CIMMYT 1988 Annual Report

International Maize and Wheat Improvement Center

Delivering Diversity

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Annual Report

International Maize and Wheat Improvement Center

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Contents

The Center and the CGIAR 2

Report From Management 4

Point of View: Perspectives on Genetic Resources, ***Sir Otto Frankel*** 10

National Perspective: Conservation of Maize Genetic Resources in Mexico 18

A Review of Programs 20
- Maize Research 22
- Wheat Research 35
- Economics Research 48
- Support Services 55

Financial Statements 59

Publications 73

Principal Staff in 1988 78

The Center and the CGIAR

The International Maize and Wheat Improvement Center (CIMMYT) is a nonprofit, scientific research and training organization. From its headquarters in Mexico and other locations across the Third World, the Center operates a global program of maize, wheat, and triticale improvement; investigates related crop management and economics issues; and supports more than 100 national agricultural research systems responsible for these three crops in developing countries. CIMMYT is one of 13 such centers supported by the Consultative Group on International Agricultural Research (CGIAR or CG), which is cosponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CG's membership includes donor countries, international and regional organizations, and private foundations.

Thomas Luba

The Origins of CIMMYT

The achievements that eventually led to CIMMYT's establishment were those of a research team assembled in 1943 by the Rockefeller Foundation in Mexico's Office of Special Studies, which was set up by the agricultural ministry. In its research on wheat, one of the team's master strokes was the introduction of Norin 10 dwarfing genes into Mexican breeding nurseries, leading to the development of semidwarf, disease resistant wheats. Norin 10 was developed in the 1930s by Japanese scientists, who crossed American wheat germplasm with an Asian landrace carrying the dwarfing gene. In 1946 Norin 10 was brought to the USA and later supplied to plant breeder Norman Borlaug by a US colleague. By making more efficient use of inputs, the semidwarf varieties enabled Mexican farmers to increase yields dramatically. International distribution of these varieties was begun almost immediately and continued after the closing of the Office of Special Studies under a new cooperative arrangement between the Rockefeller Foundation and Mexican Ministry of Agriculture, which led to CIMMYT's founding. Wide adoption of semidwarf wheats throughout the Third World benefitted millions of farmers and consumers directly and brightened the prospects of many more by demonstrating the worth of investment in national and international agricultural research.

Improvement of maize production in developing countries has not been of the same magnitude as that of wheat, but improved maize germplasm has been widely adopted across the Third World. As with wheat the development of more productive maize varieties was achieved through the application of modern breeding techniques to plant genetic resources that had evolved over the centuries under the discriminating eye and purposeful selection of farmers and under extremely varied ecological conditions. Marshalling the genetic resources of maize, however, was a different sort of operation from the incorporation of Norin 10

Maize landraces in the Americas evolved over many centuries under the discriminating eye and purposeful selection of farmers.

dwarfing genes into Mexican wheats. What it entailed was the systematic collection of thousands of seed samples representing Mexico's maize races, followed by classification and close study of this tremendous catch of genetic diversity.

According to E.J. Wellhausen (who was then a staff member of the Office of Special Studies and later became CIMMYT's first director general), collection of the maize races was initially considered a "sideline effort," intended to identify production constraints and uncover promising germplasm complexes for the Mexican breeding program. But at the urging of botanist Paul Mangelsdorf in the mid-1940s, Wellhausen and other breeders adopted the view that they "were obligated to collect and preserve for future use all the existing native indigenous germplasm that the introduction of [their] own improved varieties would someday... replace and in some cases extinguish." The short term effect of collection and initial breeding with indigenous germplasm was that Mexico's annual maize production more than doubled between 1943 and 1958. A longer term consequence was the establishment of what later became CIMMYT's global maize improvement program, which has distributed modified versions of the Latin American germplasm all across the Third World.

Formation of the CGIAR

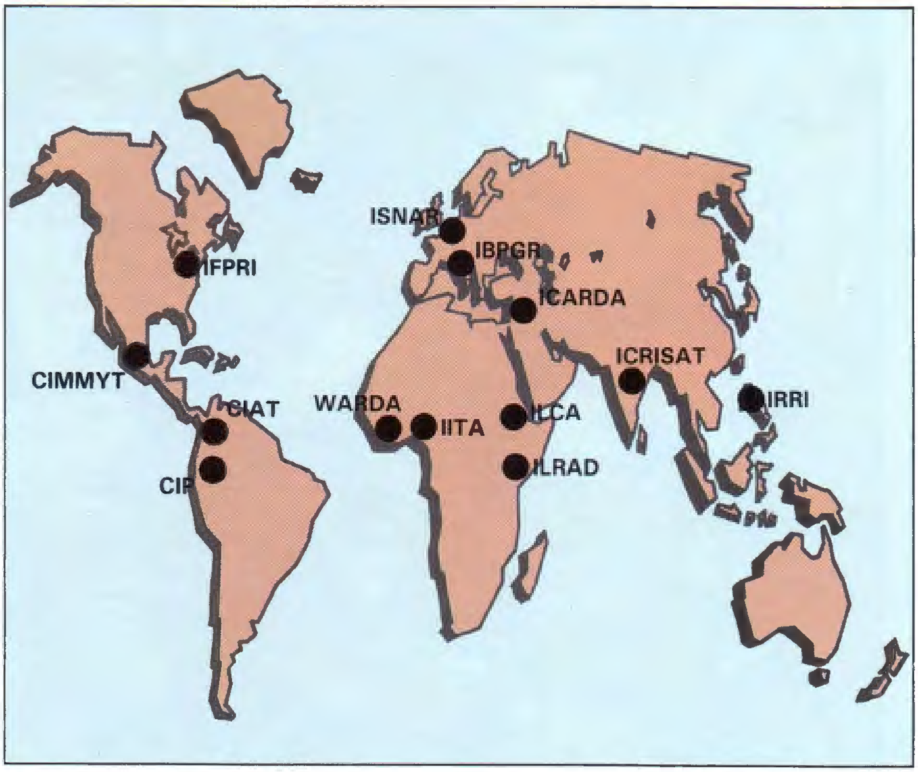
Early advances in the development and dissemination of improved cereals varieties encouraged the Rockefeller and Ford Foundations to develop several international agricultural research centers, including CIMMYT, during the 1960s. By the decade's end, the complexity and extent of the research in which the centers were engaged had made it apparent that new arrangements would have to be drawn up for establishing additional centers, guiding their management, and ensuring their long term financial support. That recognition prompted a series of international brainstorming sessions and deft negotiations that led to the formation in 1971 of the CGIAR.

Through an innovative approach based on commitment and consensus, the CG has managed to enlarge the financial base of the centers from an initial annual budget of US$9 million to US$212 million in 1988. CIMMYT's share of CG core funding is provided by the European Economic Commission, Ford Foundation, Inter-American Development Bank, OPEC Fund for International Development, UNDP, World Bank, and the international aid agencies of the countries listed at the right margin. In 1988 the Center also received non-CGIAR extra-core support from Belgium, the International Development Research Centre (IDRC), the Rockefeller Foundation, and various of its core donors (see Financial Statements for details on donor contributions).

In guiding the work of the centers, the CG tries to ensure that they confront challenges of international scope and enduring importance. These are identified and articulated by the CG's Technical Advisory Committee (TAC), which consists of prominent scientists from around the world. Each center reconciles the views and recommendations of TAC with its own capabilities and experience and then devises cost-effective approaches for accomplishing the tasks it considers to have highest priority. One urgent task to which the CG centers have made a large commitment is the conservation of plant genetic resources. Nine of the centers are major repositories or users of key collections, and in 1974 the CG created the International Board for Plant Genetic Resources (IBPGR), whose purpose is to provide a focal point for plant genetic resources work (see map). Cooperating with CG centers, other international and regional organizations, and 110 national programs, IBPGR has contributed to the collection of more than 166,000 crop samples and initiated other programs aimed at improving the ability of developing countries to store plant genetic resources.

Australia
Austria
Brazil
Canada
China
Denmark
Finland
France
Germany, West
India
Ireland
Italy
Japan
Mexico
The Netherlands
Norway
The Philippines
Spain
Switzerland
United Kingdom
USA

CIMMYT's Core Donor Countries



The 13 international agricultural research centers supported by the CGIAR.

Report From Management

CIMMYT's *1987 Annual Report* featured our involvement in strategic planning, an activity that continued well into 1988. By the middle of the year, the work was essentially completed. The draft plan was endorsed by the Board of Trustees, used by the External Programme and Management Review panels to help guide their deliberations in August of 1988, and subsequently considered by the CGIAR's Technical Advisory Committee (TAC). These reviews and applications resulted in many useful suggestions for the final version of the plan, now scheduled for publication later in 1989.

The phrase ''delivering diversity'' denotes the conveyance of genetic diversity as well as its rescue through collection, storage, and regeneration.

Among the ''elements of strategic planning'' discussed in the *1987 Annual Report* were issues identified by the CGIAR and TAC as being especially relevant to the work of the international centers. One such issue is plant genetic resources, whose conservation and utilization are of fundamental importance to production of the world's staple foods.

Our Theme for 1988

To evoke the theme of this *Annual Report*, our front cover features the phrase ''delivering diversity.'' In one sense this phrase denotes the conveyance of genetic diversity through germplasm dissemination. In a second sense it suggests the rescue of diversity, to which the CG system contributes through collection, storage, regeneration, and networking activities in various centers. The phrase thus captures both the conservation and utilization of genetic resources.

By plant genetic resources we mean landraces, obsolete cultivars, and wild relatives—the earlier definition of the term—as well as modern materials emerging from current breeding efforts—a recent addition to the concept. As for the first part of our definition, we conserve and characterize, ensuring widespread access to the materials and to information describing them. Toward the future, especially if the promise of molecular biology and new science is realized, these genetic resources will become ever more valuable to the global community.

As for the second aspect of our definition, the continually emerging products of plant breeding, we focus on the current needs of developing countries, again emphasizing widespread access. These germplasm products result from the combined efforts of CIMMYT and colleagues around the world, together comprising an international network integrating the energies, expertise, and experience of hundreds. Within this network each generation of improved products rests on preceding generations and to a growing extent on collections of older materials—especially for specialized materials with tolerance to particular stresses. In this *Annual Report* we reflect the two dimensions of our work in genetic resources—conservation and utilization—and the growing interaction between them.

From Controversy to Consensus

The possession and transfer of germplasm have been tinged with controversy in recent years. In what has amounted to a discussion of international equity in germplasm exchange, held under the auspices of FAO, developing and developed countries have emphasized quite different concerns. The former have expressed frustration over their inability to exploit sufficiently the plant genetic resources that evolved largely in what is now the developing world. The latter have emphasized the importance of unhindered exchange of plant materials, which has unquestionably benefitted plant breeding and seed production organizations. Such exchange, many agree, has also contributed greatly to agricultural development in the Third World.

The controversy surrounding plant genetic resources has proved divisive, but it has also had the salutary effect of focusing worldwide attention on issues related to the conservation of plant germplasm. And as the discussion of these issues has progressed, heated debate has given way to a process of consensus building. The Keystone International Dialogue on Plant Genetic Resources, whose first session was held in August 1988, contributed significantly to the search for a common ground. Various publications (among them *Gene Banks and the World's Food* and *Seeds and Sovereignty*) have also helped clarify divergent views as well as compile accurate information upon which a consensus can be based.

In this same spirit of consensus building, we describe in this *Annual Report* what CIMMYT considers to be its responsibilities in the conservation and utilization of plant genetic resources. Sir Otto Frankel kindly accepted our invitation to prepare the Point of View essay. Few, if any, scientists can bring to the discussion as much experience and insight as Sir Otto. In the course of his career as geneticist and plant breeder, he has written or edited three seminal books and many scientific articles on the subject. He also played a vital role in mobilizing international support for the conservation of plant genetic resources, a movement which eventually led to the establishment of the International Board for Plant Genetic Resources (IBPGR).

Sir Otto stated his position on the global germplasm controversy in the recently published book *Seeds and Sovereignty*. He discusses it briefly here in the context of a wide range of other issues, such as national germplasm collections, which he refers to as the ''backbone'' of the global ''genetic resources system.'' Evidence of strong national commitment to conserving and studying these resources is provided from Mexico in a new section entitled National Perspective. In other sections of this *Report*, we follow Sir Otto's lead, concentrating on aspects of germplasm conservation and utilization that are included in CIMMYT's work. In the future, because we believe that germplasm exchange favors the improvement of varieties available to farmers, we will follow carefully the Keystone Dialogue and other initiatives aimed at achieving a broad consensus.

CIMMYT's Germplasm Strategy

Over the years CIMMYT has formulated an effective three-part germplasm strategy for meeting the demands of agricultural development. Part one of our strategy involves harnessing what some refer to as ''useful'' genetic diversity through multidisciplinary research programs involving plant breeders, crop protection specialists, physiologists, and others. The maize and wheat germplasm products derived from this research make efficient use of available nutrients and moisture while maintaining yield stability in the face of various biotic and abiotic stresses. They also possess sufficient genetic diversity to permit steady improvement in yield as well as resistance or tolerance to many insects, diseases, and physical stresses. These germplasm products are freely available to maize and wheat programs in developing countries.

In working only with a certain segment of the entire maize or wheat genetic base, CIMMYT researchers are resorting to what genetic resources expert Garrison Wilkes (University of Massachusetts, USA) refers to as a ''plant breeding expediency'' for developing high yielding genotypes quickly and efficiently. As he also points out, however, ''the price of this expediency is constant vigilance and backup of the gene banking system.'' This is the second part of our strategy: banking plant genetic resources, even those whose value may be revealed only in the future (see page 7). This

Conservation is fundamental to the Center's germplasm strategy. Some species, such as the teosinte (Zea diploperennis) examined here by CIMMYT trustee Donald Duvick (left) and Suketoshi Taba, head of the maize germplasm bank, require in situ conservation. Mexico has created a special biosphere reserve to ensure preservation of this and other plant and animal species (see page 19).

Thomas Luba

work, too, features strong collaboration with national programs—in sharing materials and information, in developing and reinforcing networks of gene banks, and in training.

Part three of our strategy addresses a prominent concern in the current germplasm controversy, namely the capacity of developing countries to wield the powerful tool of genetic diversity in improving the varieties available to farmers. While much has been achieved toward augmenting that capacity, significant differences remain among national programs. CIMMYT's direct support to them attempts to concentrate on the areas that most limit their productivity. In the future we will continue to place particular emphasis on training in germplasm improvement for staff of the less advanced national programs, and we will seek new ways for the more advanced programs to contribute to international networks.

This, then, is the essence of the CIMMYT strategy: harnessing useful genetic diversity through aggressive plant breeding programs; banking even that which may not appear useful now so as to ensure its availability in the future; and training national program scientists to conserve and make better use of genetic diversity in their own research programs. Common to each of the three dimensions is easy access—to materials, to information, and to experience.

A primary objective of CIMMYT's germplasm strategy is to develop and distribute improved materials. Each year the Center ships thousands of experimental lines and varieties to hundreds of maize and wheat researchers around the world. They in turn select and further improve those expermental materials for eventual release to farmers.

CIMMYT files

Program Activities and Highlights

A number of specific circumstances in 1988 gave the theme of plant genetic resources high visibility at CIMMYT and made it prominent in our thinking about the Center's research. In March we hosted the Global Maize Germplasm Workshop. Along with IBPGR, we are working to establish a global network for maize genetic resources. To facilitate these efforts, IBPGR transferred its Latin America regional coordinator to CIMMYT headquarters in mid-1988. We also made important advances in our cooperative relations with two other centers: the Maize Program reached a new agreement with the International Institute of Tropical Agriculture (IITA) on the division of responsibilities for maize research in sub-Saharan Africa, and the Wheat Program signed a memorandum of understanding with the International Center for Agricultural Research in the Dry Areas (ICARDA) that covers a wide range of tasks both in research and in germplasm conservation relating to bread and durum wheats, barley, and triticale.

Two events, the start of construction on a biotechnology laboratory and the Second International Symposium on Genetic Manipulation of Crops (held at CIMMYT headquarters in August), focused our attention on new and potentially more efficient methods for employing landraces and wild relatives to bolster the elite germplasm in our breeding nurseries. The benefits accruing to Third World countries from products of these nurseries were recognized by the presentation of the King Baudouin International Agricultural Research Award to CIMMYT for its work on the Veery wheats.

Several important developments in 1988 were prompted by recommendations from the CGIAR External Programme and Management Review panels, which were with us in August. Among these were changes in the organization of the Maize and Wheat Programs, which were planned late in 1988 and implemented early in 1989. Among new ventures initiated in the Economics Program were research on the economics of "maintenance" breeding and studies designed to supply information for setting priorities in germplasm development.

One recommendation that underscored the importance of the theme of this *Annual Report* was a request that we publish a statement of

Continued on page 8

CIMMYT's Responsibilities in the Conservation of Plant Genetic Resources

Maize

- The CIMMYT maize germplasm bank maintains base and active collections of landraces, the former for long term storage and the latter (kept in medium term storage) for seed distribution. Each incorporates the world's largest representation of landraces, with emphasis on those originating in the Western Hemisphere.

- CIMMYT's conservation mandate also includes teosinte and *Tripsacum*. Seed of these wild relatives of maize is kept in base and active collections. An active collection of teosinte is maintained by collecting seed during in situ monitoring tours of the remaining populations in Mexico and Guatemala. Collection is done in cooperation with the national programs. An active collection of *Tripsacum*, representing the variation in this genus, is maintained at one of the Center's experiment stations, and seed is available from these plantings.

- In addition to conserving landraces, the maize germplasm bank occasionally augments its collections with seed of elite populations developed by breeding programs at CIMMYT or other institutions. Storage facilities will be expanded to accommodate new accessions.

- Duplicates of base collections are placed at other institutions, such as the National Seed Storage Laboratory (NSSL) in the USA. These serve as a backup for the base collections and are not for distribution or use.

Wheat

- The CIMMYT wheat germplasm bank currently maintains bread wheats, durum wheats, triticales, barley, primitive wheats, and wheat wild relatives in medium term storage. The material is divided into two collections: one consists of international screening and yield nurseries, spring and winter crossing blocks, primary triticales, progenitors, and interspecific and intergeneric crosses, and the other contains germplasm entries with known potential for improvement as well as landraces and wild species.

- CIMMYT has taken on new wheat conservation responsibilities under a recent agreement with ICARDA in consultation with IBPGR. ICARDA will be responsible for maintaining a base collection for durum wheat and the wild relatives of wheat; CIMMYT will maintain a base collection for bread wheat and triticale. Each center's base collections (in long term storage) will be duplicated in the other center for safety. Seed collection will be done in cooperation with national programs. Active collections in medium term storage will be formed for evaluation and seed distribution.

- As part of its base collection responsibilities, CIMMYT will actively seek all commercial varieties and obsolete cultivars of bread wheat. It will also maintain a representative collection of landraces.

- To fulfill its new mandate, CIMMYT will expand its facilities to include a long term seed storage facility for base collections of bread wheat and triticale.

Distribution of Bank Holdings

- Requests for seed and information from the maize and wheat germplasm banks are filled from active collections to any bona fide researcher free upon request. First priority in seed distribution is given to national programs in developing countries. Other agencies, whether public or private, receive seed according to availability on a first-come, first-served basis. Private companies are expected to pay shipping costs.

- CIMMYT abides by national policies limiting or directing seed distribution to organizations within the country, assuming that a written statement of these policies is received from the appropriate authorities.

This statement of CIMMYT's responsibilities in no way implies their appropriateness for other institutions, public or private. For additional information on the operational aspects of our germplasm banks, contact Suketoshi Taba (Maize Program) or Bent Skovmand (Wheat Program) at CIMMYT headquarters, Mexico.

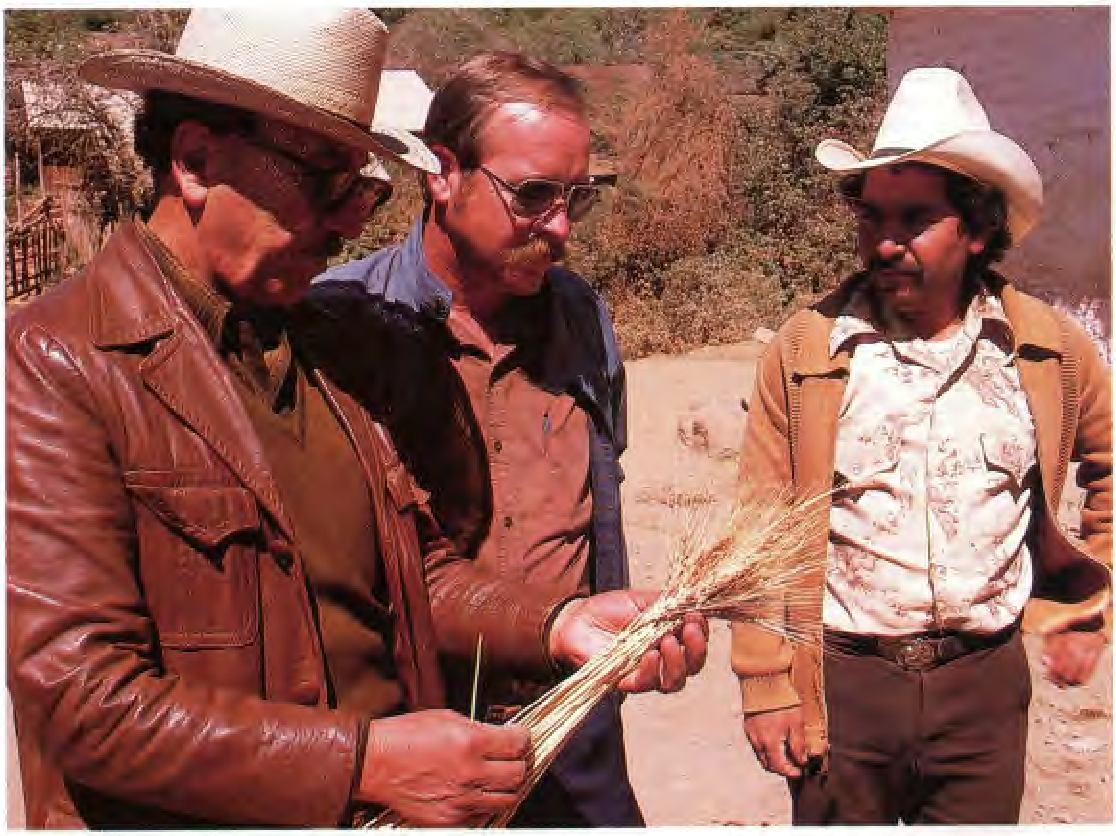
CIMMYT's policy on plant genetic resources. Our response is in preparation, and some of its salient features are explained on page 7. Several achievements in the Center's genetic resources work are mentioned in the accompanying list of research highlights and described in A Review of CIMMYT Programs.

Changes in Senior Management

A witness to much of the improvement in national program research capacity mentioned earlier and a contributor to it in his own right, first through his research as a maize breeder and later in a succession of management positions in CIMMYT, has been Dr. Robert D. Osler. The Oslers first arrived in Mexico in 1954, intending to stay a year or two. They left in 1960 but returned in 1966 when Dr. Osler was named Head of CIMMYT's Maize Improvement Program. Twenty-two years later, in early 1989, Dr. Osler reached mandatory retirement. On behalf of all Center staff, our heartfelt thanks to the Oslers and our best wishes for the future.

Dr. P. Roger Rowe, who came to us from the International Laboratory for Research on Animal Diseases (ILRAD), Nairobi, Kenya, where he served as Director of Administration, took up the post of Deputy Director General for Administration and Finance in early 1989. Dr. Rowe earned a PhD in plant genetics and breeding in 1963 from the University of Wisconsin. He spent the first 10 years of his career as a US Department of Agriculture research geneticist, before moving into the international arena as Head of the Breeding and Genetics Department at the International Potato Center (CIP) in Lima, Peru. In January 1978 he was appointed Deputy Director General of CIP, a position he held until moving to ILRAD in October 1981. Dr. Rowe has published widely in his field. He is, as well, an astute, experienced administrator. The changing climate of research management and administration in an ever more complex environment will require the full use of his skills and experience.

Dr. Robert B. Tripp was appointed to the position of Assistant Director of the CIMMYT Economics Program. Dr. Tripp, an anthropologist who came to CIMMYT in 1978 as a Rockefeller Postdoctoral Fellow, brings considerable experience in research and training to his new administrative responsibilities.



Thomas Luba

The CIMMYT Wheat Program is now placing particular emphasis on collecting obsolete varieties, such as this sample of Supremo 211, the first improved wheat variety released by the Government of Mexico-Rockefeller Foundation cooperative program set up in the 1940s. Collecting is done in cooperation with government representatives like Anastasio Morales (left), shown here with the head of our wheat germplasm bank, Bent Skovmand (center), and Ignacio Rico, the farmer who provided the sample.

Research Highlights From 1988

- A project was completed for making passport information about CIMMYT's maize germplasm bank accessions available on CD-ROM (compact disc, read-only memory). This technology will provide developing country researchers with a convenient means of searching bank records for useful genetic resources (page 25).
- The Maize Program took part in four projects involving RFLP (restriction fragment length polymorphism) related technology. One is an effort by a network of public and private organizations in Europe to employ RFLPs for examining the molecular diversity of elite maize lines and determining the usefulness of these molecular probes in identifying loci for quantitative traits (page 29).
- In the Wheat Program, a computer based pedigree management system that greatly facilitates various information functions was put into operation. Through hierachical cluster analysis based on pedigrees of germplasm bank accessions, one can quickly determine the original landraces and old varieties that form the base of modern wheat varieties (pages 36-37).
- Screening of wheat germplasm confirmed the existence of genetic variability for resistance to Karnal bunt, a quarantinable disease that seriously affects germplasm movement. As part of its effort to develop Karnal bunt resistant germplasm, CIMMYT formalized a breeding partnership with Punjab Agricultural University (page 42).
- In the Economics Program, an analysis of variability in wheat yields from 1951 to 1986 for 57 countries showed that technological variables such as adoption of high yielding varieties had no effect on differences in yield variability across countries. Moreover, study results indicated that yield variability has consistently declined since 1975, especially in larger developing countries that experienced rapid technological change in wheat production (page 54).

Financial Highlights

The most significant factor affecting CIMMYT's financial performance continues to be the combined effect of inflation and exchange rates in Mexico. During 1988 the value of the peso against the dollar was held virtually constant while local inflation exceeded 50%. This resulted in a substantial increase in our local costs, and we found it necessary to make a large claim on the CGIAR stabilization fund. This claim accounted for a major portion of a 10% increase, some US$3.3 million, in core and extra-core revenues in 1988.

The externally audited Financial Statements presented later in this *Report* show the Center's financial condition at year end and the effects of financial flows during the year. Total assets increased by 9% over their 1987 level, a change reflected in cash and short term deposits and in property, plant, and equipment. Construction of a biotechnology laboratory was initiated during the year, and advance payments by donors for construction resulted in higher than usual year-end cash balances. These larger cash balances combined with rising interest rates to produce higher interest income on short term investments.

Conclusion

The conservation and utilization of plant genetic resources are of fundamental importance to the pursuit of CIMMYT's mission, that of opening options to the poor. The issues are complex, the opportunities abundant. Our own comments and those of our guest essayist are offered in the spirit of consensus building. We hope they will be viewed by donors, sister centers, and colleagues in national programs as both relevant and constructive contributions to the international discussion of the theme.

Donald L Winkelmann

Donald L. Winkelmann
Director General

April 1989

Point of View
Perspectives on Genetic Resources

Sir Otto Frankel, Honorary Research Fellow,
Division of Plant Industry, Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia

Sir Otto Frankel, CSIRO, Australia.

Plant genetic resources have become the subject of political and economic controversy, remote from the conservation issues that motivated the 'genetic resources' movement.

