CIMMYT in 1996-97

Widening the Circle of Partnerships

CIMMYT

Sustainable Maize and Wheat Systems for the Poor

CIMMYT An international, non-profit, agricultural research and training center dedicated to helping the poor in low-income countries.

Focus Increasing the productivity and sustainability of maize and wheat farming in low-income countries; protecting the natural resources upon which agriculture is based. Work concentrates on maize and wheat, two crops vitally important to reducing poverty and to ensuring food security for the poor. These crops provide about one-quarter of the food (total calories) consumed in low-income countries, are critical to the diets of the poor and, for poor farmers, are an important source of income.

Activities

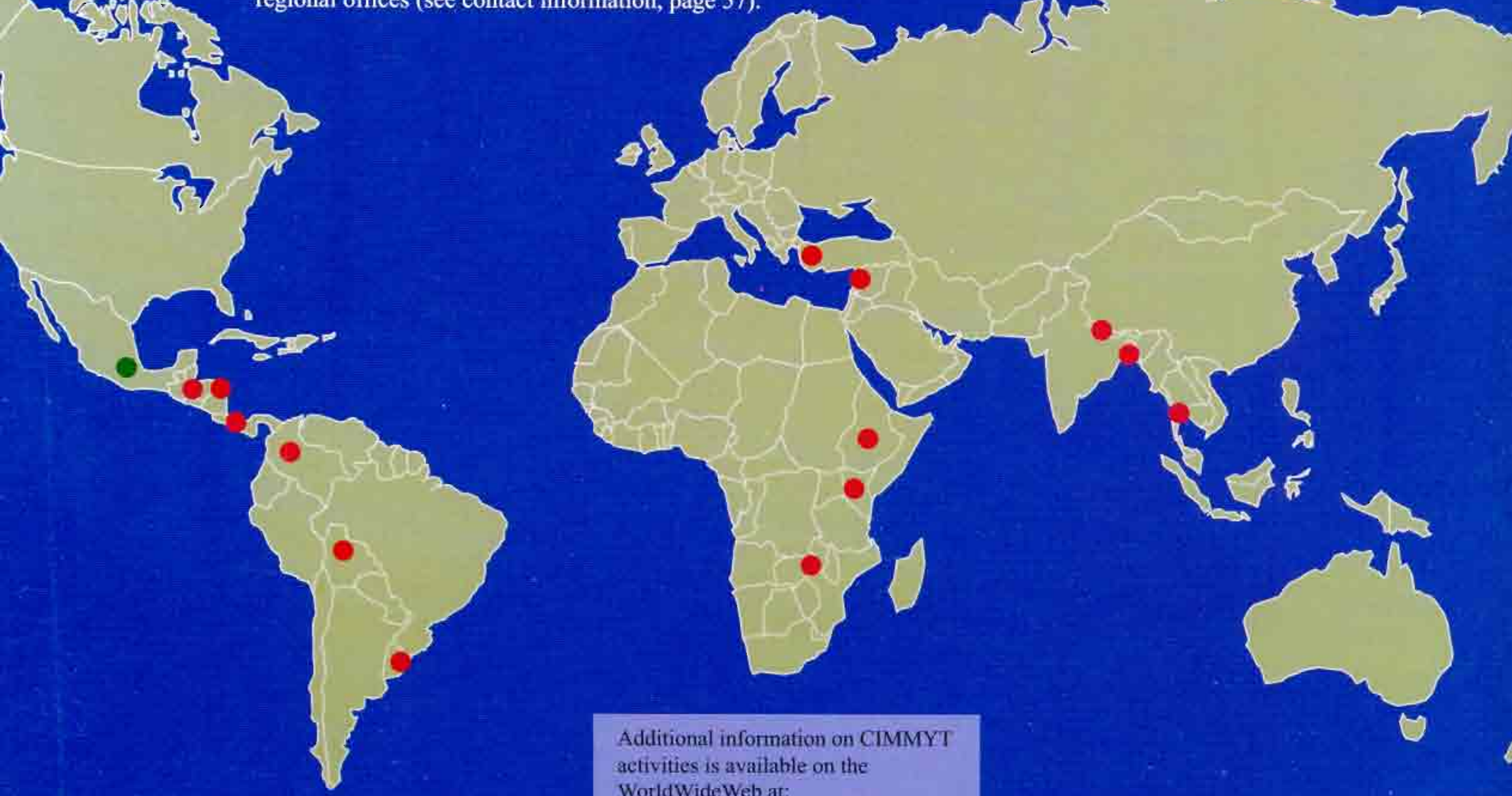
- Development and worldwide distribution of higher yielding maize and wheat with built-in genetic resistance to diseases, insects, and other yield-reducing stresses.
- Conservation and distribution of maize and wheat genetic resources.
- Strategic research on natural resource management in maize- and wheat-based cropping systems.
- Creation and documentation of new knowledge about maize and wheat.
- Development of more effective research methods.
- Training of various types.
- Consulting on technical issues.

Partners Staff work with colleagues in national agricultural research programs, universities, and other centers of excellence around the world, in the donor community, and in non-governmental organizations.

Impact

- 50 million hectares in low-income countries are now planted to CIMMYT-related wheat varieties (about 70% of the total wheat area in those countries, not counting China).
- CIMMYT-related wheats were sown on an additional 16 million hectares of farmland in low-income countries during the 1980s alone.
- 13 million hectares in low-income countries are now planted to CIMMYT-related maize varieties (about 50% of the total nontemperate area devoted to improved varieties in those countries).
- Nearly US$ 4 billion in extra grain production each year can be traced to the higher genetic yield potential and built-in pest resistance of CIMMYT-related varieties.
- More than 4,500 researchers are alumni of the Center's training programs.

Location Headquarters are in Mexico, but activities and impact extend to over 100 countries via 14 regional offices (see contact information, page 57).



Additional information on CIMMYT activities is available on the WorldWideWeb at:
www.cimmyt.mx or
www.cgiar.org

Widening the Circle of Partnerships

October 1997 marks the beginning of my third year with CIMMYT. As hard as it is for me to spend time looking backwards, it *is* good for people, and for institutions, to pause occasionally and take stock of their accomplishments – not so much to feel good about what they have done, but rather to measure progress against milestones and, if necessary, adjust their course into the future.

Timothy Reeves

Prof. Timothy G. Reeves
Director General

The introduction to last year's *Annual Report* highlighted many changes that were afoot throughout the Center, conveying the impression (I hope) of a world-class research institution moving quickly to meet new challenges and capitalize on new opportunities while, at the same time, striving to maintain its comparative strengths. The resulting mix of products and services – both the new and the proven – aims to satisfy the diverse and expanding needs of our many partners around the world. Clarifying those needs through extensive consultations, in a variety of fora and with a wide range of research partners and financial supporters, was only one of my primary objectives after assuming my new post, albeit an absolutely indispensable one. Other major goals included:

- a clearer understanding of, and better communication about, the fundamental importance of our products to the welfare of the hundreds of millions of rural and urban poor living in developing countries;
- focusing additional research resources on the special challenges presented by tougher, more marginal maize and wheat production environments;
- increasing the breadth, depth, and variety of our research partnerships, particularly with national programs and financial supporters;
- strengthening the role of biotechnology and natural resources research in achieving CIMMYT's research objectives;
- broadening the Center's role vis-à-vis maize and wheat genetic diversity;
- stabilizing, and then strengthening, our financial circumstances; and
- initiating a variety of important organizational and managerial changes.

In any process of institutional change, of course, considerable energy is spent initially on setting things in motion. That certainly was true of my first year in CIMMYT! With helpful counsel from our Board of Trustees, and drawing on the good will and seemingly boundless energy of all CIMMYT staff, together we undertook initiatives relative to virtually all these goals.

In year two, we were able to consolidate gains made in a number of areas, even as we pushed ahead with positioning the institute to better meet the projected, though far from certain, demands of the on-rushing millennium. Because of that uncertainty, consultation with the full range of CIMMYT's partners continued (and will continue still) as a critical underpinning to our research planning and decision making. Our course for the immediate future is charted in our new Medium Term Plan, 1998-2000+, released in May 1997. Titled *People and Partnerships* to give prominence to two key shifts in focus, this plan lays the foundation for a more flexible, more responsive CIMMYT in the years ahead – and flexibility and responsiveness will be sorely needed.

During the next three decades, the population of the developing world will continue growing at a around 200 people per minute. That staggering growth in numbers, combined with other changes, leads us to expect that overall demand for maize and wheat will grow dramatically during the same period. By 2020, two-thirds of the world's wheat and 55% of the world's maize will be consumed in developing countries. Even if productivity growth continues at current levels, developing countries will need to import more than 120 million tons of wheat and about 40 million tons of maize *each year* by 2020. Whether such abundant supplies of maize and wheat will be available then is, of course, open to debate, as is the ability of many poor countries to participate in the global market.

While incomes will grow throughout the developing world, there will continue to be substantial differences in rates of income growth and income distribution, both between and within regions. Those unavoidable realities will mean significant differences in food security among the developing world's poor. Given the continued concentration of poor people in sub-Saharan Africa and in South Asia, these two regions will remain CIMMYT's primary geographic focus (though our efforts in Latin America will remain very important). Increasing maize and wheat productivity in these regions will be absolutely critical to enhancing the food security of the hundreds of millions of people living there. Moreover, there will continue to be important differences in food security within regions, contrasts that are often tied to climate and natural resource issues. Areas where soils are poor, or that are prone to drought, will be particularly at risk. We are therefore shifting CIMMYT research resources in order to more quickly produce better adapted varieties and new production methods suitable for these more difficult production systems (see pages 22-26, 32-35).

Even in more productive areas, however, differences in food security between households will continue because production resources are, and will continue to be, unevenly distributed. And within households, women and children will continue to face higher risks of malnutrition resulting from poorer access to food and to the means of producing it. CIMMYT will work to take these realities into account in shaping its research activities and, wherever possible, will address more directly the needs of the disadvantaged groups amongst the resource poor, especially women (see pages 32-45).

The new technologies that farmers must implement these days to increase their productivity is becoming ever more complex. As the trend toward more knowledge-intensive technologies continues, the way we produce and disseminate research results – indeed, the very nature of our partnerships – must change. CIMMYT's major comparative advantage is, and will remain, the development of improved maize and wheat varieties. We will continue to emphasize this work and we will make every effort to build as many desirable characteristics as possible into our new varieties so as to encourage sustainable productivity increases. Still, we know that we must gain a better understanding of the socioeconomic and natural resource systems where maize and wheat are important food crops to improve the effectiveness of CIMMYT's products.

To do that, as we reported last year, both our Economics Program and our Natural Resources Group have been strengthened, both to build our in-house skills and capabilities (for example, in gender analysis, participatory research, crop-soil modeling, and geographic information systems — GIS), and to provide a "credible mass" for working with partners whose comparative advantages lie in these areas of work. This credible mass is now firmly in place and is making research collaboration with CIMMYT much

more attractive to a wider range of partners. We believe that the kind of partnership arrangements now being established, such as those with NGOs and advanced research institutes, both public and private, will greatly improve the development and transfer of new technologies to poor farmers (see pages 13-14, 22-31, 49-51).

One area in which new forms of partnership are playing a key role for CIMMYT is biotechnology. To capitalize on the tremendous potential of this rapidly changing science, we significantly expanded our in-house research capacity with the further development of the Applied Biotechnology Center. Beyond that, we are working to strengthen the biotech capabilities of our national program partners (through intensive training and extensive networking) and are now investigating various new forms of partnerships with public – and with private – advanced research institutes, both in developing and developed countries (see pages 28-29). We are exploring these potential partnerships in a stepwise fashion and with great care, because of their complex implications for such important considerations as intellectual property rights. Our Board of Trustees is involved in all major policy decisions relative to these new ventures.

CIMMYT has long been involved in the area of genetic resources, mainly through *ex situ* conservation of maize and wheat landraces and varieties, as well as their use to produce improved cultivars for farmers. We are expanding our role in this important arena, with an eye to reducing genetic vulnerability in farmers' fields and to preserving existing diversity – and even increasing available diversity through the introgression of genetic material from alien species. In addition to fully participating in key CGIAR-wide activities, we are initiating *in situ*, farmer participatory conservation activities – for now, "close to home" in Mexico, the center of maize genetic diversity (see pages 7-11).

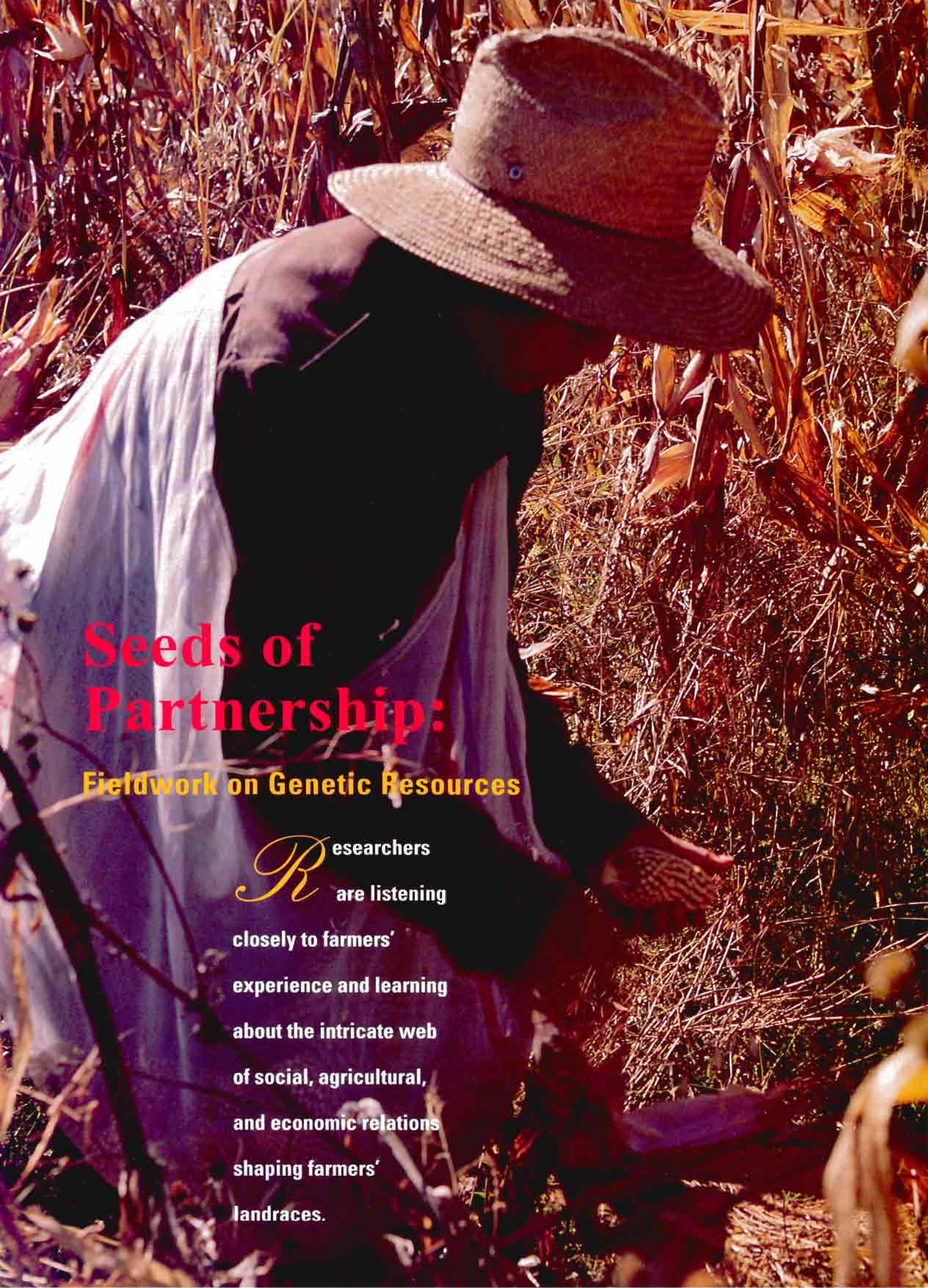
Moreover, to facilitate all our genetic resources work, we have established in our new Medium Term Plan a Global Project (GP1) that embodies the full range of our conservation and management objectives, activities, and outputs. I am leading this project.

As can be seen in the financial highlights for this year (pages 52-53), CIMMYT's financial circumstances have stabilized after a difficult few years in the early 1990s. As we look to the future, we remain concerned about broad trends in funding for agricultural research, yet we are cautiously optimistic about our ability to engender financial support for CIMMYT's work, both from our traditional core donors as well as from new sources. Our basic strategy is one of true partnership with potential financial supporters, working hand in hand with them to identify new opportunities and define truly relevant research activities, *always* in collaboration with national program partners and a range of other institutions. We will continue to invest the time and energy needed to increase the visibility of agriculture (and its research) on the political landscape, as well as to assure the continued viability of CIMMYT's own research program, not as an end in itself, but rather because the future welfare of so many people in the developing world depends on it.

Finally, we have implemented a number of important organizational changes during the past two years, all of which are detailed in our Medium Term Plan. Most notable among them is our shift to a true multidisciplinary, project-based approach to managing our work. This strategy, which will be fully implemented in 1998, will underlie virtually all of our activities. We have organized CIMMYT's research into 21 projects. Eight of these are global in scope (and are inclusive of our mainstream genetic improvement, economics, and training activities); five are regional in nature, providing the mechanism by which outputs from our global projects are refined and transferred to developing countries; seven Frontier Projects support the above, focusing on higher risk research and involving the application of new approaches in science and collaboration; and one Special Project centers on wheat research and development for the Newly Independent States. We have also been working with outside consultants and professional facilitators to assess – and wherever necessary to modify – the influence of gender on our work environment. Our objective here is and will remain the creation of a more equitable and more productive workplace. CIMMYT staff have enthusiastically embraced this initiative, and we are making progress in a number of related areas, from a more transparent (and professional) staff classification and compensation system all the way through to more effective ways of evaluating the effectiveness and productivity of our personnel.

All in all, it has been a fast-moving first couple of years for me in CIMMYT. I am extremely proud to be associated with this great institution, with its traditions of service to the poor and its forward-looking and highly competent staff. The future is indeed full of uncertainties, but of one thing our growing number of partners can be sure: we will do *all* in our power to continue providing the best products and services possible – secure genetic resources, new varieties, better methodologies, new scientific information, and high quality training.

Of one thing our growing number of partners can be sure: we will do *all* in our power to continue providing the best products and services – secure genetic resources, new varieties, better methodologies, new scientific information, and high quality training.



Seeds of Partnership:

Fieldwork on Genetic Resources

Researchers are listening closely to farmers' experience and learning about the intricate web of social, agricultural, and economic relations shaping farmers' landraces.

"Working" the Seed: Farmers' Management of Genetic Resources in Two Indigenous Communities

When the farmers of two indigenous communities of southern Veracruz, Mexico, speak about which maize landraces they plant, they say they "work" the seed, much as artisans say they "work" their raw material to transform it into folk art. "My grandfather — I'm named after him — worked white maize," recalls one farmer, expertly husking an ear of maize to reveal rows of pale kernels. "I work it, too, along with some of the red and black types."

Over the past three years, maize farmers in these communities have carefully recounted their seed stories to José Luis Blanco. Blanco, a sociologist from the Proyecto Sierra de Santa Marta (PSSM), a Veracruz-based non-governmental organization (NGO), collaborated with CIMMYT to monitor adoption of recommended seed selection techniques in the communities. "These stories vividly document the links between farmers' personal histories and the way they manage their maize seed — their genetic resources," says Blanco. "They show that the conventional understanding of farmers' traditional seed selection and management practices may be oversimplified."

