960s.

CIMMYT is commited to offering high-quality, practical training courses intended to enhance the research capabilities of national agricultural research programs.

In a complementary fashion CIMMYT remains committed to providing high-quality training intended to enhance the research capabilities and productivity of national agricultural research programs in developing countries. In this regard the Center will continue to focus attention on the development of procedural tools designed to heighten the impact of scientists in national programs.

The "thoroughgoing pragmatism" that has guided the work of CIMMYT staff and all who have played a role in facilitating the Center's impact is still a dominant trait. This includes a heavy commitment to field work, to hands-on science. The "generation of scientists that moved from the desk to the field" remains committed to this approach. As well they recognize that this same pragmatism may one day suggest a tempering of their own field activities in favor of providing guidance to the next generation of front-line researchers.

CIMMYT continues to draw on its strength as a nonpolitical entity, rising above global and regional geopolitical forces as it strives to contribute to the well-being of millions of poor farmers in developing countries. The Center's role as an "impartial clearinghouse" for the dissemination of genetic materials and scientific information to national program colleagues remains unchanged.

And finally, CIMMYT will continue to take the "long view" in addressing the research opportunities and priorities affecting maize, wheat, and triticale in the Third World. The Center's ability to do so, of course, rests squarely on sustained financial support by its donors, but the advantages inherent in this "long view" are evident to those who fund international agricultural research.

These hallmarks do more than describe the *modus operandi* of one of the world's premier agricultural research institutions; they provide guidance to an organization that is today as dynamic as it was 20 years ago. This dynamism springs from CIMMYT's strong sense of itself, a confidence born of its history and its global reputation; this in turn enables the Center to respond to new circumstances as they arise.

CIMMYT's mission has changed over the years as the needs of its clients have changed and as research has created new opportunities. But the hallmarks that characterize CIMMYT have not changed and, because of this secure identity, the Center is able to respond effectively to the changing needs of others. CIMMYT today reflects the same dynamism, the same integrity, and the same commitment to standards as at its inception, 20 years ago.

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During the past 20 years, CIMMYT has benefited from the counsel of a number of eminent individuals from around the world who have served on its Board of Trustees. Included in this distinguished group are two people who have served their countries as presidents: Galo Plaza of Ecuador and Virgilio Barco of Colombia. In addition a number of trustees have held cabinet rank in their countries: Lucio Reca, Argentina; Luis Fernando Cirne Lima, Brazil; C. Subramaniam, India; Abdoulaye Sawadogo, Ivory Coast; Manuel Bernardo Aguirre, Oscar Brauer Herrera, Horacio Garcia Aguilar, Francisco Merino Rabago, Juan Gil Preciado, Eduardo Pesqueira Olea, all from Mexico; Carlos P. Romulo, the Philippines. Listed below are the Trustees who have guided CIMMYT since its inception (grouped by country):

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