Today plant genetic resources stand in the forefront of public interest, especially in the USA. Globally they have become the subject of political and economic controversy, remote from the issues of conservation and use which have motivated the 'genetic resources movement'. But the beginning a hundred years ago was modest enough. Germplasm collections started as plant breeders' working collections consisting of successful cultivars, breeding lines, and introductions obtained from anywhere.

A new dimension was added in the 1920s by Vavilov's discoveries of geographical centres of genetic diversity; and by the large and widely representative germplasm collections which Vavilov established and subjected to intensive study. Vavilov's discoveries failed to stimulate widespread activity elsewhere until it was realized that the introduction of modern cultivars as part of the rapid agricultural development since the second world war was rapidly displacing the multitude of traditional landraces that Vavilov had discovered.

Widespread scientific concern and, incidentally, the term 'genetic resources' started with a Technical Conference at the Food and Agriculture Organization (FAO) in Rome in 1967 which brought together scientists from many countries. It resulted in the formulation of scientific principles, methodologies and strategies of exploration, conservation, evaluation, and documentation. The books that resulted from this and a follow-up conference in 1973 (Frankel and Bennett 1970; Frankel and Hawkes 1975) laid the foundation for developments in the next decade. The establishment of the International Board for Plant Genetic Resources (IBPGR) by the CGIAR's Technical Advisory Committee (TAC) and the assumption by the international agricultural research centers (IARCs) of responsibility for genetic resources of their mandated crops, and the widespread participation of national institutions provided an organizational framework which has proved reasonably effective. IBPGR has a wide range of solid achievements: encouragement and support for collecting on an unprecedented scale, establishment of a world-wide system of seed conservation, promotion of research, a veritable library of useful publications, a wide range of technical consultation and cooperation, and many more.

In recent years, as already mentioned, the performance of the genetic resources system has been subjected to criticism at the administrative-political level. Particular issues raised are the participation of national and local organizations, and the ownership of and access to genetic resources in both developing and developed countries. In an attempt to reconcile the different viewpoints which have come to the fore in this controversy (Kloppenburg 1988), the Keystone Center convened a Dialogue among representatives of the genetic resources community and commentators and critics in social and political spheres. The report from this meeting is drawn on in the discussion which follows (Keystone Center 1988). This

The views expressed here are those of the author and do not necessarily reflect the views of the CGIAR Secretariat or CIMMYT.

paper examines these and other issues of concern in the management of the world's genetic resources in which the international centres play an important part.

The Status of Germplasm Collections

Germplasm collections occupy the prime area of genetic resources activities. What is not contained in a collection or is not available in situ, is of no functional significance for breeding or other research or application. What they contain, or lack, will also influence the direction of further collecting.

There can be no doubt that germplasm collections have substantially grown in number, in the size of holdings, and in competence of management. Emphasis was given to landraces, in response to the threat to their continuing existence in many developing countries; in developed ones they had largely disappeared, though some remained in older collections. A key role was assumed by the IARCs for their mandated crops, joined by national institutions both old and newly created, many of them in developing countries. IBPGR established a 'global network of base collections'; active collections have only recently attracted its attention (see below).

Landraces Versus Wild Relatives

Germplasm collections of all major and minor crops consist prevailingly of landraces and obsolete cultivars. Now that for many crops representative collections of landraces are more or less accomplished and that the interest in related wild species and concern for their preservation have grown, the time has come for reconsidering collecting priorities. This is supported by the increasing use of wild species, the spread of prebreeding programmes, and the likelihood of widespread application of molecular technology. However, common sense and practical consideration should prevail in keeping collections of wild relatives within manageable and useable bounds. The principles of setting up core collections (see below) might well be applied in forming collections of wild relatives.

'Prebreeding' or 'germplasm enhancement'—the incorporation of 'alien' genes in more or less adapted cultivars—will play an important role in making wild species acceptable as breeding materials. CIMMYT and other IARCs now practise prebreeding—mainly of landraces—in the breeding populations distributed to plant breeders in many countries.

The Global System: Base and Active Collections

'Base' and 'active' collections were defined by the FAO Panel of Experts on Plant Exploration and Introduction as interacting components of the proposed genetic resources system. Base collections were to be responsible for preserving germplasm, active collections for making it available to plant breeders and other users (FAO 1970, 1973). Base collections were to be maintained in low temperature storages, with subsidiary facilities for drying, seed testing, etc. Their function was to serve as long-term safe deposits and as backstops against loss or exhaustion of stocks at active collections; but they were not to supply seeds to users. Active collections were charged with the multiplication of stocks, regeneration for base collections, distribution to users, and with characterization, preliminary evaluation and the record system. To maintain stocks for reproduction, distribution and research, they required medium-term storage facilities.

Tiff Harris

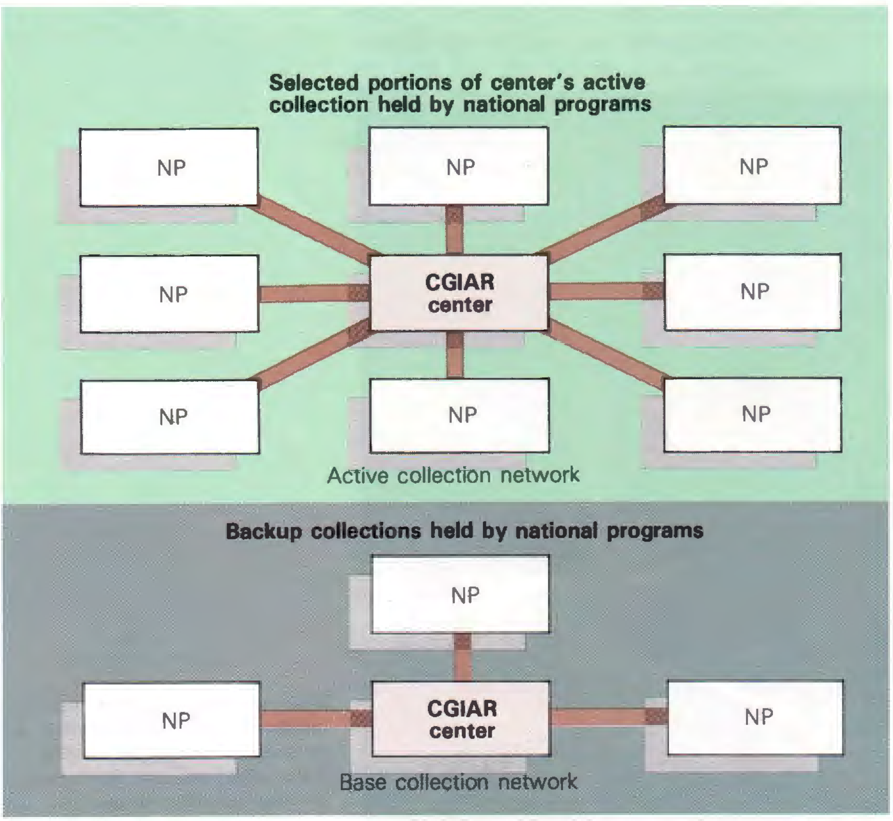
Wild relatives of wheat, such as* Elymus giganteus*, provide a reservoir of potentially useful traits. They are not, however, an easy solution to the problems that plague their domestic relatives. Much work is required to incorporate their beneficial traits into improved cultivars.

These definitions have been widely adopted in principle. While base collections have vital long-term functions, active ones perform essential services in the short term. There could be—and of course there are—unattached active collections (or centres), but a base collection can't exist—or is frustrated—without one or more collaborating active collections. On a global scale there need not be a large number of base collections as long as they are geographically distributed, for safety and accessibility. Requirements for storage of different crops are fairly standard, and facilities are very expensive to build and to maintain. Active collections, by way of contrast, should be widely distributed and in close contact with users. One (or more, depending on the ecological spread of a species) would be designated as principal active collection interacting with the respective base collection and the information network. Base and active collections can be, and often are, in the same institution, as in some IARCs; or in separate ones, as in the US Department of Agriculture.

These concepts are still 'on the books' as is evident from the frequent use of the terms. IBPGR established a crop-based system of base collections, with the cooperation of national centres and institutes holding significant global or regional collections, and of a number of IARCs. Presumably the reason was that neither international nor national funds were available to develop and maintain a small number of multicrop base collections which had been envisaged. This is despite the fact mentioned before that a much smaller number of highly efficient storage laboratories could have safeguarded the world's germplasm far more effectively than a plethora of smaller ones some of which, as is now evident, are poorly conducted. Even more importantly, had they not been burdened with the responsibilities of base collections, many of the crop-based collections in the network could have emphasized their role as active collections and developed the services on which utilization by plant breeders depends.

Whatever the reason it seems that the lack of emphasis on active collections was responsible for some of the more significant shortcomings of the system noted by the director of IBPGR, Dr. J.T. Williams (Williams 1989). At any rate, IBPGR has begun to redress the imbalance between base and active collections. A brief paragraph in the last annual report (IBPGR 1988) notes that 'now that the global network of base collections has been largely established it is logical to turn efforts towards an adequate network of active collections'. 'Ultimately' the two networks would be integrated. Put in commercial terms, what is needed is a 'consolidation' of base collections, and a 'take-over' of the network by active ones. But this will take time—and diplomacy.

One can envisage a network of crop-based active collections located where the whole of a crop species, or of a section of a species, can be successfully grown. One or more such centres would be designated as principal centres for a species. They would be linked with the base collection responsible for long-term storage of their crop. The responsibilities of active centres would be those outlined early in this section. They should also include establishing links with other active collections concerned with their crop, and initiating collaborative characterization and databases. The role of designated principal active collections would be filled by national institutes, as is now the case with base collections. IARCs participating in the network already discharge the functions of principal active collections for mandated crops.



CIMMYT and other CGIAR centers are moving toward a network approach in handling base and active germplasm collections. The former are designed to guarantee the survival of the genetic diversity represented in the collection. Active collections are intended to promote utilization of bank holdings through germplasm characterization, evaluation, and distribution and the exchange of information.

National Collections

National collections are, or should be, the backbone of the system. They should have links with other active collections concerned with the crop (or crops) with which they are concerned. They should give prominence to the characterization of their accessions, cooperate with scientific specialists and plant breeders in evaluation (see the next section), and maintain a database. While participation in the international system is of mutual benefit, national centres should regard the support for plant breeders in their country or region as a foremost responsibility. This may include the introduction of materials required by plant breeders in their programmes and the maintenance of indigenous materials at a level of representation in excess of that appropriate for a world collection.

This outline of the national collections is in general agreement with that given in the Keystone Report (Keystone Center 1988), except for one important issue. The Report, in accord with the spirit of the FAO's International Undertaking (see below), stipulates that 'every nation should have a well-defined national plant genetic resources policy and an effective and adequately supported instrument...'. This would seem of doubtful value for nations without an active plant breeding programme. It would seem rather purposeless to devote scarce technical personnel to assembling genetic resources for which there is no current application. The Keystone Report recognized this difficulty and proposed that 'support for genetic resources conservation should be supplemented by support for plant breeding activities'. But to develop a strong plant breeding base takes time, especially if technical staff are to be shared with genetic resources activities. In such circumstances it would seem sensible to give priority to developing the plant breeding base. Threatened resources requiring urgent collecting could be salvaged with the help of neighbours or of international agencies. Genetic resources activities should be a national requirement, not a status symbol.

Is there a real need for every nation to have a programme of its own? Australia has six States, the smaller ones of the size of an average European country, but one genetic resources programme. The European countries have joined in one cooperative programme. A single well-staffed and funded institute serving neighbouring countries might be a good deal more effective than several separate second-rate ones. Funds no doubt are helpful; but what is most essential and scarce and can't be readily bought is the quality of the staff.

Evaluation

Characterization and evaluation result in the information required by plant breeders and other users to select accessions for use in their work. Characterization is a record of the plant's morphology which, together with 'passport data' on origin, goes a long way towards identifying an accession. Evaluation gives account of the plant throughout its life cycle, including its interactions with other organisms, and its performance. The environment in which the tests take place is of crucial importance; it is doubtful whether a breeder would be helped by comparative climate data as suggested by IBPGR (Williams 1989). Ideally, evaluation for characters strongly affected by the environment should be carried out in the plant breeder's own environment, as is, of course, the case in IARCs. As a rule, however, breeder and curator are separated. Breeders insist that curators are responsible for the evaluation which is needed to make collections accessible for users.

In fact, evaluation is, and needs to be, a cooperative, multidisciplinary exercise involving specialists in various fields—cytogenetics, physiology, pathology, entomology, biochemistry, and agronomy—co-ordinated by the curator who is also responsible for the resulting database. All too often, the essential link with application is missing—the plant breeders. Their role should be to point the direction, the purpose of the exercise, and to ascertain the validity of the information in their programmes and in their environments.

That such procedures are not only feasible but practicable and successful is demonstrated by the IARCs, to the great advantage of breeders in developing countries, especially where outreach programmes bring the results into their own environments. However, they appear too costly and elaborate to some private breeders who regard evaluation as a responsibility of public institutions. Yet the lack of breeder participation is responsible for the only moderate extent to which collections are used in breeding practice. It would seem reasonable to expect larger breeding concerns to make their contribution to R and D, as is the case in other industries. For a fuller discussion see Frankel (1989).

Evaluation of genetic resources should involve specialists in various fields, including plant breeders, who are the essential link with application.

Widespread public awareness and support are essential if the international genetic resources movement is to 'take off'. It can't develop in a social vacuum.

Core Collections

The larger size of existing collections of crop species has already been mentioned. Even the largest ones will have gaps that justify attention; but for most of the major and many minor crops, alleles that are not extremely rare are likely to be represented in accessions now in collections. (A major gap, as pointed out previously, is an adequate representation of wild relatives.)

While this is a comforting thought, it has been suggested that it is these very large numbers that inhibit rather than facilitate the close study needed for effective utilization of a collection. The problem is how to reduce numbers while holding the loss of genetic information within tolerable limits. We have proposed a 'core collection' consisting of some 10% of accessions in a collection. It should be as representative as can be contrived on the basis of available information—passport data used in the IBPGR system, biogeographical information, characterization data, and if possible genetic markers. The core collection would be available for detailed evaluation and research; the rest of the collection would be retained as a reserve to follow-up leads, and to search for rare alleles (Frankel and Brown 1984).

The idea has been further elaborated (Brown 1989). It has aroused a good deal of interest, but as far as is known only limited practical application; a core collection of okra was established by Hamon and von Sloten (1989). It is to be hoped that experimental core collections will be set up in collections, or sections of collections, for which there are extensive passport data. Once credible core collections emerge these could be distributed to any country or institution concerned with research or plant breeding, giving direct access to genetic resources that now are geographically, and probably ecologically, remote.

Minor and Subsistence Crops: Local Action and Germplasm Conservation

In countries, and in crops, where modern plant breeding or introductions from elsewhere have not replaced the traditional landraces, the genetic resources for plant improvement are landrace populations and their components. This is relevant for the composition of national (versus global) germplasm collections (see above). It is also relevant for local communities which may be directly involved. 'Local action' has been discussed as an important component of genetic conservation in the writings of P.R. Mooney, and is rationalized in the Keystone Report (Keystone Center 1988).

It is necessary to define the material that is involved. Let us first consider staple crops like the cereals. The Report includes 'free landraces' and locally adapted ecotypes, with emphasis on disease resistance; such material 'may well be able to compete with modern high-yielding varieties'. This may indeed be the case if the introductions are not locally adapted, and/or there is an inadequate nutrient supply; but yields are likely to be low. Distinctive landraces of major food crops should certainly be included in a national collection, but the subtle differences of local variants do not generally justify preservation measures since they could not be identified in a plant breeding programme.

However, local variants, produced by 'local action' for local consumption can have a significant place. Where local, and indeed family selection is likely to make a contribution is in satisfying taste preferences. Our taste buds are a great deal more sensitive than our balances, and taste choices in staple foods, especially of rural populations, have a considerable social value. Thirty years ago I was told by the Botanical Survey of India in Poona that they were collecting family rices selected on taste preferences. But these are transitory treasures. One wonders whether they survived the advent of the high-yielding semidwarfs. Indeed, in spite of food preferences for indigenous cultivars, high-yielding wheats and rices have all but replaced them.

The position is different with respect to the 'life-sustaining' species of tropical horticulture which are grown for home consumption or the local market. Here yield is of secondary importance to flavour, appearance, keeping quality, time of maturity, and many more. They are readily observed and some are strongly heritable. Such selections reflect the individuality of families, possibly going back for generations. They provide interest and satisfaction. Altogether they are of social value. Such endeavours expose genetic differences which are worth preserving in national gene banks for direct use and for plant breeding if and when it eventuates. But the elaborate arrangements proposed in the Keystone Report, such as seed storage, training courses, seminars and workshops, etc. seem somewhat exaggerated. It seems doubtful whether people who have the will and the competence to conduct an effective selection programme would enjoy or profit from formalization, or that the product would be greatly enhanced; or that presumably scarce technical personnel would be best employed in guiding such activities rather than in formal plant breeding.

Public Awareness, Controversy, and Support

Widespread public awareness and support are essential if an international enterprise like the genetic resources movement is to 'take off'. It can't develop in a social vacuum. As related in the introduction, scientific information had been generated in the 1960s and early 1970s. FAO was in support. But governments and the interested public had scarcely been touched. The United Nations Conference on the Human Environment, Stockholm 1972, with its strongly worded resolutions on genetic conservation, gave an entry to the political arena and generated much publicity. TAC, alerted by M.S. Swaminathan, was able to convince the CGIAR to set up IBPGR. It fell to the new official body to carry the message to governments, the scientific community, and the public.

But none of these efforts had anything like the effect of marshalling worldwide interest and awareness as did a small book, *Seeds of the Earth*, by P.R. Mooney (1979). Mooney claimed that the 'gene-poor' developed countries had robbed the 'gene-rich' developing ones of their genetic heritage, and were now precluding the latter from access to the products by introducing restrictive Plant Breeders' Rights legislation. It is scarcely relevant that much of the evidence was flawed (Frankel 1981) and many of the arguments and claims invalid or impracticable (W.L. Brown 1988). They were sufficiently convincing to Third World politicians to arouse a bitter controversy at FAO. Economists and lawyers joined in (Kloppenburg and Kleinman 1987; Kloppenburg 1988). In 1983 FAO established an International Undertaking to safeguard the universal access to all kinds of genetic resources and set up a Commission to put it into effect. Most developed countries failed to join or entered reservations. For a concise account of these events see Witt (1985).

With the declared intent to achieve consensus recommendations on the conservation and utilization of plant genetic resources as a blueprint for the future, the Keystone Foundation brought together protagonists in the controversy and representatives of genetic resources institutions. If the purpose of the Dialogue was to bring the contending parties together and to bring the 'seed war' to an end,

Thomas Luba

Local variants of 'life-sustaining' species of tropical horticulture, such as the squash shown here, can have a significant place in genetic resources collections. In rural areas cultivar selection is often based more on taste criteria than yield, and centuries of selection by farm families have produced local variants with considerable social value.

the Statement on Plant Genetic Resources (Keystone International Dialogue 1988) suggests that it was successful. First, the concept of compensation is not mentioned and appears to be a dead issue. Second, the concept of free exchange is strongly upheld; breeders' lines and genetic stocks—a major stumbling block in the Undertaking—are not mentioned. Third, an international fund is proposed for the support not only of genetic resources work, but of plant breeding in developing countries, to my mind a precondition of genetic resources activities (see the section on National Collections above).

These are constructive contributions. But as a blueprint for future scientific activities the full report (Keystone Center 1988) has little to offer that has not been said before. The lengthy statement on organizational aspects reads more like a catalogue of possible actions than a programme of necessary and urgent ones. There is strong emphasis on local level action which has been discussed in a previous section. The Keystone Report makes no distinction between staple crops where the emphasis must be on productivity, and horticultural ones where criteria of social rather than economic value can be predominant. Regional organisation, which is strongly featured, has not proved a success where it has been attempted. But in spite of doctrinaire rather than practical precepts of this kind, the Report suggests an end to a time and energy wasting controversy in which the scientists who do the work took no part.

Is there a positive outcome? Like in all wars, very little that is constructive: possibly an increased interest in some developing countries; hopefully, increased funding, including some for plant breeding; possibly, base collections to be vested in FAO, as an insurance against a collection being withdrawn from international access. Certainly, there is a greatly increased public awareness in developed countries, especially in the USA. This is a curious phenomenon after years of relative indifference. Welcome as it must be to all involved in genetic resources work, one wonders at the cause for the almost religious fervour. As emphasized before, genetic resources are now safer, and far more available than ever before. Large collections of landraces are in store, at a time when their continuing usefulness as breeding materials—compared with wild relatives—is being questioned, at least for the major crops. Is it time for a rational reassessment of prospective needs and uses to set genetic resources on an even keel?

The Future

In an excellent book on gene banks, Plucknett et al. (1987) present a perceptive and realistic view of future needs and likely developments. I offer a few rather speculative further comments.

(i) The present trend is for 'macro-collections', aiming at '90% of the remaining variation' (Plucknett et al. 1987). There is an opposite trend towards small, representative 'micro-collections', ushered in as core collections (Frankel and Brown 1984). The future may well find ways to reduce useful diversity to micro scales. DNA libraries contain diversity on a much smaller scale than do germplasm collections.

Kathryn Elsesser

Froylan Rincon (IBPGR) participates in CIMMYT's annual monitoring tour for determining the status of populations of maize wild relatives and collecting seed.

(ii) Wild species will take over from landraces, especially in the much explored cereals. This will be facilitated in the first instance by extensive prebreeding ('enhancement libraries'), in the second by transformation. Ex situ collections will be needed for research and breeding; large collections of wild species are expensive to maintain and unnecessary. Does it matter if an odd endangered relative is lost? But *in situ conservation of all lifeforms is important:* valuable genes have come from micro-organisms.

(iii) Scientific discovery is advancing at breathtaking speed. The real future of genetic resources and their application is being determined in laboratories far removed from the germplasm collection. The use of genetic resources may be enhanced, as it has been by recombinant DNA; or they may become altogether redundant.

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Efraím Hernández Xolocotzi, recipient of the Society of Economic Botany's 1986 Distinguished Economic Botanist award and in 1987 of the Frank N. Meyer Memorial Medal.

National Perspective

Conservation of Maize Genetic Resources in Mexico

Mexico counts among its national treasures a wide array of food crops, including maize, bean, squash, tomato, chile, and avocado and a variety of centuries-old agricultural traditions. A central feature of these traditions, according to Garrison Wilkes, a long-time student of maize and its wild relatives in Mexico, is a special ''cultivator-to-plant relationship'' that is maintained through farmers' selection of seed for planting.

This ''plant sensitivity,'' as Wilkes puts it, has survived the trend in recent decades towards monoculture and the introduction of new, higher yielding varieties, both made necessary by rapid population growth. But as farmers have responded to the call for intensified production, an increasing share of the responsibility for conserving plant genetic resources displaced in the process has been assumed by the nation's scientific institutions. In fact, some of the builders of these institutions were laboring to conserve and use the genetic diversity of maize, Mexico's staple cereal, as early as the 1930s, long before this type of work became the subject of international controversy or even of wide concern within the global scientific community.

The first pioneering collection of indigenous maize for breeding was conducted in the 1930s by two distinguished Mexican maize scientists, Ings. Edmundo Taboada and Eduardo Limón, both working at the Experiment Station Office, the research agency of the Ministry of Agriculture at that time. Taboada and Limón collected a large number of indigenous races in Central Mexico and developed from them several of Mexico's earliest open-pollinated improved varieties (a number of which are still used as breeding materials) as well as many inbred lines.

In the 1940s a larger maize collection effort was made under the Government of Mexico-Rockefeller Foundation cooperative program in agricultural research and training. Much of the collection work was done by Mexican scientists, who collected seed samples in the fields surrounding villages throughout the country's principal maize production areas in the high valleys of Central Mexico, and part by students from the National School of Agriculture at Chapingo. ''The more remote areas,'' says E.J. Wellhausen (CIMMYT's first director general), were the special preserve of Efraím Hernández Xolocotzi (professor emeritus of the Postgraduate College at Montecillo), who ''was especially good at ferreting out the rare types grown and preserved for ceremonial and other reasons.'' Hernández brought to this task an intimate understanding of the Mexican ecology, traditional maize cultivation, and farmers' role in developing maize variants. He coauthored the publication *Races of Maize in Mexico*, which reported a scheme for classifying landraces collected during this period, and afterwards made collecting expeditions to Cuba, Colombia, Ecuador, Guatemala, and Peru.

The efforts of Hernández and others ensured that the global maize gene pool was more thoroughly collected than that of any other major food crop. Much of the diversity they captured is now contained in two complementary maize germplasm banks in Mexico, one managed by INIFAP and the other by CIMMYT. The germplasm bank under the care of INIFAP has been enriched by additional accessions collected by Hernández Xolocotzi, Rafael Ortega Paszka, and others. It has also been the subject of cytological and morphological studies by T. Angel Kato of the Postgraduate College, Juan Manuel Hernández (the bank's current curator), and by other scientists with INIFAP and the Postgradute College, whose aim is to generate information that could facilitate the use of landraces in maize improvement. Maize evolution studies by Salvador Miranda Colín and others are also underway.

Now that the collection of these landraces is nearly complete and their evaluation and utilization well advanced, more attention is being focused on the wild relatives. As in the case of the maize landraces, Mexico undertook the conservation and study of the crop's wild relatives at an early stage. Hernández Xolocotzi and others have been investigating *Tripsacum* species since the 1940s. Mexican researchers are also making important advances in the study of teosinte. Botanist Rafael Guzmán Mejía, with the encouragement of University of Guadalajara plant taxonomist Luz María de Puga, began a quest that resulted in the

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Prepared by CIMMYT staff in collaboration with Dr. Francisco Cárdenas Ramos, National Expert, Genetic Resources, National Institute of Forestry, Agriculture, and Livestock Research (INIFAP), Mexico.

rediscovery in 1977 of a long-lost perennial species of teosinte, *Zea perennis (2n=40)*, and in 1978 of an entirely new perennial species, *Zea diploperennis (2n=20)*. The first event was important enough by itself, but the second aroused great excitement in the scientific community and was widely publicized in the international press. What commanded attention was the fact that *Z. diploperennis* possesses the same chromosome number as maize and crosses readily with it, suggesting the possibility that the perennial growth habit of this wild relative might be transferred to the cultivated crop.

An important outcome of the discovery of the new taxa was the establishment in 1987 by the Mexican government of the Sierra de Manantlán Biosphere Reserve, which encompasses 140,000 ha of rugged, mountainous terrain in the state of Jalisco. Efforts to create the Reserve were begun in 1979 by de Puga and Guzmán and University of Wisconsin botanist Hugh Iltis, who later received assistance from Mexican university officials and public figures (including the former governor of Jalisco state), various international environmental groups (such as the World Wildlife Fund), and many other organizations and individuals.

Setting aside 140,000 ha of forest was necessary for the in situ preservation of *Z. diploperennis* (which cannot survive unless the entire system that supports it is left intact) and the hundreds of other plant and animal species in the reserve that constitute a valuable part of the country's national heritage. Apart from the purely national considerations, though, establishment of the Sierra de Manantlán Biosphere Reserve has secured a role for Mexico in an international campaign for conservation of the earth's ecologies. The Reserve is one of two in Mexico, and both are part of the Man in the Biosphere Reserve System being promoted by the United Nations Education, Scientific, and Cultural Organisation (UNESCO). In keeping with the aims of this system, the interdisciplinary team of the Las Joyas Natural Laboratory is developing a research program in the Reserve that combines preservation with development goals, a task that Mexico's own experience has shown to be difficult but absolutely essential.