The idea of indigenous farmers retaining seed of their landraces from harvest to harvest and generation to generation, virtually unchanged, is inaccurate. Elizabeth Rice, an affiliate scientist with the CIMMYT Economics Program, who worked with Blanco on the data he collected, notes that the flow of seed is more complex. When a farmer marries, leaves his parents' home, and starts to grow maize on his own fields (few women in these communities farm), he usually takes seed of some, but not all, of his family's maize varieties. Over the years, this seed is frequently replaced or changed. Sometimes this occurs because of circumstances outside the farmer's control; sometimes his interest is simply piqued by a variety he chances to see. In this way, seed is substituted by other seed, lost, or reintroduced in a lifelong tidal flow of genetic material into and out of the farmer's collection.

For example, one farmer interviewed by Blanco tried growing a variety of yellow maize (called Pu'uchmok, literally "yellow maize" in the Populuca language) which he found on the road. He was looking for a good yellow maize — farmers in the area agree that such maize is the best for planting on steep, sloping fields — but the new seed proved disappointing. The farmer replaced it with seed of another yellow maize, Tsabastspu'uchmok ("reddish-yellow maize"), favored by his brother. The farmer grew that maize for 15 years, until a hurricane hit during one cropping season and left his maize crop in tatters. Because little grain could be harvested for food or seed, he obtained Tsabastspu'uchmok seed from his son for the next season's planting (see figure, next page). The same farmer stopped growing his usual black maize when he saw that the black maize grown by one of his laborers made a more appealing dark purple *pozol* (a drink made from fermented maize) compared to the grayish *pozol* the family had been drinking.

What began in Santa Marta as a simple monitoring study is yielding unexpected insights into how farmers might be altering the genetic makeup of their landraces.* Although researchers and others have long recognized farmers' traditional role in shaping the evolution and diversity of crops, they have only just started rigorous investigations of the complex scientific and socioeconomic issues involved in farmers' efforts to manage their genetic resources. The findings from Santa Marta are corroborated by other work in Mexico, using different methods, by researchers Alfonso Aguirre in Guanajuato and Dominique Louette in Jalisco. This growing body of work shows that as Mexican maize farmers continuously substitute, replace, and introduce maize seed into the family seed collection, they are not simply exchanging seed of one variety for another. Instead, farmers frequently renew their collections with seed of the *same varieties* they already grow but obtained from another source. (In this context, a "variety" is defined as a folk variety — a crop population that a group of farmers recognizes and names as a unit.) Thus the seed that farmers inherit

* E. Rice, J. Blanco, and M. Smale, *Can Improved Seed Selection Practices Help Farmers Maintain the Diversity of the Maize They Grow? Evidence and Issues from the Sierra de Santa Marta* (Mexico, D.F.: CIMMYT, forthcoming).

"What happens when farmers adopt a breeding or seed selection practice that alters the seed of a landrace they already use? How can we measure the impact of a practice whose effect is to allow landraces to keep evolving?"

from their families is subtly and continuously transformed by the farmers themselves.

All of these practices have implications for implementing an on-farm program to conserve something as mutable as a maize landrace. Mauricio Bellon, a CIMMYT human ecologist who specializes in the study of biodiversity and *in situ* conservation, is familiar with the difficulties involved. "Whereas *ex situ* conservation 'fixes' genetic material at the time it enters a germplasm bank, *in situ* conservation of wild plant species allows adaptive

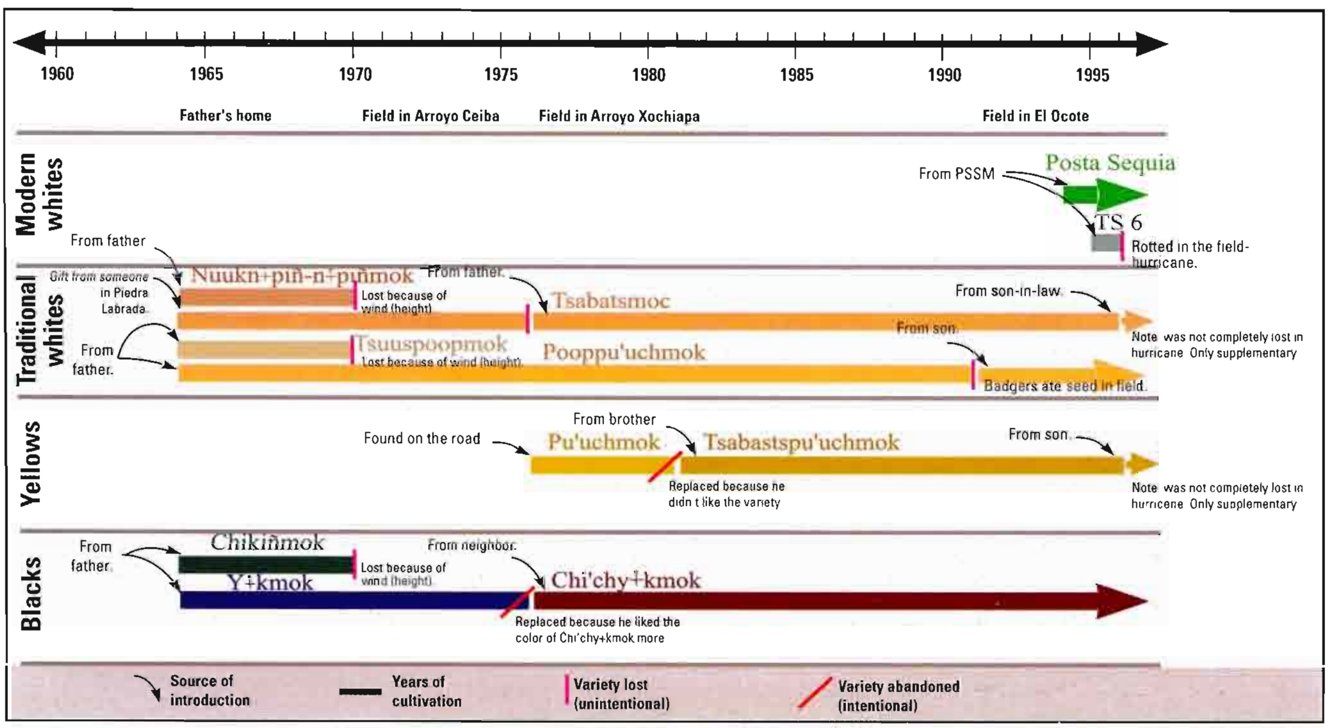
evolutionary processes to continue. However, *in situ* conservation of a domesticated species or subspecies is a bit more complicated, because it involves management by *farmers* in the systems where the crop evolved."

On-farm crop improvement through breeding and/or seed selection practices has been proposed as one way for farmers to continue cultivating key landraces and also to benefit from some additional improvement in them (see the story, next page). "This means that we need to think carefully about what incentives farmers have to use new practices on their landraces — many of which are likely to be labor-intensive," says Melinda Smale, a CIMMYT economist studying genetic diversity issues.

Another challenge is to measure the impact of strategies for on-farm maize improvement or modified seed selection practices. "Usually we are concerned with what happens when a new variety simply replaces an old one," notes Smale. "But what happens when farmers adopt a breeding or seed selection practice that alters the seed of a landrace they already use? How can we measure the impact of a practice whose effect is to allow landraces to keep evolving?"

As Rice emphasizes, "Strategies that enable farmers to maintain their own maize landraces must be based on an accurate knowledge of how farmers manage those landraces." In learning about the intricate web of relations shaping farmers' landraces, researchers are moving closer to that goal.

History of seed used by one farmer in the Sierra de Santa Marta, Mexico. The names of the varieties are in color.



Farmer Management and Genetic Resource Conservation in Oaxaca, Mexico

In certain writings about the *in situ* conservation of crop genetic diversity, one encounters a flavor somewhat reminiscent of the work of late US painter Frederic Remington, whose action scenes helped popularize a romantic view of the 19th century American West. Like a Remington painting, this model of *in situ* conservation would faithfully capture an idyllic image for posterity, holding farmers and their seed fixed, heroic against the onslaught of time and change.

To begin with — as anyone who has visited rural areas in the developing world knows — farmers' circumstances may be heroic but are seldom idyllic, and most will gladly embrace change that improves their well-being. In fact, various studies show that maize farmers who grow local varieties have long practiced dynamic seed management strategies in which they purchase, mix, exchange, and replace varieties to maintain diversity, specific grain qualities, and productivity. Moreover, maize landrace diversity seems linked to open systems and deliberate, farmer-driven evolution, so fencing off landraces will stop this evolutionary process as surely as replacing landraces with other crops, cattle ranches, or housing projects.

Recent, rapid shifts in the economic and social environments of many traditional maize production areas are disturbing the balance in these seed management systems, however, and certain maize landraces are now grown less often or not at all. "If you just want to conserve the varieties as they are, you can put them in a germplasm bank," says Suketoshi Taba, head of maize genetic resources at CIMMYT. "The challenge here is, given the dynamic nature of the production system — these landraces are going to evolve, whether we like it or not — how can we ensure that some forms are conserved and improved to benefit farmers?"

It seems clear to Taba and research associates from CIMMYT and the Mexican National Institute for Forestry, Agriculture, and Livestock Research (INIFAP) that the way forward lies in farmer participation. With funding from the government of Mexico, the International Development Research Centre (IDRC), Canada, and the International Agronomic Research Commission, France, they began work in 1997 to help smallholders in the Central Valleys of Oaxaca, Mexico, preserve selected maize landraces in danger of extinction. "The only way to give these landraces a fighting chance is to give farmers a reason to grow them," Taba says. "So we will help farmers improve specific traits — such as grain quality or yield — which they recognize and which add value to the local varieties, drawing on local diversity, other races, or improved germplasm."

> "The only way to give landraces a fighting chance is to give farmers a reason to grow them."

The Central Valleys of Oaxaca surround the populous Oaxaca state capital and include nearly 9,000 square kilometers of rolling, occasionally mountainous land ranging from 1,500 to 2,500 meters above sea level. Nearly a third of the region's economically active population is involved in agriculture, and many grow maize. Most maize farmers plant traditional varieties of the race "Bolita" in rainfed systems. "The local varieties have certain, special grain qualities that the farmers value," says Flavio Aragón Cuevas, INIFAP researcher in the project. "These include color, texture, and the capacity to produce a large kernel even under suboptimal growing conditions." Average yields are only 0.8 tons per hectare — the lowest for maize in Mexico — and farmers have little capital and use few inputs on their crop. Most maize is consumed at home, although there is a market for Bolita as tortillas and for forage, and fresh ears from hybrids are steamed and sold on street corners. Aragón and

"Of all the efforts that people make on behalf of others, the most praiseworthy will always be those to alleviate hunger.... The Wellhausen-Anderson Plant Genetic Resources Center, inaugurated today, is charged with collecting and conserving genetic resources...., which will be distributed to research organizations in other countries to produce varieties adapted to the conditions in each country.... I would like to express the most sincere wish that this center of hope achieve its objective."

These words were spoken by His Excellency Terusuke Terada, Ambassador of Japan to Mexico (left), upon inaugurating the Wellhausen-Anderson Plant Genetic Resources Center in late 1996. Funded in part by the Japanese Government, the Center's specially designed seed storage, treatment, and packaging installations support CIMMYT's unique, global role in germplasm conservation and distribution. (Mexico's Minister of Agriculture, Francisco Labastida Ochoa, stands to the right of the Ambassador.)

INIFAP colleagues have noted a marked decline in maize landrace diversity in the Central Valleys in recent years. "Prices for maize have fluctuated considerably over the last decade, and the local grain market simply does not pay well for certain farmer varieties," Aragón says. "Added to this is the fact that farmers' storage facilities for maize are poor or non-existent, so they are forced to sell soon after harvest, when prices are at their lowest."

In the initial step of their work, Taba, Aragón, and associates visited farmers in villages throughout the Central Valleys, collecting more than 150 samples of the major local varieties grown there and general information about farmers' households, cropping practices, and uses for maize. They next sowed a small plot of each sample in fields donated for this purpose by village members. "Farmers will be able to visit the field, observe the performance of different varieties, and later request seed of those they like," Taba says. "For our part, we will be able to take data on the yield and agronomic traits of the varieties in their natural habitats, and will try to establish links between the varieties and previous collections from the region now kept in the CIMMYT maize germplasm bank. We can then form representative subsets of the collections and the bank seed that embody their genetic diversity, and, together with farmers, identify target traits for on-farm and on-station improvement." The steps of collection, characterization, and utilization are normal activities in the *ex situ*

preservation of crop genetic resources, according to Taba. "But these actions are often performed in fits and starts over many years," he says. "Here, they will be telescoped into a tight sequence. Farmers will be more closely involved in all steps to ensure they benefit and, in this way, to promote conservation."

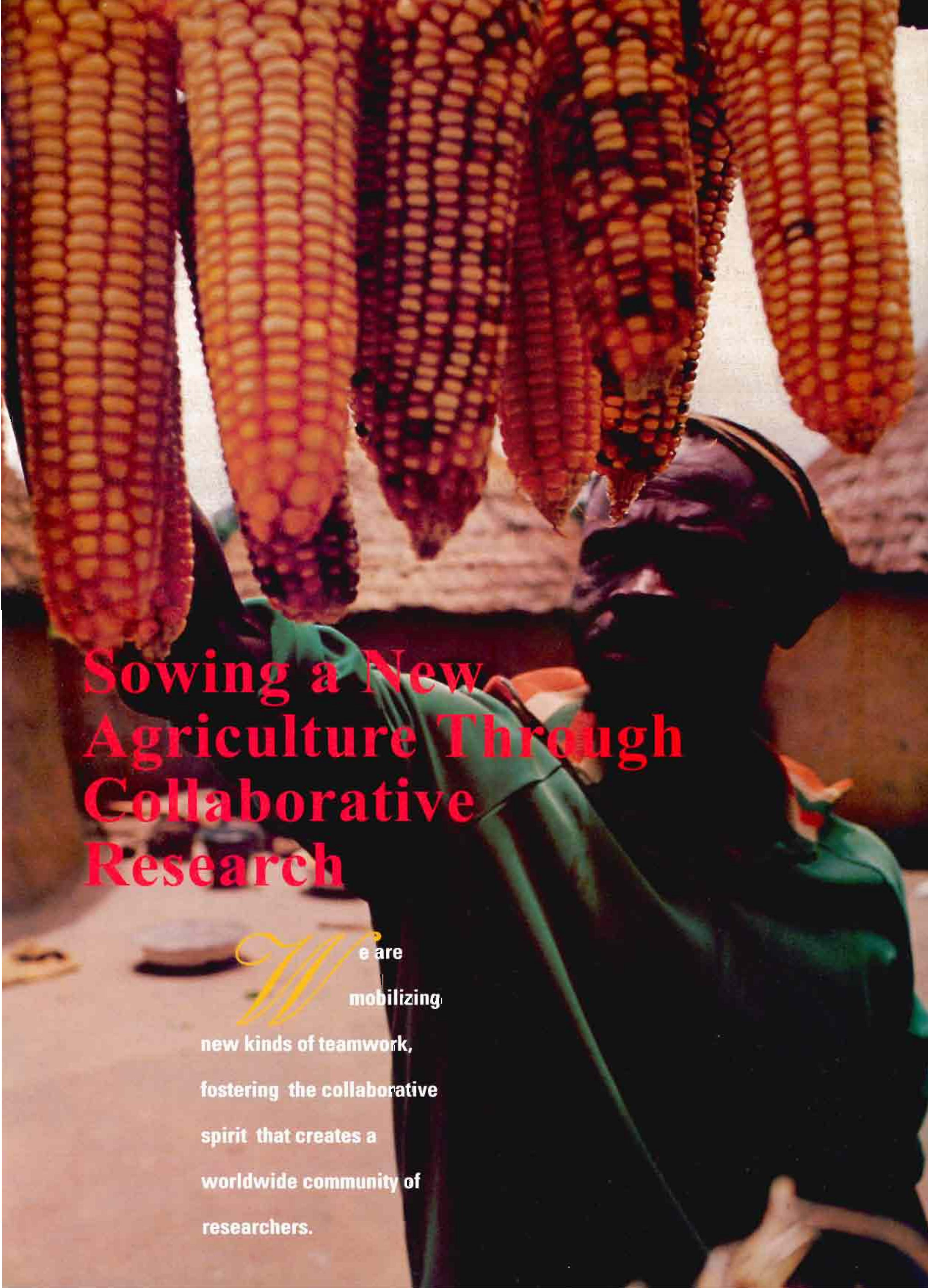
CIMMYT social scientists will play a crucial role, helping to devise an on-farm improvement strategy that provides a welfare benefit to farm households while maintaining or enhancing genetic diversity. They will help interpret local farmers' varietal and environmental classification schemes, identify key varietal traits, and rank their priority and level of expression by variety. "Farmer decision-making is usually based on unique, internally consistent systems for classifying varieties, varietal characteristics, topography, and soil type," says Mauricio Bellon, CIMMYT human ecologist in the project. "These may or may not coincide with current scientific taxonomies for land, soil, and variety. Part of my job is to understand farmers' terminology and perceptions and relate them to researchers' categories for such things." According to Melinda Smale, CIMMYT economist in the project, farmers' seed management practices constitute a key piece in the mosaic of knowledge required. "Over the longer term, we need to understand how seed flows among them, as well as the social organization that affects this flow, to predict and monitor the impact of our research," Smale says.

One other key feature of this work is that it brings to bear the power of CIMMYT's comprehensive maize germplasm bank and databases in backing up samples of endangered landraces, conducting joint farmer-breeder selection for improved grain quality and productivity, and transferring traits of interest from improved maize or other non-local seed sources. "In the bank we may even have seed of certain landraces that have disappeared but which farmers may wish to grow again, after adding or improving selected grain quality traits," Taba says.

If successful, the methodology for this project could be applied elsewhere for maize and other cross-pollinating crops. "Many people talk about *in situ* conservation," Taba says, "but actually doing it has turned out to be more complicated, especially when it involves farmer management of a cultivated crop like maize. We feel this approach to be both practical and scientifically rigorous."

Taba and other project members are also on the advisory committee of another, broader effort funded by the McKnight Foundation to conserve crop genetic diversity and improve crop production in Mexico through farmer-based methods.

"Farmer decision-making is usually based on unique, internally consistent systems for classifying varieties, varietal characteristics, topography, and soil type. Part of my job is to understand farmers' terminology and perceptions and relate them to researchers' categories for such things."



Sowing a New Agriculture Through Collaborative Research

We are mobilizing new kinds of teamwork, fostering the collaborative spirit that creates a worldwide community of researchers.

A New Community of Socioeconomists Strengthens the Spirit of Collaborative Research in East Africa

A CIMMYT's principal economist for East Africa, Wilfred Mwangi has a job that is concerned with more than excellence in his own research. His task is to mentor the new generation of social scientists working in East Africa's national research programs, to develop networks that bring those scientists together with their more experienced colleagues, and to create opportunities for international collaboration in social science research for researchers at all levels.

Wilfred Mwangi is eminently suited to the task he has been given. Formerly an Associate Professor and Chairman of the Department of Agricultural Economics at Kenya's University of Nairobi, Mwangi knows how to elicit critical thinking from students accustomed only to rote familiarity with a subject. He is a master at fostering the collaborative spirit that transforms a group of students into a community of researchers.

These skills can make the difference between success and failure in a project such as that led by Mwangi. "Our goal — which is the goal of the European Union, the agency supporting our project — is to stimulate and contribute to high quality economics research and policy analysis by national program staff in East Africa," he says.

How can social scientists from understaffed and underfunded national programs, people struggling with challenges that would daunt some of the best-endowed research programs in the world, combine forces to work more effectively? This is done through collaborative research and training in areas that the national programs themselves deem important. "You can't do this job without investing time in people and learning what is important for them," says Mwangi, who spent 120 days on the road last year, consulting with researchers in Uganda, Kenya, Ethiopia, and Tanzania. "Aside from talking with the economists and other social scientists, we met the biological scientists who work on the great array of crops in East Africa, including CIMMYT's mandate crops, maize and wheat. Under this project, social science research is not conducted for its own sake but to further the objectives of the national research program. This project is about mobilizing new kinds of teamwork."

"Regional networks do not form out of simple good will: people have to be convinced that they are useful," adds Mwangi's coworker in the regional program, Hugo Verkuijl, an Associate Expert funded by the Government of the Netherlands.

Workshops that bring the region's social scientists together are an invaluable means of sourcing the collaborative spirit. In July of 1996, the CIMMYT/European Union (EU) project helped sponsor the first training workshop organized for socioeconomists from East African national research programs, and the first to cover natural resource policy analysis. Meeting at Kenya's Egerton University, 14 participants, four of them women, spent two weeks sharpening their policy analysis skills.

"The workshop participants were looking for analytical tools to deal with the problems of resource use and degradation that threaten agriculture in East Africa," explains Musembi Manundu, a Senior Lecturer in the University of Nairobi's Department of Economics and one of the resource persons at the workshop. "For example, how do we determine which existing policies affect the use of natural resources? How do we know who will win and who will lose if the current situation changes? What economic policy solutions can reverse or halt natural resource degradation?"

"My research benefited immediately," recalls Francis Musembi, a workshop participant, "because I am studying a natural resource issue — farmers' soil fertility management strategies in Kiambu District, Kenya." In this district, even though nearly 90% of smallholders use animal manure on their farms and more than half apply inorganic fertilizer, continuous cropping has depleted soil fertility and limited crop yields. Musembi is trying to determine whether a better combination of soil fertility treatments could help farmers improve the soil as well as maize yields.

"Our collaboration should be the basis of an enduring network of researchers whose work is increasingly visible, increasingly appreciated within their own borders, and recognized outside as well."

All of the researchers who attended the workshop, and many others besides, conduct research funded under the regional project. "The research topics are not only high priority topics for the national program involved," explains Mwangi, "but they have common themes. This enables the entire group of researchers to focus on methodological issues of concern to all of them." These themes are related to farmers' seed management practices, gender and technology adoption, and the adoption of seed-fertilizer technologies.

"As part of the network of regional economists, I studied the adoption of recommended maize technologies in Mbeya Region of the southern highlands of Tanzania," explains Shekania Bisanda, a sociologist at the Uyole Agricultural Research and Training Institute. "Results of the study* will be combined with results of similar studies in other regions of my country to assess the national impact of maize research over the past 20 years."

"Bisanda's work shows how the CIMMYT/EU project enables people to join forces and build on each other's research," observes Verkuijl. "Social scientists are often posted to regional research institutes, where they remain isolated from others in their discipline. The research funded by the project gives these scientists an opportunity to contribute to a larger body of research, whose results are of national as well as local interest."

Isolation and lack of training are not the only problems that Mwangi and Verkuijl hope to overcome. Mwangi is frank about the difficulties of maintaining a network of public sector researchers. "The challenges that we face include high turnover of economists in national research programs; working with young and inexperienced economists; poor communications in the region; and the reluctance of national programs to share data among themselves and even with me before it is published by the national program," he says.

Progress is being made, however, as the growing list of research results attests. "I certainly hope that the project produces lasting accomplishments aside from the research findings," comments Mwangi. "Our collaboration should be the basis of an enduring network of researchers whose work is increasingly visible, increasingly appreciated within their own borders, and recognized outside as well."

* S. Bisanda and W. Mwangi, *Adoption of Recommended Maize Technologies in Mbeya Region of the Southern Highlands of Tanzania* (Addis Ababa, Ethiopia: CIMMYT and United Republic of Tanzania, Ministry of Agriculture, 1996).

Wheat Researchers and Farmers Devise New Tactics in the War Against Hunger

Resource-poor farmers in the developing world have to be canny in choosing new, productivity-enhancing technologies. In their precarious circumstances, a wrong choice could have disastrous consequences.

In developing productivity-enhancing technologies, CIMMYT works in concert with national agricultural research systems (NARSs) to ensure that the technologies will suit farmers' needs. Partnerships are essential for developing and transferring relevant technologies to farmers. "Our partnerships in wheat research are built on the principal needs of NARSs," says Sanjaya Rajaram, Director of the Wheat Program. "As breakthroughs occur in the different sciences, it is imperative that we bring those advances together as soon as possible for the benefit of farmers in diverse production systems."

As every wheat researcher knows, speed is of the essence. For example, in densely populated and intensively cropped Bangladesh, the demand for wheat is growing at a fast-paced 3% a year. "This upward spiraling demand for wheat is not unique to Bangladesh; it is observed in many other developing nations where population is increasing," says Maarten van Ginkel, head bread wheat breeder at CIMMYT.

Experts at the International Food Policy Research Institute (IFPRI) estimate that by 2020 the demand for wheat will be 40% greater than it is today. "The challenge confronting wheat researchers is as daunting as that faced by Borlaug and his colleagues more than 30 years ago," says Prabhu Pingali, Director of CIMMYT's Economics Program. "We cannot afford to be complacent."

Concurs Rajaram, "Any sense of complacency disappears when you consider, for example, that the grain area per person has declined by one-third in the past 25 years. This is due primarily to the continuing population explosion. Just to keep up, we must increase wheat productivity by at least 2.1% per year until 2020, when population increases may taper off."

"Any sense of complacency disappears when you consider that the grain area per person has declined by one-third in the past 25 years."

To understand what reaching this goal would entail, one must remember that the hugely successful wheats of the Green Revolution and the superior water and nutrient management practices that went with them have increased yields in the irrigated environments of the developing world by about 2% a year in the past three decades. "Though we're cautiously optimistic about prospects for increasing yields in irrigated environments, it is certainly becoming more difficult to keep up the rate of progress," says Ken Sayre, Wheat Program agronomist.

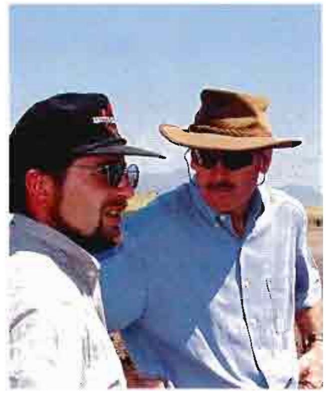
Wheat production in marginal environments, especially where little water is available, has also benefited from CIMMYT research, for example, through Veery-derived lines, which use nutrients more efficiently and tolerate drought better. This enables them to yield at least as much as local varieties when conditions are poor and more when conditions improve. Consequently, the risk farmers face because of yield variability from year to year is reduced.

These improvements notwithstanding, in the past 10 years, annual yield increases have started to slow down in some of the most productive environments in the developing world, despite the use of high levels of fertilizer and crop management. This compounds the problem of producing enough wheat to meet future demands.

Fully aware of the seriousness of this challenge, CIMMYT wheat researchers are devising new tactics in the war against hunger. CIMMYT's strategy is twofold: first, to boost the wheat plant's yielding capacity and

Specialists in physiology, biotechnology, and breeding presented innovative ways to extend wheat yield potential. Their ideas provided fertile ground for discussion.

efficiency and, second, to develop efficient crop production systems that unleash the new varieties' higher yield potential and reduce the impact of agriculture on natural resources. "We aim to integrate improved germplasm with cost-reducing and efficient wheat management practices. By joining forces with our research partners to pursue this combined strategy, we should succeed in staying abreast of the growing demand for wheat," says Timothy Reeves, CIMMYT's Director General.



only influenced the strategies CIMMYT has chosen to pursue in seeking to improve wheat's yield potential, but will no doubt be factored into similar decisions in the future.

"The synergy generated at the workshop by bringing together experts in different disciplines would be hard to recreate," says Matthew Reynolds, wheat physiologist involved in organizing the event. "The ideas they presented and the discussions emanating from them will help shape our research agenda for many years to come."

Enhancing the Wheat Plant's Inherent Yield Capacity

To explore both conventional and modern tools that might aid in raising the wheat plant's capacity to yield more, the CIMMYT Wheat Program called upon 12 recognized specialists in physiology, biotechnology, and breeding to participate in a workshop held in Ciudad Obregon, Sonora, Mexico, in March 1996.* They were asked to think about innovative ways to extend yield potential beyond current levels and present them to workshop participants, which included not only CIMMYT scientists, but many NARS researchers as well.

The workshop was a good example of how CIMMYT interacts with advanced research institutions (from which most of the specialists came) and collaborates with its principal research partners, the NARSs. The collegial atmosphere stimulated the open exchange of ideas and provided fertile ground for discussion. The outcomes of the workshop have not

Building Yield on a New Plant Architecture

Some of the most productive discussions at the workshop took place in small working groups that concentrated on specific topics. The group focusing on morphological and physiological ideotypes suggested that new plant types be developed that combine a number of physiological traits known to be associated with higher yield potential. As it happens, work of this kind was done at CIMMYT in the past; it culminated in the creation of a new plant type embodied in an experimental line dubbed "Buitre," which has an unusually large spike (more than 12 inches long), a robust stem, and produces many grains. It represents years of painstaking effort that started in the early 1970s, when Ricardo Rodríguez, a CIMMYT scientist (now retired), under the guidance of N.E.

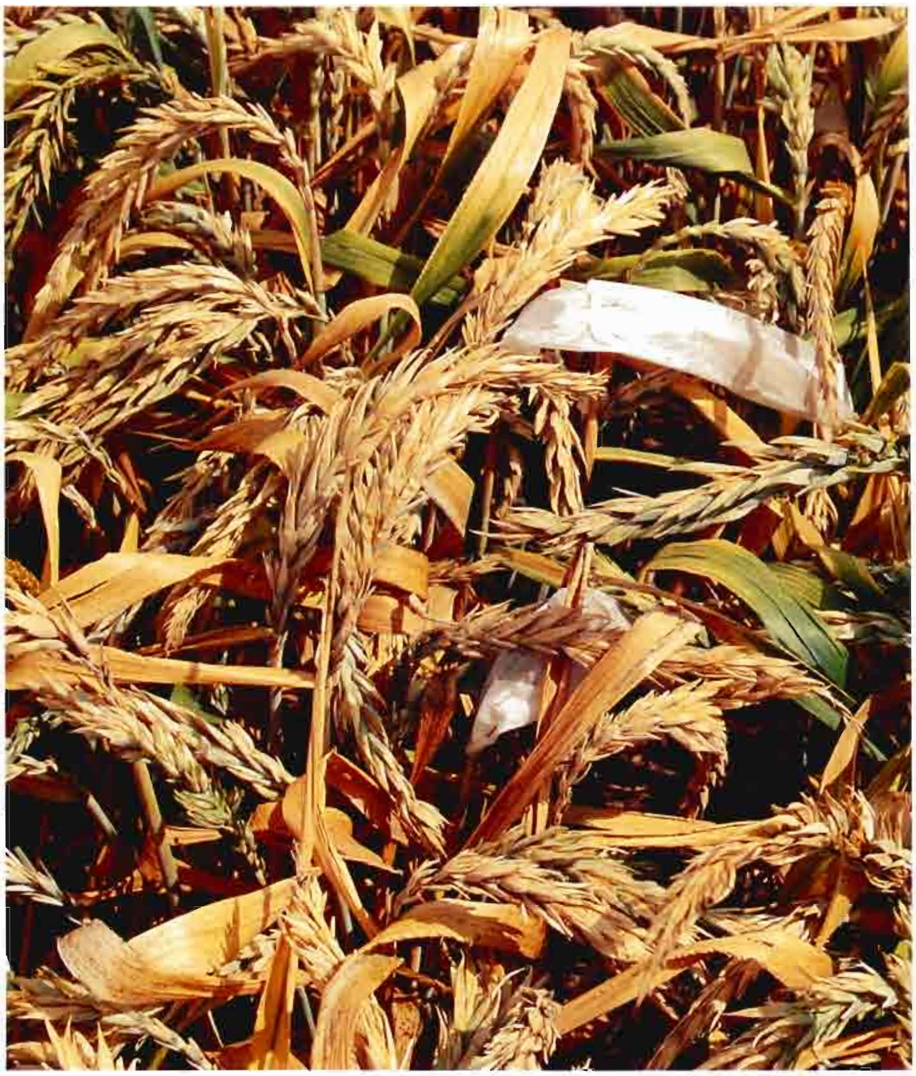
* M.P. Reynolds, S. Rajaram, and A. McNab, (eds.), *Increasing Yield Potential in Wheat: Breaking the Barriers* (Mexico, D.F.: CIMMYT, 1996).

Borlaug, patiently extracted traits from different sources and constructed the new plant type.

"We took a variety that had a large number of grains per spike and crossed it with another that had a few, but very big, grains per spike. The end result was Buitre, a completely different plant with an unusually large spike and a lot of grains," relates Rodríguez.

Although it is a source of fascination for breeders, the new plant type is far from perfect. For example, Buitre tends to topple over under the weight of its enormous spikes. And though it produces lots of grains, most are shriveled. Rodríguez believes that the solution to the latter problem may lie in making the wheat plant more efficient in extracting nutrients from the soil and water, photosynthesizing them, and transforming them into more dry matter for the grain. He is not alone in seeing the promise of his handiwork. "We plan to cross Buitre with the most recent advanced lines in our breeding program," says Rajaram. "By doing that, we aim to achieve a balance: a slightly smaller spike but with full, plump grains."

Buitre has other shortcomings — it is susceptible to leaf and stripe rusts, two serious wheat diseases. All of these problems will be solved on the way to making Buitre — or rather, its derivatives — available to farmers. "We're fairly confident we'll be able to use Buitre to develop rust resistant wheats that yield a lot more than current varieties," says Rajaram. "If we succeed, there's an 80% chance that these wheats will be ready to be tested on farmers' fields in as little as five years."



Buitre – an experimental wheat possessing traits associated with higher yield potential – is a valued resource for developing the next generation of high-yielding wheats.

Directing Hybrid Vigor Toward Higher Yields

Also proposed at the workshop was another yield-enhancing strategy that CIMMYT is implementing: hybrid wheat development. The more advanced NARSs represented at the workshop, in particular the Indian and Chinese national programs, strongly supported the recommendation. In their view, CIMMYT is in a unique position to apply the latest technologies to develop hybrids and transfer the resulting research products and methodologies to national breeding programs. Since CIMMYT's research is largely client-driven, such strong endorsement by NARSs gives us a powerful incentive to initiate work on hybrids.

Hybrid versions of any crop usually yield more than "normal" varieties because of their exceptional vigor (called heterosis), a result of the hybrid crosses from which they spring. Though successful maize and rice hybrids have been available for years, creating hybrid wheat has proven much more difficult and costly. "In fact, hybrid wheats *have* been developed, but so far they haven't produced more grain than improved varieties, whose yield potential is hard to top," says Belgin Çukadar, Wheat Program breeder concentrating on hybrid wheat development. "If hybrids can't produce enough to compensate for the higher price of hybrid seed, why would farmers want to plant them?"

Successful maize and rice hybrids have been available for years. Creating hybrid wheat has proven more difficult.

An additional complication is that to realize the full advantages provided by hybrids, farmers must buy new seed every cycle. The problem is that farmers do not do this, often preferring to save seed from their previous wheat crop to sow in the next cycle. Hybrid seed is more expensive than regular wheat seed, partly because seed production costs are higher. One reason for those higher costs is that wheat plants have to be treated, for example, with chemical hybridizing agents (CHAs), before they can be crossed to produce hybrid offspring.

These seeming disadvantages raise a pertinent question: should CIMMYT invest in developing hybrid wheat? The hybrid expert at the yield potential workshop, J.P. Jordaan, from the Central Seed Growers Cooperative (SENSAKO) in Bethlehem, South Africa, has suggested that hybrid wheats should be reconsidered in light of recently emerging knowledge. For example, trials conducted by Jordaan using low seeding rates and narrow row spacing revealed that these practices promote the greatest expression of heterosis in traits that contribute to better yields. "In our trials, conducted in rainfed conditions, heterosis was high, with hybrids yielding 11.5-14.8% more than non-hybrids," reports Jordaan. "These results also show that hybrids have a greater yield advantage in environments where water is scarce and temperatures are high."

Yet another argument for pursuing this research arises from new technologies that could lower the costs or help solve the problems of producing

hybrids. For example, of great concern in the past was the toxicity of the CHAs applied to prepare wheat plants for hybrid crosses. Today this problem has been largely solved by a new generation of CHAs that are not only less toxic than previous versions, but in fact much less harmful than other chemicals utilized in agriculture. Genesis,® the CHA being used at CIMMYT under a working agreement with its manufacturer, the Monsanto Company, was recently approved by the US Environmental Protection Agency. Another strategy that may speed up hybrid development and reduce costs is the application of molecular markers and genetic transformation.

A big limitation in hybrid generation has been lack of knowledge about the genetic background of potential parents. The more diverse the genetic background of the parents, the stronger the resulting heterosis is likely to be. A useful tool that could be wielded to facilitate the choice of genetically different parents is CIMMYT's recently developed International Wheat Information System (IWIS).* This highly efficient information management system could aid breeders to identify appropriate breeding materials by investigating their pedigrees.

* Available on CD-ROM from CIMMYT's Publications Department.

One of the biggest limitations in breeding wheat hybrids has been the lack of knowledge about the genetic background of potential parents. Now CIMMYT and its partners can access the genealogical information that will break this breeding deadlock.

In an additional application of the new Buitre plant type, CIMMYT intends to use Buitre to increase the potential payoffs of hybrid crosses. The idea is to pass on the large spike trait to Buitre's hybrid offspring and use their hybrid vigor to direct more dry matter toward filling the grains.

If successful, the combined contributions of hybrid wheat and the new plant type could eventually raise wheat's yield potential by an estimated 25-30%. Cautioning against the expectation of seeing the new wheats in farmers' fields very soon, van Ginkel remarks, "Although the first phase of this research should be completed within three years, the actual development and dissemination of hybrids could take as long as 10 years."

Genetic Resources: An Abundant Source of Higher Yields

In the effort to make the wheat plant yield more, CIMMYT will continue to make extensive use of genetic resources. Right from the start, the "secret" of the successful improved wheats bred at CIMMYT by Borlaug, Rajaram, and their successors was the utilization of genetic diversity from numerous sources in an untold number of crosses, selections, and recombinations. By applying this strategy, CIMMYT breeders have tapped into the genetic diversity of wheats from all over the world, winter wheat (its genetic base differs from that of spring wheat), rye, and wheat's wild relatives. Genes taken from such an ample spectrum of materials have endowed CIMMYT wheats with resistance to many diseases and tolerance to adverse environmental conditions such as drought, cold, and heat. The accumulated genes have also conferred other traits, including short stature, solid stem, and more spikes, that helped raise wheat yield potential. In the drive to boost that potential even more, CIMMYT will continue to capitalize on the genetic wealth of alien species and genera by applying technologies (for example, wide crosses, molecular markers, and genetic transformation) that have made that wealth more accessible.

Crosses conducted at CIMMYT between wheat and one of its wild relatives have yielded a plethora of "synthetic" wheats, so called because the durum wheat (*Triticum turgidum*) x goat grass (*T. tauschii*) crosses that give rise to them mimic the original cross that occurred in nature thousands of years ago and produced the first bread wheat. Because they are true wheats and can be crossed directly with improved wheat, synthetics provide a ready means of transferring desirable qualities from wild species to improved wheats. The Wheat Program's Wide Crosses Section has successfully produced stable synthetics that possess a surprising range of positive traits, from resistance to such diseases as leaf rust, stripe rust, and helminthosporium leaf blotch to tolerance to heat, salt, drought, and waterlogging. Another significant application of synthetics that may generate major yield gains could be to use these wheats — or their derivatives — as parents in the production of hybrid wheat.

Minimum Tillage Technology for Irrigated Environments

Until recently, agricultural research had not developed a sustainable system that would reduce the ecological impact of wheat cropping in well-watered environments, which account for almost half the wheat area in the developing world. Nor had these environments benefited from new technologies for managing crop residues.