In the case of the Sierra de Manantlán Reserve, part of the difficulty lies in the complicated institutional arrangements occasioned by its development, which involved the federal, state, and local governments, the University of Guadalajara, and the communities in and around the Reserve. Such arrangements reflect a conviction that everyone has a stake in the preservation and prudent development of the nation's resources and a responsibility for seeing that the task is properly done. Local participation is receiving special emphasis, because the researchers at Las Joyas Natural Laboratory believe that preservation and development goals cannot be imposed upon communities but must be generated from within them. One way in which these researchers are encouraging local participation in project activities is a public education program that attempts to instill in the people living in and around the Reserve and thoughout the state of Jalisco a sense of the value of their natural resources. Researchers are aware, of course, that it will take much commitment and time to realize the ambitious goals of the Sierra de Manantlán Reserve but are hopeful that their own and other countries' participation in the biosphere reserve system will succeed, as Guzmán suggested, in "revolutionizing the concept of conservation."

Courtesy of Hugh Iltis, University of Wisconsin

Rafael Guzmán Mejía combed the tropical forests of the Sierra de Manantlán in search of a lost perennial species of teosinte—his persistence was rewarded with the discovery not only of that species but another entirely new perennial teosinte.

Thomas Luba

The "plant sensitivity" that characterizes Mexico's centuries-old agricultural traditions has survived the trend in recent decades towards monoculture and the introduction of new, higher yielding varieties.

A Review of Programs

One important element that has not been very evident in the recent debate about plant genetic resources is an awareness of the complementarity between this theme and many others that are equally relevant to sustained agricultural development. In stressing the need to preserve germplasm for future generations, participants in the debate have largely neglected the point that human welfare is just as dependent on the resolution of a forbidding array of agronomic and economic problems. For that reason the Center's work, though it strongly emphasizes germplasm improvement, embraces other types of investigations as well.

As agriculture has taken on a more forceful role in development, CIMMYT has come to place more emphasis on helping national programs increase the productivity of agricultural resources in research and on the farm.

The Structure Behind the Strategy

CIMMYT's strategy for meeting challenges in germplasm improvement (as outlined in the Report From Management) and in other areas of research is reflected in its organizational structure. The Center contains three research programs—Maize, Wheat, and Economics—together with various research service units. These groups are staffed by about 140 scientists and other specialists, who are ably assisted by a local support staff of about 850. Some 30% of the Wheat Program, 40% of Maize, and more than 50% of Economics staff work out of offices at 17 locations around the Third World, while the rest are stationed at our headquarters in Mexico and periodically consult with clients in other regions. Most of the staff in Mexico are engaged in germplasm improvement and related activities. Those stationed abroad provide support to national researchers within the framework of regional programs or bilateral projects and conduct germplasm improvement, crop management, and economics research that complements the work at headquarters. Of the total number of researchers at headquarters and abroad, 70% concentrate on aspects of germplasm improvement and the remainder on problems in agronomy and economics.

The results of their work take the form of five products and services for researchers in developing countries:

- Improved maize and wheat germplasm for major production environments in the Third World (as well as unimproved accessions from germplasm banks)
- Efficient methods for plant breeding, crop management research, and agricultural decision making
- New scientific knowledge stemming from the Center's own research and from the work of others
- Training of various types
- Consulting services

Although these categories have not changed much over the years, the offerings within each have been amplified, and recently we have reinterpreted our overall aim in providing them. For most of its 22 years, the Center has concentrated on increasing crop production because of worldwide concern about rapid population growth and precarious food supplies in the Third World. However, as agriculture has taken on a more forceful role in development (being viewed increasingly as an ''engine of growth''), CIMMYT has come to place more emphasis on helping national programs increase the productivity of agricultural resources in research and on the farm.

Broadly Adapted Germplasm for Diverse Environments

Long before major responsibility for plant breeding was assumed by scientists, germplasm of our major food crops was steadily, but slowly and sometimes haphazardly, improved by farmers and transferred beyond its centers of origin. With the advent of modern plant breeding, chance hybridization in farmers' fields was complemented by controlled crosses at experiment stations, and the pace of improvement increased. But until recent decades, scientific breeding programs seldom reached beyond national horizons, and consequently their products were adapted to the relatively narrow range of growing conditions found within individual countries, as were many of the original races developed under the stewardship of farmers. What CIMMYT and other CG centers have done is to extend modern crop improvement beyond national boundaries by developing broadly adapted germplasm for diverse environments and creating international networks for testing and further refinement of this material.

At CIMMYT this activity takes place within the framework of what we have dubbed the mega-environment concept. Each mega-environment is an area of no less than a million hectares throughout which a given type of germplasm is adapted to prevailing conditions. Any point at which this germplasm is no longer suitable (because of inappropriate maturity and moisture requirements, poor performance under the dominant biotic and abiotic stresses, and lack of acceptance in local markets) marks the discontinuation of one mega-environment and the beginning of another that requires a different type of germplasm. Mega-environments do not necessarily consist of contiguous areas of maize or wheat production, and on the contrary are frequently transcontinental, encompassing various "pockets" of production that may be separated by thousands of kilometers. What binds these individual areas together is the uniformity of the response of a specific genotype grown within them and of the climatic and other conditions affecting this response.

Our international maize and wheat breeding programs are greatly facilitated by this transnational scheme of classifying environments. CIMMYT's resources are simply too limited for it to establish individual maize and wheat breeding programs for its scores of developing country clients. Nor would such an approach be in keeping with our aim of strengthening national research capacity, which can best be accomplished if each nation bears its responsibility for fostering agricultural development through plant breeding and other research. The more efficient and appropriate course is for Center scientists to develop broadly adpapted maize and wheat germplasm for mega-environments, which are far less numerous than our client countries. The experience of CIMMYT and its clients has shown that it is possible to develop a maize population which performs well in representative areas of a mega-environment as remote from one an other as El Salvador, Ghana, and Vietnam or a wheat variety that beats the competition in the semiarid zones of Mexico, Morocco, and Pakistan.

A key benefit of the mega-environment concept is that it provides a means of keeping CIMMYT's resource allocations in line with the needs of its clients. We are gradually shifting our investments in the various classes of germplasm toward a rough correspondence to the extent of the corresponding mega-environments worldwide, taking into account other considerations such as the strength of national programs operating within this environment and the presence of alternative suppliers of germplasm. The deployment of the Center's resources and the returns accruing from its investments are the subjects of the following sections on maize, wheat, and economics, research and support services.

1. El Batán, Mexico (headquarters)
2. Les Cayes, Haiti
3. Guatemala City, Guatemala
4. San José, Costa Rica
5. Cali, Colombia
6. Quito, Ecuador
7. Asunción, Paraguay
8. Kumasi, Ghana
9. Ankara, Turkey
10. Aleppo, Syria
11. Addis Ababa, Ethiopia
12. Nairobi, Kenya
13. Lilongwe, Malawi
14. Harare, Zimbabwe
15. Islamabad, Pakistan
16. Kathmandu, Nepal
17. Bangkok, Thailand
18. Dhaka, Bangladesh

Locations of CIMMYT offices.

Virtually all of the Maize Program's current breeding populations can be traced back to accessions of its germplasm bank. But since the former have undergone up to 20 years of recurrent selection, there is now a considerable gap between the modern populations and their precursors, both in outward appearance and performance. Partly because of such differences, direct use of the landraces by Program staff has remained fairly static until recent years.

Several developments have strengthened the bank's connections with other breeding and related units. One is the Maize Program's increased emphasis on special purpose gene pools, which are agronomically acceptable germplasm complexes possessing resistances to one or a few biotic or abiotic stresses. An obvious place to search for sources of these traits is the germplasm bank, and staff are starting to avail themselves of this option with greater frequency. A second development is that new gene technologies promise to facilitate the identification of useful genes and possibly their transfer from landraces to modern cultivars. It remains to be seen just how effective the new techniques will be, but in anticipation that they will greatly reduce the time required to employ bank accessions in maize improvement, Program staff are gradually stepping up their examination of landrace and other materials.

Maize germplasm improvement at CIMMYT was built upon a foundation of landraces collected throughout the Americas, and the Center's maize researchers continue to draw upon this resource in developing new germplasm products for the Third World.

Thomas Luba

Support of Germplasm Development

In no other area of the Maize Program is there greater interest in landraces and maize wild relatives than in the various subprograms that support germplasm development (see figure, page 32). And upon this group as a whole, falls much of the burden of improving the accessibility and enhancing the utility of such materials for maize breeding. For that reason support of germplasm development receives particular emphasis in this *Annual Report.*

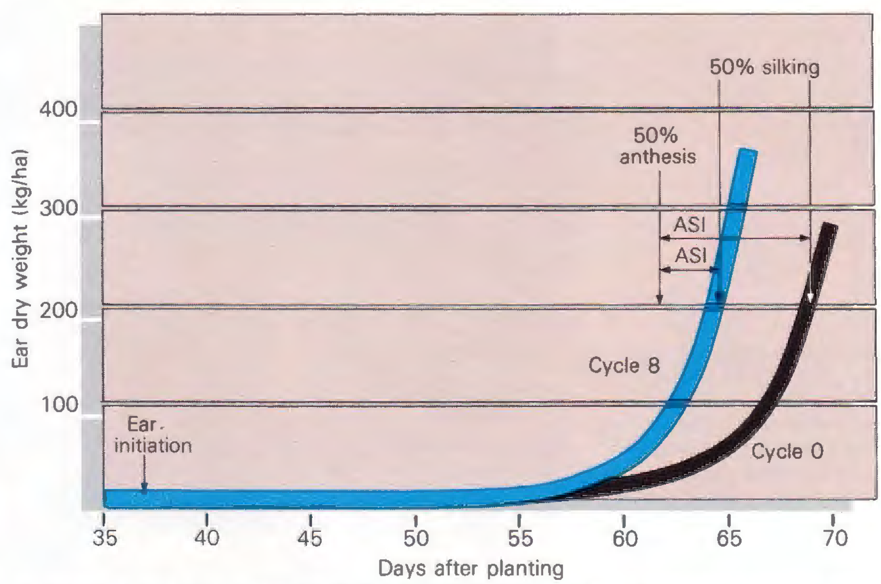
Germplasm bank—Over the past several years, the Maize Program has made a sizeable investment in this unit, giving special attention to improvements in storage facilities, management procedures, and information distribution. By 1988 new systems for handling bank functions were essentially in place, and we began to concentrate more on cooperation with other institutions. For example, this year in Ecuador, the national maize program finished regenerating all accessions that originated in that country; scientists in Guatemala increased 40 collections; and we explored possibilities for similar arrangements with Bolivia, Colombia, and Peru. Without the assistance of these countries, the bank would be unable to regenerate certain accessions, mainly highland materials, which are not adapted to growing conditions at our stations in Mexico.

The bank also embarked upon new joint ventures with the International Board for Plant Genetic Resources (IBPGR). One of these was the preparation of a list of maize descriptors to be published by IBPGR and CIMMYT. This document will provide what IBPGR staff refer to as a "standard format" or "universally understood 'language'" that should help increase efficiency in the recording and communication of data about maize genetic resources and thereby facilitate worldwide utilization of this material. The two centers took another step this year toward establishing an international maize genetic resources network by planning a global maize germplasm database, which will be modelled on a CD-ROM version of the CIMMYT bank's computerized management system (see page 25). Although details of an agreement are still under discussion, the project is likely to entail the creation of a database for Mexico's collection and either a single database or separate ones for other Latin American collections. Upon completion of this project, researchers in developing countries will have better access to passport information not only on CIMMYT's accessions but thousands of other collections held at various institutions in Latin America.

Cooperation among national banks and international institutions was further reinforced this year by the Global Maize Germplasm Bank Workshop, held at our headquarters in March under the joint sponsorship of Mexico's National Institute of Forestry, Agriculture, and Livestock Research (INIFAP) and CIMMYT. Its main purposes were to introduce the 27 germplasm bank managers attending the meeting to our CD-ROM database and address technical issues pertaining to the role of germplasm banks. The organizers also recognized 13 maize germplasm collectors, including Efraím Hernández Xolocotzi, professor emeritus of the Postgraduate College at Montecillo, Mexico, and E.J. Wellhausen, former director general of CIMMYT. Mario Gutierrez G., who first established and operated a modern cold storage facility for maize germplasm at the Center, was given special recognition by IBPGR for his work during the formative period of modern germplasm banks.

The development of new cooperative relations left little time in 1988 for research on the conservation and utilization of germplasm bank accessions. Nevertheless, we did participate in a project on seed storage and initiated a study with collections of the race Tuxpeño. Partners in the seed storage study are the Boyce Thompson Institute for Plant Research and Cornell Agricultural Experiment Station (both in the USA), CIMMYT, and Mexico's Experiment Station for Seed Science and Technology at Aguascalientes. The aim of this project is to improve our ability to assess and control deterioration of maize seed in storage by applying contemporary biochemical and genetic methodologies to the study of traits in maize that are related to maintenance of vigor in storage. The purpose of the study on Tuxpeño (and materials showing introgression of this racial complex) is to identify the best collections and determine heterotic patterns among them. This information, in addition to shedding light on the genetic background and evolution of the race, might reveal new opportunities for exploiting hybrid vigor and increasing the use of bank accessions.

Physiology—In the work on drought, which receives first priority in physiology research, we fully confirmed the results of a study conducted in 1987 on the population Tuxpeño Sequía by examining a wider range of materials. From the work in 1988, it is apparent that, regardless of whether the germplasm is a landrace, elite population, inbred, or hybrid, its performance under drought can be improved by selecting for reduction of the anthesis-silking interval (ASI). This measure enables plants to direct more nutrients into the production of grain (see figure). That the outcome is not an improvement in the water status of the plants was evident from a study of the root system of Tuxpeño Sequía and other materials, the results of which suggested that the reduction in ASI and greater flow of nutrients to the ear possibly occurred at the expense of the roots. Nonetheless, changing dry matter partitioning by selecting for reduced ASI appears to be a precondition for any further progress through selection for traits that may enable maize to use available water efficiently during drought. The difficulty of working with such traits was underscored by our inability in 1988 to observe differences within a diverse collection of tropical maize materials in osmotic regulation, which is one of the principal mechanisms by which plants of some species maintain growth under drought.



In cycles 0 and 8 of selection in the population Tuxpeño Sequía, ear initiation and anthesis occur at roughly the same time, but then cycle 8 reaches the critical ear biomass necessary for silking much earlier than does cycle 0, giving it a reduced anthesis-silking interval (ASI) and higher grain production under drought.

Obstacles to the use of bank germplasm are being reduced, the scientific ones through interdisciplinary research and the problem of information availability through applications of CD-ROM.

We proceeded in 1988 with two approaches to the development of drought tolerant germplasm: one is recurrent S_1 selection in elite maize populations and the other formation of a special purpose pool. We continue to search for sources of drought tolerance to be incorporated into the pool. In the latter task, we took advantage this year of the germplasm bank's computerized database, which helped us identify accessions that were collected in areas up to 1,000 masl and where less than 500 mm of rainfall is received annually. Interestingly enough, though, some of the most drought tolerant materials we have found so far are not bank accessions but inbreds and hybrids from private company breeding programs in the USA and a hybrid released by Kasetsart University in Thailand.

We are continuing our recurrent selection program for yield under low soil nitrogen conditions in an improved lowland maize population. At the same time, we are developing a database on the response of unimproved materials, primarily from the germplasm bank, to N stress. Entries are grown under high and low N levels, and key characters such as biomass yield, total N uptake by the plant, N partitioning, and leaf area are measured. We hope to identify a range of strategies that improve performance under low N and to develop special purpose pools for characteristics such as the maintenance of leaf area under N stress and the ability to move a large fraction of the total plant N to the grain. While these pools will not have an outstanding plant type, they may serve as a source of traits related to adaptation to low N conditions that are not available in improved populations.

Germplasm bank accessions also figure in our cooperative project with the Plant Environment Laboratory of the University of Reading, UK, in which we are determining photoperiod and temperature responses in a wide array of tropical and temperate maize materials. The aim of this three-year project is to describe the responses of CIMMYT's germplasm to daylength and temperature and develop a simple model that can predict the maturity of this material when grown under different temperature and daylength regimes.

In our ongoing project to develop semiprolific germplasm with general stress tolerance, we conducted an evaluation of four cycles of selection and on this basis merged two populations. Screening of germplasm bank accessions for possible inclusion in the

Continued on page 26

Thomas Luba

Each year Suketoshi Taba, head of the maize germplasm bank, conducts an in situ monitoring tour in Mexico and Central America to check the status of annual teosinte populations and other wild relatives of maize. In doing so he also visits farmers' fields, like that of Edwiga and Lucila López, in search of landraces that might not be adequately represented in the Center's collection.

Wedding Agricultural Research With Information Technology

CIMMYT's maize germplasm bank is a paradoxical institution. At the same time that its holdings are considered a priceless resource for future maize improvement, they are currently underrated and underused. One US expert has even questioned whether the term "seed morgues" would not be a more appropriate term for many seed banks. The preference of many breeders to concentrate on elite populations and to neglect the landraces has a scientific basis but is also linked to information. We simply do not know enough about the germplasm contained in the bank, and what we do know is not as widely available as it needs to be. Both obstacles to the use of bank germplasm are now being reduced, however, the scientific ones through joint endeavors involving plant breeders and specialists in biotechnology and other areas and the problem of information availability through applications of CD-ROM (compact disc, read-only memory).

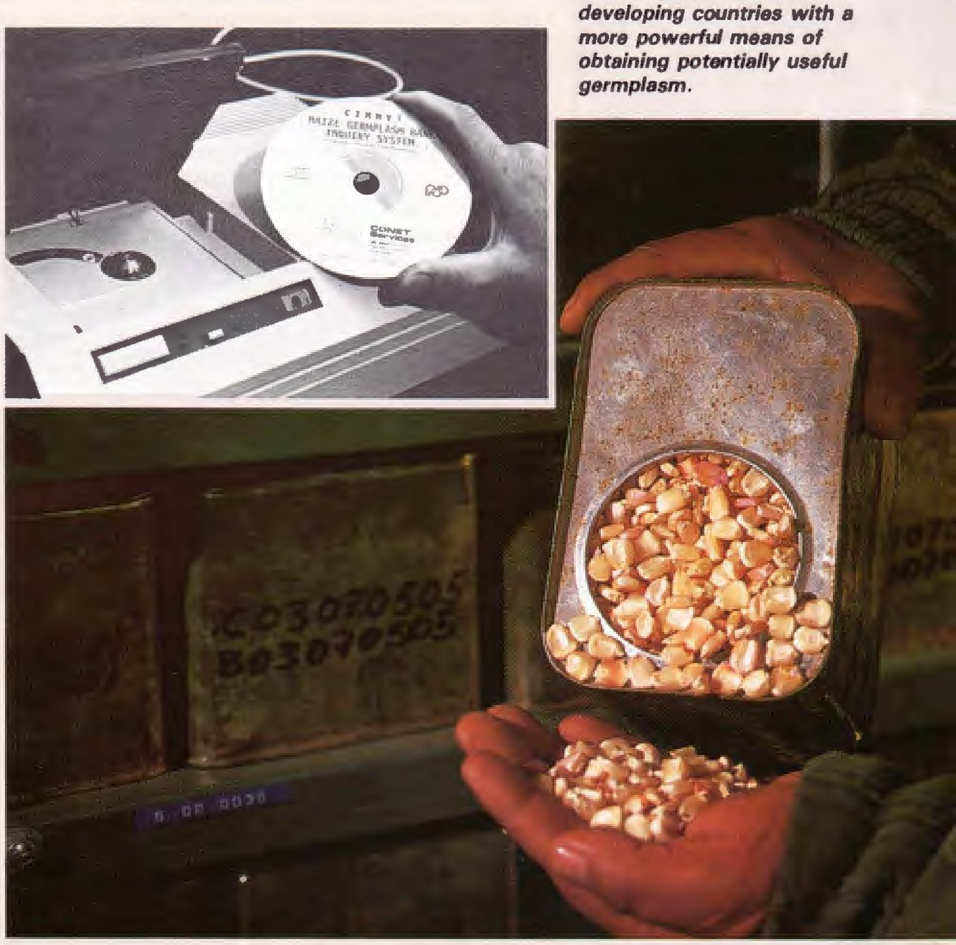
The Making of the Marriage

A few years ago CIMMYT staff began developing a system for compiling and accessing information about germplasm stored in the bank. This system, supported by the Center's mainframe VAX computer, contains files for all the major categories of bank information—passport, regeneration, evaluation, and storage. Currently, the first category, passport data, is the most voluminous and important. Our original idea for sharing this information was to distribute a limited number of copies of the reams of paper produced by the passport file. But then it occurred to staff working on this project that, by taking advantage of new CD-ROM technology, they could disseminate the data in a much more convenient form and to a larger number of researchers in developing countries. With funding from the Technical Centre for Agricultural and Rural Cooperation (CTA) in The Netherlands, CIMMYT and CGNet Services in California, USA, developed the software required to operate the passport file on CD-ROM. An initial lot of 300 copies of a master disc has been produced, of which about a third will be distributed by CTA, along with disc readers, to selected developing countries. With this equipment, researchers will be able to search records on the bank's 10,533 accessions and on the basis of as many as 29 descriptors identify potentially useful items. They can then obtain seed of these accessions free of charge from the Maize Program.

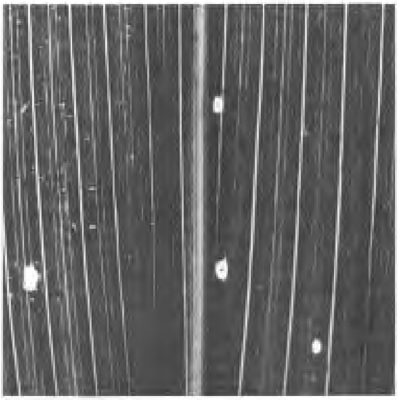
An Appropriate Technology for Developing Countries?

The answer to this question is an unqualified yes. Neither the disks nor the equipment required to use them are beyond the means of many developing country research programs. Although it cost about US$5000 to produce the master disc, the price of copies is only US$5-10, depending on how many are made. The operational requirements are quite reasonable as well, including a few basic items of computer hardware and software to which a growing number of professionals in the Third World have gained access during recent years. There is thus no practical reason why CIMMYT's CD-ROM database (or other such databases) could not be readily and widely employed by scientists in developing countries.

By making available on CD-ROM complete passport data for the approximately 10,500 accessions in its maize germplasm bank, CIMMYT is providing researchers in developing countries with a more powerful means of obtaining potentially useful germplasm.

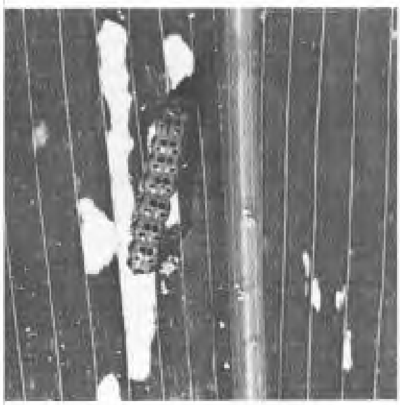


Sergio Pastén



Resistance

Intermediate susceptibility



Sergio Pastén

Complete susceptibility

CIMMYT's Multiple Borer Resistance Population offers excellent crop protection against southwestern corn borer (shown here) and several other insect pest species. On resistant plants like the one shown at top, larvae are unable to survive.

semiprolific populations proved disappointing, as none of the materials showed enough prolificacy to warrant the effort of employing them. We did, however, make use of a cross between maize and the maize wild relative *Tripsacum*.

Entomology—Since most improved germplasm is susceptible to insect pests, we search the germplasm bank fairly often in the hope of finding additional genetic diversity for resistance. In working with bank and other materials, we have found it useful, even essential, to establish relations of mutual benefit with organizations in developed countries. The effect of this cooperation is to reduce the cost and time required to provide our colleagues in national programs with resistant germplasm.

These relations often entail interesting patterns in germplasm exchange, of which our work on the Multiple Borer Resistance (MBR) Population provides some examples. Among the materials making up this population are eight lines resistant to southwestern corn borer and fall armyworm, which were derived from Antigua collections supplied by CIMMYT some 10-15 years ago to scientists at Mississippi State University. The population also contains seven lines resistant to European corn borer, which were developed through "shuttle" breeding between the Center and Cornell University. These materials have since completed their round-trip to the USA and now form a part of the MBR population, which has been tested in several countries for resistance to several borer species and fall armyworm. Resistant varieties developed from this population are now ready for broader testing in developing country programs.

We hope to derive similar benefits from a cooperative project begun last year on insect pests of stored grain and another started in 1988 on spider mites. In the latter, germplasm bank accessions have been screened for resistance in the USA, and we are in the initial stages of developing a resistant population. Shuttle breeding between CIMMYT headquarters and Texas A&M University will ensure that any benefits derived from this germplasm in the USA will be available to us and ultimately to our clients in developing countries. The difficulty of transferring insect resistance from landraces into more acceptable genetic backgrounds is well illustrated by the current state of work on corn earworm. Scientists in the USA have known for some time that the presence of a chemical called MAYSIN in the Mexican landrace Zapalote Chico (of which several accessions are stored in the maize germplasm bank) prevents earworms from feeding on maize silks. But no one has been able to incorporate this resistance into useful germplasm, because the resistance mechanism has so far proved inseparable from serious agronomic defects.

Such barriers are starting to seem less formidable in light of the new gene technologies available for plant breeding. As a start toward exploring the possibilities of these techniques, we initiated a project this year in which molecular genetic markers will be employed in selecting for resistance to *Diabrotica* rootworms. The project grew out of work done several years ago at South Dakota State University, where screening of 100 germplasm bank accessions showed that 20 originating in Mexico and Central America have significant levels of resistance. Those materials are the focus of the current project, in which laboratory work with the markers is being done by a private US company, Agrigenetics, and field studies by CIMMYT in Mexico.

Wide crosses—The introduction of genetic variation from alien species into maize is a major objective of our wide crosses research. In working toward this goal, we have concentrated on maize x *Tripsacum* hybrids and their progeny, examining various pathways for introgression of genetic variation from this wild relative. Cytogenetic analysis completed in 1988 suggests that the apomictic pathway warrants further investigation.

Increasingly, though, wide crosses work will center on the application of new gene technologies to the introgression of *Tripsacum* genes into maize and also to other research in the Maize Program aimed at improving tolerance to biotic and abiotic stresses (see page 29). For several reasons we will focus on wide crosses, entomology, and physiology in the initial testing of these techniques. One is that in previous studies with *Tripsacum* we have been concerned primarily with insect resistance, assisting in such activities as the development of methodologies for selecting and using resistance to southwestern corn borer. The most compelling reason, however, for concentrating on the above-mentioned areas at the outset of our venture into biotechnology is that in each one we are working on traits that are especially difficult to improve. The application of new gene technologies to this research therefore offers high returns in efficiency.

Pathology—Without a doubt, landraces contain unexploited genetic diversity for disease resistance, and the new gene technologies promise to be an effective means of increasing efficiency in selection for disease resistance. The utility of landraces in combatting disease in sub-Saharan Africa is well illustrated by the use of a local variety from the island of Réunion as a source of resistance to maize streak virus in a breeding program (see page 31) involving CIMMYT and the International Institute of Tropical Agriculture (IITA).

The germplasm products of that program are being developed entirely through conventional techniques in breeding and related research, and such approaches continue to permit steady improvement in the disease resistance of our elite maize germplasm. In fact, the demand among CIMMYT maize breeders for one of our most effective techniques—disease inoculation for resistance screening—has increased nearly 10-fold in the last several years, and we completed a study in 1988 whose results should enable us to inoculate even more reliably for ear and stalk rots.

Moreover, we are seeing good progress in the development of multiple disease resistance and in programs dealing with specific diseases, such as the tar spot complex discussed in the *1987 Annual Report*. This is not to say that we foresee no use of the new gene technologies in our pathology research. On the contrary, one of the most exciting achievements in the use of RFLPs for maize improvement came from work on maize dwarf mosaic virus at Agrigenetics, USA, where scientists succeeded in genetically marking nearly all of the variation for resistance to this disease in the progeny of a cross between a resistant and susceptible line. For us the issue is not whether but when to begin drawing on these techniques in our own work, and the timing will depend on the degree and pace of progress in our initial efforts to apply the new gene technologies in wide crosses, entomology, and physiology.

Hybrid maize—With respect to the new gene technologies, the hybrid program is in a position similar to that of pathology. These developments will certainly have important implications for our work, but until the proper time comes for us to apply the resulting techniques and information, we are pursuing other approaches aimed at exploiting the Maize Program's current pools and populations in hybrid development. In 1988 we continued along much the same lines described in last year's *Annual Report*. Our primary activities were to: 1) evaluate the per se performance of 200 inbred lines, assess the combining ability of lines in two trials, and increase seed of promising lines; 2) conduct interpopulation improvement of Tuxpeño-1 and ETO Blanco to increase their general and specific combining ability; 3) cross promising lines with testers to establish a basis for classifying the lines into distinct heterotic groups; 4) improve the inbreeding tolerance of tropical and subtropical materials; 5) test hybrids in seven trials for conventional and five for nonconventional materials at various locations; and 6) conduct diallel studies to identify tester lines for the hybrid program. We also evaluated crosses made among highland pools and populations in 1987 and will continue the evaluations next year to determine heterotic patterns in this germplasm. Two other activities—the development of parents with lesser degrees of inbreeding and of synthetics with a narrow genetic base—supplemented our program of nonconventional hybrid development. According to reports from our maize specialists in Central America, products of the hybrid program are already proving useful in the hybrid development efforts of several countries.

A sizeable portion of the Third World's maize is destroyed in storage each year by insect pests, and the hazard is particularly great with on-farm structures in which no chemical protection is used. In a cooperative project with CIMMYT, Canadian scientists have, through laboratory tests, identified resistance to pests of stored maize in some Maize Program materials as well as a mechanism of resistance.


Thomas Luba

Germplasm Improvement at Headquarters

As Sir Otto has mentioned in the Point of View section of this *Report*, the evaluation of genetic resources should be a multidisciplinary exercise, with plant breeders making the "essential link with application" or utilization. It is evident from the foregoing report on support of germplasm development that various groups of specialists in the Maize Program are examining and finding uses for germplasm bank accessions and materials from other sources. These activities are also on the rise in the breeding subprograms, being occasioned by our adoption of a wider variety of breeding methods and by the creation of new germplasm complexes.

Their involvement in the European RFLP network will put CIMMYT staff in a good position to advise developing country clients on appropriate uses of the new gene technologies.

Lowland tropical gene pools—In the work on early and intermediate maturity materials, we screened germplasm from numerous sources, including other Maize Program units, national programs, and private seed companies. We examined more than 700 accessions from the maize germplasm bank, selfed the most promising materials, and crossed them to an elite early maturing experimental variety. Bank accessions also proved useful in the formation of new extra-early germplasm complexes. In addition, we continued recurrent selection in four early pools, proceeded with the formation of a series of synthetics targetted for specific mega-environments, and screened various materials for drought tolerance.

A key event in the work on late maturing tropical germplasm was our development of the "minipool" approach, which can be applied to elite or germplasm bank materials. With the latter we form a pool from crosses between a bank accession and a complementary variety or a tester. After selection for disease resistance and reduced plant height, we test S_1 progeny and from the superior fraction form a variety. Toward this end we evaluated 400 bank accessions in 1988, topcrossed 90 to an elite population, and evaluated them for yield and anthesis-silking interval. Accessions that performed better than the check are now being handled as minipools. In addition, we took the initial steps toward formation of two new general purpose pools, evaluated lines for general combining ability, and employed single crosses of the four best lines as testers for germplasm bank accessions.

Subtropical gene pools—To identify sources for new pools, we regularly evaluate a wide range of materials, with a view to broadening the genetic base of our germplasm. This provides us with new opportunities to select for disease resistance and other traits and increases our chances of finding valuable and previously unknown gene combinations. This year we observed and introduced into our program bank accessions from Brazil as well as commercial hybrids and breeding populations from Brazil, Turkey, and various countries of eastern and southern Africa. In the improvement of current pools, we continued to concentrate on resistance to diseases and lodging, screening various materials under disease inoculation and evaluating them at three sites in Mexico. We also proceeded with the development of some new germplasm complexes, whose composition will be based on results from various evaluations of lines and crosses among them.

Highland maize—A basic assumption of this program in recent years has been that marked improvement of highland maize requires an influx of exotic germplasm. Thus, in the mid-1980s we introgressed temperate and subtropical germplasm into Mexican highland materials to form the semident pools and populations that are the current focus of the highland program. Some of the germplasm incorporated into our early maturing tropical highland materials came from an unexpected source—New Zealand. In the mid-1970s a breeder there (Dr. Howard Eagles, who spent several months at our headquarters in 1988 as a visiting scientist) obtained seed of a CIMMYT highland pool for its cold tolerance and subjected it to inbreeding in his improvement program. In 1985 a Maize Program staff member brought back from New Zealand seed of some hybrids formed with inbreds from this highland pool and others developed by crossing the inbreds with US Corn Belt material. The introduction of the New Zealand hybrids into our program helped enhance the highland adaptation of the early materials and gave them some of the high yield potential of

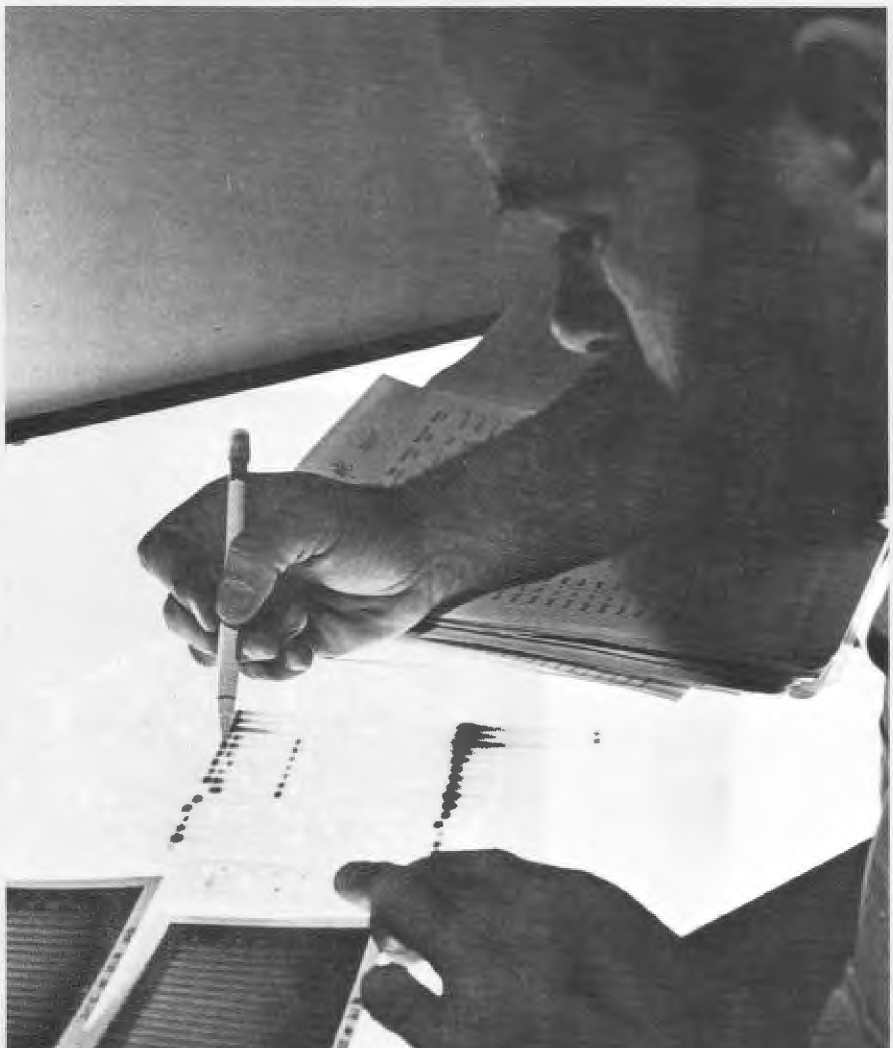
Continued on page 30

Applications of New Gene Technologies to Maize Breeding at CIMMYT

In 1988 the Maize Program staff member responsible for wide crosses research completed a study leave at the University of Minnesota, where he explored the use of restriction fragment length polymorphisms (RFLPs) to monitor the introgression of genetic material from *Tripsacum* into maize. Based on this experience, he prepared several papers on the possible applications of new gene technologies to plant breeding at CIMMYT. A summary follows of key points relevant to maize research.

Of the numerous techniques making up what is popularly referred to as "biotechnology," the one that offers the widest range of immediate applications and the most promise for increasing efficiency in maize improvement is the use of RFLPs and other DNA probes. These have many advantages over traditional phenotypic markers such as seed color. One of the most important is that, since maize shows tremendous variation at the DNA level, numerous markers are available that make it possible to identify, map, and select genetic regions that control important agronomic traits. Other advantages are that DNA polymorphisms are unaffected by environment and all are detected by a single, relatively rapid technique. Among the various maize research activities in which these probes might prove useful are: identification of heterotic groups in tropical maize, selection for quantitative traits such as insect resistance and drought tolerance, and utilization of germplasm bank accessions.

Although it would be premature to draw up a fixed, long term agenda for such applications of RFLPs, the Maize Program is already engaged in four projects involving RFLP related technologies. One of these will be a continuation of the above-mentioned study initiated at the University of Minnesota. The second, which is being conducted in cooperation with the Center for Advanced Studies (CINVESTAV) at Irapuato, Mexico, and is near completion, is an investigation of the relationship between heterozygozity and yield and yield stability in open-pollinated tropical maize varieties. In the third, another joint project with CINVESTAV, we will use RFLPs to identify genetic segments associated with drought tolerance. In another even more extensive project, the Maize Program is participating in a network of public and private organizations in Europe. The group plans to employ RFLPs in examining the molecular diversity of 240 elite maize lines and to determine the usefulness of these probes in identifying loci for quantitative traits. Each network participant has selected 40 lines and will concentrate on a trait in which it is particularly interested; in the case of CIMMYT this is resistance to the southwestern corn borer. As the work proceeds, the Center expects to build a database that will be shared with the global scientific community. This experience will put CIMMYT staff in a good position to advise developing country clients on appropriate uses of the new gene technologies.



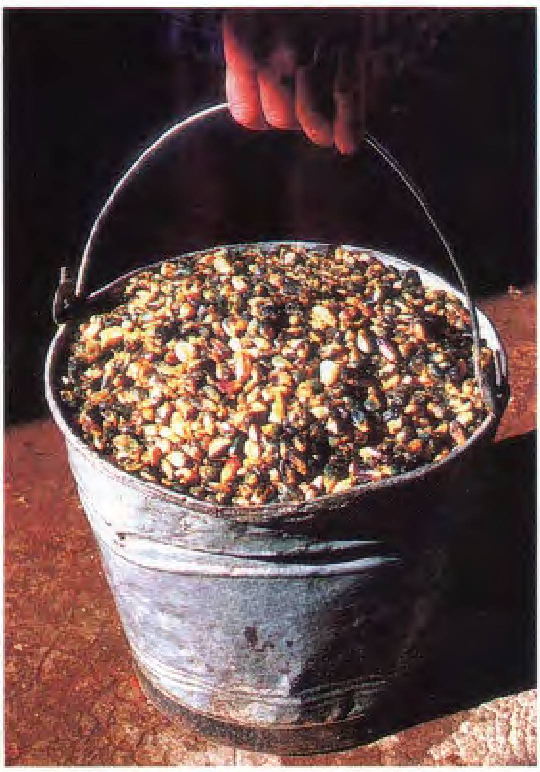
Sergio Pastén

David Jewell of the maize wide crosses unit examines a Southern blot, which is employed in work on RFLPs and is named after its originator, E.M. Southern. The Maize Program has recently become involved in four projects using RFLP related technologies.

temperate germplasm. The benefits were obvious from this year's results of trials at our own and other experiment stations in Mexico, which indicated that under stresses typical of highland environments the populations containing exotic germplasm yield a little less than twice as much as improved indigenous highland material.

We expect to achieve further improvement in the early materials as well as late tropical highland, transition zone, and temperate highland germplasm from recurrent selection at our El Batán and Toluca stations. There the materials are typically grown under difficult conditions characterized by drought, frost, and hail, which are ideal for improvement of stress resistance.

Quality protein maize (QPM)—When the proper niche has been found for QPM in developing country maize production, farmers and consumers benefitting from it will owe a debt of gratitude to the US farmer in whose field the opaque-2 mutant was found in the 1920s, to the Purdue University scientist who discovered in the 1960s that it carries a gene for high lysine and trytophan (amino acids that are essential for humans but deficient in maize), and to the CIMMYT breeders who have incorporated this gene into elite germplasm. In our program for improving and distributing QPM, we are currently focusing on the development of open-pollinated varieties, synthetics, inbred lines, and various types of hybrids for selected national programs that have shown a strong interest in this material. Two countries, Brazil and Ecuador, released QPM varieties in 1988, and about 55 seed shipments were dispatched, apart from distribution of 204 sets of five different QPM experimental variety trials. We received valuable assistance this year in the work on QPM hybrids from the regional maize programs in Central America and the Andean zone, which conducted a total of 31 QPM trials. Based on the results we will form a new set of hybrids and evaluate them in 1989.



Thomas Luba

One bucket of highland maize will yield about a day's supply of tortillas for a Mexican farm family of six to eight. The grains shown here, referred to as nixtamal, have been boiled in water with lime and will next be ground into a kind of dough (masa) for making tortillas.

Population improvement—As a result of many cycles of selection, the tropical and subtropical populations represent a narrowing of the genetic base from which they were derived, but they still contain ample genetic diversity to permit effective selection for important traits in the mega-environments to which the populations are individually targetted. Based on data obtained from a Maize Program study of these environments, we have altered the selection criteria for certain populations, in most cases increasing selection pressure for resistance to particular diseases. By placing more emphasis on *Helminthosporium turcicum* in the subtropical populations, for example, we have achieved intermediate to high levels of resistance in three of them after two cycles of selection. In addition to improving the populations for these specific traits, we are increasing the plant densities under which selection takes place as a means of boosting overall stress tolerance as well as yield.

To collect new information on which to base decisions about the improvement of particular materials, we regularly conduct various types of special studies. This year we evaluated seven populations to determine progress from selection and heritabilities for yield and disease resistance. The results will give us some indication whether the populations are due for a change in breeding strategy and possess genes for the traits under selection at sufficient frequency to permit reasonable gains. We also initiated studies for comparing two methods of selection for yield and yield stability, evaluating all of our populations for insect resistance, and examining the effectiveness of selection indices to improve multiple traits simultaneously.

Nathan Russell

Although it represents a narrowing of the genetic base from which it was derived, most of CIMMYT's germplasm contains ample genetic diversity for further improvement of yield and resistance to biotic and abiotic stresses.

International testing—Trial distribution increased by about 10% over last year, with a total of 1,000 trials sent to 75 countries (see table). Among these were 55 sets of the highland maize Experimental Variety Trial 17, which was last distributed in 1978 and went this year to 21 countries. Based on the results of variety trials, researchers in 64 countries requested 2,418 kg of seed. In our ongoing study of maize mega-environments, we stored information from 64 countries in our computer database, published a preliminary compilation of this information, and transferred the database to a Lotus file for PCs, so that it can be used by staff in regional maize programs.

Germplasm Improvement in "Outreach"

For solving particular research problems or dealing with certain categories of germplasm, the Maize Program has established several programs whose work complements that at CIMMYT headquarters but which can be more conveniently handled at other locations under the coordination of staff working out of regional offices.

Resistance to downy mildew, Southeast Asia—By 1988 we had completed improvement of two populations for resistance to downy mildew and returned them to Mexico for further testing and distribution in international progeny trials.

Corn stunt resistance, Central America—Researchers in national programs are selecting for resistance to corn stunt in four maize populations under the coordination of a maize specialist in the Central America and Caribbean regional program. During 1988 three stunt resistant varieties were released, one each in the Dominican Republic, Honduras, and Nicaragua, and in the latter country 60,000 ha were planted to stunt resistant varieties. In addition, four stunt resistant hybrids became available, two in Guatemala, one in Honduras, and one in El Salvador.

CIMMYT/IITA breeding program, West Africa—This cooperative project was initiated at IITA headquarters in Nigeria during 1980 to incorporate genes for resistance to maize streak virus into CIMMYT populations and experimental varieties for the lowland tropics of sub-Saharan Africa. By 1988 a high level of resistance had been attained in the population La Posta, and 14 resistant varieties had been developed from it. Another 16 varieties from other sources had been converted to streak resistance through backcrossing, 23 were still in this process (including 11 released varieties from national programs), and 14 varieties based on streak resistance conversions had been released in six countries.

Tolerance to acid soils, Andean zone—In the Andean regional maize program, we are developing germplasm that is tolerant to acid soils. This year, on the basis of results from international trials conducted in 1986-87, we selected and recombined promising entries from the 600 S_1 lines tested and formed four populations. We also continued improving tolerant populations formed previously and began developing experimental varieties from them.

Midaltitude maize station, Zimbabwe—In this breeding program, we are handling a large volume of germplasm complexes, a number of which perform well in comparison with hybrids already available in Zimbabwe and which will soon provide maize breeders of this region with many new options for improving midaltitude germplasm. We tested 23 new populations for overall performance and resistance to three prevalent diseases in midaltitude environments and advanced them to subsequent stages of breeding. We placed another 21 new complexes in recurrent selection based on their performance in multilocation testing. In addition, we visited or received visits from researchers in Malawi, Zambia, and Zimbabwe to discuss their breeding programs and sent trials to these countries and Mozambique.

Distribution of Maize Program international trials, 1988

Region	Progeny trials	Variety trials
Africa	10	255
Asia	11	393
Europe	0	3
Latin America and Caribbean	19	279
Middle East	1	29
Total trials	**41**	**959**
Total countries	**21**	**75**

The in-service maize improvement course now includes much more extensive instruction on the conservation of genetic resources and an introduction to biotechnology.

Direct Support of National Programs

Apart from their research responsibilities, all Maize Program staff provide some direct support to clients in national programs, mainly through training and consultation. Some staff concentrate almost exclusively on this task, particularly those involved in training at headquarters and in regional or bilateral programs outside Mexico.

Training at headquarters—In 1988 the Maize Program received 31 visiting scientists from 23 countries, two recipients of fellowships from chemical companies and five visiting scientists sponsored by the government of Japan, plus a total of 68 participants in the in-service maize improvement and crop management research courses (see table). In the curriculum of the improvement course, we made several adjustments that parallel recent developments in the Maize Program. It now includes, for example, much more extensive instruction on the conservation of genetic resources and an introduction to biotechnology. In addition, course participants are concentrating more on the choice among diverse breeding methods and are expressing greater interest in hybrid development. Other innovations are more intensive training in the use of microcomputers and research projects (on the utilization of germplasm bank accessions, for example) that yield information of value to CIMMYT and the course participants.

Although the crop management research course proceeded much as in previous years, we planned important changes that should result in even more appropriate training for developing country researchers. Our intention is to reduce the amount of time spent on crop management courses at headquarters (leaving us more time to develop training materials), reorient the training here toward more experienced researchers, and gradually increase the amount of instruction offered in national and regional programs. The latter shift ought to bring more national program scientists into the training effort and thus improve our chances of achieving a ''multiplier'' effect. Although implementation of these changes will not begin until 1989, they were foreshadowed during the 1988 courses by greater emphasis on diagnosis of problems in experimental plots and research planning and by the wider experience participants gained with maize production in different ecologies.

Support of germplasm development

Genetic resources:
- Germplasm bank
- Wide crosses

Crop protection:
- Entomology
- Pathology
- Physiology
- Hybrid maize

Germplasm improvement at headquarters

- Lowland tropical gene pools
- Subtropical gene pools
- Highland maize
- Quality protein maize (QPM)

Germplasm distribution:
- Population improvement
- International testing

Germplasm improvement in outreach

- Downy mildew resistance, Southeast Asia
- Corn stunt resistance, Central America and Caribbean
- CIMMYT/IITA breeding program, West Africa
- Tolerance to acid soils, Andean zone
- Midaltitude maize station, Zimbabwe

Direct support of national programs (in maize improvement and crop management research)

- Training at headquarters

Regional programs:
- Andean zone
- Asia
- Eastern Africa
- Central American and Caribbean
- Middle East and North Africa
- Southern Africa

Bilateral projects:
- Ghana

Headquarters

Outreach

Several changes were planned in the organization of the Maize Program during 1988 and are being implemented in 1989. Among the most noteworthy are the creation of various subprograms (crop protection, for example), the appointment of a coordinator for each subprogram, and the designation of a team leader for each outreach location.

Andean zone—In addition to developing germplasm tolerant to acid soils, we are working with our cooperators in various research areas of special relevance to the region. In support of efforts at CIMMYT headquarters to reorient QPM research, for example, we conducted 22 hybrid trials. We also worked closely with scientists in Ecuador on the improvement and dissemination of floury maize germplasm for the Andean zone, emphasizing seed production and resistance to fine stripe virus (the latter in cooperation with the Peruvian national program) and to corn earworm. A project on seed production and postharvest technologies completed its first year in Ecuador and was so successful that in 1989 the number of farmers participating will be doubled. In addition, we helped organize a wide range of staff development activities and conferences, including a course on microcomputers in Peru, a travelling seminar in Ecuador, and our 13th regional meeting, held in Peru and attended by 80 scientists from 15 countries.

Asia—Apart from the ongoing project for improvement of downy mildew resistance (page 31), we assisted in research on germplasm for acid soils by initiating selection in Indonesia for tolerance to aluminum toxicity in materials provided by the Andean Regional Program. We also offered several courses, including two on seed production (one in Thailand and the other in Nepal), participated in numerous planning sessions throughout the region, and contributed to various scientific meetings, including our third regional workshop, held in China and attended by 60 scientists representing 10 countries.

Eastern Africa—In this program we support maize improvement and crop management research, the latter with extra-core funds from the US Agency for International Development (USAID). An important challenge for many countries in the region is the rapid spread of maize streak virus from the lowlands to the medium and high elevations. Plant breeders in Burundi have responded by starting to incorporate streak resistance into Pool 9a, a highland material provided by CIMMYT, and in Uganda seed of several streak resistant varieties is being multiplied on a large scale for testing and distribution to farmers.

Both plant breeders and crop management specialists are addressing the aluminum toxicity/acid soil complex, which is still limited in extent but devastating where it does occur. In Burundi and Rwanda 120 highland materials from CIMMYT (including some germplasm bank accessions) and in Kenya five varieties from the Center's highland maize program were screened under this stress. More important than the genotype per se, however, are agronomic practices for acid soils. Another problem that requires input from breeding and crop management researchers is the parasitic weed *Striga*, on which collaborative research has been initiated in Kenya.

Central America and the Caribbean—Corn stunt resistance is one of four major areas in which maize breeders in Central America are concentrating, the others being germplasm adapted to limited moisture, improved resistance to ear rot, and hybrid development. In addition to the stunt resistant materials mentioned on page 31, two cultivars adapted to low moisture were released, one each in Honduras and El Salvador. A hybrid released in Guatemala outyielded 35 hybrids from other national programs and transnational seed companies in trials conducted at 20 locations in nine countries by the Central American Cooperative Program for the Improvement of Food Crops (PCCMCA). This organization, which held its 24th annual meeting in 1988, is responsible in large part for effective cooperation in the region, which has contributed much to the individual achievements of maize programs like Guatemala's. Seed production is another endeavor in which the region is progressing rapidly. CIMMYT contributed to this advance during 1988 by offering a seed production course in Panama and organizing seed industry workshops in El Salvador, Guatemala, and Honduras.

Countries of origin of participants in maize in-service courses, 1988

	Maize improvement	Crop management
Africa		
Congo	1	-
Ethiopia	1	1
Ghana	-	2
Kenya	-	3
Malawi	2	4
Mali	-	1
Somalia	1	1
Tanzania	1	4
Uganda	1	-
Zambia	3	-
Zimbabwe	1	-
Total	**11**	**16**
Asia		
Bangladesh	1	-
Bhutan	-	1
China	3	1
Indonesia	1	2
Malaysia	1	1
Nepal	1	1
Pakistan	-	1
The Philippines	2	1
Thailand	3	2
Vietnam	4	2
Total	**16**	**12**
Caribbean		
Haiti	-	1
Total	-	**1**
Middle East and North Africa		
Algeria	-	2
Egypt	1	1
Morocco	1	1
Syria	-	2
Turkey	2	2
Total	**4**	**8**
Total participants	**31**	**37**
Total countries	**19**	**22**

Middle East/North Africa—In recent years the national programs in some countries of the region have lost many of their better trained personnel to private seed companies. To help the public sector continue fulfilling its responsibilities in the improvement of maize production, we are placing even more emphasis than before on training. A regional program for training in seed production, for example, was initiated this year with a course held in Egypt.

Southern Africa—Like the eastern Africa regional program, we support both maize improvement and crop management research and in the latter work closely with CIMMYT economists. Through delivery of germplasm and consultation, we assisted with several variety development efforts in the region, particularly in Malawi, Mozambique, and Zambia. In support of crop managment research, we made a heavy commitment to in-country training, emphasizing on-farm diagnostic techniques (in a regional workshop in Zimbabwe, for example, and two workshops designed specifically for extension staff) and analysis and interpretation of on-farm trial results. We expanded the latter category of training this year in response to heavy demand across the region. In research on diagnostic techniques, we emphasized detailed monitoring of farmers' fields in cooperation with researchers in Zambia and Zimbabwe. In Malawi we helped establish closer links between the maize commodity and adaptive research teams by encouraging research on topics of mutual interest to the two groups.

Ghana—The Ghana Grains Development Project is funded by the government of Ghana and the Canadian International Development Agency (CIDA) and executed by the country's Crops Research Institute (CRI) and CIMMYT. In 1988 the project concluded its ninth year and, upon the strength of an impressive set of accomplishments, moved toward a new five-year phase. Its primary contributions have been to 1) develop improved technologies for maize and cowpea production (with IITA coordinating the work on cowpea) through multidisciplinary research at experiment stations and on farm and 2) increase the effectiveness of extension staff (of the Grains and Legumes Development Board and Ministry of Agriculture) by providing training, improving links between research and extension, and implementing a strategy for transferring improved technologies to farmers. Now that the national program is strong in technical ability, we will emphasize management skills during the next phase, in preparation for passing leadership of the project entirely to Ghanaian staff.

Nathan Russell

Ghanaian farmer Ama Amponsah cultivates maize and cassava, with various other crops, to obtain a secure food supply for her family. The GGDP, a bilateral venture in which CIMMYT participates, has developed recommendations that could improve the efficiency of her intercropping system.

Wheat Research

A major reorganization of our Program, new wide-ranging cooperation with the International Center for Agricultural Research in the Dry Areas (ICARDA), and the presentation of the King Baudouin International Agricultural Research Award to CIMMYT highlighted a busy 1988 for wheat staff at headquarters and in "outreach."

Our new structure, which evolved partially from deliberations during the External Programme and Management Reviews, will decentralize the administrative responsibilities and facilitate shifts in activities as well as the general move toward more strategic research. With the reorganization, germplasm will still be our main product, but we will empasize the strengthening of disciplinary research and more efficient management. One of four new subprograms is that of genetic resources (see figure, page 36). The creation of this subprogram reflects our awareness that genetic diversity is fundamental to sustaining wheat production in the future; the change also formalizes our comitment to collect, preserve, evaluate, document, distribute, and utilize all types of wheat genetic resources.

An important part of our agreement with ICARDA involves genetic resources activities in consultation with the International Board for Plant Genetic Resources (IBPGR). We will share responsibilities and backup support with ICARDA for various germplasm categories (for details on the agreement, see section on developments in outreach, page 45).