"The problem of residue incorporation or removal, which is costly, or worse, the use of fire to clear harvested fields, had us looking for alternatives for some time," says Ken Sayre, CIMMYT wheat agronomist. So, some years ago, when CIMMYT scientists working in northwestern Mexico noticed local farmers planting wheat on raised beds (instead of on level land, as is usual in the region), they were extremely curious about the reasons for the new practice.

"I asked farmers why they had changed to beds. They claimed it made irrigation easier, plus they could control weeds with little or no herbicide application. Beds also help keep the crop from toppling over and could be used for the following crop with just a little reshaping," explains Sayre.

These are just a few of the advantages that induced farmers to try planting wheat on raised beds and persuaded CIMMYT agronomists to look at the technique more closely. They found that some of its features dovetailed nicely with a similar agronomic system called ridge tillage that is used by farmers in some parts of the US. Four years ago, CIMMYT wheat agronomists, in cooperation with farmers and agronomists from INIFAP, Mexico's national agricultural research organization, initiated research to combine this innovative wheat bed-planting system with ridge tillage. They dubbed the resulting technology FIRBS — for "furrow-irrigated, reduced-tillage, bed-planting system."

To have an idea of the potential for FIRBS, it is important to know that irrigated wheat accounts for about 35% of the wheat area and more than 45% of wheat production in developing countries. In South Asia alone, nearly 25 million hectares of irrigated wheat are grown. More than 13 million hectares of irrigated wheat are planted in China and sizable areas are also grown in other developing countries, including Turkey, Afghanistan, Iran, Iraq, Egypt, Sudan, Ethiopia, Zimbabwe, Nigeria, Mexico, and Chile.

Raised beds allow nitrogen to be applied when and where the wheat plant can use it most efficiently. If nitrogen is applied just when the wheat plant starts to pull it rapidly from the soil, higher yields are the result.

Raised beds, the basic feature of the system, resemble long platforms of soil built up a few inches above the ground. Instead of flattening them out at the end of each cycle, farmers can re-use the same beds in the subsequent crop cycle, with only a superficial reshaping. Crop residues are chopped up and left on the surface, where they either break down naturally or are built back into the beds during the reshaping process. No soil inversion tillage is used. FIRBS is also efficient in areas where crop residues are removed for forage, and because the system eliminates the need to burn off the crop residues, it diminishes environmental damage significantly.

Raised beds allow nitrogen to be applied when and where the wheat plant can use it most efficiently, which is not readily done with a conventionally planted crop. If nitrogen is applied just when the wheat plant starts to pull it rapidly from the soil, this results in higher yields. These improvements in nitrogen use efficiency lead to increased grain protein levels, enhanced baking quality, and higher nutritional value. Nitrogen losses into the environment are also significantly reduced, as are farmers' production costs.

The particular features of the new system require machinery specifically designed for use with it. Farmers, NARS researchers, and CIMMYT scientists in Mexico have developed prototype equipment for forming and reshaping the beds and for controlling weeds between the beds. The prototypes are actually modifications of standard agricultural equipment and are expected to be affordable to resource-poor farmers, perhaps through shared ownership or through producers' associations.

A very timely and environmentally friendly advantage of FIRBS is that it provides an alternative weed control method that greatly diminishes the need to apply herbicides. The new system has allowed wheat farmers in Mexico's Yaqui Valley to implement an integrated weed management approach to control *Phalaris minor*, a highly competitive weed that has been showing increased tolerance to once-effective herbicides. Such herbicide-resistant weeds are an increasingly strong and worrying presence in the Indo-Gangetic Plains and other major wheat-growing areas of the developing world.

The technology also improves water conservation in irrigated cropping systems. "Better water management is, and will continue to be, an increasingly urgent problem in the years ahead," said Sayre, "particularly as water resources become scarcer and subject to greater competition."

All in all, FIRBS is providing Yaqui Valley farmers with an estimated 30% savings in production costs, which has resulted in the technology being widely adopted in the region. It has also started to be used in the Indian Punjab and in the Henan and Shandong Provinces of China. CIMMYT researchers are convinced that it has much to offer in other areas where wheat is grown under irrigation.

Sayre, who has spent the last decade perfecting FIRBS in the Yaqui Valley, was recently asked about the potential for FIRBS in other parts of the developing world. Sayre said knowingly, "Ten thousand farmers in northwestern Mexico would never have switched cropping practices without good reason."

Stress Tolerant Maize: Protecting Food Security and Natural Resources

Maize production in developing countries faces severe natural constraints, chief among them drought, infertile and acid soils, and insect pests. Alone or in tandem, these hostile agents hammer yields, often reducing them to far less than half the levels possible under optimal circumstances.

To manage natural production constraints, farmers in industrialized nations can draw on an arsenal of agricultural chemicals, machinery, irrigation, and technical information. These types of resources, though, most often lie beyond the grasp of developing country producers, who also lack government support programs or even viable alternatives to subsistence agriculture. In essence, they and their families walk a continual knife edge from harvest to harvest, with hunger just a crop failure away.

To enhance the food security of these farmers without damaging natural resources, CIMMYT, with support from the United Nations Development Programme (UNDP), began work in 1990 to "help maize help itself" against the threats of stressed production environments. The effort sought to deliver protection in the most traditional and convenient of packages, the seed. "We set out to breed maize that would secure harvests under harsh conditions and to develop methodologies that research partners could use to generate resistant varieties, hybrids, and management recommendations for farmers they serve," explained Gregory Edmeades, Interim Director of CIMMYT's Maize Program and maize physiologist who participated in major aspects of the project. "In addition to fostering food security, these products provide environmental payoffs that include more efficient use of water and nitrogen — especially relevant for marginal production zones — and a reduced need for potentially harmful chemicals."

The project, which concluded in 1996 and involved extensive global collaboration, has been a fruitful source of experimental seed and breeding methodologies, (see "A Legacy of Useful Seed and Knowledge," page 24). It has also given rise to myriad collaborative activities and relationships, several of which are outlined in the accompanying stories. Work includes both basic research on stress tolerance in maize and, increasingly, efforts to implement results in benefit of food security and natural resources on the farm. "Now that the methods are well proven, our urgent aim — and certainly the thrust of future maize stress research at CIMMYT — will be ensuring that stress tolerant maize reaches farmers' fields," Edmeades says.

Creative Partnerships Bring Results Home to Farmers

With this goal, CIMMYT has begun assisting national maize programs to apply products and principles from the UNDP stress breeding project in sub-Saharan Africa, where smallholder maize farmers typically wrest meager harvests from infertile soils and, all too often, lose entire crops to drought. Three interrelated initiatives — two already underway and a third to begin soon — will contribute significantly to more stable yields for these farmers.

- One, launched in 1996, will support efforts of researchers in the Southern Africa Development Community (SADC)* to develop locally adapted drought and low nitrogen tolerant maize cultivars. Financed by the Swiss Development Cooperation (SDC), this innovative partnership complements current activities of CIMMYT in the region and is fully integrated with the Maize and Wheat Improvement Research Network (MWIRNET).** In addition to setting priorities for regional research — among which stress tolerant maize cultivars ranked

* SADC member states: Angola, Botswana, Lesotho, Malawi, Mauritius, Mozambique, Namibia, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe.

** A network of national program scientists established in 1994 and funded by the EU.

highest — national programs provide overall guidance for the network and the drought and low fertility tolerance project through a steering committee comprising commodity research leaders from each country and a representative from the Southern African Centre for Cooperation in Agricultural Research and Training (SACCAR), along with donor representatives and technical advisors from CIMMYT.

- A second, larger project, to begin in late 1997 with support from UNDP, the International Fund for Agricultural Development (IFAD), and the Swedish International Development Cooperation Agency (SIDA), will expand the development of stress tolerant cultivars into Eastern, Western, and Central Africa. Coordinated by CIMMYT through its regional office in Kenya and the International Institute for Tropical Agriculture (IITA), Nigeria, this project will focus on resistance to insect pests and to the parasitic weed *Striga* spp., in addition to drought and low soil fertility. Activities will link closely with those of Southern Africa and, like the Southern Africa project, with research networks of national programs.
- As of mid-1997, CIMMYT began to assist the national programs of Kenya and Zimbabwe in the use of biotechnology tools in maize breeding for drought tolerance and insect resistance (see story, "Biotech Partnerships with Kenya and Zimbabwe," page 28). This undertaking, which is financed by the General Directorate, International Cooperation, of the Government of the Netherlands (DGIS), brings high-tech expertise available at the CIMMYT Applied Biotechnology Center to bear on the very immediate threat of famine in sub-Saharan Africa. In doing this, it will build on the more conventional approaches described above.

These collaborative arrangements are as complex as any in which CIMMYT has ever participated. Can they bring results home to farmers? The following comments from the CIMMYT technical advisor for the drought and low soil fertility project in Southern Africa provide firsthand insights into the potential of the new approaches in the region.

Breeding Under Stressed Conditions: A Revolution in Thinking

"Breeders who target farmers' fields in sub-Saharan Africa may have been working under selection conditions that are somewhat removed from the reality of smallholders' circumstances," says Marianne Bänziger, maize physiologist posted to the CIMMYT-Zimbabwe regional program. "As in other parts of the world, most maize breeding is done under well-fertilized, well-irrigated conditions, typically at a yield level of about 6 to 10 tons per hectare. Breeders expect that the cultivars selected under these conditions will perform well in farmers' fields — even though the average maize yield in farmers' fields in Africa is well below 1.5 tons per hectare. Maize in farmers' fields in Africa is exposed to stresses — drought, low soil fertility, insect pests, acid soils — to which maize is rarely exposed during the breeding process. What we are doing in this new

Our new collaborative arrangements are as complex as any in which CIMMYT has ever participated. Can they bring results home to farmers?

Stress tolerance breeding supported by UNDP has constituted a major effort for CIMMYT and our research partners in recent years. The work is long-term and costly, and requires specialized methodologies. Developing insect resistant maize, for instance, involves rearing hundreds of thousands of pest larvae, delivering the insects uniformly to hectares of experimental maize, and then assessing the damage to select the resistant plants, each cycle. Likewise, selection for drought, low nitrogen, or acid soil tolerance must be conducted under repeated seasons of carefully controlled stress conditions.

Why go to all the expense and effort? The answer is simple. "Maize in developing countries is grown under more varied and generally marginal conditions than any other major food grain," say Gregory Edmeades, Interim Director of CIMMYT's Maize Program and maize physiologist. "Stress tolerance is of vital importance for the crop and for smallholder farmers, especially in sub-Saharan Africa, who depend on maize for their livelihoods." The following selection of major outputs, which among many others from the project are now used in maize research programs worldwide, provides a rough idea of the impact of this work:*

- Eight tropical or subtropical maize populations with high levels of resistance to major insect pests that attack the crop in the field, as well as methodologies for mass rearing insect pests, for field infestation, and for repeatable damage scoring. By-products include information on resistance mechanisms (low leaf protein levels, high fiber, phenolic acid in cell walls, and leaf toughness appear to be key factors) and insect resistant maize that can also withstand major diseases in target environments.
- Sources of resistance to the major storage pests of maize.
- A proven methodology that can provide a 25-40% increase in maize yields under severe drought during flowering and grain filling, with no yield penalty under good conditions.
- The discovery that selection under drought also provides improved tolerance in maize to low nitrogen conditions, and that the same regions of the maize genome are involved in rapid ear growth at flowering under stress in both cases.
- A range of experimental maize tolerant to the acid conditions of lowland tropical soils on large expanses in South America, as well as in Africa and Asia.
- The release in Colombia and Peru of Sikuani V-110, an acid-tolerant maize variety developed from CIMMYT materials that yields 30% more than local checks on acid soils and is already sown on at least 15,000 hectares. Recently tested acid-tolerant hybrids from the project yield 70% more than Sikuani on acid soils.
- More than 30 elite inbred lines of tropical or subtropical adaptation that resist insect pests, drought, or infertile or acid soils and provide outstanding yields in hybrid combinations.
- Global development, testing, and distribution networks for drought and low nitrogen tolerant maize and for maize that resists insect pests.
- Progress in applying molecular markers to transfer resistance traits to elite maize lines and varieties. Advances include genome mapping of regions associated with resistance traits (lately using recombinant inbred lines), comparisons between marker-assisted and conventional selection, combined use of restriction fragment length polymorphisms (RFLPs) and polymerase chain reaction (PCR)-based methodologies to improve efficiency, and suitable strategies for using marker-assisted selection in breeding programs.
- A range of information-sharing, institution-building activities to help ensure that our research partners partake in the benefits of this work, including: ♦ A four-week course on the development of host plant resistance to maize insect pests, attended by 14 researchers from 7 developing countries. ♦ A course entitled "Breeding for Drought Tolerance in Maize," attended by 19 researchers from 13 developing countries. ♦ The course "Molecular Marker Applications to Plant Breeding," offered twice, attended by 46 scientists from 21 countries.

- Two international conferences: "Insect Resistant Maize: Recent Advances and Utilization," November 1994, attended by some 40 developing country scientists; and "Developing Drought and Low N-Tolerant Maize," in March 1996, attended by 70 national program representatives. A proceedings from the first was distributed to cooperators worldwide; another from the second event was printed in October, 1997.

* For a detailed account of project activities and outputs, see *Development of New Stress-Resistant Maize Genetic Resources (UNDP Project GLO/90/003)* (Mexico, D.F.: CIMMYT Maize Program Special Report, 1997).

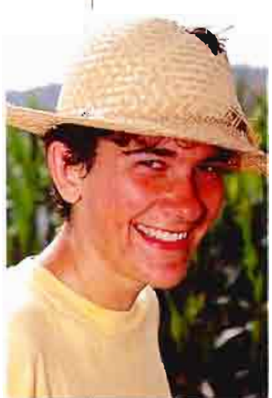
“What we are doing in this new project is looking at the major stresses in farmers’ fields and taking those onto our breeding stations.”

project is looking at the major stresses in farmers’ fields and taking those onto our breeding stations.”

The project she is referring to is the SDC-funded partnership of CIMMYT with researchers from the SADC member states to develop maize varieties and hybrids with improved drought and low nitrogen tolerance.

Having worked for several years at CIMMYT headquarters as part of the global stress breeding project, Bänziger was an ideal choice to provide assistance for national programs in applying methodologies from that research to circumstances in Southern Africa. Notwithstanding, she admits to feeling surprised at the significant change in thinking that the stress breeding approach appears to represent.

“Like any professionals, maize breeders are proud of their achievements: high yields and well-managed fields,” Bänziger says. “Thus, when you say, ‘You should evaluate your trials under drought or without applying fertilizer, to select effectively for tolerance to these conditions’ — well, this runs counter to their previous experience. It’s not enough here in the region that results from our research in Mexico have proven the technology works; local breeders have to experience the new approach themselves, using their own germplasm.”



With technical support from Bänziger and funds from the project, local maize researchers are establishing breeding programs and screening facilities for drought and low soil fertility, the latter at five sites for each stress. To make effective use of this infra-structure, 15 leading maize breeders from the region — two from private seed companies and the others from public programs — discussed breeding approaches for drought and low fertility tolerance during a 10-day advanced course at the CIMMYT regional office in Harare, Zimbabwe. “Results from the UNDP stress breeding project provided a wealth of relevant experience to draw upon,” Bänziger says. “We profited as well from the expertise of irrigation researcher Adiel Karima, University of Zimbabwe, and Dieter Mulitze, AGROBASE,® Canada.” Bänziger also notes the influence of the 1996 drought and low nitrogen breeding symposium held at CIMMYT as part of the UNDP stress tolerance project. “Several local researchers who attended the symposium are keen to apply their knowledge in breeding programs and farmers’ fields,” she says.

As a first step, she and her associates have begun screening leading local cultivars under drought and low soil fertility. “We have sketchy information about the performance of current releases,” Bänziger says. “We urgently need solid data to recommend existing materials that perform well under stress and to open researchers’ eyes about other, supposedly good materials which in fact do poorly under drought or low fertility." The long-term aim, though, is consistent stress screening to raise the yields of cultivars under the challenging conditions of resource-poor farmers in sub-Saharan Africa.

Breeding under controlled moisture and fertility conditions requires considerable resources — something which public agricultural research programs increasingly lack. "The situation in Southern Africa is in a state of flux," Bänziger points out. "Funds for public research are disappearing, while the private sector is becoming stronger and new markets are opening up. We would like to involve private companies in this research, but applying such new methodologies represents a risk they are reluctant to take, given the competition they face. So this is one example of an area where public sector researchers can take the lead and fill an important gap for smallholder farmers."

Right now, for example, the Center is tackling such issues as developing varieties and hybrids which possess combined resistance to two or more major stresses for specific areas, the use of DNA markers to handle tolerance traits, and the incorporation of at least some stress tolerance into all its elite maize products.

One challenge CIMMYT faces is to document impacts from this research — much harder in the case of smallholders in Africa than of farmers in high-input environments. "There are important benefits from using stress tolerant maize, which escape simple figures on area sown to CIMMYT-derived seed," Edmeades said. "The question is how to measure improvements in the well-being of smallholders and in the quality of natural resources in maize-based farming."

"No one else in the world — not private companies, national programs, or NGOs — is doing work like this, specifically targeted to food security for marginal areas and smallholder farmers."

Fundamental Science Underlies Gains for Smallholders

The need for basic research at CIMMYT headquarters on maize stress tolerance also continues. "We mustn't forget that basic research on stress tolerance for maize is one area where CIMMYT has a clear responsibility and comparative advantage," says Edmeades. "No one else in the world — not private companies, national programs, or NGOs — is doing work like this, specifically targeted to food security for marginal areas and smallholder farmers."

Giving Maize Farmers an Edge in Risky Environments

These maps are just one of the tools that Kevin Pixley and Marianne Bänziger, maize breeder and maize physiologist at CIMMYT-Zimbabwe, use when devising breeding strategies to give some of the world's poorest maize farmers an edge in one of the world's riskiest crop production environments. Their research focuses on Southern Africa, where maize is a highly valued staple but where many farmers live in areas repeatedly afflicted by drought.

The maps are two of several developed by CIMMYT's Geographic Information Systems (GIS)/ Crop Modeling team, which is part of the Natural Resources Group. They show the length of the maize growing season (top) and rainfall distribution (bottom). How does CIMMYT-Zimbabwe use the maps? Bänziger explains that maize breeders can pursue two strategies to combat yield losses brought on by drought. They can develop maize that matures early enough to escape drought, or they can develop maize that tolerates drought. The first strategy is useful in areas where rainfall is fairly reliable but of short duration, effectively limiting the growing period. The second strategy is desirable in areas of highly erratic rainfall.

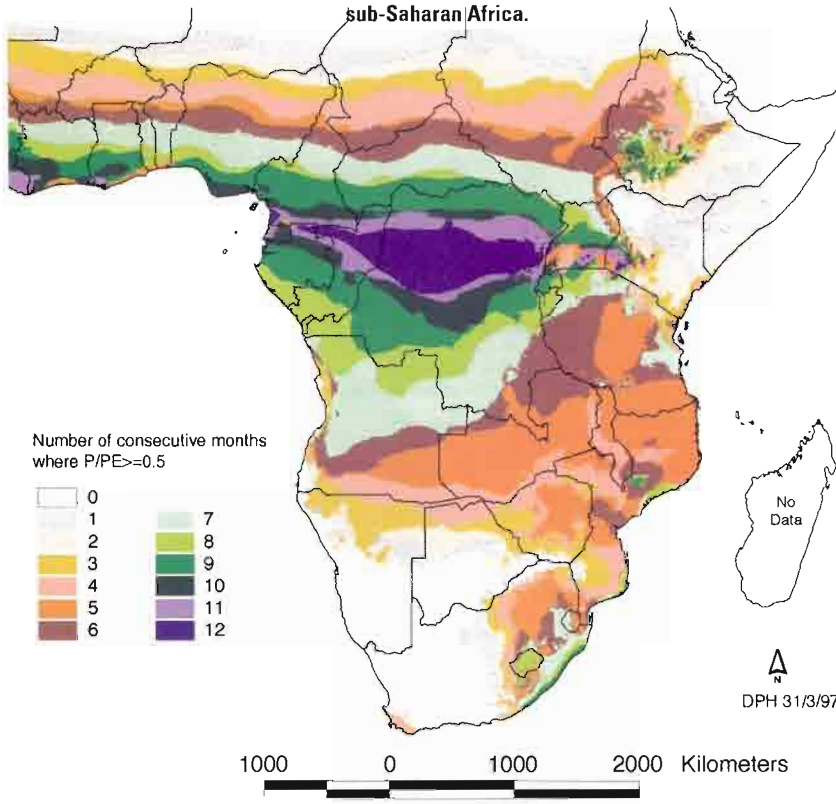
Geographic information systems can determine the average or probable length of the growing season in different locations and assess the risk of drought at various stages of the maize crop's development. "This helps us evaluate which areas require maize that tolerates drought and which areas requires maize that escapes drought to make the greatest impact on maize production," Bänziger says. "It also helps us decide whether drought tolerance will be needed at a certain stage of plant development in different regions. We can see whether we will need early, intermediate, or late-maturing maize to fit the growing season. All of this information will help us get our breeding priorities right."

"There are tradeoffs with each breeding strategy," Pixley warns. "Breeding early maturing maize is relatively simple. However, in years of ample rainfall, early maturing maize yields less than later maturing maize. Breeding drought-tolerant maize is more difficult, but when the rains are good, drought-tolerant maize can yield as well as maize that succumbs to drought. That is why we have to assess farmers' requirements and environmental constraints with care before deciding on a breeding strategy."

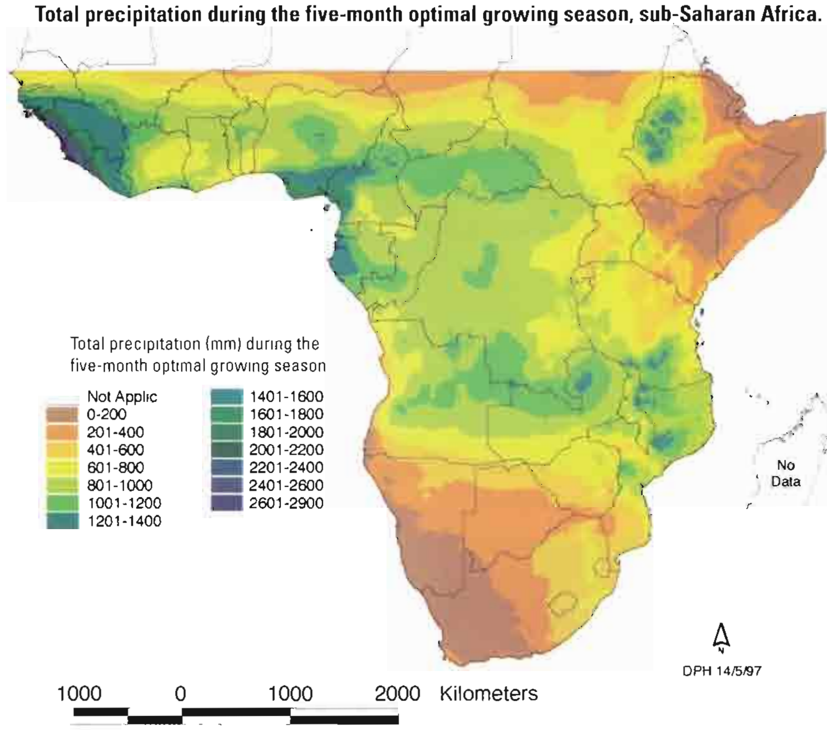
David Hodson, a member of the GIS/Crop Modeling team, explains that the maps produced for CIMMYT-Zimbabwe capture complex relationships between geographic location, rainfall, effective length of the growing season, and other information. In combination with field knowledge of farmers' practices, needs, and constraints, that information helps researchers answer crucial questions about farmers' germplasm requirements.

"In the short term, the tools of GIS can help set breeding priorities that result in the development of appropriate maize varieties and assist farmers to obtain more reliable maize yields," says Jeff White, head of the GIS/Crop Modeling team. "In the longer term, GIS can help researchers develop better recommendations for farmers, such as improved tillage practices or soil fertility management both for years of ample rainfall and scant rainfall."

Length of maize growing season (number of consecutive months where P/PE>=0.5), sub-Saharan Africa.



Total precipitation during the five-month optimal growing season, sub-Saharan Africa.



Biotech Partnerships with Kenya and Zimbabwe: Bridging the Gap Between Gene Maps and Maize Fields

While the distance between some biotech labs and farmers' fields may be only a matter of miles, it has at times seemed like light-years for researchers attempting to apply their promising tools to real-life crop breeding — even for high-tech farm settings.

Now a project involving CIMMYT and national research programs in Kenya and Zimbabwe, with support from DGIS, could help bridge that gap, but for small-scale, low-tech maize farmers in sub-Saharan Africa. The five-year effort aims to establish applied agricultural biotechnology programs in both countries and, eventually, using DNA markers and other biotech tools and working closely with breeders, to generate locally adapted, stress tolerant maize. Four researchers from those countries — a breeder and a biotech specialist from each — began two-year stints in CIMMYT's Applied Biotechnology Center (ABC) in early 1997 to hone the skills they will need to accomplish the formidable task.

"We are under tremendous pressure to bring this technology home and apply it to improve stress tolerance in maize," says Kahiu Ngugi, Kenyan biotech expert in the initiative. "There is special interest on the part of farmers, who have participated in every step of planning and should be the primary and major beneficiaries."

Though the project began recently, the groundwork was laid as far back as 1991, according to Baldwin Chipangura, Zimbabwean researcher in the project. "At an international conference on plant biotechnology which CIMMYT also attended, Kenyan and Zimbabwean researchers approached donors," Chipangura says. "Coincidentally, the Netherlands was looking for an opportunity to support this type of work, and identified Kenya and Zimbabwe as potential players." A series of planning workshops involving farmers, researchers, and decision makers were held to list and prioritize research aims, select appropriate methods, identify pertinent issues, and draft a document synthesizing the discussions. "The Kenyan farmers cited maize as the number-one priority, with drought and insect pests as the leading yield constraints," Ngugi says.

With a commitment in hand from DGIS, Kenya formed an agricultural biotechnology committee whose first tasks included choosing a technical counterpart. "We looked at several institutes," Ngugi says, "but CIMMYT had state-of-the-art research on drought tolerance in maize, as well as an effective biotechnology unit. This was really the place."

In addition to the four visiting scientists, two technicians from each country will spend four months at CIMMYT mastering the necessary lab protocols. ABC scientists will help Kenya and Zimbabwe outfit the project laboratories and will later spend time there as needed to expedite the work, according to Jean-Marcel Ribaut, CIMMYT molecular geneticist working in the project. "Our primary goals are capacity building and technology transfer; through these we expect to improve drought tolerance and insect resistance in local maize varieties and hybrids," Ribaut says.

Timeline for project to develop biotech programs in Kenya and Zimbabwe.

"We looked at several institutes, but CIMMYT had the-state-of-the-art research on drought tolerance in maize, as well as an effective biotechnology unit. This was really the place."

Kenya and Zimbabwe were chosen largely for their advanced research capacities, but their divergent maize farming circumstances should also provide interesting insights on the application of biotech tools. Nearly all maize farmers in Zimbabwe, for example, grow hybrids and purchase seed from commercial suppliers. In contrast, most farmers in Kenya — especially those in the arid or semiarid areas that account for 80% of the maize lands — grow open pollinated varieties. "This means that Ngugi and I will first work with inbred lines, which are more suited to DNA marker-assisted selection because of their genetic purity, and later use them to form open pollinated varieties," says Zachary Muthamia, Kenya's maize breeder in the project. Activities and outputs from each country will feed into the other maize stress tolerance initiatives mentioned in this Report (the SDC drought and low fertility project for Southern Africa, MWIRNET, and the UNDP/IFAD/SIDA stress breeding project for Eastern, Western, and Central Africa).

"In farmer participatory discussions in Zimbabwe, low soil fertility followed drought as a major maize production constraint," says Godfree Chigeza, maize breeder from Zimbabwe working in the project. "CIMMYT's expertise on this subject should serve us well." Researchers expect to capitalize on the close correlation between low fertility tolerance and selecting under drought stress, which was discovered as part of the UNDP stress breeding project.

Chipangura foresees that Kenya and Zimbabwe will eventually serve as biotechnology resource nations for their respective neighbors. "The idea is to offer training and consulting on breeding methodologies and lab establishment in the region, as well as molecular genetics services," he said.

Right now, however, his sights are set on applying advanced techniques to improve the well-being of people in Zimbabwe. "Drought brings hunger and exacerbates poverty, because people in our country get their living from agriculture," Chipangura says. "We view this as an important project with far-reaching effects."

Finding Resistance to Maize Storage Pests

Post-harvest insect pests jeopardize food security throughout the developing world. Small-scale maize farmers, who generally store their grain as whole ears in slatted bins, in adobe rooms, among the rafters of their dwellings, or even in the field, are especially hard hit.

"The pests not only ruin grain saved for home consumption," says David Bergvinson, CIMMYT maize entomologist, "but also make it impossible to store any surplus. Farmers are thus forced to sell extra grain right after harvest, when the market is glutted and prices are lowest." Bergvinson adds that chemical controls work, but only for shelled grain (i.e., removed from the cob) in closed containers. Most smallholders have no access to shelling devices, and the chemicals themselves tend to be highly toxic, posing a serious hazard for farm households. For these reasons, under the UNDP stress breeding project the CIMMYT Maize Program began work to develop maize seed that would carry pest resistance as part of its genetic inheritance.

The two most damaging species for maize are the maize weevil, *Sitophilus zeamais*, and the larger grain borer (LGB), *Prostephanus truncatus*. The maize weevil is ubiquitous and first colonizes maize ears in the field. Farmers restrict weevil attacks somewhat through use of varieties with closed, sturdy husks and through practices that regulate the storage temperature and humidity of the grain, such as sun drying or keeping ears above hearth fires.

The LGB, though, is nearly impervious to these simple control measures. The pest was brought from its native Central America to sub-Saharan Africa in the early 1980s and has appeared in at least 13 African countries since then. A forestry pest by nature, LGB is nevertheless at home on maize. "The larger grain borer can destroy an entire grain store within five months," Bergvinson says. "Adult beetles also penetrate and survive in the wooden frames of highly infested stores, complicating control." In Central America certain insect species seem to keep LGB at least partially in check, but an experiment in which one such natural enemy was released in Africa's LGB zones has left pest populations there virtually intact. "In general, we know little about the biology and population dynamics of the larger grain borer in Africa, so we still can't suggest a relevant, integrated set of control measures," Bergvinson explains.

A major contribution CIMMYT can make, however, both for the maize weevil and LGB, is to develop pest resistant maize. Through five years of cooperation with Canadian research centers under the UNDP project, for example, three maize collections resistant to the grain weevil were found. To test the effectiveness of these resistance sources and to improve their agronomic qualities, they were crossed to an elite cultivar from Ghana with enhanced grain protein quality, because this type of maize is thought to be especially vulnerable to weevil attacks. The lines derived from this cross not only perform well in the field but also show moderate resistance to maize weevils.

For further clues on how best to utilize this resistance, CIMMYT conducted a series of studies on the biological mechanisms responsible. Results suggest that, in resistant maize, phenolic acids toughen the outer layers of the kernel, making it less palatable for both weevil and borer. "These substances bind to cell-wall carbohydrates and then to each other, strengthening the tissue and providing a first layer of defense," Bergvinson says. Apparently the female parent in crosses (i.e., the pollen recipient) accounts for most of the genetic contribution to the associated kernel tissue. This finding is significant because it suggests that, to produce a resistant hybrid, only one of the parent lines (the female) need carry resistance. A breeder in the CIMMYT-Zimbabwe regional program is performing genetic studies that will elucidate the way in which resistance is inherited. Bergvinson and his group have also adapted a technique that uses fluorescence microscopy to identify certain chemicals associated with resistance. The technique should help sidestep the long, arduous process of putting pests on stored grain and measuring the damage to screen for resistance.

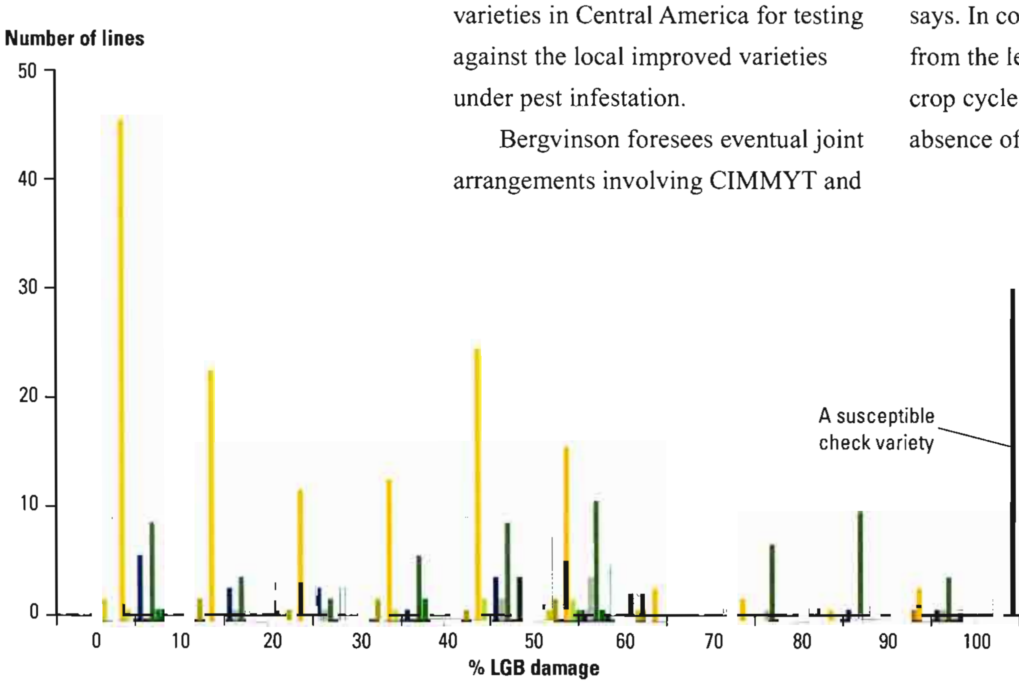
A major contribution CIMMYT can make is to develop pest resistant maize. Five years of cooperation with Canadian research centers under the UNDP project yielded three maize collections resistant to the maize weevil.

Since 1993 CIMMYT has also intensified the search for resistance to LGB. In tests of landraces from the maize germplasm bank, some Caribbean samples show promising levels of resistance (see figure). To locate additional resistance sources, the entomology group is systematically screening some 350 select inbred lines from the CIMMYT Maize Program under intense, artificial LGB infestation. There is already evidence of resistance in CML 268, a lowland tropical line.

Bergvinson's work has included limited studies to check farmers' frequent claim that their local cultivars withstand storage pests better than improved maize varieties and hybrids. "Farmers may have naturally selected for resistance in local varieties," Bergvinson points out. "Logically, anything that didn't store well wouldn't germinate either." In his tests to date, however, which have involved only dehusked ears, farmers' local varieties seem just as susceptible as improved materials. "The husk may be a key factor, as well as farmer practices such as breaking the stalk and bending it over when the crop reaches maturity," he says. CIMMYT researchers are collecting a range of local maize varieties in Central America for testing against the local improved varieties under pest infestation.

Bergvinson foresees eventual joint arrangements involving CIMMYT and advanced institutes concerned with grain drying and storage technologies. He is already working closely with IITA, Ibadan, Nigeria, in global research to develop integrated management strategies for LGB in maize. This includes developing computer crop models to ascertain the relative importance of host plant resistance in integrated control schemes, particularly in deterring insect population growth.

Finally, Bergvinson and his associates will explore the use of DNA markers to tag the maize genome regions involved in resistance to post-harvest pests and, possibly, to transfer the genes from unrefined sources (such as landraces) to elite inbred lines. Because of the complex and time-consuming nature of testing grain under weevil or LGB infestation, this type of resistance is a prime candidate for marker-assisted selection. Presently, researchers must first harvest experimental plants and then wait as long as three months for sufficient pest damage in the grain to classify and select resistant individuals. "These results often come too late to help you decide which plants to pollinate the following cycle, so you can lose a whole season of experiments," Bergvinson says. In contrast, DNA can be sampled from the leaves of plantlets early in the crop cycle to confirm the presence or absence of resistance genes.



Sources of resistance to larger grain borer (LGB): The reaction of inbred lines derived from Caribbean maize landrace collections in CIMMYT's maize germplasm bank.

Moving Beyond Marginal Yields in Marginal Environments

In the push to raise wheat production to levels that would allow us to satisfy demand into the next century, we cannot forget the marginal areas where wheat is cropped under harsh conditions.

While much research for favorable environments has ultimately benefited people who live in less favored regions (for example, varieties bred for favorable environments tend to do well in marginal environments), the specific problems in those areas merit special attention. Limited water availability is probably the most common stress that affects farmers in marginal environments, but they also have to contend with factors such as diseases, acid soils, extreme cold and heat, waterlogging, and mineral deficiencies and toxicities. A region is defined as marginal when wheat production drops to 70% of optimal yield levels, as in, for example, the highland areas from Turkey to Afghanistan, the dryland areas of West Asia/North Africa (WANA), much of Ethiopia, and the dryland areas of central and southern India (see table). Although modern varieties have a role to play in these areas, it is likely that the greatest gains will result from improved crop and resource management, especially measures to conserve and utilize moisture more efficiently in rainfed areas. As the following sampling of CIMMYT's efforts in the world's less favored wheat environments indicates, Center researchers and their collaborators are implementing a combination of strategies to ensure that farmers in marginal areas are not destined to obtain only marginal yields.

West Asia/North Africa

About one-third of the area planted to wheat in the developing world is located in marginal environments plagued by drought, soil problems, or poor infrastructure. Most of the drought-prone areas are concentrated in the WANA region. Wheat is the principal food source for people in WANA, who on average consume more than 145 kilograms per capita every year, one of the highest per capita consumptions in the world. CIMMYT efforts aimed at improving wheat production in WANA are conducted in conjunction with the International Center for Agricultural Research in the Dry Areas (ICARDA), based in Aleppo, Syria.

The CIMMYT/ICARDA Joint Dryland Bread Wheat Program for West Asia and North Africa. This program has as its main goal to increase wheat productivity by developing spring bread and durum wheats that are better adapted to the WANA region. "We recently re-focused our research activities and are now dedicating special attention to low rainfall areas in the region," says Guillermo Ortiz-Ferrara, CIMMYT breeder until recently assigned to the program.

Portions of wheat producing regions of the world that are defined as marginal.

Regions	Total wheat area (000 ha)	% marginal
WANA	28,300	65
Central Asia and the Caucasus	15,000	80
South Asia (Subcontinent)	34,500	35
East Asia (including China)	30,100	13
Eastern Africa	1,500	27
Southern Africa	1,300	91
Southern Cone of South America	7,400	60
Andean Region of South America	300	18
Mexico/Central America	900	43
Total	119,300	45

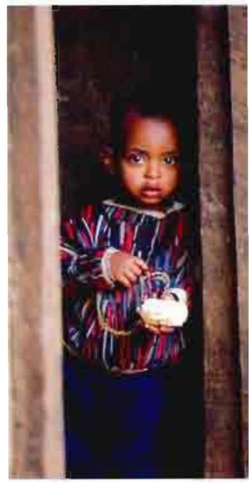
Wheats developed or identified by the program are widely adapted and possess enhanced disease and insect resistance, as well as better tolerance to the prevalent abiotic stresses in the region, which is why NARS collaborators in WANA increasingly select them for use in their own breeding programs. In 1996, the program identified a number of wheat lines highly resistant to Hessian fly, a devastating insect pest in North Africa. Some of these lines are soon to be released for commercial production in Morocco. Epidemiological surveys conducted in collaboration with NARSs have identified several sources of resistance to new races of yellow rust, an important foliar and spike disease of spring wheat in the WANA countries.