During International Center's Week in November, the King Baudouin International Research Award was presented to CIMMYT for the development of the Veery wheats. Veery-derived varieties, now grown in nearly 20 developing countries encompassing more than 4 million ha on five continents, have an average yield potential that is some 10% higher than Siete Cerros 66 and other widely adapted, high yielding varieties that gained broad acceptance in the early 1970s. The development of these wheats is an excellent example of the results that can be achieved when a wide array of genetic resources is available to breeders. In this case the better traits from the two major gene pools (spring- and winter-habit wheat) were combined by crossing a Russian winter wheat, two Mexican spring wheats, and an Indian spring wheat.

Genetic Resources

This new subprogram encompasses the wheat genetic resources section (germplasm bank), wide crosses, and germplasm enhancement. In general, activities are directed toward germplasm conservation and toward broadening the diversity of the wheat gene pool available to breeders (see page 38 for an explanation of our new base collection responsibilities in conjunction with ICARDA).

Thomas Luba

A Mexican farmer delivers his bountiful harvest to a station of the National Basic Foods Enterprise (CONASUPO), the government organization responsible for the country's grain marketing.

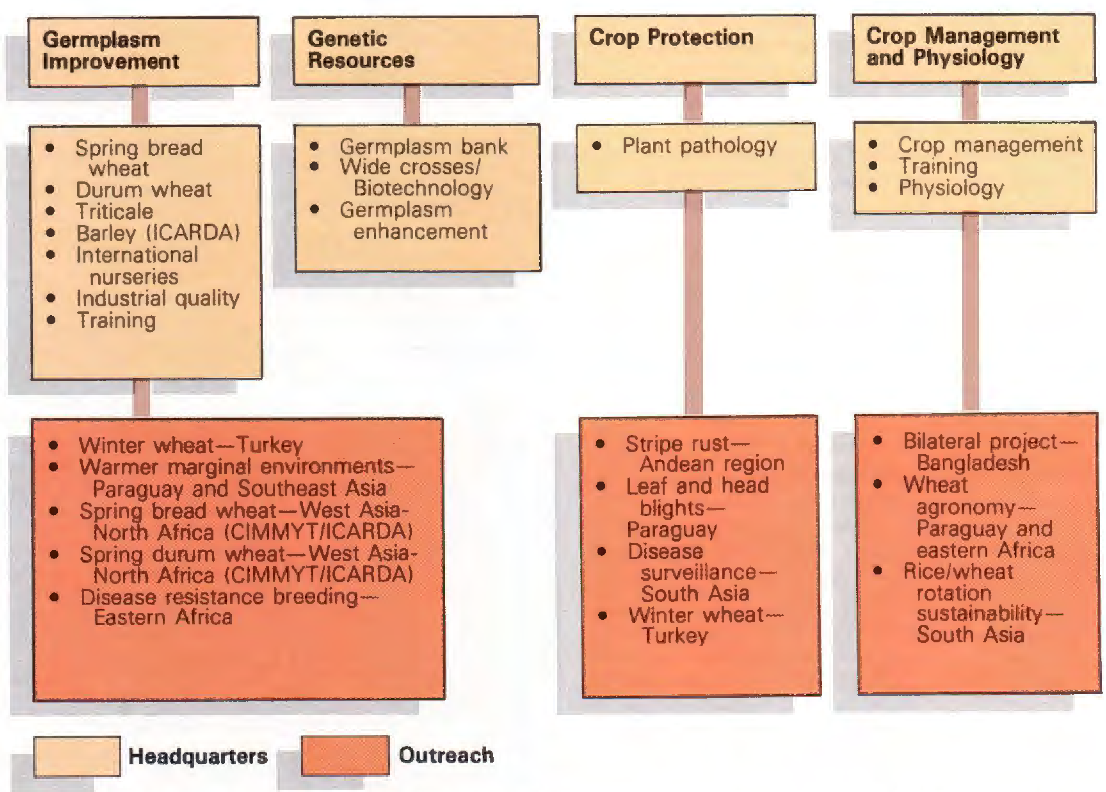
Because the world wheat germplasm collection is lacking in old spring bread wheat varieties, CIMMYT will be making a special effort to accumulate and preserve them.

As Sir Otto Frankel mentions in the Point of View section of this *Report*, accepting responsibility for a world base collection implies obligations, primarily in the areas of germplasm collection, evaluation, and documentation. We fear that the world wheat germplasm collection is lacking in old spring bread wheat varieties (material selected and developed by breeders), which are either cultivated on a limited basis in isolated regions or no longer planted at all. We will be making a special effort to accumulate them. For example, there are undoubtedly many useful characters in the nearly 800 varieties developed by Indian breeders since the early 1900s, most of which have been replaced by the Mexican wheats. CIMMYT and India must make sure that these varieties—and the special traits they may have—are saved from extinction. Similar situations involving old varieties exist in Pakistan, Turkey, North Africa, and elsewhere.

Collection of landraces (materials selected and maintained by farmers over the centuries) will have a lower priority since, as Sir Otto Frankel points out, for many crops—especially wheat—representative collections of landraces have already been accomplished. However, we will not pass up an opportunity to collect landraces when feasible. For example, recently the wheat genetic resources section collected several 16th century Spanish landraces still being grown by small scale farmers in the remote mountain areas of the state of Michoacán, Mexico. We became aware of these wheats through a geographer working in the region for the CIMMYT Economics Program (see Economics Research).

The current CIMMYT collection contains over 9,600 bread wheat and 3,900 durum wheat landrace accessions, and there are many others in regional and national banks around the world. We will be evaluating landraces that have not yet been included in wheat breeding programs for 1) passport data, 2) classification, and 3) evaluation of selected traits. These landraces may offer new opportunities for selection and utilization.

Regarding documentation and information exchange, a computer based pedigree management system (PMS) within the Wheat Program is already in place. The PMS is a genealogical database that identifies released



The Wheat Program now consists of four new subprograms. This reorganization will help decentralize administrative responsibilities and facilitate strategic research.

varieties, advanced lines, and breeding lines by their parents and registers the segregating populations in the breeding programs. For landraces, primitive, wheats, and wild species, the database contains various limited types of passport information, such as country of origin, name, and year of collection or release. Various database publishing functions are possible with the PMS. For example, we have agreed to publish the Catalog of Wheat Cultivar Abbreviations, formerly done by Oregon State University, USA. Another useful feature is the ability to perform hierachical cluster analysis based on pedigrees of germplasm bank accessions (see figure, page 40). Such analysis will enable us to group germplasm in our wheat germplasm bank and to determine the original landraces and old varieties that form the base of our modern wheat varieties. In 1989 we will start linking the databases of the germplasm bank, international nurseries, and yield trials to the PMS system. The total scheme may someday be electronically compatible with other major systems such as those in the USA, Japan, Turkey, Ethiopia, India, and eventually the Soviet Union, so that valuable genetic information can be freely exchanged.

Molecular biology appears to hold great potential for wheat breeding. Since the late 1970s. CIMMYT has been applying wide cross techniques to introgress useful genes within and between distantly related species. The newer gene technologies promise to speed that and other work. That this research is redefining breeding potential became evident when CIMMYT hosted the Second International Symposium on Genetic Manipulation in Crops, which was held in August and attended by more than 50 specialists from developed and developing countries. Jointly sponsored with the International Rice Research Institute (IRRI) and China's Academia Sinica, the meeting provided an opportunity to synthesize current research achievements in genetic manipulation and to chart broad pathways for the future. Proceedings of the meeting will be published in 1989. By hosting the symposium, CIMMYT demonstrated its interest in this research. The Wheat Program will become involved in this work to facilitate the rapid exploitation of new techniques and to link our breeders with CIMMYT's new biotechnology unit, for which a laboratory is currently under construction. Procedures involving tissue culture, RFLPs, isozymes, and incorporation of genes from wild species promise to make prebreeding efforts even more efficient by providing our breeders with new genetic resources. In light of our new base collection responsibilities and the movement into molecular research activities, the genetic resources subprogram is targeted for expansion over the next five years.

Thomas Luba

Tarascan ruins at Ihuatzio in the state of Michoacán, Mexico, are a reminder of the indigenous culture into which Spaniards introduced wheat during the 1530s. Bent Skovmand, head of the wheat germplasm bank, collects landraces of Spanish origin that are still grown by the region's small scale farmers.

Germplasm bank—We distributed over 2,100 lines during 1988—some 1,700 to CIMMYT breeders and more than 350 to 19 national programs. We obtained over 3,500 lines for inclusion in the bank—about half from eight national programs and the rest from our breeders at headquarters. Considerable emphasis was placed on clarifying the names and pedigrees of accessions for inclusion in the pedigree management system described above.

Wide crosses—In 1988 new material from our intergeneric work was delivered to the breeders. Advanced stable derivatives from the alien species *Agropyron distichum* and *Elymus giganteus* for leaf rust resistance, grain color variation, maturity, and 1B/1R or 1B homozygosity were turned over to the bread wheat section for further evaluation. Lines of this material are currently being tested in the

Continued on page 40

Conserving and Utilizing Wheat Genetic Resources

CIMMYT acknowledges the importance of conserving genetic resources on a wider scale and has agreed to share wheat germplasm responsibilities with ICARDA.

Conservation

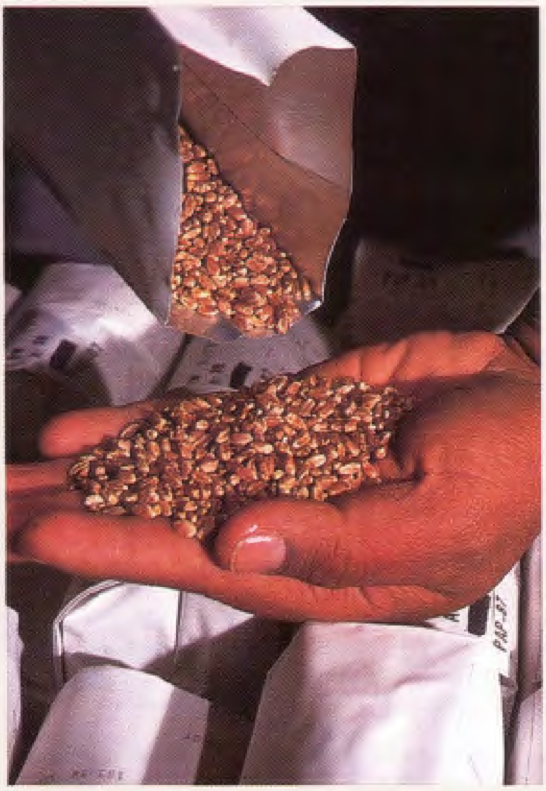
Conservation of wheat genetic resources at CIMMYT has evolved from a small cold storage facility (during 1966-81), which safeguarded a limited amount of important breeding materials, to the present seed house with four cold rooms. This modern germplasm bank currently maintains under medium term storage (10-20 years at 0°C) nearly 62,000 accessions of bread wheat, durum wheat, triticale, barley, primitive wheats, and wild wheat relatives and has, since its establishment in 1981, distributed some 67,000 samples of this stored germplasm to national programs around the world.

Current bank makeup—Germplasm in the bank is divided into two collections, one consisting of 30,758 accessions (international screening and yield nurseries, spring and winter crossing blocks, primary triticales, progenitors, and interspecific and intergeneric crosses) and the other of 31,025 accessions (germplasm entries with known potential for improvement as well as landraces and wild species).

New mandate—Our main concern up to now has been to conserve germplasm developed by our own breeders. However, in 1988, as part of our strategy for the future, we acknowledged the importance of conserving genetic resources on a wider scale. After conferring with IBPGR, we have agreed to share wheat germplasm conservation responsibilities with ICARDA as part of our new accord with them. We have accepted world base collection responsibilities for bread wheats and triticales; ICARDA has assumed base collection responsibility for durum wheats and wild relatives of wheat. The respective base collections of one center will be duplicated as a backup at the other center. To carry out these new base collection responsibilites, a long term seed storage facility (20 years or more at -18°C) will be added to the complex in the near future.

Germplasm evaluation—CIMMYT breeders foresee the need for increased genetic variability in the next 10-15 years. For example, our greater emphasis on breeding for marginal areas requires variablity related to tolerance to drought and other abiotic stresses. A major mission of the wheat genetic resources section will be to identify such variability and make it available to breeders. Therefore, we are formulating a systematic evaluation program to satisfy such needs. One element of this evaluation work may be to develop a "core" collection, which Sir Otto Frankel discusses in the Point of View section of this *Report*. This core would be representative of the entire collection that would be available for evaluation and distribution to national programs in need of greater variability. A core concept also offers the advantage that the representative collection would be thoroughly evaluated and could be distributed with the complete database.

Information management—We are presently developing databases to handle passport information, characterization, and evaluation information. These databases are foreseen to be interactive with the newly developed pedigree management system (see figure, page 40), which will make the program accessible not only to CIMMYT breeders but, with additional software, to regional and national wheat genetic resources programs. Eventually, the bank's catalog of accessions will be available on CD-ROM, as is already the case for maize germplasm bank accessions.



A major activity of the wheat germplasm bank is to identify genetic variability for key traits in the more than 60,000 accessions currently contained in the bank.

Sergio Pastén

Utilization

Storing genetic resources in a germplasm bank ensures their preservation, but it is only half the battle in efforts to develop improved varieties—the other half is the utilization of these resources. After material preserved in our germplasm bank and elsewhere has been evaluated for valuable characters, it is the job of two sections (wide crosses and germplasm enhancement) in the genetic resources subprogram to make these genetic traits available to CIMMYT breeders and collaborators for varietal improvement.

Wide crosses—As new races of pathogens appear and wheat cultivation is extended into new areas, a stock of alien genetic material introduced from wide hybrids may prove to be of great value as a source of additional variability in the conventional gene pool. Toward this goal much has been accomplished in our wide crosses work since the initiation of this research at CIMMYT in 1979. Parts of the work are being done in collaboration with laboratories in the USA, UK, Pakistan, and India.

Sergio Pastén

The aim of the wheat wide crosses section, headed by A. Mujeeb-Kazi, is to transfer useful alien genetic material from wide hybrids to the conventional wheat gene pool.

The alien genera involved include approximately 325 annual/perennial species of the tribe Triticeae such as *Agropyron, Elymus, Haynaldia, Secale*, and *Hordeum*. Over the last decade, we have made significant progress in producing complex hybrids by overcoming constraints imposed by crossability barriers and by improving embryo development. Procedures have been developed to advance F_1 hybrids through applied cytogenetics to facilitate development of advanced derivatives for breeder use that have resistance to leaf rust, helminthosporium, and fusarium and tolerance to copper and salt. We have turned over to breeders several wheat x *A. distichum* and x *E. giganteus* derivatives that have improved grain color and leaf rust resistance. In some cases these have already reached the yield testing stage in some national programs.

In 1988 we began intensive work to incorporate biotic and abiotic variability from closely related sources (principally *Triticum* species). Here we are manipulating the A, B, and D genomes of wheat by hybridizing them with similar or near-similar sources, such as *T. monococcum* for the A genome, *T. speltoides* for the B genome, and *T. tauschii* for the D genome. A series of synthetic wheats having parents with very high levels of tolerance to Karnal bunt are currently being evaluated for tolerance to this and other diseases and stresses.

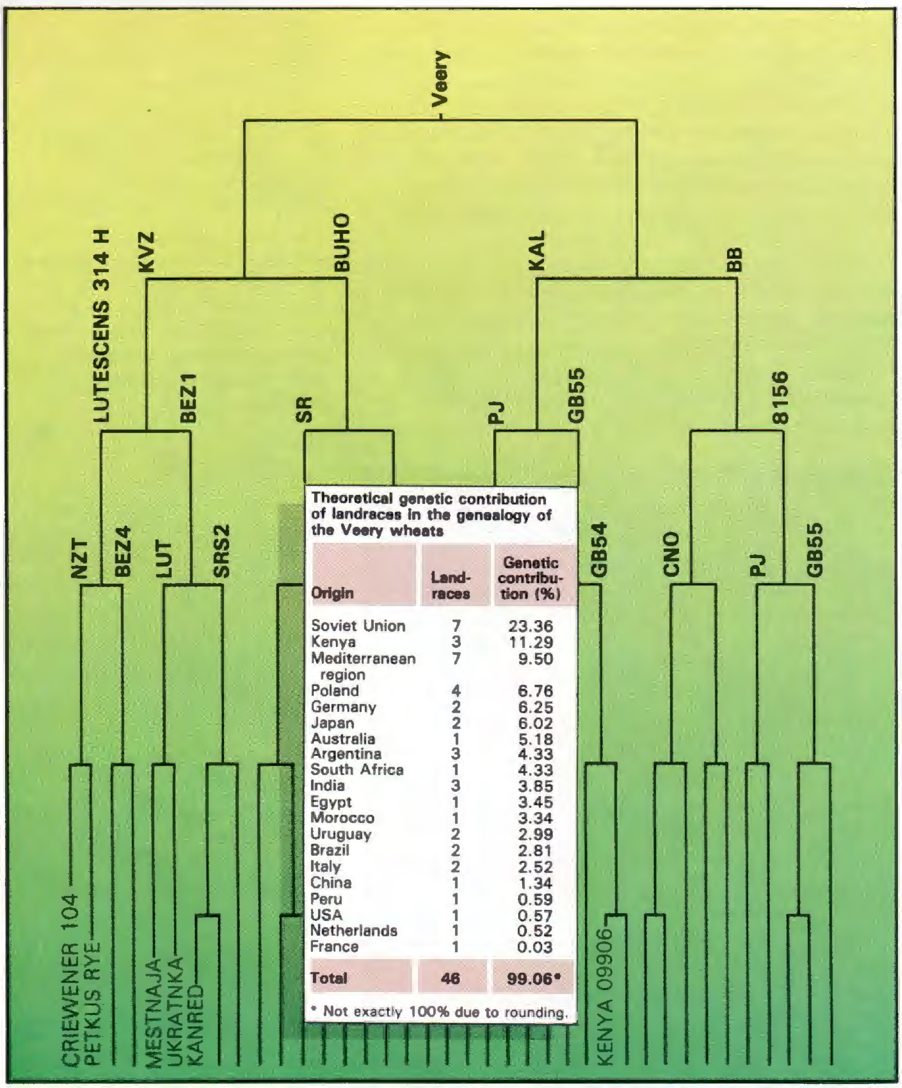
Germplasm enhancement—Many useful genes are widely dispersed in landraces, primitive wheats, and old varieties. Through traditional breeding techniques in the field, the germplasm enhancement section (formerly basic germplasm development) attempts to transfer these genes to lines with good agronomic characters that the breeders can use in their crossing programs. For example, we know there are certain landraces and old varieties from Mexico and Pakistan that can tolerate salt in the soil. We are currently attempting to combine their genetic backgrounds into lines for the breeders. If we are successful, it will enhance the salt tolerance potential of advanced lines that we deliver to national programs.

There have been significant successes in transferring genes conferring high protein, high yield components, and solid stems from primitive lines to better genetic backgrounds. Current activities include the transfer of Karnal bunt resistance from durum wheat and triticale to bread wheat, the transfer of fusarium resistance from bread wheat to durum wheat, and on the introduction of dwarfing, earliness, and good grain type into triticale.

Thomas Luba

The wheat germplasm enhancement section transfers genes that influence yield components, such as large spike size (right), to lines with good agronomic characters (left) for use in crossing programs.

international bread wheat screening nursery, the bread wheat crossing block, and in yield trials at Ciudad Obregón and in national wheat yield trials in Pakistan. Advanced derivatives from crosses of *Triticum aestivum* (bread wheat) with *A. distichum, E. giganteus,* and *A. curvifolium* selected for *Fusarium graminearum* tolerance in Toluca simultaneously continue to express higher tolerance to *Helminthosporium sativum* at Poza Rica where the disease caused by *H. sativum* develops naturally. These lines are undergoing tests in China, Brazil, Nepal, and West Germany.



Theoretical genetic contribution of landraces in the genealogy of the Veery wheats

Origin	Land-races	Genetic contribu-tion (%)
Soviet Union	7	23.36
Kenya	3	11.29
Mediterranean region	7	9.50
Poland	4	6.76
Germany	2	6.25
Japan	2	6.02
Australia	1	5.18
Argentina	3	4.33
South Africa	1	4.33
India	3	3.85
Egypt	1	3.45
Morocco	1	3.34
Uruguay	2	2.99
Brazil	2	2.81
Italy	2	2.52
China	1	1.34
Peru	1	0.59
USA	1	0.57
Netherlands	1	0.52
France	1	0.03
Total	**46**	**99.06***

* Not exactly 100% due to rounding.

This partial genealogy of the Veery wheats, generated with the Wheat Program's new pedigree management system (PMS), goes back only five generations but already shows six landraces. Using PMS to go as far back as possible shows 46 landraces, as indicated in the table. Comparing sets of landraces among the hierarchical trees of modern varieties will help breeders trace useful traits to specific landraces and identify landraces that have not yet been used in improvement programs.

Germplasm enhancement—This section continues to have as its goal the placement of useful traits in germplasm that can be used in our conventional wheat and triticale breeding efforts. For example, in our current work to assist in the development of bread wheats resistant to a wide range of diseases, we continued forming lines with good agronomic type using Brazilian wheats. A number of our crosses involving these wheats have shown good Karnal bunt resistance over three test cycles. In addition, special efforts are being made to transfer leaf rust resistance, high bread making quality, and plant types with large spikes and high fertility.

Germplasm Improvement

This subprogram encompasses seven sections at headquarters and activities in five locations in outreach. During the next five years, we envision a small shift in activities within the subprogram but plan to keep the overall number of international staff relatively constant. In November subprogram leader Sanjaya Rajaram was named a fellow of both the American Society of Agronomy and the Crop Science Society of America. Both organizations cited him for the more than 120 wheat varieties released in 30 developing countries that have been derived from germplasm developed under his leadership at CIMMYT over the last 20 years.

Spring bread wheat—The yield potential of our spring bread wheat germplasm continues to increase. In 1988 Kauz (= Ures/Opata), a recent advanced line, broke the yield plateau of its Veery parent (Ures) by an average of 3% when tested in optimum, high temperature, and reduced irrigation environments in the state of Sonora, Mexico. In optimum environments in Sonora and Spain, it yielded 10 t/ha. Kauz, characterized by higher tiller survival, produces a white grain that is popular in many developing countries.

Durum wheat—Varieties and advanced lines in the 16th Elite Durum Wheat Trial were found to have high yield potential and yield stability. They included Mexicali 75, Yavaros 79, Altar 84, Chen'S', Aix'S', Yavaros 79'S'/H.Reo/ 4*Sx, Wulp'S', and Chichicuilote'S'/ Sandpiper'S'//Yavaros 79'S'. These entries will be used frequently in the crossing plan to combine their high yield potential and yield stability with different sources of disease resistance and semolina quality. Varieties with the unique erect-leaf plant type, such as Altar 84 and Yavaros 79, continued to break records (up to 8 t/ha) in farmers' fields under high inputs. These varieties and their reselections or derivatives are becoming the basis for durum wheat production in North Africa and the Middle East as well as forming the beginning of a new durum wheat industry in the southwestern United States. Our agronomists achieved record yields of more than 11 t/ha on station with Altar 84 by using some improved cultural practices (see section on crop management and physiology).

Triticale—Markedly improved yields were obtained in 1988; 19% and 30% of advanced lines exhibited superior yields over the best checks under optimal and reduced irrigation conditions, respectively. The most outstanding lines identified were derivatives of interspecific, winter x spring, and complete x substitute triticale crosses. These lines displayed high yield potential and high stable test weight across several environments. Recent information from our drought trials show complete triticales to be superior to substitute triticales in low moisture environments. A project initiated in 1988 and financed by the Directorate for Development Cooperation and Humanitarian Aid, Switzerland, aims at elucidating the genetic control and biochemistry of bread making quality in CIMMYT triticale germplasm.

ICARDA/CIMMYT barley—Under the new ICARDA/CIMMYT agreement, ICARDA will continue to post a barley breeder at El Batán. This person will concentrate on yield potential and disease resistance for the wetter barley growing regions, such as the Andean zone, China, Nepal, and Ethiopia. High yielding barley lines with multiple disease resistance emanating from this collaborative program were released in Latin America in 1988 or will be released in the near future. In Bolivia yield tests identified disease resistant ICARDA/CIMMYT barleys that outyielded the national check by 2 t/ha. With the appearance of stripe rust race 24 in Mexico in 1988, resistant ICARDA/CIMMYT materials are in demand by the Mexican national program. Several lines that combine stripe rust resistance with good malting quality were identified and are being increased.

International nurseries—In 1988 we conducted a users survey on the format and function of international nurseries bulletins. Based on responses we plan changes that will make these documents more useful to CIMMYT staff and cooperators. For example, cluster analysis of across-site data was recommended in the survey. To make across-site clustering and other analyses more precise, we are already planning to use a lattice design in our nurseries which would provide greater within-trial accuracy. In the coming cycle, we will test a generalized lattice design in the International Triticale Yield Nursery in which entries will be independently randomized at each site. We will be evaluating the anticipated increased trial accuracy that this should confer.

In collaboration with the Biometrics Unit, we began using a relatively new statistical analysis, the Additive Main Effects and Multiplicative Interaction (AMMI) procedure. We are applying it to large genotype-by-site data sets from the international yield trials. The analysis can aid in reducing the "noise" inherent in these data. In a three-replicate trial, two replicates were repeatedly selected at random for every combination of genotype and site and were used by the model underlying the AMMI analysis to predict values for the remaining replicate. The predicted values approximated the observed values better than means of the two replicates used.

Triticale's hardiness in harsh environments is exemplified by Eronga 83, planted by Mexican farmer Mateo Campos (left, inset, with Judith Carney, geographer in the CIMMYT Economics Program). Campos, who adopted triticale in 1965 and has been growing it ever since during the dry season, applies no fertilizer but can still obtain a yield of up to 1.5 t/ha.

Gene Hettel Thomas Luba (inset)

Gene Hettel

Wheat Program director Tony Fischer (left) and George Varughese, associate director, assumed their positions in 1988.

In 1988 we sent collaborating scientists in 84 countries over 2,000 sets of bread wheat, durum wheat, and triticale nurseries plus 630 sets of germplasm development and special nurseries (see table). In cooperation with ICARDA, we prepared and distributed almost 300 sets of barley nurseries for testing in 56 countries.

Industrial quality—In the wheat quality laboratory, we evaluate physical and chemical characteristics associated with end product quality. In 1988 we observed that dough stickiness did not appear in several 1B/1R translocation wheats when moderate speed mixing was applied. This is significant because it has been claimed that these wheats generally have this undesirable trait at higher dough mixing speeds. In another study we confirmed that flours from substitute triticales have better bread making quality than complete triticale flours because the substitutes tend to have a higher gluten content than the completes.

Wheat mega-environments—Identifying and refining world wheat mega-environments continues as we set priorities within our new Program structure. We recognize that the true value of delineating mega-environments for our various crops in the germplasm improvement subprogram becomes especially apparent when we closely relate them to genotype x environment interactions. An important objective during the next five years will be to validate the seven mega-environments listed in the figure. Much work remains to strengthen our database on these target environments, to validate the mega-environments listed in the figure, and to better quantify abiotic and biotic stresses as well as socioeconomic factors by mega-environment.

Distribution of Wheat Program international nurseries, 1988

	Bread wheat	Durum wheat	Triticale	Barley	Germplasm development	Special nurseries[a]
Africa	253	106	59	69	57	71
Asia	289	47	44	69	75	46
Europe	178	115	90	58	48	59
Latin America	307	106	83	42	63	80
Middle East	126	75	24	37	36	40
North America	56	19	20	21	18	24
Oceania	15	10	10	3	3	10
Total nurseries	**1224**	**478**	**330**	**299**	**300**	**330**
Total countries	**83**	**61**	**65**	**56**	**59**	**58**

a Special nurseries include International Disease Trap Nurseries, the Karnal Bunt Screening Nursery, and Barley Yellow Dwarf Virus Nurseries.

Crop Protection

This subprogram currently encompasses one section at headquarters and activities in four outreach locations. The activities of the eight international scientists currently assigned to crop protection cover most major wheat diseases. During the next five years, we hope to strengthen strategic research on all major wheat pathogens. This would place us in a strong position to take advantage of initial applications in molecular biology, which are likely to be in the area of disease management.