National research programs in the newly independent states view CIMMYT as an avenue for re-integrating their scientists into the world scientific community.

Farmer adoption of CIMMYT- and CIMMYT/ICARDA-derived varieties in WANA continues to increase, with more than 90 wheat varieties released in 21 countries in the region over the past 10 years. These improved varieties have replaced old, low yielding ones in such countries as Syria, Lebanon, Sudan, Egypt, Morocco, and Tunisia.

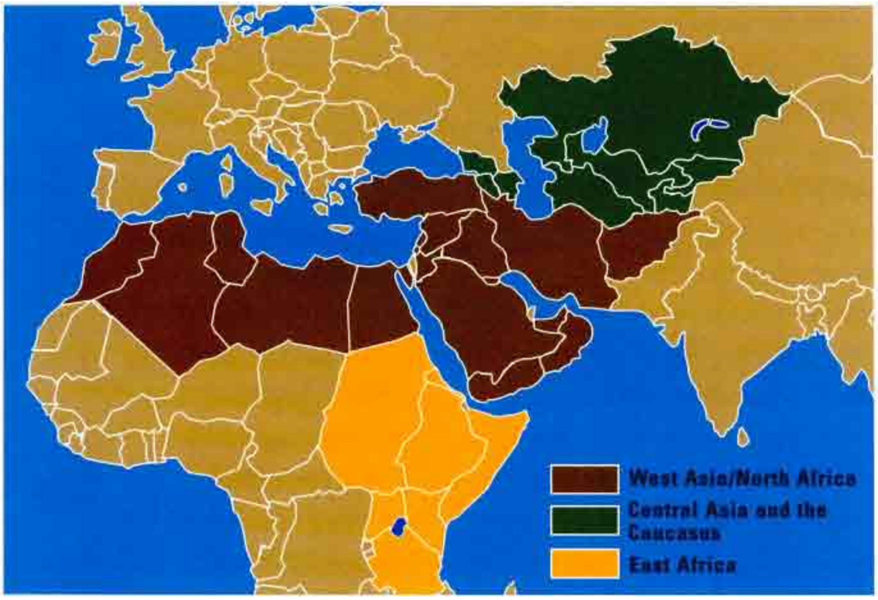
Collaboration has been essential to these achievements. "The close partnership between researchers and farmers has made it possible to identify the main agricultural constraints in the region, develop well-adapted wheat varieties, and transfer improved technologies to resource-poor farmers," comments Miloudi Nachit, CIMMYT/ICARDA durum wheat breeder. The program has also engaged in the continuous training of young scientists and promoted the open exchange of information as a way to enhance the infrastructure of national programs in WANA and the research collaboration among them.

The International Winter Wheat Improvement Program for the Drier Areas of the World. The Turkey/CIMMYT/ICARDA International Winter Wheat Improvement Program (IWWIP) based in Ankara, Turkey, came into existence 11 years ago with the purpose of generating winter wheats for developing countries, particularly in the WANA region. Over the past two years, IWWIP has expanded its collaboration with winter wheat programs in the developing world, as evidenced by the current list of cooperators (170 in 58 countries) who receive its facultative and winter wheat nursery. New research partnerships with colleagues from the Commonwealth of Independent States has greatly increased the number of cooperators.



The program is devoting particular attention to improving resistance to yellow rust, which is the most serious winter wheat disease in WANA. It conducts trials using artificial inoculation in Ankara, Konya, and Eskisehir (Turkey), ICARDA/Aleppo, and Iran. It is also conducting research on micronutrients aimed at identifying zinc-efficient wheats to be used in crosses and alien materials that may be potential sources of zinc efficiency. At present, rye and triticale seem to be the best sources, but other alien species are being tested at Turkey's Çukurova University.

CIMMYT activities in Central Asia and the Caucasus. The newly independent states of Central Asia and the Caucasus are relatively diverse in climate, agricultural production, and population. What these eight countries (Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tadjikistan, Turkmenistan, and Uzbekistan) have in common is that they are all in transition from being centrally planned economies to becoming market-oriented ones. Nearly 15 million hectares are planted to wheat in the region, but with the exception of Kazakhstan, all countries have to import wheat to satisfy domestic demands. A major objective of their



governments is to become self-sufficient in wheat.

After years of virtual isolation, regional NARSs are looking to initiate collaboration with the outside world in general and the international agricultural research centers in particular. Relations between CIMMYT and the region began in the late 1960s, when the first semidwarf wheats were introduced. Around that time, several countries released varieties based on the materials they received from CIMMYT in Mexico. However, in the 1970s and 1980s, political constraints impeded the flow of wheat materials and severed links to the international scientific community.

In 1992, after the political situation changed, CIMMYT re-established contacts with the NARSs in the region. Breeders and research administrators from the region have since visited IWWIP in Ankara or CIMMYT in Mexico, and CIMMYT scientists have visited several of the newly independent nations. In 1995-96 CIMMYT signed formal agreements with most of these countries, and there is now active exchange of germplasm, information, and publications with all of them. "Thanks to their new openness, in the past few years regional NARSs have become more familiar with each other's objectives and have realized they need to work together to address common problems," reports Hans Braun, CIMMYT breeder posted to the program in Turkey.

"The political obstacles to collaboration may have disappeared, but researchers in the newly independent states are still struggling with the language barrier that keeps them from communicating with their colleagues," points out Alex Morgounov, CIMMYT breeder also working with IWWIP. Regional NARSs view CIMMYT as an avenue for re-integrating their scientists into the world scientific community. Heeding this call for support from NARSs, IWWIP, assisted by CIMMYT, ICARDA, and Turkey, has launched new training activities aimed at bridging the science/language gap. Recently the program organized a three-month course on wheat breeding and production in Ankara, Turkey. Five young researchers from Azerbaijan, Kazakhstan, Turkmenistan, Uzbekistan, and Kyrgyzstan attended the course, which was given partly in English and partly in Turkish to facilitate understanding.

In another training initiative, Braun went to Azerbaijan to participate in a traveling workshop that also visited Russia, Ukraine, and Belarus. The President of Azerbaijan held a special ceremony to greet workshop participants. Relates Braun, "The President expressed that the people of Azerbaijan view their cooperation with CIMMYT as essential for accessing and adopting modern wheat technologies and consequently achieving wheat self-sufficiency."

In the future, CIMMYT will maintain active germplasm exchange with the region, and initiate shuttle breeding programs with each country. "We're extremely interested in collaborating with CIMMYT, specifically in the areas of genetic resources, human resource

Researchers in Central Asia and the Caucasas have realized they need to work together to address common problems.

development, breeding, and information exchange," states A. Satybaldin, Director General of Kazakhstan's National Academic Center for Agricultural Research.

A joint CIMMYT/Kazakhstan breeding program to combine quality, drought tolerance, and disease resistance in high latitude spring wheat is in the planning stages. If successful, it would contribute to the food security not only of Kazakhstan, but of the whole region.

Eastern Africa

Now in its fourth and final phase, the CIMMYT/Canadian International Development Agency Eastern Africa Cereals Program (EACP) has as its main objective to increase maize and wheat production and productivity in eastern Africa.* During its third phase, the wheat component of the program focused heavily on developing sustainable production systems for the major wheat growing environments in the region and on strengthening NARS commitment and capacity for long-term experimentation. The program reported as the main impacts of Phase III a marked increase in on-farm research and more frequent application of longer-term approaches to studying farmers' problems. Remarkable as well was the distinct increment during that period in the quantity (a total of 62) of scientific publications by NARS scientists. "Increasing the number and quality of these publications is essential because they allow scientists to share research results with peers in the region and throughout the world," explains Douglas Tanner, CIMMYT agronomist assigned to the EACP.

During 1993-96, Kenya, Ethiopia, and Uganda released 13 CIMMYT-related bread wheat and durum wheat varieties. "Our role has been to train NARS scientists in effective breeding and selection techniques," explains Osman Abdalla, CIMMYT breeder until recently posted to the region. Also during this period, the EACP formulated agronomic recommendations aimed at raising wheat yields, increasing fertilizer use efficiency, and attenuating the risks of wheat production in the region. Other research focused on developing systems that control soil erosion by rotating wheat with grain and forage legumes, which provide crop cover and reduce the use of fallow.

Studies conducted by the EACP in collaboration with NARSs in Ethiopia and Kenya found that reduced or zero tillage produced either the same or better yields than conventional tillage systems. The EACP also developed agronomic recommendations to improve yields and nitrogen use efficiency in areas that experience waterlogging problems. An encouraging fact brought to light in a recent report by the EACP is that several decades of breeding durum and bread wheats from CIMMYT semidwarf wheats in Ethiopia have resulted in annual increases of 1.5-2.0% in yield potential based on rainfed experiments.

As for training and networking, over the four-year period of Phase III, the EACP organized numerous specialized short courses, traveling working groups, and regional wheat workshops on such varied subjects as sustainable crop production, integrated pest management, GIS, and equipment maintenance. In addition several students from the region received support for post-graduate training and a number of visiting scientists were sent to CIMMYT headquarters in Mexico.

* The EACP is complemented by a CIMMYT/EU project aimed at strengthening wheat breeding and pathology research in the NARSs of eastern Africa. This work began in 1995 and is conducted in collaboration with the NARSs of Ethiopia, Kenya, Tanzania, and Uganda.

Seeking Sustainable Wheat Systems in Bolivia

On a recent trip to Bolivia, Timothy Reeves, CIMMYT's Director General, met with that country's Secretary of Agriculture, Oscar Ponce Blanco. "The Secretary told me that CIMMYT is a key part of their agricultural development program and that they are seeking funding on our behalf," recounts Reeves. "This show of support is undoubtedly a consequence of the research and development partnerships that we have forged at all levels of the national system."

Much of the credit for establishing these partnerships goes to Pat Wall, CIMMYT agronomist posted to Bolivia. "About 95% of the work we do in Bolivia is conducted in collaboration with other institutions," estimates Wall. "To capitalize more fully on this cooperation, we're planning to set up a more formal research network as part of a project on national wheat research and extension."

Most of Wall's work is done in collaboration with the Bolivian national program, growers' associations, the extension services of several NGOs, the Food and Agriculture Organization (FAO), and various universities. "One of the most encouraging aspects of our work in Bolivia is the range of partners we're cooperating with. This is an excellent example of the innovative and entrepreneurial approaches necessary to fund and implement our research," notes Reeves. "As for funding, it is remarkable that donors as diverse as ANAPO, a local producers' association, and the US Agency for International Development through the PL480 food aid program, are contributing to our work."

Contrasting Settings, but Similar Constraints

In Bolivia wheat is grown mostly in two regions: the inter-Andean highlands and valleys and the lowland eastern plains. Despite contrasting topographical and socioeconomic circumstances, the major production constraints confronting farmers in these regions are similar. Field studies conducted in these areas have indicated the major factors determining yield are insufficient water and soil degradation. Water runoff increases soil erosion and also drought frequency and severity in the highlands, where farmers also have to deal with nutrient deficiencies in the soil and with weeds. In the lowlands, higher temperatures mean increased incidence of diseases such as leaf rust and helminthosporium leaf blotch.

Other factors that affect both areas are government policies that influence agricultural production. For example, lack of credit is a crucial issue for small farmers in the highlands, while lowland producers need access to more open markets. "I can tell you one thing that is *not* a problem in either region: varieties. They have good, well-adapted, CIMMYT-derived wheat varieties," says Pat Wall. "However, the breeding work must go on to keep ahead of diseases, especially in the warm lowlands."

About 70,000 hectares of wheat are sown every year in the Bolivian highlands (2,000-3,800 meters above sea level), most of it in the traditional wheat producing provinces of Cochabamba, Chuquisaca, and Potosí. Due to the summer rainfall pattern and very little irrigation, only one crop can be grown per year, and average yields are extremely low (650-700 kilograms per hectare). Wheat is a subsistence crop, generally planted in rotation with such crops as potatoes, faba beans, and/or maize. "Farmers usually have spreads of 2-3 hectares where they plant 1 hectare of wheat, mostly for home consumption," explains Wall. "Production is very labor intensive, since wheat is seeded, harvested, threshed, and winnowed by hand. Land is usually prepared using ox-drawn plows."

Sustainable Solutions

"In the Bolivian highlands, CIMMYT is focusing on helping resource-poor subsistence farmers who live in Cochabamba and Chuquisaca Provinces," reports Reeves. "In that difficult physical and socioeconomic environment, we're applying the principles of sustainable agriculture to help small-scale farmers achieve more sustainable cropping systems."

In the lowlands situated in Santa Cruz Province, wheat is a relatively new crop, produced on large, mechanized farms. About 100,000 hectares are currently sown to wheat, with average yields of 1.4 tons per hectare. Wheat is cropped in the winter, when there is very little rainfall. CIMMYT has initiated large-scale demonstration plots in a combined multi-institutional

"People think erosion is inevitable, and we need to show them it can be stopped."

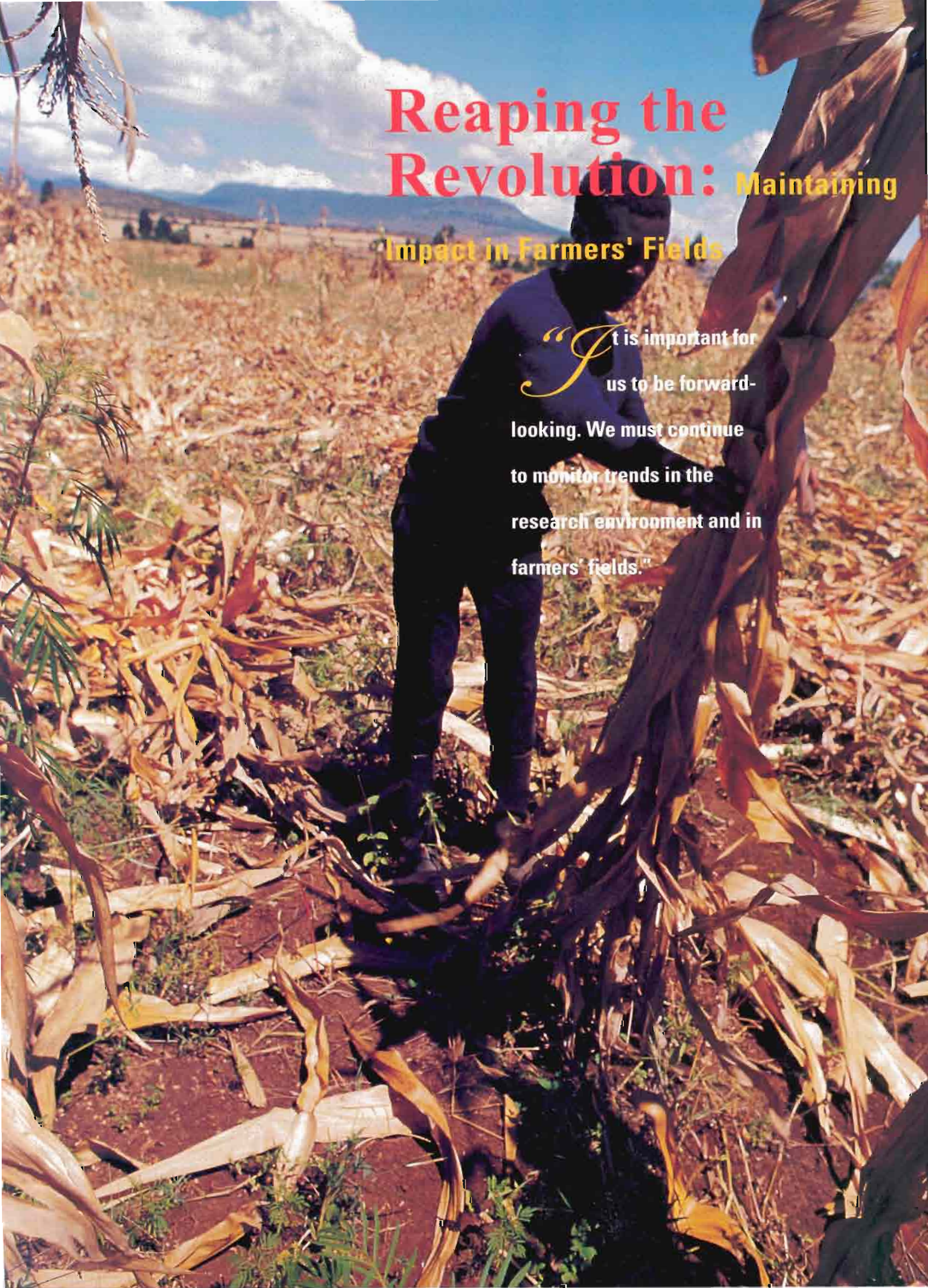
effort that includes two growers' associations, ANAPO (oilseeds and wheat) and PROMASOR (maize and sorghum), CIAT (a local research institution), a university (UAGRM), and an FAO project (FAO-Fertisuelos). These plots are used to demonstrate the medium- to long-term effects of such practices as reduced tillage and crop rotation in reversing soil degradation in the region.

"We believe a system that couples residue retention and reduced tillage would be the best method for solving the problem of soil degradation as well as limited moisture in both the highlands and the lowlands," says Wall. Straw cover helps water to filter into the ground, where it can be used by the crop, instead of running off the field. Residues also improve soil fertility and keep the topsoil from being washed or blown away. "People think erosion is inevitable, and we need to show them it can be stopped," says Wall.

One potential difficulty is that small farmers in the highlands who feed crop residues to their animals may be reluctant to use crop by-products for other purposes. "Farmers use straw for animal feed, so convincing them to leave straw in the field is not so simple," says Wall. He and his colleagues are considering several ways of solving the dilemma. Possible alternatives are to leave some straw in the field and remove some for animal feed, or to plant a forage crop—perhaps triticale, vetch, or oats—in part of the field. An added difficulty in the highlands is that wheat is hand harvested and then taken from the field to be threshed. Residue retention would mean having to bring the straw back to the field after threshing. A partial solution to this problem may lie in using small, inexpensive machines to do the harvesting and threshing in the less sloping fields. "Since doing these operations by hand is extremely expensive, the use of machines would actually be cheaper, reducing farmers' production costs by more than 35%," comments Wall. "That could be the key to farmer adoption of this resource-conserving technology." Wall is planning a pilot project to show that machines are a viable option that could be made available to farmers either through pools for sharing equipment or growers' associations.

Multiplying the Benefits

If the reduced tillage/residue retention system is successful in Bolivia, its benefits could be multiplied by implementing it in other areas of the world where farmers face similar problems. The GIS/Crop Modeling Team of CIMMYT's Natural Resources Group, which helped characterize the wheat-producing areas in Bolivia for this project, is identifying areas of the developing world where constraints and conditions such as elevation and rainfall are similar to those in this region. "If the methods we're testing work out, we believe they could be useful in other parts of the world as well," says Wall. "The tools of GIS and crop modeling will make it easier to find matching environments where the solutions we've devised could be put into practice." The application of this residue retention/reduced tillage system in multiple locations would be a fitting end for a technology that has accrued from the collaboration of so many players.


Reaping the Revolution: Maintaining Impact in Farmers' Fields
"It is important for us to be forward-looking. We must continue to monitor trends in the research environment and in farmers' fields."

Why Wheat Farming Still Makes Sense in Bangladesh

During the last three decades, Bangladesh metamorphosed from a voracious client of famine relief into a nation nearing self-sufficiency in cereals. The transformation was not sudden, nor did it eliminate the nation's chronic food security problems, but it *was* remarkable, born out of the government's strong commitment to strengthening agriculture, the mainstay of the economy.

In the 1980s the Government of Bangladesh launched a series of policy reforms to increase production of cereals, particularly wheat and rice. The results speak for themselves — rice production soared, wheat production rose significantly — but they have also provoked new dilemmas over cereal production policy.

With the prospect of national self-sufficiency in cereals a distinct possibility in Bangladesh, the case for promoting domestic wheat production bears re-examination. Some observers, citing the high yields of winter-grown *boro* rice (which competes with wheat both in farmers' fields and on consumers' tables), have concluded that wheat production represents a relatively inefficient use of resources. They maintain that efforts to promote wheat should be scaled back to give greater rein to *boro* rice. Given the scarcity of resources for agricultural research and development, it would be difficult to justify continued investment in wheat if its production represents a wasteful use of resources.

An IFPRI/CIMMYT study* has sought to address lingering concerns about the value of continuing to encourage national wheat research and production. The study, based on intensive interviews with 420 rural households, supports an important finding of earlier research: *boro* rice frequently generates greater returns to farmers' labor and management and to land than other winter crops. True, the financial profitability of *boro* rice has declined now that Bangladesh is nearing self-sufficiency in rice and domestic market prices for rice have fallen, but *boro* rice remains the most profitable option in areas where it is technically feasible to produce the crop — taking into account the effects of taxes, subsidies, exchange rate misalignment, and other policy-induced distortions that influence the environment in which farmers make their choices. One reason that *boro* rice is financially more profitable than wheat is that farmers' incentives to plant wheat are undermined by the government's policy of accepting large quantities of low-cost wheat food aid, which serves to depress domestic wheat prices.

However, *boro* rice may not be profitable for every farmer. Although *boro* rice tends to be more profitable in areas that are well-suited to *boro* production, it cannot be grown everywhere. "An important finding of our study is that differences in land elevation and soil texture matter when the profitability of alternative crops is assessed," says Craig Meisner, CIMMYT agronomist and coauthor of the study. Farmers plant *boro* rice predominantly in heavy soils located in low-lying areas well-served by irrigation. *Boro* rice is rarely grown in lighter soils in more elevated areas, and it is never grown where reliable irrigation services are absent. These latter conditions are present in the northwestern, north central, south central, and southwestern regions of the country, precisely where most wheat production is concentrated. In such areas, wheat is often very competitive.

Michael Morris, a CIMMYT economist who also worked on the study, contends that wheat production is not only profitable for many farmers but can also represent an efficient use of domestic resources. When production inputs and outputs are assigned economic prices representing their scarcity value, the relative profitability of wheat increases considerably. Wheat is the most efficient crop in many non-irrigated areas and is competitive with *boro* rice in a number of irrigated areas as well. Should Bangladesh become a consistent rice exporter — in which case additional rice production could be disposed of only by exporting at relatively unremunerative prices — the economic case for wheat could become even stronger.

In Bangladesh, as in many other developing countries, maintaining productivity growth across the entire agricultural sector will depend on increasing the productivity of secondary crops and "niche" commodities that exploit specific *locational and seasonal* advantages.

An unexpected finding of the study is that two-fifths of the survey respondents grow wheat primarily to ensure adequate household food supplies during the "hungry season" before *boro* rice can be harvested. Lacking resources to buy food during the hungry season, these households pay little attention to market prices when they decide to grow wheat.

These results help explain why more than two million rural households in Bangladesh continue to produce wheat despite pronouncements by influential analysts that the crop is unprofitable. They also cast doubt on recent calls to reduce support to wheat research. Keeping this in mind, policy makers, researchers, and extensionists must now determine how Bangladesh can make the most of its potential for efficient wheat production.

"Bangladesh is not the only country confronting the problem of uneven productivity growth in agriculture," remarks Nuimuddin Chowdhury, an economist and the third researcher participating in the IFPRI/CIMMYT study. In Bangladesh, as in many other developing countries, maintaining productivity growth across the entire agricultural sector during the post-Green Revolution period will depend on increasing the productivity of secondary crops and "niche" commodities that exploit specific locational and seasonal advantages. One lesson from the IFPRI/CIMMYT study is that economic analyses conducted at a high level of aggregation often miss these potential sources of growth and see only limited prospects for further productivity gains in agriculture. "This study confirms that seasonal and locational details matter," says Morris, "and it shows how policy analysis done at an appropriate level of disaggregation can help identify efficient production activities."

* Morris, M.L., N. Chowdhury, and C. Meisner, *Wheat Production in Bangladesh: Technological, Economic, and Policy Issues* (Washington, D.C.: International Food Policy Research Institute, forthcoming).

Winter Maize in Northern India: Knowledge-Based Farming

What directions is agriculture taking in developing countries? Opinions vary on many points, but most experts agree on this: with unused arable land becoming scarce, future food production increases will have to come from higher yields. This will mean boosting productivity on a finite resource base, which in turn implies the *intensive* yet intensely *protective* use of farm resources if resources are to last.

How will farmers deal over the long term with this complex and ostensibly conflicting set of demands? For current insights on meeting future food production challenges, one good place to look is Asia. This section briefly describes the intensive cropping practices of small-scale farmers in the northeastern Indian state of Bihar who, with help from various agricultural research organizations, have gained a foothold of food security in an environment characterized by rising populations and shrinking land reserves.

Rabi Is the Right Time for Maize

At over 17 million hectares, Bihar is comparable in size to Uruguay, but where the South American country has a population of just over 3 million, Bihar is home to almost 90 million people — approximately one-tenth of India's entire population. The state is 85% rural and mostly poor; the average annual income per inhabitant is not much more than US$ 100, roughly one-third the national average. Household food security is a concern, since per capita cereal production averages about 120 kilograms per year, some 40% below the mean for India. Crop failures and terrible famines are writ large on the collective memory of the region.

The Ganges River runs straight across Bihar from west to east, creating a massive, level plain where most people live and practice agriculture. Rice and wheat are the staple crops of the region. Wheat dominates the cropping pattern during the winter, or *rabi* season, the dry, cool period from October to April that counterbalances the monsoon when much rice is grown. Farmers also grow myriad other crops throughout the year, including pigeon pea, sorghum, pearl millet, pulses, peppers, and tobacco. Maize was traditionally a wet season crop, suffering from waterlogging, seasonal pests, and inadequate management.

In the early 1960s, national program researchers, with assistance from the Rockefeller Foundation, studied the suitability for Bihar of a range of maize hybrids and management practices, taking data on such factors as planting density, sowing dates, fertilizer requirements, maturity class, storability, and pest control. The work ran from basic research to extension and seed production. As part of this, the researchers tested maize in the *rabi* season. Yields were high and consistent, due among other things to the great number of sunny days and the long growing season, as well as the drier and cooler conditions, which were amenable to the crop but less so to pests. Farmers quickly began planting winter maize in Bihar, and the practice eventually spread to parts of Uttar Pradesh and Punjab. Although maize area can vary considerably from season to season, as farmers switch crops in response to shifting market conditions, *rabi* maize is grown on about 400,000 hectares in Bihar. Given its profitability (around US$ 250 per hectare, according to a 1986 study) and the availability of credit and inputs, most farmers practice fairly intensive management,

Maize cropping in northern India can provide insights on intensive agriculture and other strategies for meeting future food production challenges.

seeding at high densities, irrigating and weeding the crop, and applying generous amounts of fertilizer.

Outside of these general similarities, approaches vary greatly from farmer to farmer. Binay Kumar Choudry, for example, works 1.5 hectares of land in Mohamada Village, Bihar, about a third of which he sows to a winter maize-potato intercrop. Many of his neighbors grow maize as a cash crop or produce seed on contract for companies who sell it in maize producing states throughout India. "We have been growing maize for more than 20 years," Choudry says. "Before we grew cash crops like tobacco and peppers, as well as wheat and potatoes. We switched to maize because it can be intercropped and is more profitable." He and his family first till and fertilize the land and plant potatoes in October. They then hill up the soil and seed maize into the potatoes, using either hybrid maize or the improved, open pollinated variety Lakshmi, depending on the availability of commercial seed. The potatoes are harvested in January, when they sell at a premium. The money covers maize production costs and usually more, allowing Choudry to hire field labor at key points (planting, weeding, harvesting) during the production cycle. After maize harvest in March and an April-May fallow, he might sow either sorghum or more maize.

Choudry learned these practices from various sources: his parents, extensionists from the Rajendra Agricultural University in Bihar, and research demonstration trials. The development and spread of winter maize in Bihar was a truly collaborative effort based on informal networking between various organizations and projects, including the Maize and Millet Scheme of the government of Bihar, the All India Coordinated Maize Improvement Project, the Messina Joint Farming Cooperative Society, Ltd. (now Messina Beej Private Limited seed company), the Indian Agricultural Research Institute (IARI), and the Rockefeller Foundation.

Since then, CIMMYT-derived seed has helped the *rabi* maize rotation flourish as yields of other crops in the region are leveling off. The open pollinated variety Lakshmi, a direct derivative of CIMMYT Population 44, is grown on as many as 100,000 hectares, and several other popular varieties and hybrids have CIMMYT material in their backgrounds. Exciting new offerings include subtropical hybrids which in recent trials in India outyielded the best public and private checks by an average 45%. "Additional experiments with these hybrids are being conducted at 20 sites representing environments like the Bihar *rabi*," says Hugo Córdova, leader of CIMMYT's subtropical maize subprogram. "The idea is for our partners to sow verification trials in farmers' fields with the best four or five." The latest withstand not only major diseases but also the attacks of maize stem borers, a key pest of the crop during the rainy season.

Dr. N.N. Singh, Project Director at the Directorate of Maize Research, IARI, observes that "Germplasm from CIMMYT's subtropical maize program has particulary impressed maize breeders in India. The white hybrids developed using these materials show great promise in the Winter Maize Program in Bihar and the yellow hybrids show promise throughout the country, especially for the winter season." CIMMYT has shipped some 80 kilograms of experimental seed to meet breeders' requests.

Improved Technology Helps Farmers Shape Their Future

Agricultural innovations such as winter maize have helped dispel the specter of near-term starvation for many smallholders in Bihar. As do people everywhere, many now work to

achieve goals that lie beyond mere survival. "Crops are enough to maintain a family, but for the extras — a marriage celebration or a good school for your children, for example — you cannot earn that much money from the field," says Raman Phakur, whose family farms three hectares in northern Bihar. As occurs throughout the developing world, rural youths in Bihar frequently seek their fortunes in cities. Phakur himself now sells jewelry in Calcutta and sends money back to his family, leaving his brother to tend the farm. "If a family has more members with some education, they look for work outside and this makes the family well."

Such urbanization seems inevitable in many areas. Although increased agricultural prosperity may not reverse the trend, it can help rural inhabitants make the transition in the way and at the time they choose, rather than out of desperation. It can also allow those who would rather remain on the farm to do so, thus reducing outmigration to already overcrowded cities.

CIMMYT-derived seed has helped the *rabi* maize rotation flourish as yields of other crops in the region are leveling off. The open pollinated variety Lakshmi, a direct derivative of CIMMYT Population 44, is grown on as many as 100,000 hectares.

Hybrid Maize in Malawi: Full Granaries or Empty Promises?

Pounding maize by hand is a laborious but necessary task, enlivened in Malawian villages by the "pounding songs" that women compose to sing as they work. As late as 1987, some women could recall the songs from the 1949 famine, when the sound of maize being pounded meant that families would survive another day.

Fortunately famine — an extremely rare event in Malawi — has not returned in the post-colonial era, but food security remains a preoccupation. Maize constitutes a greater proportion of people's diets in Malawi than in any other country in the world. Ninety percent of rural households produce the crop, usually on less than one hectare, a very small area. Most of these households cannot produce enough maize to meet their subsistence needs: nationwide, production has not kept pace with consumption requirements, partly because the population is proliferating by 3% yearly and partly because maize yields have not risen along with population growth.

Wider adoption of hybrid maize could improve food security in Malawi, where FAO described half of all smallholder families as "food insecure" in 1994. Elsewhere in Eastern and Southern Africa, particularly Zimbabwe and Kenya, poor smallholders have adopted hybrids enthusiastically and have grown them with some success. Malawi began to reform its maize seed industry in the late 1980s, which contributed to an encouraging rise in smallholders' adoption of maize hybrids. Around that time, CIMMYT researchers and their Malawian counterparts began tracking farmers' acceptance of new maize hybrids, particularly MH17 and MH18, released in 1990. These hybrids were increasingly popular because farmers valued their processing characteristics and their impressive resilience under drought and poor soil fertility. They were non-conventional hybrids, made from a top-cross of Malawian hybrids and a CIMMYT population.

Even as greater numbers of farmers resolved to plant the new hybrids, their ability to do so was undermined by several events. The smallholder credit system collapsed in 1993/94; inflation soared; in the throes of structural adjustment, the government cut all input subsidies. More smallholders resorted to purchasing hybrid seed with cash or obtaining seed distributed free of charge by NGOs. Virtually all of the 350 farmers interviewed by researchers early in 1997 asserted they wanted to grow hybrid maize — MH18 more than any other — but few could pay for seed (see figure).

"Obviously farmers have 'adopted' the new hybrids, in the sense that they are convinced of their attractive yield and processing characteristics, and want to grow them," concludes Melinda Smale, a CIMMYT economist participating in the hybrid maize study. "But the impact of the research that produced the new hybrids remains low because of intervening economic factors and institutional change. Research delivered on its promise — the right seed has been developed, and farmers know that. But production cannot increase if farmers cannot purchase and plant the seed."*

"Without a doubt, one reason for the limited impact in farmers' fields is that the public marketing and credit institutions that once supported small-scale maize farmers are gone," says Alex Phiri of Bunda College, who studies credit issues. "Private institutions have not necessarily arisen in their place, leaving a terrible gap in support services for farmers. There is no official credit program for smallholders, and their chances of obtaining credit some other way are small. Extending commercial credit to such small-scale farmers for producing maize is unlikely to be viable."

Smallholders have tried to meet their needs for hybrid seed in several ways. A few have had a cache of free hybrid seed left over from the previous year, or they may have obtained hybrids as gifts from neighbors and friends. But most farmers who planted hybrid seed in 1997 used seed retained from a previous crop — theirs, or another farmer's, from whom they obtained seed — though they knew the yields would not be as good. "This year's survey suggests that some 30% of the maize area in the most important maize-producing districts is planted to hybrid seed that has been recycled, sometimes for as many as six generations," comments Smale. "In contrast, 10% of the area is planted to new hybrid seed." This seed management pattern may explain the increasing divergence observed between official crop estimates of the area planted to hybrids and estimates based on commercial seed sales.

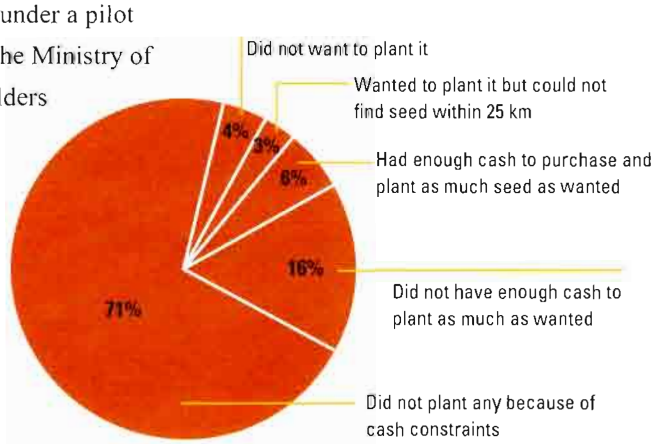
Obviously the trend toward recycling seed poses a problem for the maize seed industry. A considerable portion of the potential market for maize seed consists of geographically dispersed smallholders facing seasonal cash constraints. Because large transnational seed companies lack strong economic incentives to serve all of these farmers, new strategies may be needed if improved maize seed is to reach smallholders.**

Faced with the purchasing power problems of smallholders, government authorities and NGOs have started exploring new approaches for farmers to produce open pollinated varieties and hybrids and sell them at lower prices. For example, under a pilot project managed by the Ministry of Agriculture, smallholders receive breeder seed, which they multiply into commercial seed. Two scientists involved in the project, Elizabeth Sibale and Geoffrey Luhanga of Chitedze Agricultural Research Station, believe that such decentralized seed production operations offer some hope that smallholders will gain better access to the technology they clearly want to use.

Paul Heisey, a CIMMYT economist who has also studied hybrid adoption in Malawi, points out an additional, albeit slim, source of hope. "Some policy makers in Malawi believe that in the wake of this rough adjustment period, as the national economy settles, increased cash cropping could pay for investment in maize by the 'larger' smallholders, who can then produce a surplus." He adds that eventually — in the medium to long term — economic forces will raise maize grain prices in relation to maize seed prices, which could also encourage the use of improved seed.

In any event, the government is greatly concerned that smallholders escape their cash-constraint trap. Everyone wants to ensure that hunger remains nothing but a distant folk memory from Malawi's colonial past.

"Research delivered on its promise – the right seed has been developed, and farmers know that. But production cannot increase if farmers cannot purchase and plant the seed."



Farmers' demand for new hybrid maize seed in Malawi, 1996-97.
Source: CIMMYT/Ministry of Agriculture survey data.

* M. Smale, A. Phiri, and contributors, *Institutional Change and Discontinuities in Farmers' Use of Hybrid Maize Seed and Fertilizer in Malawi: Findings from the 1996/97 CIMMYT/ MoALD Survey* (Mexico, D.F.: CIMMYT, forthcoming).

** For more information on the seed industry, see J. Rusike and M. Smale, "Malawi," Chapter 16 in *Maize Seed Industries in Developing Countries*, ed. M.L. Morris (Boulder, Colorado: Lynne Rienner, forthcoming).

CIMMYT Wheats Lead the Charge Against Karnal Bunt

Diseases that have negligible effects on yield may nonetheless affect farmers' welfare considerably, for example, by reducing their capacity to produce wheat for export. When a disease regarded as potentially damaging is reported in a certain region or country, other countries may impose quarantine regulations that restrict grain and seed imports from the contaminated areas.

As a result, farmers in those areas may be left with a harvest they cannot sell and in subsequent years have to replace wheat with other, non-susceptible crops. Such quarantine restrictions can also affect CIMMYT's wheat research activities, which rely to a great extent upon the international exchange of experimental seed.

One such disease is Karnal bunt (KB), so called because it was reported for the first time in Karnal, India. It is caused by a fungus (*Tilletia indica*) that spreads mainly through the seed, although the spores (disease-spreading units) it produces can survive in the soil for several years after the fungus is introduced. Spores are often found in places where infected grain has been stored or in trucks and railroad cars used to ship it. When infected wheat is harvested and threshed, the grains shatter and release a multitude of spores that may be picked up and carried over considerable distances by the wind. Spores may also be released into the air when crop residues in infected fields are burned. A major means of controlling this disease is through seed treatments, including washing and disinfecting seed, or through fungicide applications. Other methods of control are of the type imposed by quarantine authorities, such as banning wheat cropping and wheat seed production in KB-infected areas and limiting or prohibiting the shipping of seed and grain from regions where KB has been found. The difficulties involved in implementing any of these methods suggest that the most effective strategy for controlling the disease is to develop KB-resistant wheats.

Karnal bunt was found in other countries, including Mexico, where it was reported in the early 1970s. Some time later, the plant health authorities of many KB-free countries banned the commercial importation of wheat grain and seed produced in KB-contaminated areas. Fortunately, they allowed the movement of experimental seed produced in certified KB-free areas and appropriately treated with certain prescribed fungicides. By rigorously following the mandated procedures for multiplying and shipping seed, CIMMYT's international seed exchanges have continued (see "Safeguarding Seed Health," page 48). However, the ban in effect halted most wheat exports from quarantined nations, including Mexico, CIMMYT's host country.

As diseases go, KB is not much of a productivity threat. For one thing, outbreaks of the disease are not a yearly occurrence, since they depend on a specific combination of climatic factors. The losses KB causes are not usually significant and are due mainly to a loss of quality, which results in lower prices for grain showing unacceptable levels of infection. To ensure high quality wheat products, many affected countries have established a maximum infection level for wheat grain. Millers will reject wheat lots containing more than the allowed level, but since the contaminated grain is not toxic, it can still be safely used for animal feed. Beyond losses to producers, the reductions in wheat exports and the loss of efficiency in seed production owing to quarantine restrictions, plus

While the effort to keep Karnal bunt from spreading and/or maintain it within economically negligible levels is fully warranted, it is essential to determine how much risk of disease spread can be tolerated in trying to control the disease.

the cost of additional seed treatments, have had a detrimental effect that is out of all proportion to the damage the fungus actually inflicts on the crop in the field.