Karnal bunt—Although Karnal bunt, caused by the fungus *Tilletia indica,* is a disease of low to moderate severity in India, Pakistan, Nepal, and Mexico, as a quarantinable disease it seriously affects germplasm movement globally as well as within the CIMMYT breeding program in Mexico. Following the experience of India, our pathologists place great emphasis on genetic resistance as a long term, inexpensive solution. Therefore, we are screening wheat germplasm in search of genetic variability for resistance, and 1988 results confirm the existence of this variability. Against a maximum level of 86% kernel infection after artificial inoculation, 58 bread wheat lines from the Fourth Karnal Bunt Screening Nursery showed less than 4% infection. These lines have shown consistently low susceptibility to the fungus for at least four years. In addition, we confirmed the efficacy of propiconazole in reducing infection levels when sprayed at the onset of flowering. As part of our effort to develop Karnal bunt resistant germplasm, we formalized a breeding partnership with Punjab Agricultural University (PAU) in 1988. There will be a constant exchange of germplasm and scientists between PAU and CIMMYT in this shuttle breeding venture. Germplasm developed in this partnership will be distributed throughout our international nursery system as a joint product of CIMMYT and PAU.

Global disease monitoring and genetics of rust resistance—Since the 1970s we have conducted a disease surveillance program in which a network of cooperators has helped monitor and survey prevalent diseases and pathogen races. During 1986 this activity was expanded to include prevalent races of the three rust diseases. Various aspects of the monitoring work and related research on the genetics of rust resistance are supported by the German Agency for Technical Cooperation (GTZ).

In Mexico during 1988, we made a detailed study of the pathogenicity variation in *Puccinia recondita tritici* (leaf rust) and identified 18 pathotypes (races). Similarly, six races of *P. graminis tritici* (stem rust) were identified. Also, the presence of known leaf rust resistance genes and additional genes for partial (adult plant) resistance was postulated in 47 Mexican varieties released from 1960 to 1988. We conducted detailed pathological and genetic analyses of partial resistance to *P. recondita tritici* in the CIMMYT bread wheat germplasm. It was found the germplasm had high variability and that the components of partial resistance were under control of the same genes. We were able to demonstrate that these genes for partial resistance, though they have small individual effects, interact in a complex additive manner whereby a combination of three to four such genes could result in very effective partial resistance.

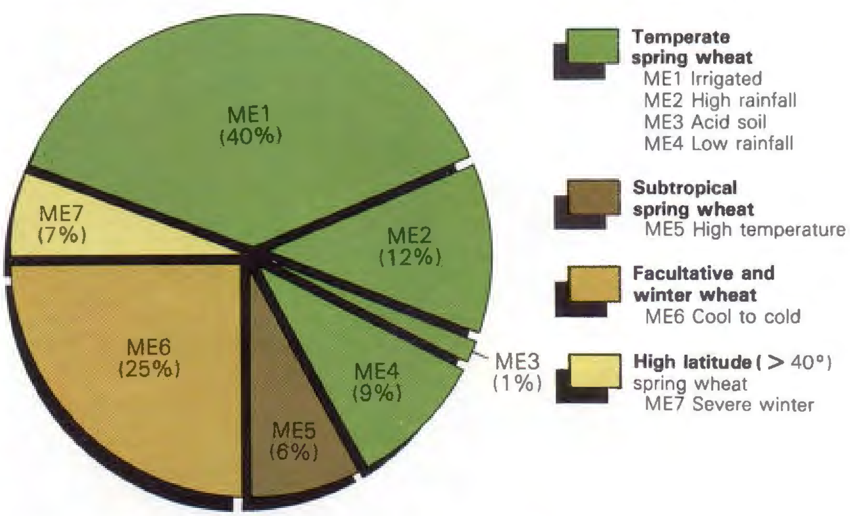
Barley yellow dwarf virus (BYDV)—Research on this significant virus disease of cereals continues to be supported in part by the Government of Italy. Through capture of live aphids at El Batán and Toluca, we confirmed that *Metopolophium dirhodum* is the major vector of BYDV in the high valleys of Mexico. It appears that the most common isolate of BYDV is MAV-like but that there are also some PAV- and RPV-like isolates present. On leaves sampled from labelled plants grown during both the 1988 winter and summer growing cycles at Toluca, we found that the relative proportions of isolates differ depending on the time of year. This finding has far-reaching consequences in our efforts to breed for resistance.

Soilborne pathogens—Research on soilborne pathogens was initiated during 1988. Our long term goal is sustainability of crop yields in all farming systems, including intensive ones in which the buildup of soil pathogens, causing diseases such as common root rot and take-all, is thought to be more critical. Progress was made in identifying plant parasitic nematodes, evaluating direct crop losses, and assessing the indirect role of nematodes in inciting or contributing to other soilborne diseases.

Bacterial diseases—Research on bacterial diseases is supported by the Belgian Administration for Development Cooperation (BADC). Its aim is to reduce losses, and major emphasis is given to bacterial leaf streak caused by *Xanthomonas campestris* pv. *undulosa*. As bread wheat, durum wheat, and triticale push into the high rainfall, humid mega-environment, *X. c.* pv. *undulosa* is increasingly affecting these crops worldwide. CIMMYT is conducting research in Mexico on field aspects of the disease related to epidemiology, development of inoculation techniques for screening of varieties, evaluation of economic losses, transmission by seed, and control methods. In 1988 we developed a technique using a semiselective agar medium for routine detection of the presence of *X. c.* pv. *undulosa* in seed. We also conducted epidemiological studies to determine favorable climatic factors for the disease.

Crop Management and Physiology

This subprogram currently encompasses three sections at base and activities in four outreach locations. Some of the activities of the seven international scientists currently assigned to crop management and physiology are related to germplasm improvement (physiological screening and management of breeders'



Wheat mega-environments in developing countries as used by the CIMMYT Wheat Program, January 1989. Percentages reflect each mega-environment's share of the combined average bread and durum wheat production of 208 million metric tons per year for the 1984-86 growing seasons.

nurseries and experiments). However, much of the work involves adaptive agronomy in South America, East Africa, and South Asia (see section on developments in outreach).

Over the next five years, we expect some reallocation and growth of activities in this subprogram. In 1988 strategic work on sustainability of the rice-wheat rotation commenced in Nepal. We may shift adaptive agronomy work in South America to strategic research on the sustainability of the region's highly erodible cropping systems using wheat, particularly the predominant wheat-soybean rotation. At headquarters we foresee expanding our strategic research on components of wheat crop management, with the ultimate objective of producing an expert system for wheat research agronomists in the irrigated, temperate, high input mega-environment.

Crop management—A significant development occurred in our management practices at the CIANO station in the Yaqui Valley of northwestern Mexico. During the last five to six years, breeders have been concerned that advanced lines and other materials have not been realizing the yield increases experienced in the past under the high yield environment of the CIANO station. Agronomists have been looking at the possibility that some of the traditional cultural practices on the station may be limiting the expression of yield potential.

From the beginning we felt the main constraints were soil related—organic matter in the soil was low (0.5%), and deteriorating soil physical properties along with increased soil compaction may have been problems. We compared three new practices with the traditional management regime: 1) application of chicken manure as a source of organic matter to improve physical properties in addition to providing nutrients, 2) subsoiling (through deep knifing) to break up any compaction layers, and 3) plow down of a green manure crop (sesbania) to provide another source of organic matter. Trials compared subsoiling and no subsoiling, plow down of a summer green manure crop and a commercial summer soybean crop (common on the station and in local farmers' fields), and combinations of chicken manure and nitrogen fertilizer. All other management practices (basal levels of phosphorus, irrigation, etc.) remained the same across these treatments. With the durum wheat Altar 84, an additional and independent yield response was obtained with the new practices of subsoiling and plow down of sesbania and with chicken manure application. It is apparent that putting these new practices into effect stationwide should provide an environment that will allow experimental materials to express their true yield potential. In these trials we also discovered that in reducing the soil constraints to yield potential, we are also maintaining, in some cases actually increasing, the protein level in the grain. The relationship between yield and protein content is normally inverse; the effects of the new management practices on it warrant more investigation.

Barley yellow dwarf virus at the Toluca station attracts the attention of Rey Villareal, CIMMYT wheat improvement training officer, and trainees (from left) Dong Jinying and Xia Zhengang (China), Jinantana Kongchit (Thailand), Rose John Mongi (Tanzania), and Alicia Del Blanco (Argentina).

Gene Hettel

Training

In-service training in Mexico is an integral part of the germplasm improvement, crop production, and crop management and physiology subprograms. In 1988 the wheat improvement and production courses provided practical training for 41 wheat researchers from 25 countries (see table).

Improvement—Key features of this 32-week course included:

- A trainee-organized and conducted field day at Toluca
- Intensive exercises in disease diagnosis
- Increased integration of breeding, pathology, and crop management
- Involvement of eminent visiting scientists to serve as guest lecturers and to interact with trainees

- Encouragement of trainees to make crosses for their own programs
- Experience in preparing and presenting a project proposal

Production—Participants in this 30-week course studied both theoretical and practical principles of agronomy research. Trainees conducted trials in farmers' fields at Chalco in the State of Mexico and on station at El Batán and Toluca. Each trainee was assigned primary responsibility for an on-farm trial; on-station trials were conducted in groups. Trainees also conducted a harvest survey of 38 farmers in the Chalco area. This exercise required them to apply their agronomic knowledge to identify limiting factors in the area. In light of their findings in the survey, the trainees were able to more accurately assess their on-farm trials.

Visiting scientist fellowships—In 1988, nearly 50 visiting scientists from 22 developing countries spent time (totalling approximately 1,200 scientist-days) with the Wheat Program in Mexico. Two visiting scientists from Ethiopia and one each from India and Tanzania completed more intensive fellowship programs within the Wheat Program. These fellowships, funded in part by international seed and chemical companies, emphasize longer and more substantial research projects. We will use the cash prize associated with the King Baudouin International Research Award mentioned earlier to set up two to three additional fellowships. These will be earmarked for experienced senior staff in national programs to expand their research capabilities.

Developments in "Outreach"

CIMMYT/ICARDA wheat—Late in 1988 we held substantive discussions with ICARDA regarding wheat and barley improvement. The aim is to achieve efficient deployment of CGIAR resources for the benefit of cereal researchers in national programs and cereal farmers in the West Asia-North Africa (WANA) region. The general thrust is for closer collaboration in regional breeding of spring, facultative, and winter wheats in WANA. Collaboration will be expanded to cover such related activities as genetic resources, pathology, entomology, physiology, biotechnology, agroclimatic zoning, crop management, and training. Joint research and training at ICARDA will be focused on lower rainfall areas, while CIMMYT will concentrate on the higher rainfall and irrigated areas.

In view of the numerous complementarities between CIMMYT and ICARDA, close collaboration is essential, particularly in genetic improvement. This is reflected in the acknowledged need for a fully operational wheat breeding activity within the WANA region. The best advanced bread and durum wheat lines from Aleppo and Mexico will be tested in key locations in the WANA region from which further selections will be made for placement in low rainfall, high rainfall, and irrigated screening nurseries for each crop. A triticale nursery will be planted alongside the joint key location nursery in North Africa.

In addition to the CIMMYT bread wheat and durum wheat breeders already stationed at Aleppo, we will post a third scientist at ICARDA, who will act as overall project liaison and have scientific responsibilities, primarily for breeding facultative bread wheats for the high elevation areas of the WANA region (see next section on winter and facultative wheats). For discussions on how the agreement affects wheat genetic resources and barley, see the sections on the genetic resources and germplasm improvement subprograms.

While the new agreement was being forged, important work continued on bread and durum wheats in the WANA region. In 1988 bread wheat breeding efforts maintained their focus on developing germplasm suitable to the low rainfall (less than 400 mm) areas of WANA, where approximately 7.3 million ha of bread wheat are grown. In close collaboration with colleagues from ICARDA, the CIMMYT breeder identified genetic stocks that have tolerance to stresses predominant in the region, such as drought, cold, heat, stripe rust, septoria, sawfly, and Hessian fly. In collaboration with ICARDA and national program scientists, our durum breeder achieved notable progress in increasing dryland durum wheat yields, reflected in the release of several genotypes in the dry areas of the WANA region and the performance of advanced and promising lines in the dry areas. Since the genetic base of these improved durum wheat varieties is narrow, particularly for biotic and abiotic stresses, quality, and earliness, work was continued to broaden that base. Several crosses with landraces from North Africa and from West Asia were made to upgrade tolerance to drought, cold, and premature desiccation and resistance to common bunt and *Septoria tritici*.

Countries of origin of wheat in-service trainees, 1988

	Improvement	Production
Africa		
Algeria	1	1
Ethiopia	1	2
Libya	1	-
Madagascar	-	1
Morocco	1	1
Rwanda	-	1
Somalia	-	1
Sudan	1	1
Tanzania	1	-
Total	6	8
Asia		
China	2	2
Indonesia	-	1
Nepal	1	1
Syria	1	-
Thailand	2	1
Total	6	5
Latin America		
Argentina	1	-
Bolivia	-	2
Brazil	1	-
Chile	1	-
Colombia	1	1
Guatemala	1	1
Mexico	1	-
Paraguay	-	1
Peru	1	2
Total	7	7
Europe		
Spain	1	-
Romania	1	-
Total	2	-
Total trainees	**21**	**20**
Total countries	**19**	**16**

Nigeria, Zambia, Burma, Thailand, Brazil, and Paraguay have released varieties that yield up to 3 t/ha in rainfed, warmer marginal environments.

Winter and facultative wheats (Turkey)—There are currently two independent projects for these crops: the CIMMYT/Turkey winter wheat and facultative breeding project and the ICARDA high elevation breeding project. We recognize that winter and facultative wheats form part of a continuum and that it will be important to integrate the Turkey based and ICARDA projects. For the duration of the CIMMYT/Turkey agreement, we will continue to develop true winter wheats and distribute germplasm from nurseries in Turkey. Afterwards, in consultation with Turkey's national program, an integrated joint project involving ICARDA will be developed for all the high elevation areas of West Asia and North Africa. In 1988 the CIMMYT/Turkey project concentrated on the introduction and evaluation of winter wheat germplasm, which was obtained from 11 programs outside Turkey involving about 4,000 lines. The bread wheat and durum wheat crossing programs in Mexico expanded their efforts to include special winter x spring crosses for the CIMMYT/Turkey project. F_1s from these crosses were planted at Izmir, and topcrosses to selected lines were made. These materials are now being advanced and evaluated.

Warmer marginal environments—The widening gap between wheat consumption and production in the warmer regions led to the initiation of this United Nations Development Programme (UNDP) sponsored research in 1982. Now midway through its second phase, the project has made substantial progress in the development of germplasm and crop management practices for the warmer, marginal climates. Nigeria, Zambia, Burma, Thailand, Brazil, and Paraguay are some of the countries that have released varieties through our international testing system. With appropriate cultural practices, these varieties yield up to 3 t/ha in certain rainfed areas.

New drought tolerant germplam was identified and selected in Bolivia and Paraguay and will be combined with previous selections for further testing. Scab screening under field and semicontrolled conditions in Brazil and Paraguay again demonstrated the superiority of germplasm for this trait coming out of the China/CIMMYT partnership. Advanced lines selected for powdery mildew, spot blotch, and head scab resistance were distributed for testing at key locations. We posted an agronomist in South America in 1988 to help national programs better understand and overcome agronomic limitations to wheat production and sustainability problems in warmer areas.

In Southeast Asia 1988 was the first year for multilocation testing in Vietnam, and the trials were composed primarily of CIMMYT lines. Vietnamese breeders face the task of combining tropical and South China requirements, which include earliness, early heat tolerance, and resistance to leaf rust, *Helminthosporium sativum*, scab, powdery mildew, and sprouting. In the Philippines, where the current aid package includes free or low priced wheat, prices of white flour dropped substantially. Under these discouraging circumstances for local production, it was decided to continue wheat research at the current level. In contrast, Thailand's strongly supported wheat research efforts received a further vote of confidence in 1988 from both the public and private sectors as favorable prices were fixed and dealers, for the first time, announced their intention to purchase grain from farmers. Agronomy research in Thailand emphasized finding the reasons for low stand establishment and sterility. Plant tissue analysis using different varieties, locations, and growth stages revealed a variable pattern of deficiencies in both macro- and micronutrients.

East Africa—Our agronomist funded by the Canadian International Development Agency (CIDA) worked with scientists in Tanzania, Burundi, Rwanda, and Uganda but concentrated on collaborative research with the agronomy staff of Ethiopia's Institute of Agricultural Research (IAR). On-farm orientation of agronomic research has been particularly emphasized at IAR's Kulumsa, Sinana, Holetta, and Adet stations. Our core funded pathologist/breeder in Addis Ababa continued assisting the national program in a variety of activities including prioritizing diseases as to prevalence and crop losses, conducting host and pathogen surveys, and developing a multi-location germplasm network.

Andean region—Aiming to obtain wider adaptability and resistance to stripe rust and other diseases in an overall attempt to sustain the wheat productivity of small scale farmers in the region, a shuttle breeding program is now underway in this European Economic

Commission (EEC) supported project between CIMMYT and national programs. In 1988 early generation materials were harvested in Ecuador and Colombia for shuttling to Mexico. 1988 analyses of stripe rust samples made at the Research Institute for Plant Protection (IPO) at Wageningen, The Netherlands, revealed a large diversity of races in the Andean region during the 1986-87 growing seasons.

South Asia—Stripe rust pathotyping indicated that race 7E150 continues to predominate in South Asia. No new stripe rust races have been detected in the region. The *Yr9* resistance gene continues to be effective. Studies were initiated in Nepal to determine if soil pathogens play a role in constraining yields in the rice-wheat cropping pattern. In a project supported by the Overseas Development Agency of the UK, experiments to study the stability of wheat varietal mixtures versus pure lines were implemented in Nepal, India, and Pakistan. In August we placed a wheat agronomist in Kathmandu. His work will focus on the region's crop management research constraints and sustainability issues in the rice-wheat rotation. In collaboration with the Indian Council of Agricultural Research and IRRI, initial work in India aims to compile the large amount of data available on the rice-wheat rotation. Work on zero tillage and weed control is continuing in the rice-wheat areas of Pakistan. A diagnostic survey done by IRRI, CIMMYT, and Nepalese scientists will develop research themes for future activities in Nepal.

Bangladesh—Wheat production and productivity continued to decline in the 1987-88 crop season. It is now almost certain that on-farm yields are really declining and that the trend is not an aberration of statistics or the result of a shift of wheat production to more marginal lands. For this reason, emphasis in the two-year extension of this CIDA-funded project (begun in July 1988) has been placed on identifying the factors involved in this yield decline.

Courtesy of ICARDA

Separating chaff from grain on a still day is made easier with the aid of a fan. This resourceful Syrian wheat grower is one of many farmers throughout the WANA region who ultimately benefit from the cooperative efforts of CIMMYT and ICARDA.

Economics Research

That the use and conservation of genetic resources should be a prime concern of the Maize and Wheat Programs seems inarguable, but one might well ask how the issue of genetic resources impinges on the work of the Economics Program. Occasionally the connection between the two can be surprisingly close. In the course of her field work in Erongarícuaro, Michoacán, Mexico, a geographer in the Economics Program observed farmers growing triticale without irrigation in the *invierno* (dry season) cycle along with other crops, including a wheat that farmers called *Aventurero*. Because the geographer was interested in the extent to which triticale had displaced wheat in Erongaricuaro, she asked farmers how long they had grown *Aventurero*; they said that they had grown it as long as anyone could remember. Seeking a more precise answer to her question through library research, she found that this ''variety''—actually three landraces of Spanish origin—probably spread to Michoacán in the 1530s from prime wheat growing areas of the Bajío region, where wheat was cultivated as a tribute crop for Spain. The Wheat Program's genetic resources section, which preserves seed of old spring wheats from throughout the Western Hemisphere, was interested in *Aventurero* and collected seed for the germplasm bank.

Admittedly, the case of *Aventurero* is exceptional, and other links between genetic resources and the activities of CIMMYT Economics may not be so direct. But the value of genetic resources ultimately depends on the efficiency with which they are developed by researchers and used by farmers, and CIMMYT social scientists study issues related to both of those processes (see figure).

For example, CIMMYT economists working with staff of the Maize and Wheat Programs have developed methods for on-farm research that help clarify farmers' varietal and other needs, so that researchers can develop technologies appropriate to farmers' circumstances. By providing information to help guide breeding objectives or research on crop management practices, on-farm research can ensure that genetic resources benefit their ultimate users, farmers. Setting clear research goals and efficiently allocating resources to achieve them are also important in exploiting genetic resources and delivering the products of research to farmers in a form that they can use. For that reason, the Program studies issues related to research resource allocation and the impacts of technological change. We also analyze the environment in which decisions about research are made, including long term trends in the production, utilization, and trade of maize and wheat, as well as policies influencing the maize and wheat sectors. The results of those analyses supply decision makers at CIMMYT and in national programs with information that will help determine how those trends might affect research objectives.

Thomas Luba

The availability of machinery is one of many variables affecting farm operations. Information gathered from farmers is used to construct a profile of their circumstances and helps identify potential research topics.

During 1988, Economics staff continued research and training in all of the areas described above and initiated several new studies (details are given in the sections that follow). New and visiting staff made it possible to explore these additional research topics.

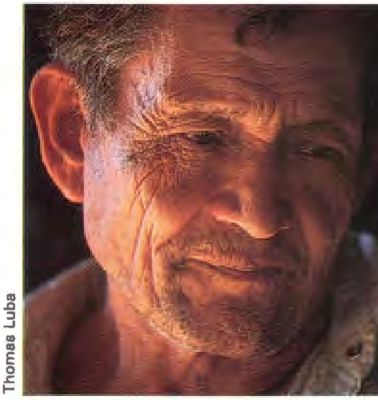
Technology Design, Evaluation, and Utilization

This research focuses on designing new technologies and evaluating whether they are appropriate for farmers' circumstances and help sustain the resource base; it includes studies of policies affecting the efficient utilization of technology at the farm level. A chief product of this research is methods that national programs can use in designing and evaluating technologies. For that reason, more than half of CIMMYT economists are posted to regional or bilateral programs, where they work with national program colleagues to conduct research on issues relevant to national programs and CIMMYT, and also offer training.

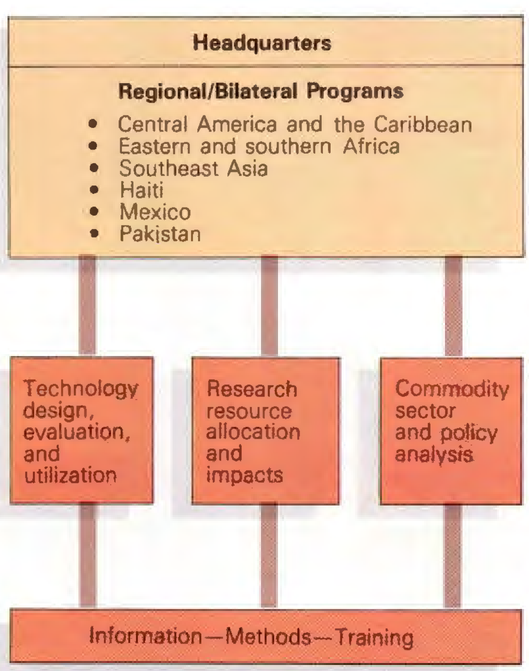
On-farm research/Farmers' perspective in research—CIMMYT economists participated in an array of on-farm research projects with staff of national programs and the Center's Maize and Wheat Programs in 1988. In rainfed areas of southern Mexico, a CIMMYT regional economist sponsored by France's Center for International Cooperation in Agronomic Research for Development (CIRAD) has worked since 1983 with Mexicc's National Institute of Forestry, Agriculture, and Livestock Research (INIFAP) on several on-farm research projects to improve small scale maize production. Since 1987 he has been joined in this work by a Maize Program agronomist, also sponsored by CIRAD. In 1988 the results of five projects were synthesized and presented at a workshop attended by over 70 professionals, including research directors and regional policymakers. One highlight of the workshop came from on-farm research conducted in La Fraylesca, Chiapas, which indicates that returns to the practice of liming soils are high. To cover research costs so far, the liming recommendation needs to be adopted on only 700 ha of maize by about 110 farmers; the potential area for the recommendation includes 31,500 ha and 5,000 farmers.

On-farm research in Haiti is funded through the Canadian International Development Agency (CIDA), which sponsors a project to assist Haitian researchers in developing and diffusing improved technologies. During 1988 on-farm trials continued in Petit Goave, where maize and other crops are grown on steep, eroded hillsides. The trials emphasized mulching to retain moisture and reduce erosion as an alternative to burning. In Les Cayes trials comparing the profitability of zero tillage with conventional tillage were initiated. Researchers hypothesize that zero tillage using the herbicide Glyphosate will reduce the costs of conventional plowing with draft animals, eliminate the need for a first hand-weeding, and possibly improve the timeliness of planting.

Work with on-farm research programs throughout Southeast Asia continued in 1988. The CIMMYT economist there also organized and participated in numerous training courses, workshops, and conferences intended to strengthen the on-farm research capacity of national programs in the region and share research results. One highlight of 1988 was the Asian Regional Workshop on On-Farm Adaptive Research, organized by the Coarse


Thomas Luba

An awareness of farmers' circumstances is integral to the research process.



The chief products of research conducted by Economics Program staff at headquarters as in regional/bilateral programs include information, improved methods for conducting research and allocating research resources, and training.

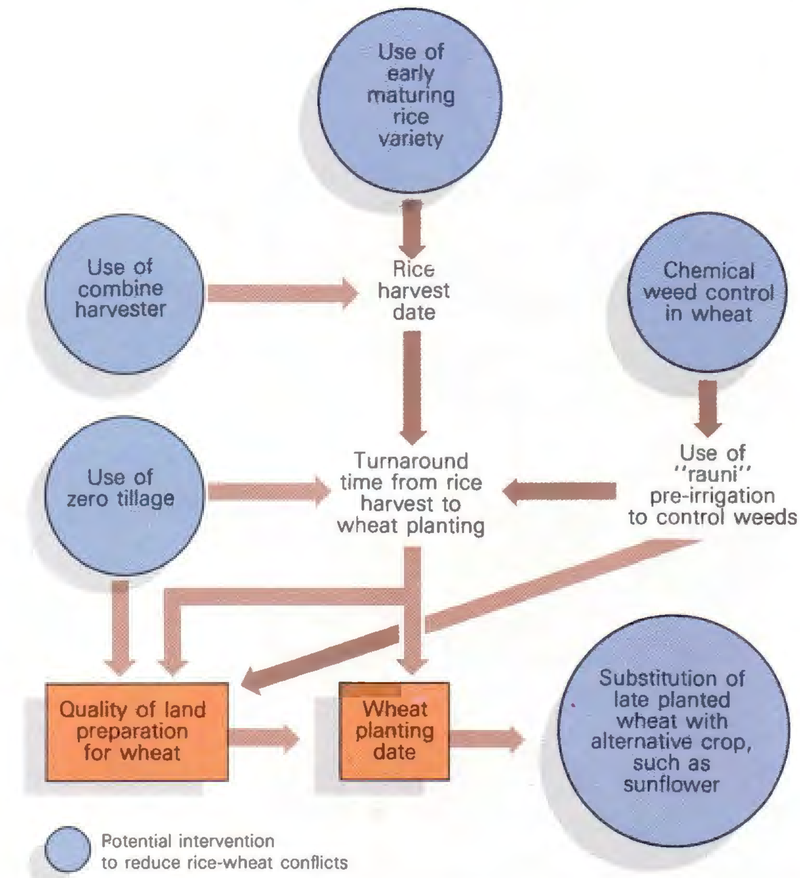
Recent upheavals in world grain markets have made studies of the maize and wheat economies increasingly important for decision making.

Grains, Pulses, Roots, and Tubers (CGPRT) Center with funding from the United Nations Development Programme (UNDP). About 20 participants from Bangladesh, Indonesia, Korea, Pakistan, the Philippines, Thailand, Sri Lanka, and Vietnam discussed the objectives of on-farm adaptive research, sources of information for diagnosing farmers' problems, and ways of setting research priorities. Participants also developed and conducted a survey of farmers in Malang, Indonesia, which confirmed earlier findings and elicited new information on variability in cropping patterns and rice-maize interactions. Results were used to focus discussion on the planning and implementation of adaptive research programs.

Information and analysis for varietal development—The large amount of information now generated in many national programs by on-farm research can be channeled to varietal development. Such information often provides a useful perspective on how varietal needs (and management practices) for a particular crop are affected by the demands of other elements of the farming system.

An example of the usefulness of farm level data comes from Pakistan, where CIMMYT and national program staff, with a grant from USAID, conduct economics research on wheat and maize. A persistent problem in the rice-wheat cropping system of the Punjab of Pakistan is that late harvesting of Basmati rice reduces the time needed to prepare land for wheat and delays wheat planting (see figure). On-farm experiments showed that planting wheat after 15 November led to a grain loss of 30 kg/ha for every day's delay. After the old tall rice variety, Basmati-370, was replaced by the shorter, higher yielding Basmati-385 on over 70% of the rice-wheat area in only three years, researchers wished to know if Basmati-385, which matured about 14 days earlier than Basmati-370, would reduce time conflicts in planting wheat and thus raise wheat yields. A survey in the rice tract found that wheat was planted an average of five days earlier after Basmati-385 than after Basmati-370. Rather than taking full advantage of Basmati-385's earlier maturity to plant wheat earlier, farmers were using some of the extra time to improve their land preparation for wheat. Farmers estimated the mean yield of wheat after Basmati-385 was 350 kg/ha higher than wheat planted after Basmati-370, partly because of the earlier planting date and partly because of improved land preparation.

Another instance in which farm level research has alerted researchers to farmers' practices and varietal needs is a study of the economics of late planted maize, conducted by Economics and Maize Program staff in southern Africa. Most farmers attempt to plant as soon as possible after the first rains, but many cannot, especially those without draft animals. Problems with late planting are compounded by the fact that farmers' maize varieties tend to be late maturing. Earlier maturing varieties would give farmers more flexibility in determining planting dates to fit their resource constraints, especially if those materials perform well under the practices used on late planted maize, such as those for coping with the need to plant quickly, weedy seedbeds, waterlogging, and low soil fertility.



Factors affecting land preparation and planting date of wheat in rice-wheat areas of Punjab, Pakistan.

Research Resource Allocation and Impacts

Both in national programs and in CIMMYT, the growth of resources allocated to agricultural research has slowed, putting greater pressure on research managers to justify priorities and document the productivity of research expenditures. Also, CIMMYT and many national programs are seeking ways to ensure that the poor will benefit from their research. More accurate information about how the benefits from research are distributed should help us understand what kinds of research can most successfully meet the needs of the poor. Thus, by analyzing the impacts of past research, we can gather crucial information for allocating resources among future research initiatives.

Within the Center the Economics Program provides information and analyses requested by the Maize and Wheat Programs to aid in their research resource allocation decisions. For strategic planning in 1988, we worked with the Maize and Wheat Programs to factor socioeconomic variables, such as poverty indices, into definitions of maize and wheat mega-environments, as a way of better directing resource allocations to certain types of maize and wheat and to certain regions of the world.

The study of research impacts treats two themes: the productivity of specific types of research and the impacts of technological change on the poor. Three studies related to these themes were initiated in 1988: 1) an analysis of the size at which a full scale breeding program becomes economically viable; 2) a study of the returns to crop management research in the Yaqui Valley of northwestern Mexico; and 3) a study to identify how the benefits of technological innovations are transmitted between favored and marginal environments and to determine how certain technological innovations have affected various groups of people, especially the poor.

Commodity Sector and Policy Analysis

This research deals with all aspects, including policy issues, of long term trends in demand and supply for maize and wheat that have a bearing on decision making for agricultural research. Recent upheavals in world grain markets and widespread policy adjustments instituted by many countries in the 1980s suggest that studies of the maize and wheat economies, on a global or national level, will be increasingly important for decision making at CIMMYT and in national programs.

In 1988 we expanded our computer database on maize and wheat to enable us to better analyze trends in the production, utilization, and trade of maize and wheat. Some of those trends are summarized in the *1987-88 World Wheat Facts and Trends*, which reviews recent developments in Third World wheat production. The report focuses on regions that are either irrigated or receive good rainfall, for they constitute the major wheat producing area of the developing world (reference is also made to more marginal areas—see page 53).

Our analysis leads us to take a rather conservative view of the extent to which the main sources of wheat yield increases in recent years—the spread of modern varieties, increased fertilizer use, and improved irrigation—will help Third World farmers meet

Dagoberto Flores (right) of the Economics Program observes as a National Basic Foods Enterprise (CONASUPO) agent tests the storage quality of a sample of wheat that has been brought for sale.

Thomas Luba

the demand for wheat in years to come. The study suggests that achieving future gains in productivity may depend on a strategy somewhat different from the past one, which relied heavily on the benefits to be obtained through the interaction of improved varieties, fertilizer, and irrigation. The new strategy, which would apply to favorable, well-watered environments as well as more marginal areas, would further exploit available technology by increasing the efficiency with which inputs are used. This approach suggests that improved crop management will play a greater role relative to improved varieties in raising productivity in the future.

At the national level, several studies of comparative advantage continued or were completed in 1988 to estimate the efficiency from a national viewpoint of using resources for maize or wheat production in special regions or with special technologies. A distinguishing feature of our work in comparative advantage is that CIMMYT economists play a supporting role: national program scientists are the principal participants. Another feature is that these studies—the one from Panama in particular—are intended to develop methods that national programs can use to conduct comparative advantage analyses.

One study, completed in 1988, analyzed the relative efficiency of alternative wheat production technologies on a range of farm sizes in Kenya. Most wheat in Kenya is grown on large farms using capital intensive methods that differ little from those used in industrialized countries. Kenyan policymakers, faced with difficult decisions about land use and agricultural development, are deciding whether it would be economically attractive to produce wheat on small holdings using more labor intensive technologies characterized by greater use of draft power and/or human labor. The results suggest that labor intensive technologies would be efficient for farmers with small fields but that wheat production remains most efficient on large holdings at high levels of mechanization. One consideration in deciding about a strategy for smallholder wheat technology is the availability of labor to perform farming operations. Another important consideration is whether smallholders can be persuaded to grow wheat instead of maize and buy maize for home consumption; the analysis suggests that small scale farmers presently have little incentive to do so.

Other studies of comparative advantage continued in Panama and El Salvador. The Panama study focuses on maize and sorghum production; the El Salvador study examines maize-bean relay cropping on hilly land. CIMMYT has received a number of requests for assistance with comparative advantage studies in Latin America. Those requests are being

Continued on page 54

Kathryn Elsesser

CIMMYT economists study the efficiency of alternative technologies from the producer's point of view. They also contribute to studies on the efficiency of producing maize and wheat in certain regions or with special technologies. Such studies can reveal how government policies influence agricultural production.

New Wheat Varieties and Farmers in Marginal Areas

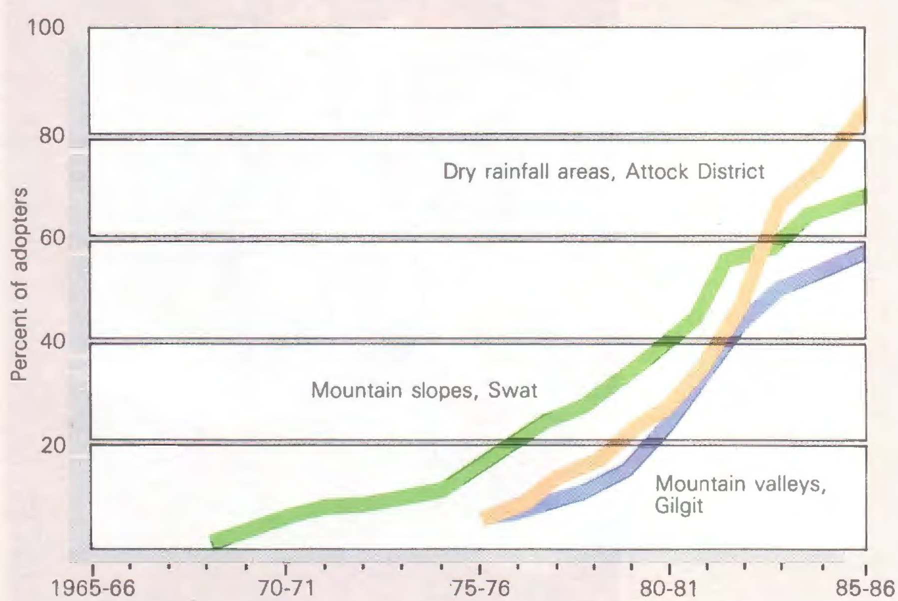
Considerable controversy arose in the 1970s concerning the distribution of benefits from the new wheat and rice varieties. Critics asserted that the new germplasm benefited mostly larger and wealthier farmers who could afford the inputs needed to exploit the new varieties' yield potential. The critics' claims were not supported by studies in the late 1970s and 1980s showing that small farmers had widely taken up the new technology, although in some cases adoption lagged behind that of large farmers.

The controversy arose in part because of the mistaken belief that the new varieties would not provide any benefits without high levels of purchased inputs such as fertilizer, irrigation water, and pesticides. In fact, even without fertilizer, semidwarf wheat varieties yield better than the old, taller varieties. Most new varieties also have improved disease resistance, an advantage for small farmers who cannot always afford chemicals to control diseases. Furthermore, in the main wheat growing areas where semidwarfs have been widely adopted, better input marketing and irrigation have enabled most smaller farmers to use levels of inputs similar to those used by larger farmers.

Today, millions of small farmers, including almost all of those in the irrigated wheat growing areas of South Asia, grow semidwarf wheats with moderate doses of fertilizers and increasing use of other inputs. But what about the marginal areas where many of the poorest farmers live? The diffusion of semidwarf wheat varieties in three difficult environments of Pakistan provides some idea of how farmers in marginal areas have fared. The first area is Attock District in northern Punjab, where rainfall in the wheat growing season averages under 200 mm with high year-to-year variability. The second area, in the Swat mountains, receives relatively high rainfall; farmers grow wheat on very small holdings on steep slopes above 1,500 m elevation. The third area, Gilgit, lies in the remote, high mountains near the Chinese border, where water from glacial melt irrigates the wheat crop.

In recent years all three places have seen rapid adoption of semidwarfs, rising from low rates in 1975 to over 50% adoption in each area by the mid-1980s (see figure). Several factors probably contributed to the initial delay in adoption, including the fact that not all semidwarf wheats were immediately suited to such difficult environments. Another factor that may have held back adoption in these areas is that all have been neglected by research and extension. Even when the technology was available, poor infrastructure prevented its transfer to remote areas. Finally, in all three areas wheat straw is highly valued as livestock fodder because the dry season and/or winter is long and it is expensive to transport fodder from other areas. The high value of straw, together with somewhat higher straw yields provided by tall varieties *when no fertilizer is used,* may negate the value of the extra grain obtained from new varieties.

In the past five years or so, some impediments to adoption have been overcome. Access to many areas has improved, sometimes dramatically. Improved access, in some cases combined with great efforts by development agencies, has led to the widespread adoption of fertilizer by farmers. The use of fertilizer together with the release of more appropriate varieties has made it profitable for farmers to switch to semidwarf varieties. In particular, the increase in straw yields of semidwarf varieties when fertilizer is applied appears to compensate for their disadvantage in straw yields when no fertilizer is applied. More recent semidwarf varieties have higher biomass production, which increases straw yields even if little or no fertilizer is applied.



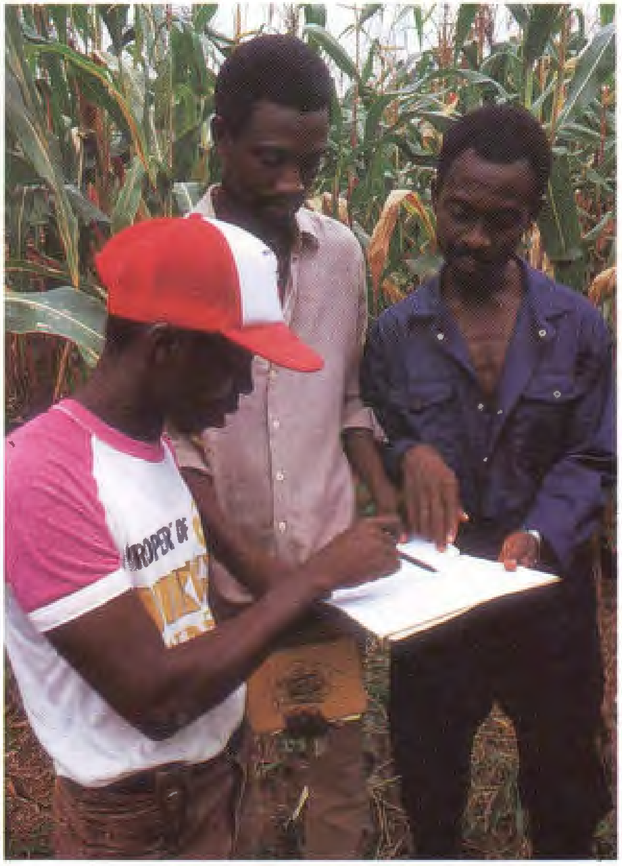
Diffusion curves for fertilizer and semidwarf varieties in marginal environments in Pakistan.

Variability in crop production is a critical factor in the food security of poor producers and entire nations.

made partly because economic crises in several countries have focused attention on efficiency considerations in the design of agricultural policy and on studies of comparative advantage as a means of evaluating the costs and benefits of alternative crops or enterprises. In the short term, national income can often be increased by policies encouraging farmers to produce commodities that exploit existing patterns of comparative advantage; over the long term, additional welfare gains can be assured if research resources are used to strengthen future comparative advantage. Thus, information from comparative advantage studies plays a role in informing policy decisions and allocating research resources.

Training

In 1988 the Economics Program, especially regional and bilateral staff, maintained its heavy commitment to training of all kinds, ranging from the courses offered at headquarters to in-country training of various types. Although we will continue to be involved in on-farm research training, we anticipate that general introductory courses will be reduced gradually and a greater number of specialized courses for social scientists will be offered.



Nathan Russell

With a grant from the United States Agency for International Development (USAID), regional economists in eastern and southern Africa participated with a large number of agricultural research and extension institutions in training activities, including courses and workshops on data collection and analysis for economists and agronomists; on analysis of on-farm trials; on the diagnostic phase of on-farm research; and issues relevant for research and extension administrators. Similar courses and workshops were held in Asia and Latin America.

As part of its commitment to strengthen the research capacities of national programs, the Economics Program is sponsoring more scientists (chiefly economists) to travel to Mexico for three to six months to work on specific projects of interest to CIMMYT and the national program. In 1988 an economist from the Punjab Agricultural University, India, spent six months in Mexico conducting an analysis of variability in wheat yields.

The study, unusual because it analyzed variability over a fairly long period (1951-86), showed that relative yield variability across countries is determined by country size, moisture regime, and temperature. Technological variables, such as the level of adoption of high yielding varieties and levels of fertilizer application, had no effect on differences in yield variability across countries. Furthermore, analysis of wheat yield variability for the same countries for three periods between 1951 and 1986 shows that yield variability has consistently declined since 1975, especially in larger developing country producers that experienced rapid technological change in wheat production. These results suggest that it may be necessary to reevaluate the prevailing belief that yield instability in cereal crops has risen in recent decades as a result of rapid technological change. This issue merits further investigation because variability in production is a critical factor in the food security of poor producers and entire nations.

Ghanaian farmer E. Ankoma Cudjoe (center) reviews trials on his farm with two extensionists (Kofi Boa, left, and Kojo Tano) of Ghana's Grains and Legumes Development Board. Close links between extension and research, fostered through training and research planning sessions, benefit farmers by enhancing communication among all three groups and feeding information back into the research process.

Support Services

In this section we briefly portray the support units created over the years to assist CIMMYT's three principal programs in experiment design, data processing and analysis, experiment station management, information activities, and laboratory work. A special report (see page 57) focuses on the role of a new complex that will house laboratories dedicated to the unfolding area of science commonly known as ''biotechnology''—which should add considerably to our efficiency in utilizing plant genetic resources.

Biometrics

This unit was created in January 1988 to formalize and augment the mathematical and statistical support previously afforded crop program researchers by a single biometrician. International trials are the cornerstone of CIMMYT's germplasm distribution efforts and, in line with observations made by the External Programme Review panel, we came up with improved experimental designs and better methods for analyzing yield stability and assessing genotype x environment interaction in the international nurseries. We also assisted researchers in the design, analysis, and interpretation of individual trials and series of trials. An example of this is the promotion of the alpha-lattice design over the traditional randomized block design for variety trials. Besides actually performing statistical analyses of experimental results, we advised and trained researchers in the use of statistical software for this purpose.

In the short span since its creation, the Biometrics Unit has made key contributions to the management of genetic resources. Central to the maintenance of any base collection is the periodic replacement of seed that loses viability. Since only a limited sample of a given population is used to generate replacement seed, the population's initial genetic variability is imperfectly represented in the new seed. By applying probability models, the Biometrics Unit produced recommendations for regeneration sample size that ensure optimum conservation of original genetic variability. The unit also proposed a seed regeneration procedure that mininimizes inbreeding and maximizes the effective population size.

Data Processing

The importance of database software for germplasm bank operation has given this unit an especially significant role in genetic resources management at CIMMYT. In 1988 we produced a wheat germplasm bank catalog, finished a maize germplasm bank management system, and developed a CD-ROM database (see page 25) that puts key information from the system practically in the pockets of developing country users.

Work on software aids to plant breeding included the completion of a wheat pedigree management system project—as well as advances in the preparation of a related fieldbook system—which allows researchers to query on the varietal ancestry and coefficient of parentage of bread wheat lines from as far back as two decades ago (see pages 36-37). The Maize Program received support in the form of a documentation system for monitoring its projects and a seed inventory system for breeder use.

Several network power and configuration problems were solved in 1988. We replaced old VAX hardware with two new microVAX III units, greatly enhancing system reliability, and uninterrupted power supply service was extended to the entire Data Processing Services Unit, Information Services, and the local area network. In 1989 we expect to increase PC integration into the network, develop new software tools for the PC environment, and monitor VAX usage with an eye toward a possible medium term expansion in central computing resources.

Experiment Stations

In Mexico the primary responsibility of experiment station management is to oversee field operations on some 500 ha of land at various research stations and other experimental sites. The unit works closely with CIMMYT scientists and helps reduce their burden of day-to-day field supervision by attending to such routine but critical matters as land preparation, irrigation and drainage, applying chemicals, harvesting, seed storage, equipment maintenance, and personnel and administrative management. Most of this work takes place at five stations in Mexico. Of these, four (El Batán, Poza Rica, Tlaltizapán, and Toluca) are managed directly by Center staff and the fifth (Ciudad Obregón) by Mexico's National Institute for Agriculture, Livestock, and Forestry Research (INIFAP) and the Agricultural Research and Experimentation Board of the State of Sonora (PIEAES).

In the short span since its creation, the Biometrics Unit has made key contributions to the management of genetic resources.

Countries of origin of participants in the in-service experiment station management course, 1988

	Maize	Wheat
Africa		
Egypt	1	1
Ethiopia	-	1
Ghana	1	-
Kenya	1	-
Morocco	-	1
Somalia	1	-
Zambia	1	-
Total	**6**	**2**
Asia		
Syria	1	-
Turkey	1	-
Vietnam	1	-
Total	**3**	**0**
Latin America		
Brazil	1	-
Dominican Republic	1	-
Ecuador	2	-
Paraguay	-	1
Peru	-	1
Total	**4**	**2**
Total trainees	**13**	**4**
Total countries	**11**	**4**

Staff of this unit supplemented station management with research on related topics, including soil iron deficiency and chlorosis at Tlaltizapán and, at Poza Rica, two legume species—*Stizolobium niveum* K. and *Sesbania* sp.—with potential as green cover crops for rotation with maize. As in the past, the unit also responded actively to the demand among developing country researchers for preparation in experiment station management and for maize and wheat training courses. Seventeen researchers from around the world completed the regular in-service training program (see table), held at headquarters and covering a whole range of pursuits involved in station operation. Staff also helped teach courses in Peru and Costa Rica tailored to the specific needs of national programs there, as well as a conservation tillage course given at El Batán, Mexico, for Andean region researchers. Finally, support personnel at CIMMYT's Mexican stations received special training in work related skills.

Information Services

Nearly 50 publications and training materials were produced by this group in 1988. The majority were in English, but Spanish, French, Turkish, and Vietnamese translations were also printed. One publication—*The Septoria Diseases of Wheat: Concepts and Methods of Disease Management*—was singled out for special honors, receiving the Agricultural Communicators in Education (ACE) Superior Award for Outstanding Communication Materials in the technical publications category. In response to the expressed information needs of CIMMYT clients, the publications unit will continue to shift its emphasis toward assisting staff with the development of practical manuals and guidebooks similar to *Septoria Diseases*, as well as more technical publications such as journal articles and research reports.

In 1988 the section initiated a small, directed effort in the area of public awareness. The recently formed CGIAR Public Awareness Association for International Agricultural Research held its first general session at CIMMYT, and the Center is committed to participating in several Association activities, most notably a public awareness campaign focusing on the importance of genetic resources in Latin America.

The audiovisuals unit has taken on a more comprehensive role in enhancing the impact of the photographic images in our publications, as evidenced by this *Annual Report*. Work was begun on a computerized "image bank" for easy storage and retrieval of the visual resource materials used in publications, presentations, and training at headquarters and elsewhere. Considerable attention in the coming year will also be devoted to developing training materials and courses.

The scientific information unit (SIU), which includes our specialized library, implemented an integrated library system using the BASIS software package. As a result, records for all CIMMYT library holdings from 1986 on can be accessed on any terminal connected to the central computer. Several library tools on CD-ROM were also added to the array of services enjoyed by our users. Outside headquarters the SIU continued to support Third World scientists by providing SDI (selective dissemination of information) service for more than 400

Nathan Russell

Workers at the Tlaltizapán experiment station prepare grain from quality protein maize trials for weighing.

developing country researchers, sending them up-to-date information on publications in their specific areas of interest. In addition, 600 subscriptions of *Wheat, Barley and Triticale Abstracts* and 750 of *Maize Abstracts*—both copublished by CIMMYT and CAB International—were distributed to developing country libraries and some key collaborators. Finally, the SIU is working closely with its host country colleagues on networking, promoting among other things the creation of a catalog listing the serial publication holdings of the 15 major agricultural science libraries in Mexico.

Laboratories

CIMMYT's general service laboratories—**cereal chemistry,** and **soils and plant nutrition**—performed multiple analyses on approximately 25,400 samples submitted by the breeding programs, economics, and experiment stations.

In **cereal chemistry** we continued to support quality protein maize (QPM) development by evaluating the protein quality of genetic families of open-pollinated populations (35% of QPM samples) and selected lines from pools and populations used in single crosses, hybrids, and synthetics (65% of QPM samples). We conducted additional studies with selected genetic materials on the effects of environment and cycle-of-selection interactions on protein quality and, in the conclusion of a comparative assessment using three normal maize populations and their QPM counterparts, we found similar values for both maize types in agronomic characteristics, such as yield and kernel density, but superior values for QPM in nutritional quality at all stages of endosperm development. For two QPM populations whose oil content was being improved, we determined changes in protein quality (amino acid composition) and oil quality (fatty acid composition) and possible interactions through cycles of selection at different locations. Several Mexican maize races were characterized using protein electrophoresis to establish a basis for identifying similar germplasm. Cooperative work with Brazilian wheat breeding programs in developing aluminum tolerance continued as thousands of segregating materials were hydroponically screened.

Assisted by crop agronomists, physiologists, and occasionally by farmers, the **soils and plant nutrition** lab performed macro- and micro-nutrient analyses of soil and plant tissue samples from experiment stations and several farms, resulting in recommendations for improving soil conditions there.

Biotechnology Laboratory

Recent advances in biotechnology show great promise for enhancing the usefulness of plant genetic resources in our breeding programs and in those of developing countries. Rather than actually developing biotechnology techniques—an area where we believe public and private institutions involved in more basic research have the advantage—CIMMYT's role will be to test and adapt new tools for possible use in our breeding programs and, where appropriate, to transfer these tools to developing country programs. Emphasis will be placed on cost effective technologies, especially those related to diagnosis, such as the ELISA technique, and DNA probes such as restriction fragment length polymorphisms (RFLPs), expected to upgrade the efficiency of our breeding programs. Our biotechnology activities will be collaborative—that is, they will be networked with biotechnology centers in both the developed and developing worlds to ensure effective use of limited resources, to involve national programs in identifying appropriate technology, and to facilitate their access to that technology.

To carry out these new initiatives, CIMMYT is building a laboratory complex at its headquarters that will include facilities for molecular genetics, wide crosses, monoclonal antibody work, and tissue culture. The construction is funded by core grants from the CGIAR, together with donations from the Canadian International Development Agency (CIDA), Italy, Japan, and West Germany. Two levels (the basement and ground floor) will be operational in 1989; provisions exist for an additional floor at a later stage. We have appointed one core funded international staff person to head up CIMMYT's new biotechnology initiatives. Additional staff will be brought in over the next five years to reach a critical mass of specialists in this area.

Besides the general service units described above, a number of other laboratories provide support to specific projects within the crop programs. The functions of these laboratories are briefly described below. Where indicated, additional information about their 1988 activities is provided in the Maize and Wheat Program reports.

In the **industrial quality** laboratory, breeding materials from the Wheat Program are evaluated for their milling and baking properties (see page 42).

The **insect mass rearing** facility annually produces several million larvae of the insect pests that attack maize in Mexico. Most of the insects produced are used in artificial infestations to screen materials for host plant resistance and good agronomic qualities, although some serve for field and laboratory tests of less toxic and nontoxic substances in controlling field and storage pests. Besides their work with insects, maize entomologists assist breeders in research on the bases and inheritance of host plant resistance.

The **pathology** laboratories of the Maize and Wheat Programs develop techniques for the detection, isolation, and analysis of the fungal, bacterial, viral, and nematode agents that attack maize, wheat, triticale, and barley. These units also provide inocula for the disease screening of breeding materials and serve as an important element in CIMMYT's training courses.

Ensuring that all seed imported or exported by CIMMYT is in the best possible condition is the responsibility of the **seed health** unit. This involves checking for seedborne pathogens on all materials handled by CIMMYT, conducting seed treatment research, performing germination tests to guarantee acceptable seed viability, monitoring CIMMYT breeding procedures to ensure proper seed health control, and maintaining a constant awareness of the quarantine concerns of cooperators.

The **wide crosses** units of the Maize and Wheat Programs attempt to incorporate alien genes for resistance or tolerance into maize and wheat by way of crosses with wild relatives of these cereals (see page 26 for maize and pages 37 and 39 for wheat).

Thomas Luba

***CIMMYT's commitment to providing healthy seed for cooperators means constant monitoring of its materials. Seed health specialist Larry Butler employs a variety of techniques in this work, including the Oxgall agar test, where blacklight reveals fluorescing metabolites produced by* Septoria nodorum.**

Financial Statements

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Price Waterhouse

México, D.F., February 14, 1989

To the Board of Trustees of
Centro Internacional de Mejoramiento
de Maíz y Trigo, A.C.

In our opinion, the accompanying statements of condition and the related statements of activity and of changes in financial position on a cash basis, expressed in United States dollars, present fairly the financial position of Centro Internacional de Mejoramiento de Maíz y Trigo, A.C. (CIMMYT) at December 31, 1988 and 1987 and the results of its operations and the changes in its financial position for the years then ended, in conformity with accounting principles generally accepted in the United States of America for not-for-profit organizations consistently applied. Our examinations of these statements were made in accordance with generally accepted auditing standards and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

Our examinations were made primarily for the purpose of forming our opinion on the financial statements taken as a whole. We also examined the additional information presented on Exhibits 1 to 4, expressed in United States dollars, by similar auditing procedures. In our opinion, this additional information is stated fairly in all material respects in relation to the financial statements taken as a whole. Although not necessary for a fair presentation of financial position, results of operations and changes in financial position, this information is presented as additional data.

PRICE WATERHOUSE

Ignacio Vélez

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Comparative Statement of Financial Condition

Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.

Assets, Liabilities, and Fund Balances

US dollars (000s)

	Note[a]	Year ended December 31 1988	1987
Assets			
Cash and short term deposits	3	5,863	3,942
Accounts receivable			
Donors	7	867	1,232
Others	7	1,117	1,134
Inventories	3	132	63
Property, plant, and equipment	3	20,938	20,193
Total assets		**28,917**	**26,564**
Liabilities			
Accounts payable and other liabilities		718	829
Accrued benefits	3	598	467
Payments in advance from donors	7	4,801	4,028
Total liabilities		**6,117**	**5,324**
Fund balances			
Property, plant, and equipment	3,5	20,938	20,193
Capital development	5	1,100	400
Operating	5	2,765	2,765
Auxiliary services	5	485	364
Cumulative translation effect	4,5	(2,488)	(2,482)
Subtotal		1,862	1,047
Total fund balances		**22,800**	**21,240**
Total liabilities and fund balances		**28,917**	**26,564**

[a] The notes numbered 1 to 7 (pages 63-65) form an integral part of these financial statements.

Comparative Statement of Activity

Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.

Revenue and Expenses — **US dollars (000s)**

	Note[a]	Year ended December 31 1988	1987
Revenue	6		
Grants		31,655	28,594
Sale of crops		35	36
Interest on short term investments		236	108
Auxiliary services		926	762
Total revenue		**32,852**	**29,500**
Operating expenses	6		
Research programs		18,850	17,081
Conferences and training		5,537	5,460
Information services		1,431	888
General administration		2,452	1,895
Plant operations		1,593	1,395
Capital acquisitions		1,221	1,465
Auxiliary services		788	522
Accrual benefits		159	218
Total operating expenses		**32,031**	**28,924**
Excess of revenue over operating expenses		821	576
Allocated as follows:			
Operating funds	5		350
Capital development fund	5	700	
Auxiliary services	5	121	226
Translation effect for the year	4	(6)	(528)
Net excess of revenue over expenses		815	48
Fund, opening balances		1,047	999
Closing fund balances as per statement of condition		1,862	1,047

[a] The notes numbered 1 to 7 (pages 63-65) form an integral part of these financial statements.

Comparative Statement of Changes in Financial Condition on a Cash Basis

Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.

Operating activities

US dollars (000s)

	Note[a]	Year ended December 31 1988	1987
Cash receipts:			
Grants from donors	6	31,655	28,594
Other	6	1,197	906
Subtotal		32,852	29,500
Translation effect for the year	4	(6)	(528)
Capital development fund	5	700	
Operating fund	5		350
Subtotal		33,546	29,322
Cash disbursements:			
Salaries and allowances		16,574	13,484
Travel		2,619	2,170
Training, conferences, and publications		5,356	5,472
Field and laboratory		2,744	2,803
Office and vehicle		2,932	3,312
Others		1,761	1,140
Subtotal		31,986	28,381
Cash provided by operating activities		1,560	941
Other activities:			
Additions to property, plant, and equipment	3	(745)	(893)
Accounts receivable from others	7	17	(413)
Accrued benefits	3	131	90
Inventories	3	(69)	32
Payments in advance from donors	3,7	773	1,834
Accounts receivable from donors	3,7	365	338
Accounts payable and other liabilities		(111)	(375)
Cash provided by other activities		361	613
Increase in cash and short term deposits		1,921	1,554
Cash and short term deposits at beginning of year		3,942	2,388
Cash and short term deposits at end of year		5,863	3,942

[a] The notes numbered 1 to 7 (pages 63-65) form an integral part of these financial statements.

Notes to the Financial Statements

Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.

December 31, 1988 and 1987
US Dollars

Note 1: Statement of Purpose
The Centro Internacional de Mejoramiento de Maíz y Trigo, A.C. (CIMMYT) is a private, autonomous, not-for-profit, scientific and educational institution chartered under Mexican law to engage in the improvement of maize and wheat production everywhere in the world, with emphasis on developing countries.

Note 2: Creation of CIMMYT International (CIMMYT INT.)
CIMMYT INT. was formally created through an agreement signed by the United Nations Development Programme and the International Bank of Reconstruction and Development, both cosponsors of the Consultative Group on International Agricultural Research (CGIAR). A Headquarters Agreement, signed by the Government of Mexico on May 9, 1988, and ratified by the Mexican Senate on December 22, 1988, recognized CIMMYT INT. as having the status of an international organization.

While CIMMYT A.C. will continue to exist and to hold the land currently in its possession and new acquisitions, all such land will be put at the disposal of CIMMYT INT. Over time other assets and personnel will be transferred from CIMMYT A.C. to CIMMYT INT. When the transfer of assets and personnel is complete, all subsequent funding will be channeled to CIMMYT INT.

Note 3: Summary of Significant Accounting Policies
CIMMYT follows accounting policies recommended by the Secretariat of the CGIAR, an international association sponsored by the World Bank, the Food and Agriculture Organization of the United Nations, and the United Nations Development Programme. In 1986 these policies were revised, and a standard presentation for all research centers supported by the CGIAR was adopted. These policies are in accordance with accounting practices generally accepted in the United States of America for not-for-profit organizations and are summarized below:

a. CIMMYT uses the accrual method of accounting for transactions, and its books of account are kept in US dollars. Transactions in other currencies (mainly Mexican pesos) are recorded at the rates of exchange prevailing on the dates they are entered into and settled. Assets and liabilities denominated in such currencies are translated into US dollars applying Statement No. 52 of the Financial Accounting Standards Board of The United States of America (FAS 52). In accordance with that statement, CIMMYT has adopted the US dollar as its "functional currency" in consideration that the Mexican economy has been hyperinflationary, i.e., with a cumulative inflation rate for the last three years greater than 100% as measured by the National Consumer Price Index published by Banco de Mexico.

b. Purchase orders issued prior to December 31 are treated as operating expenses of the year in question and are shown on the statement of condition under vouchers payable. This is in accordance with guidelines issued by the CGIAR.

c. During periods of cash surplus, CIMMYT makes short term investments in marketable securities. Those denominated in dollars are transacted in the US money market. Interest is credited to income when the security matures or is sold. The security is recorded at cost, which approximates market, and any gain or loss from its sale is recorded at that time. Investments in pesos are held in a short term interest bearing account in a Mexican bank or in government securities. Interest is credited to income as accrued.

d. Inventories are stated at cost (first-in, first-out method), which is not in excess of market.

e. Fixed assets are stated at acquisition cost. Up to 1971 all purchases of property and equipment were recorded as expenses. In 1972 the CGIAR requested that the International Agricultural Research Centers change to the "write off, then capitalize" method of recording purchases of property and equipment. Accordingly, all property and equipment purchased under capital grants as from January 1, 1972, was recorded as an asset and credited to capital grants. Prior to 1980 replacements of capital items were recorded as expenditures of the related programs and did not enter in any way to form part of CIMMYT's capital grants, shown on the statement of condition. In 1980 that policy was revised to conform with the accounting policies of the CGIAR. Under this set of guidelines, the incremental value of a capital replacement item, i.e., the amount by which the historical cost of the replacement item is greater (less) than the historical cost of the item being replaced, is credited (debited) to capital grants fully expended on fixed assets. In this way the statement of condition reflects the historical cost of the fixed assets actually in use.

CIMMYT's buildings at certain locations in Mexico are constructed on land owned by the Mexican government and will be donated to the government when CIMMYT ceases operations in Mexico.

f. Depreciation—In accordance with the "write off, then capitalize" method, no depreciation is provided since the assets have already been written off at the time of purchase.

g. Seniority premiums, to which employees are entitled upon termination of employment after 15 years of service, are recognized as expenses as such premiums accrue. The estimate of the accrued benefit determined on the basis of an actuarial study as of the year end amounted to $297,000 in 1988 ($141,000 in 1987), and CIMMYT has recorded a liability of $216,000 in 1988 ($153,000 in 1987). The charge to income for the year amounted to $78,000 in 1988 ($50,000 in 1987), including amortization of past service cost over 10 years.

Other compensation based on length of service, to which employees may be entitled in the event of dismissal or death, in accordance with the Mexican Federal Labor Law, is charged to income in the year in which it becomes payable.

Since 1985, CIMMYT has recorded an accrual for certain unutilized benefits, such as leave time, by staff. That amounted to $383,000 in 1988 ($314,000 in 1987).

h. Revenue Recognition—Core unrestricted grants are given annually and are charged to accounts receivable when the amount of the donation becomes known. The receivable is cancelled when the funds are received. Any uncollected portion of the pledge applicable to the current year remains charged to accounts receivable and forms part of the institution's income in that year. If the pledge is later judged to be uncollectible, it is written off against income of the year in which it is cancelled.

Pledges in currencies other than US dollars are recorded at their equivalent at the date of deposit.

Core restricted and extra-core pledges, which are often for more than one year, are treated somewhat differently. In these cases the amount recognized as a receivable is equal to the expenses incurred under the grant. The uncollected portion of the pledge is not recognized as a receivable and consequently does not contribute to income. Only when expenses are incurred under the grant is an account receivable created and income recorded. This treatment matches revenues and expenses in accordance with the level of activities carried out under the grant.

This accounting policy permits CIMMYT to distinguish between income and amounts pledged in core restricted and extra-core grants. This is necessary since these grants often cover more than one year's activities or contain carry-forward provisions in cases of underexpenditure. Recognizing the total pledge in a given year as income could result in an overstatement of income. Core unrestricted grants do not require this treatment since they are given annually and the amount pledged represents income that year.

Note 4: Mexican Peso Transactions

The foreign exchange system existing in Mexico as of July 1985 permits the parallel existence of controlled and free exchange rates handled through exchange brokerage houses with rates in the latter case set on the basis of supply and demand.

At December 31, 1988, CIMMYT had Mexican peso assets and liabilities amounting to Ps 848,247,000 (Ps 577,776,000 in 1987) and Ps 1,113,972,000 (Ps 1,014,845,000 in 1987), which were included in the statement of condition at their US dollar equivalents, applying the year-end rate of Ps 2,270 per dollar.

In 1988 the value of the Mexican peso compared to the dollar fell from Ps 2,200 to Ps 2,270 to the dollar (Ps 911 to Ps 2,200 in 1987). This devaluation gave rise to a translation loss aggregating $6,000 ($528,000 in 1987). In accordance with FAS 52, where the firm is judged to be operating in a hyper-inflationary environment and the dollar is judged to be the functional currency, the translation effect in each year is charged to current income.

At February 14, 1989, date of issuance of the Financial Statements, the brokerage houses' exchange rates with the US dollar were Ps 2,315 (buy) and Ps 2,375 (sell).

Note 5: Fund Balances

The CGIAR permits CIMMYT (and all other international agricultural research centers funded through it) to maintain certain fund balances. The largest of these is the total investment in property, plant, and equipment. By the end of 1988, that had reached $20,938,000. A capital development fund may also be maintained to help finance future purchases or maintenance of capital items. In 1988, CIMMYT placed $700,000 in this fund. An operating fund may also be kept for the purpose of smoothing out cash flows and year-to-year revenue streams. In 1987, CIMMYT placed $350,000 in that fund. At the end of 1988, the Center had $2,765,000 in operating funds. The $485,000 surplus from CIMMYT's auxiliary services, such as food and housing, is also shown under fund balances. And lastly, the accumulated effect from the translation of Mexican pesos and other currencies is listed under fund balances and in 1988 amounted to $2,488,000.

Note 6: Revenue and Expenses

A. Revenue—CIMMYT's revenues are grouped into six categories:

i) Grants. These are funds received from donors and are used to support two types of programs at CIMMYT: core and extra core. Core programs must fall within the mandate of the center and be approved by the Board of Trustees. These must also be approved by the members of the CGIAR, who then provide funding. The CGIAR membership includes governments, government aid agencies, international and regional development banks, and private philanthropic foundations (see Exhibit 2). Core programs are divided into two groups: unrestricted and restricted. Unrestricted grants come with only one requirement: that the funds be used to support core activities.

Restricted grants also support core activities, but they must be used for an activity mutually agreed upon by CIMMYT and the donor.

Extra-core programs must also fall within CIMMYT's mandate and also must be approved by the Board of Trustees. They fall outside of any direct funding through the CGIAR and may be considered related, but distinct, sets of activities from the core program. In general they are of four types: 1) direct assistance (i.e., posting of staff) to national programs, 2) training at CIMMYT for persons from a specific country, 3) collaborative research arrangements with other institutions, and 4) special exploratory research activities. Coordination of this type of funding is done between CIMMYT and the donor.

ii) Administrative fees. These fees are charged on restricted and extra-core grants. They permit CIMMYT to offset the cost of administering these grants, which by design only fund specific research activities. In 1988 and 1987, this fee was generally 15%, though for some on-campus activities it was 25%.

iii) Sale of crops. CIMMYT operates four experiment stations in Mexico. Grain and other produce not required for continuance of the research programs is sold from time to time, depending on their availability and quality, and revenues received are registered as income of the period.

iv) Interest on short term investments. Surplus cash is invested in short term interest-bearing securities, and any interest earned is recorded as income. Similarly, interest expense arising from short term borrowings to cover cash deficit positions is charged to this account.

v) Auxiliary services. These comprise revenues from the following areas within CIMMYT: Cafeteria, Laundry, Guest House, Dormitories and Staff Residences. As a whole, they are intended to be self-supporting.

vi) Other income. This is a grouping of miscellaneous revenues received from the sale of surplus items such as used tires and other small pieces of equipment no longer needed by CIMMYT.

B. Expenses—The breakdown of CIMMYT's expenses as shown in its statement of activity is largely self-explanatory. Included under Research Programs, the largest single expenditure, are the expenses of the Maize, Wheat, Economics, Experiment Stations, Laboratories, and Data Processing units. In 1988 and 1987, their expenses were as follows:

	1988	1987
	(000s)	
Maize	7,006	6,201
Wheat	6,627	6,342
Economics	1,877	1,845
Experiment stations	1,887	1,455
Laboratories	346	314
Data processing	868	700
Others	239	224
Total	**18,850**	**17,081**

Note 7: Accounts Receivable and Payments in Advance

Accounts receivable from donors	**1988**	**1987**
	(000s)	
Austria, Government of		250
Canadian International Development Agency	256	108
Germany, The Federal Republic of		39
International Crops Research Institute for the Semi-Arid Tropics	25	28
International Institute of Tropical Agriculture		18
International Development Research Centre	22	101
The Netherlands, Government of	60	112
United Nations Development Programme	252	482
United States Agency for International Development	164	75
Other donors	88	19
Total	**867**	**1,232**
Payments in advance from donors		
Australia, Government of	(37)	(20)
Belgium, Government of	(64)	(30)
Canadian International Development Agency	(380)	(507)
Danish International Development Agency	(81)	(78)
France, Government of	(44)	(28)
Germany, The Federal Republic of	(261)	(183)
Italy, Government of	(649)	(420)
Japan, Government of	(1,535)	(1,200)
Norwegian Agency for International Development	(158)	
OPEC Fund for International Development		(15)
Switzerland, Government of	(1,014)	(938)
The Ford Foundation	(100)	(212)
The Rockefeller Foundation	(75)	(51)
United Nations Development Programme	(30)	
United States Agency for International Development	(109)	(185)
Other donors	(264)	(161)
Total	**(4,801)**	**(4,028)**
Other receivables (payments)		
Loans to senior staff*	172	172
Personal charges to employees	16	2
Official expenses advances	741	657
Employee credit union	(49)	(18)
Miscellaneous debtors	237	321
Total	**1,117**	**1,134**

*A program of loans to senior staff, mainly to provide partial financing for house purchases, was initiated in 1982. Those carry an interest rate of prime plus 1.75%.

Detailed Statement of Activity For the Period January 1 to December 31, 1988
Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.

Exhibit 1

US dollars (000s)

	Note	Core unrestricted	Core restricted	Extra core and cooperative	Auxiliary services	Total
Revenue	6					
Grants		19,488	6,401	5,766		31,655
Sale of crops		35				35
Interest on short term investments		236				236
Auxiliary services					926	926
Total revenue		**19,759**	**6,401**	**5,766**	**926**	**32,852**
Expenses	6					
Research programs		11,960	3,912	2,978		18,850
Conferences and training		2,287	1,335	1,915		5,537
Information services		1,431				1,431
General administration		2,452				2,452
Plant operations		1,593				1,593
Capital acquisitions		702	274	228	17	1,221
Auxiliary services					788	788
Indirect costs		(1,525)	880	645		0
Seniority premiums-accrual leave		159				159
Total operating expenses		**19,059**	**6,401**	**5,766**	**805**	**32,031**
Excess of revenue over operating expenses		700			121	821
Allocated as follows:						
Capital development fund	5	700				700
Auxiliary services	5				121	121
Translation effect for the year	4	(6)				(6)
Net excess of revenue over expenses		694			121	815

Sources of Income From Grants For the Period January 1 to December 31, 1988

Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.

Exhibit 2

US dollars (000s)

	Unrestricted	Restricted	Extra core and cooperative	Total
Australia, Government of	594		20	614
Austria, Government of	250			250
Belgium, Government of			111	111
Canadian International Development Agency	1,498		1,986	3,484
China, People's Republic of	50			50
Danish International Development Agency	554		49	603
European Economic Community		1,199		1,199
Finland, Government of	748			748
France, Government of		443		443
Germany, The Federal Republic of	460		222	682
India, Government of	45			45
Inter-American Development Bank	4,411			4,411
International Crops Research Institute for the Semi-Arid Tropics			363	363
Instituto Nacional de Investigación y Promoción Agropecuaria Peru/World Bank			34	34
International Institute of Tropical Agriculture			41	41
Italy, Government of		358	100	458
Japan, Government of		1,726	113	1,839
Norwegian Agency for International Development	168		26	194
OPEC Fund for International Development		65		65
Spain, Government of	115			115
Switzerland, Government of		533	500	1,033
The Ford Foundation	100			100
The Netherlands, Government of		313		313
The Philippines, Government of	60			60
The Rockefeller Foundation			40	40
The United Kingdom, Government of	1,310			1,310
The World Bank	3,875			3,875
United Nations Development Programme		1,764	26	1,790
United States Agency for International Development	5,250		1,720	6,970
Miscellaneous training and research grants			415	415
Total income from grants	**19,488**	**6,401**	**5,766**	**31,655**

Core Restricted Pledges and Expenses For the Period January 1 to December 31, 1988

Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.

Exhibit 3 US dollars (000s)

	Grant period[a] (month/day/year)	Grant pledged[a]	Expenses		
			Prior years	This year	Total
Government of France					
Collaborative Research—Maize	01/01/88-12/31/88			198	198
Bread Wheat	01/01/88-12/31/88			59	59
Triticale	01/01/88-12/31/88			59	59
Economics	01/01/88-12/31/89			48	48
Agronomy	01/01/88-12/31/89			54	54
Plant Protection	01/01/88-12/31/88			24	24
Total		**460[b]**	**N/A**	**442**	**442**
Government of Japan					
Wheat Disease Surveillance	01/01/88-12/31/88			501	501
Wheat and Maize Plant Protection	01/01/88-12/31/88			897	897
Wheat Southern Cone	01/01/88-12/31/88			328	328
Total		**1,726[c]**	**N/A**	**1,726**	**1,726**
OPEC Fund for International Development					
Maize West Africa, Phase V	07/01/87-06/30/88	100	35	65	100
Total		**100**	**35**	**65**	**100**
Government of Switzerland					
Central America and Caribbean—Maize	01/01/87-12/31/89	1,121	317	311	628
Central America and Caribbean—Economics	01/01/87-12/31/89	510	180	222	402
Total		**1,631[d]**	**497**	**533**	**1,030**
Government of The Netherlands					
Economics	01/01/88-12/31/88	153		153	153
Research and Technology Program	01/01/88-12/31/88	160		160	160
Total		**313**	**N/A**	**313**	**313**

Exhibit 3 (Continued) **US dollars (000s)**

	Grant period[a] (month/day/year)	Grant pledged[a]	Expenses Prior years	This year	Total
United Nations Development Programme					
International Maize Testing Program and Selected Training Activities	01/01/85-12/31/89	5,022	2,884	1,018	3,902
Development of Wheat Varieties for Marginal Areas	07/01/87-06/30/90	2,437	356	747	1,103
Total		**7,459**	**3,240**	**1,765**	**5,005**
European Economic Community					
Andean Regional Wheat and Maize	01/01/87-12/31/89	3,000[e]	1,003	1,199	2,202
Government of Italy					
Barley Yellow Dwarf Virus, Phase I	01/01/88-10/31/88	320		320	320
Barley Yellow Dwarf Virus, Phase II	11/01/88-10/31/91	1,350		38	38
Total		**1,670**	**N/A**	**358**	**358**
Total core restricted		**16,359**	**4,775**	**6,401**	**11,176**

[a] For information purposes only.
[b] Equivalent to FF 2'900,000.
[c] Equivalent to YEN 218,425,000.
[d] Includes US$38,949 of interest earned in 1988.
[e] Equivalent to ECU 3,000,000.
N/A = Not applicable.

Extra-Core Pledges and Expenses For the Period January 1 to December 31, 1988

Centro Internacional de Mejoramiento de Maíz y Trigo, A.C.

Exhibit 4 **US dollars (000s)**

	Grant period[a] (month/day/year)	Grant pledged[a]	Expenses: Prior years	Expenses: This year	Expenses: Total
United States Agency for International Development					
Barley Yellow Dwarf Virus	01/01/88-12/31/88	14		14	14
Pakistan Agricultural Research Council Wheat, Maize, and Economics	10/01/84-09/30/90	3,440[b]	2,379	440	2,819
Africa Farming Systems Research, Phase II	01/01/86-05/20/90	5,000	1,728	1,241	2,969
Maize Insect Pests	09/30/87-05/31/89	55		26	26
Total		**8,509**	**4,107**	**1,721**	**5,828**
United Nations Development Programme					
Consultancy	07/09/87-12/31/88	N/A	14	26	40
Canadian International Development Agency					
Triticale Research and Training	04/01/78-12/31/87	286[c]	284	2	286
Haiti—Economics	01/01/85-03/31/89	599[d]	392	117	509
East Africa Cereals Program, Phase I	10/01/84-05/19/88	2,040[e]	1,664	376	2,040
East Africa Cereals Program, Phase II	05/20/88-05/19/92	3,833[f]		485	485
Ghana Maize, Phase II	10/01/83-03/31/89	3,838[g]	2,858	694	3,552
Bangladesh-Wheat	04/01/82-06/30/90	3,815[h]	2,502	312	2,814
Total		**14,411**	**7,700**	**1,986**	**9,686**
Government of Switzerland					
Central America and Caribbean—Maize	01/01/87-12/31/89	714[i]	215	258	473
Central America and Caribbean—Economics	01/01/87-12/31/89	408[i]	101	177	278
Economics Training	08/19/86-02/28/89	84	51	30	81
Biotechnology Science	06/13/88-06/12/90	157		35	35
Total		**1,363**	**367**	**500**	**867**
Instituto Nacional de Investigación y Promoción Agropecuaria, Peru/World Bank					
Wheat	08/01/83-12/31/88	517	483	34	517

Exhibit 4 (continued) **US dollars (000s)**

	Grant period[a] (month/day/year)	Grant pledged[a]	Expenses Prior years	This year	Total
Government of Federal Republic of Germany					
African Students Postgraduate Fellowships	01/09/87-07/31/90	120	1	35	36
Wheat International Agricultural Research	07/01/86-06/30/89	591	251	177	428
Enhancement of Disease Resistance in Quality Protein Maize	07/01/86-06/30/89	48	18	10	28
Total		**759**	**270**	**222**	**492**
Government of Belgium					
Wheat Bacterial Disease Project	01/01/87-12/31/89	414	127	111	238
Government of Italy					
Barley Yellow Dwarf Virus	01/01/88-12/31/88	865	765	100	865
Government of Japan					
Fellowships Program	09/01/86-12/31/89	906	10	112	122
Cafeteria, Building	09/01/87-12/31/89	306	2		2
Total		**1,212[j]**	**12**	**112**	**124**
Norwegian Agency for International Development					
Predoctoral Fellowship	01/01/88-12/31/88	64[k]	N/A	26	26
Biotechnology Laboratory					
Government of Federal Republic of Germany	01/01/88-12/31/89	176[l]			
Government of Japan	01/01/88-12/31/89	500[m]			
Government of Italy	01/01/88-12/31/89	300			
Canadian International Development Agency	01/01/88-12/31/89	142[n]		207	207
Total		**1,118**	**N/A**	**207**	**207**

a For information purposes only.
b Includes RPs 28,194,206 equivalent to US$1,566,345.
c Equivalent to CA 338,944.
d Equivalent to CA 788,395.
e Equivalent to CA 2,753,000.
f Equivalent to CA 4,765,000.
g Equivalent to CA 4,977,866.
h Equivalent to CA 4,900,000.
i Includes US$38,949 of interest earned.
N/A = Not applicable.

j Equivalent to YEN 174,129,000.
k Equivalent to NOK 400,000.
l Equivalent to DM 200,000 plus US$59,844.
m Equivalent to YEN 68,360,000.
n Equivalent to CD 180,000.
o Equivalent to AD 190,000.
p Grant period not applicable.

Continued next page

Exhibit 4 (Continued) **US dollars (000s)**

	Grant period[a] (month/day/year)	Grant pledged[a]	Expenses Prior years	This year	Total
Biotechnology Consortium					
Government of Australia	01/09/84-01/09/88	149[o]	129	20	149
Danish International Development Agency					
DPS Associate Scientist	09/01/86-08/30/89	137	47	49	96
International Institute of Tropical Agriculture					
SAFGRAD	01/01/88-06/30/88	N/A	N/A	41	41
The Rockefeller Foundation					
Social Science Research Maize—Ghana	01/01/88-11/14/89	31		29	29
Social Science Research—Macro-Level	10/15/88-10/14/90	33		11	11
Total		**64**	**N/A**	**40**	**40**
Miscellaneous Training and Research Grants	p	N/A	N/A	206	206
Cooperative Projects					
IBPGR—Latin America	01/07/88-12/31/88	24		17	17
ICRISAT—Sorghum Project	01/01/88-12/31/88	348		348	348
Total		**372**	**N/A**	**365**	**365**
Total extra core			**14,021**	**5,766**	**19,787**

a For information purposes only.
b Includes RPs 28,194,206 equivalent to US$1,566,345.
c Equivalent to CA 338,944.
d Equivalent to CA 788,395.
e Equivalent to CA 2,753,000.
f Equivalent to CA 4,765,000.
g Equivalent to CA 4,977,866.
h Equivalent to CA 4,900,000.
i Includes US$38,949 of interest earned.
N/A = Not applicable.
j Equivalent to YEN 174,129,000.
k Equivalent to NOK 400,000.
l Equivalent to DM 200,000 plus US$59,844.
m Equivalent to YEN 68,360,000.
n Equivalent to CD 180,000.
o Equivalent to AD 190,000.
p Grant period not applicable.

Publications

Selected CIMMYT Publications

The following are selected publications released by CIMMYT during 1988. A more complete listing is available from Information Services.

CIMMYT. 1988. *1987 Annual Report: International Maize and Wheat Improvement Center.* Mexico, D.F. (also available in Spanish).

______. 1988. *CIMMYT Report on Wheat Improvement 1985-86.* Mexico, D.F.

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