Studies of the economic impact of KB in northwestern Mexico have estimated that the losses caused by KB in the region represented only 2% of the value of its annual wheat production. While the effort to keep KB from spreading and/or maintain it within economically negligible levels is fully warranted, it is essential to determine how much risk of disease spread can be tolerated in trying to control the disease. Policies that establish that the only acceptable risk is no risk at all do not take into account the costs they impose in relation to the benefits they provide. The appropriate strategy for countering a threatening disease or pest is to assess the risk of each control measure by comparing its concomitant costs and benefits, since control measures often have high costs. By this yardstick, one would have to ask, for example, whether the benefits of quarantine restrictions are greater than the costs, which, as we saw above, can be considerable. "It's time to relax quarantine restrictions on KB. We should concentrate instead on the epidemiology of the disease, and especially on developing and distributing KB-resistant wheats as the principal means of control," suggests Jesse Dubin, experienced wheat pathologist and Associate Director of CIMMYT's Wheat Program.

Fortunately, the perspective on KB is changing in many countries, partly because the disease was recently discovered in the US. "All of a sudden there's renewed interest in finding less stringent ways of controlling this disease," says Guillermo Fuentes, CIMMYT pathologist in charge of KB-related work. "Most efforts are focused on identifying sources of genetic resistance and using them to develop wheats that will resist KB infection."

CIMMYT has been working to develop KB-resistant wheats since 1981. Throughout those years, it has counted on the collaboration of several NARSs, universities, and other entities in conducting different types of KB-related research. For example, the Indian Council of Agricultural Research, Mexico's INIFAP, Punjab Agricultural University, and the United States Department of Agriculture (USDA-ARS) have contributed to studies on prediction models, breeding strategies, seed treatments, and the genetics of the KB fungus.

The task is complex and time-consuming. Identification of sources of KB resistance has been essential. "We've drawn on the resistance of materials from China, India, and Brazil, but the best sources we've found are the synthetic wheats developed at CIMMYT, several of which have proved immune to the disease," says Fuentes. Testing for the presence of resistance is very labor intensive. "The KB spores have to be cultured artificially," says Fuentes. "Inoculation and evaluation are done on individual spikes, and grains must

Identification of sources of Karnal bunt resistance has been essential. "We've drawn on the resistance of materials from China, India, and Brazil, but the best sources we've found are the synthetic wheats developed at CIMMYT."

be counted. All of this requires considerable staff time."

Rather than starting from scratch, countries such as Australia and the US are looking to CIMMYT for materials they can use in developing KB-resistant wheats adapted to their own cropping conditions. CIMMYT is happy to oblige, especially since it has hundreds of KB-resistant lines coming through the pipeline. It is collaborating with these countries and others such as Brazil, Iran, and Mexico, not only by sharing resistant materials and screening techniques, but also through consulting and training. "We've given lots of courses aimed at the accreditation of plant health professionals and have distributed numerous KB-related publications and training materials," says Fuentes.

The first beneficiaries of CIMMYT's work have been wheat producers in northwestern Mexico, who had to stop sowing bread wheat for several years because of KB. They are back to planting wheat, thanks to Arivechi M92, a CIMMYT-derived wheat released by INIFAP, the Mexican national program. This variety, with its superior KB resistance, is widely sown in the state of Sonora in northwestern Mexico. Adds Fuentes, "Since the KB-causing fungus doesn't mutate as fast as other wheat pathogens do, we expect the resistance in Arivechi M92 will remain stable for some time."

Safeguarding Seed Health

In 1989 CIMMYT established the Seed Health Unit (SHU) at its headquarters in El Batan, Mexico, to protect the agriculture of its cooperating countries and to ensure the problem-free movement of its experimental seed. CIMMYT was also prompted by the realization that in guaranteeing the safety and cleanliness of the seed it ships and receives it would contribute to the continuance of the free exchange of experimental materials, an activity crucial to crop improvement research by breeders all over the world. For these reasons, the spirit that animates the SHU goes beyond mere compliance with the seed health regulations of a particular country and in many ways exceeds established procedures.

The SHU, headed by CIMMYT pathologist Lucy Gilchrist, oversees the multiplication and treatment not only of seed to be included in international shipments, but of all seed (wheat, maize, triticale, barley, and materials to be stored in our germplasm bank) that comes into or leaves CIMMYT. It operates independently of the crop programs and reports directly to CIMMYT's Director General to facilitate its role as "auditor" of the viability and health of seed for international shipments. The SHU conducts laboratory tests and field inspections to monitor and vouch for the absence of all pathogens in the seed, and prevent the introduction or spread of exotic pests and diseases that may arrive in seed from outside Mexico.

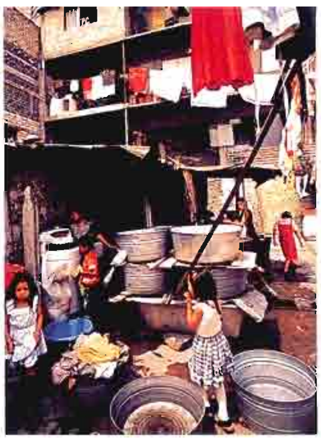
The SHU works closely with Sanidad Vegetal, the plant health authority in Mexico, which has established specific quarantine regulations to contain Karnal bunt (KB) and keep it from spreading to areas of Mexico that are currently pathogen-free. "We follow Sanidad Vegetal's procedures to keep our wheat seed free of all pathogens, especially KB," points out Gilchrist. "First and most importantly, we produce our wheat seed in Mexicali, an area of Mexico that has been certified by Sanidad and by APHIS, the US regulatory agency, as being free of the KB pathogen." Other measures, such as always using new bags and labels to pack and ship the seed, are meticulously enforced. All seed is washed and then treated with the authorized fungicides, and areas where the seed is stored are completely isolated. "The seed is transported within Mexico in trucks that have been disinfected and then sealed after loading," says Gilchrist. "For additional safety, they take roundabout routes to avoid passing through KB-contaminated areas."

Given the rigor with which the SHU monitors the application of seed health procedures, CIMMYT is confident that it is effectively contributing to inhibiting the spread of seed-borne pathogens, including KB, throughout the world.

Economists Foresee Rising Demand for International Wheat Research

"If the international wheat research system didn't exist already, we would be forced to invent it." This is the conclusion reached by Prabhu Pingali and Greg Traxler, two economists examining the future demand for international collaboration in wheat research. "Without that system, in which CIMMYT and our partners are important participants, gains in wheat production will become far more difficult to achieve," says Pingali, Director of CIMMYT's Economics Program.

Before the 1960s, wheat breeders from developing countries could not turn to any reliable system to acquire improved varieties developed outside their borders. The Green Revolution changed all of that, after South Asian nations released high-yielding wheat varieties that were brought into being through a small but rapidly expanding alliance of national and international wheat breeders. This research network has enabled developing countries to release an increasing number of varieties with each passing year.



"By making a greater number of experimental wheats available for exchange and testing, the network enormously reduces the costs of adaptive breeding for national programs," comments Traxler, Professor of Economics at Auburn University and CIMMYT affiliate scientist. This means that many small and intermediate-sized national programs have been able to increase wheat productivity without funding large pools of breeders. Global cooperation has also reinforced wheat research capacity in many countries; some, such as India, China, and Brazil, are research powerhouses that have achieved world renown for developing new cultivars.

But such an extensive system, with participants from so many nations, is not impervious to change. Will the need for international collaborative wheat research become stronger or weaker in the future? "At least three major factors will heighten the need for an international wheat research system," says Pingali. "These are urbanization and economic development; stronger national research capacity in developing countries; and advances in agricultural science."

Powerful Incentives for Collaborative Research

It is well known that in the next century, for the first time, more people will live in the world's urban areas than in rural ones. Pingali points out that provisioning the cities will become a key strategic goal of many developing country governments, because political stability has always been associated with low food prices for urban consumers. However, he is quick to add that with urbanization and economic development, resources — especially labor — will drain away from agriculture. Governments will thus face a growing dilemma: urban demand for cereals, including wheat, will rise as supplies decline.

Projected economic growth and development — and the resulting commercialization of agriculture — will further complicate the situation for wheat research. As Pingali explains, several things can happen. First, some countries may choose to direct agricultural research resources away from cereal crops and toward high-value commercial crops, especially countries with smaller populations that can buy a significant portion of their food on the international market. Second, countries with small wheat growing areas may prefer to obtain wheat varieties from the international network, including CIMMYT, and divert their research resources to more profitable ventures. Finally, even countries with large wheat growing areas could decide to economize on domestic research resources by using the network to obtain wheat varieties known to perform well in favorable

As we look ahead to the next century, we envision that the agricultural research capacity of most developing countries will become substantially more sophisticated. Does this mean that countries will withdraw from the international wheat research system?

environments and then rapidly adapting them to similar local conditions. Pingali observes that a full-scale breeding program targeted at both favorable and unfavorable wheat environments would be profitable only in countries with large wheat growing areas, such as China, India, Brazil, and Argentina. "But even these countries would continue to rely on the international system as a source of advanced experimental wheats," he says.

As they look ahead to the next century, Pingali and Traxler envision that the agricultural research capacity of most developing countries will become substantially more sophisticated. Does this mean that countries will withdraw from the international wheat research system?

"Not necessarily," comments Traxler. "Other researchers have observed that a country's incentives to develop strong capabilities in wheat research are closely associated with the size of the country's wheat market." Countries with a smaller wheat area may choose to rely on the international wheat breeding system. China and India have an incentive to develop and maintain the ability to breed their own wheat varieties. Nations with smaller wheat areas but equally strong research capacity might concentrate instead on adapting wheat varieties bred elsewhere and focus on original breeding for other crops. Finally, strong national capacity could lead to greater international interdependence in germplasm enhancement, research that deals with the collection and characterization of genetic resources and prebreeding (the development of experimental breeding lines possessing special traits that will be useful to advanced breeding programs).

Future breakthroughs in crop breeding research will also strengthen the need for an international wheat research network. This may seem contradictory, but, thanks to the international network, the breakthroughs that result when modern science meets traditional wheat breeding challenges — increasing yield

and yield stability — usually need not occur more than once. "Once you develop a wheat plant possessing a valuable new characteristic, seed can be shared and the plant can be adapted to a range of conditions," Pingali says. "Advances in wheat breeding in one place, such as CIMMYT or a large national program like India's, can thus spread easily and quickly to many places."

Such "spillover benefits" from crop breeding research are high, and developing countries may choose to take advantage of them rather than to invest in full-fledged scientific capacity themselves. The size of the wheat market, once again, often determines whether a country chooses to invest in biotechnology and other modern science capabilities for wheat improvement.

The Choice Ahead: Interdependence, or Insularity?

Although advances in research, combined with the other powerful forces described by Traxler and Pingali, will encourage international collaboration, the two researchers certainly do not pretend that the prospects for an international wheat research network are limitless. "The growing incentives to protect research discoveries through patents and other forms of intellectual property rights will undoubtedly affect the international flow of germplasm, which is the lifeblood of the network," cautions Pingali. Administrators of increasingly impoverished public research programs envision that royalty income could compensate for reduced funding. This hope has produced a spate of patents in biotechnology and varietal development.

"Breeding programs may become more insular and less open about sharing breeding lines, because they are fearful of jeopardizing royalty income," observes Traxler. "Enforcement of intellectual property rights could impose significant costs on developing countries by limiting their access to improved varieties and thus reducing wheat productivity." Also, more wheat research resources might be dedicated to cultivar development, because it holds more potential for generating patentable discoveries than other kinds of research, such as prebreeding. The effort to develop patentable materials might lead the public sector into wastefully duplicating private sector research. Genetic conservation might be hampered by fears that an agency collecting plant resources stands to gain by patenting economically useful genes obtained from its collections.

Despite such potential difficulties, demand for the international exchange of wheat germplasm will persist. Most wheat growing countries,

except the large ones, will probably demand improved varieties that require minimal adaptive work. However, Pingali warns that in a world of shrinking research budgets, the international wheat research system faces difficult choices, because the development of such varieties comes at the cost of diverting resources from valuable research on prebreeding and genetic resources. "Without adequate levels of investment in prebreeding, the ability of the international system to provide desirable varieties over the long term could decline," he says. "That is why it is important for us to be forward looking. We must continue to monitor trends in the research environment and assess the probable consequences for international collaborative research, national food security, and farmers' access to superior varieties."

In a world of shrinking research budgets, the international wheat research system faces difficult choices. What will be the effects of those choices?

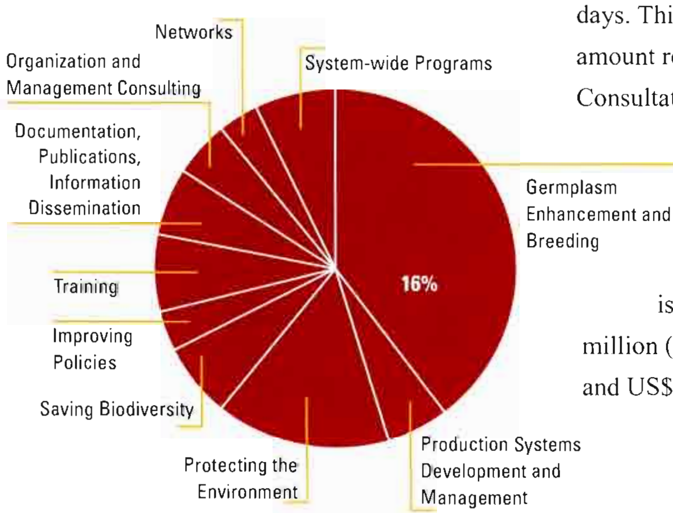
Financial Highlights

Building on the theme of partnerships, it is important to reiterate that CIMMYT's financial supporters are also partners in agricultural research and development — not only in terms of the funds provided but also in ensuring that the concerns of their constituencies are reflected in our research agenda.

CIMMYT has listened to those concerns and made them its own, as described in the Director General's message at the beginning of this Report. During 1996 we also took great strides in helping donors in many countries make the case to their constituents for the need to invest in CIMMYT and in international agricultural research generally. The objective, of course, is not to sustain any single organization but — through agricultural research partnerships like those that innovated maize farming in northern India (page 41) or that are providing options for marginal wheat farmers in Ethiopia and Bolivia (pages 35-37) — to improve the livelihoods of developing country people.

Evidence of success in communicating with partners who fund research is provided in the CIMMYT budget for 1998-2000, described in our Medium–Term Plan.* It calls for US $30 million, in constant 1997 dollars. This budget is more than many had anticipated and is attributable both to changes in CIMMYT and to improved interactions with donors. The budget contemplates streamlined and consolidated activities that can be conducted by 82 senior international staff, a number that is slightly below the average for the early 1990s.

Reflecting again a more interactive relationship with our funding partners, fully half of CIMMYT's budget is restricted in one form or another — that is, the money is given to us for use in specific activities according to priorities that are set mutually by CIMMYT, national programs, and donors. Trends suggest that the proportion of such restricted funds is likely to increase in coming years. Whereas this has certain advantages with regard to focus and accountability, it is vital that the larger proportion of CIMMYT's funds continue to be more flexible core money. A further concern with some core special projects is a reluctance of donors to fund overhead charges. This is understandable where significant core funds are also provided, but if CIMMYT is to manage all research projects effectively — i.e., in a way that achieves project goals and significant impacts — funders must also invest in our expertise as a global executing agency and the often invisible gains of working through a dynamic research center. These benefits include not only efficient administrative and financial services, but also access to improved germplasm, new technologies, consulting, and training opportunities not necessarily specified in project contracts, as well as high quality laboratory, experiment station, biometrics, computing, software, and information support.



CIMMYT 1996 research agenda by CGIAR activity.

1996-97 Highlights

Funding for 1996 was US$ 30.9 million (US$ 29.0 million from donors and US$ 1.9 million from other sources); expenditures were US$ 30.9 million. The Center ended 1996 with an operational deficit of US$ 7,000. An additional US$ 390,000 was transferred from operating to capital funds to offset capital acquisitions in excess of depreciation during the year. Capital purchases in 1997 will be held to US$ 1.0 million. Nonetheless, the operating reserve by the end of 1996 was US$ 8.5 million, enough for 94 days. This is slightly more than the amount recommended by the Consultative Group on International Agricultural Research (CGIAR) and sufficient to meet normal fluctuations in funding. Funding for 1997 is projected at US$ 31.5 million (US$ 29.2 million from donors and US$ 2.3 from other sources).

* *People and Partnerships* (Mexico, D.F.: CIMMYT, 1997).

Expenses for 1997 are expected to total US$ 31.8 million, with a US$ 0.3 million deficit which represents the cost of a program and management review this year by a panel of external experts appointed by the CGIAR Technical Advisory Committee (TAC).

Significant reductions in contributions from several major donors resulted in a nearly US$ 1.6 million shortfall in unrestricted funding in 1996. This was partially offset by US$ 1.0 in additional contributions from other donors (a greatly appreciated action) and Center income. The general reduction in long-term, unrestricted commitments means CIMMYT will need to mobilize some US$ 4-5 million each year in new projects. In 1996, 20 new projects were launched, representing more than US$ 7.0 million over the next few years and US$ 2.7 million in 1996.

Construction of a new, combined maize and wheat germplasm bank was completed in 1996 with support from Japan and other core donors. In early 1997, the Danish International Development Agency (DANIDA) funded the construction of a new screen house for the wheat germplasm bank. Also in 1997, CIMMYT will open a regional office in Beijing, People's Republic of China, representing our commitment to support sustainable food production for that country's large population, and funding is being sought for further collaborative efforts on global wheat information systems. No other major capital outlays are foreseen for the next several years.

Sources of income from grants, 1996 (US$ 000s)

Donor	Core un-restricted	Core restricted and special projects	Complemen-tary	Total
Asian Development Bank			150	150
Australia	669			669
Australian Centre for International Agricultural Research		50		50
Australian Agency for International Development		135		135
Austria	150		28	178
Belgium	96	152		248
Canadian International Development Agency	875	806	127	1,808
CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement)			3	3
China, People's Republic of	80			80
Colombia		148		148
Danish International Development Agency	1,404	100	90	1,594
European Union		2,544		2,544
Ford Foundation	400	70		470
France		410		410
Germany	530	435	53	1,018
Grains Research and Development Corporation, Australia		88	21	109
IBTA (Bolivian Institute of Agricultural Technology)			29	29
India	200			200
Instituto Nacional de Investigación Forestal Agropecuaria, Mexico				0
Inter-American Development Bank	750	699		1,449
International Council For Research in Agroforestry, Mexico			196	196
International Institute of Tropical Agriculture				0
International Irrigation Management Institute				0
Italy		82		82
International Food Policy Research Institute			22	22
International Fund For Agricultural Development			300	300
International Plant Genetic Resources Institute		105		105
International Tropical Agriculture Center			49	49
Islamic Republic of Iran		4	50	54
Japan	2,577		130	2,707
Korea, Republic of	50	11		61
Leverhulme Trust		53		53
Mexico	40			40
National Association of Oilseed and Wheat Producers, Bolivia (USAID PL480)			66	66
National Institute of Agriculture Research, Uruguay			77	77
NAFINSA, Mexico		3		3
Netherlands		177	3	180
Norwegian Ministry of Foreign Affairs	124			124
Overseas Development Administration, UK	864	284		1,148
OPEC Fund for International Development				0
Philippines	62			62
Rockefeller Foundation		219	37	256
Sasakawa Africa Association			26	26
Spain	20	80		100
Stanford University			11	11
Switzerland		803	231	1,034
Tropical Agriculture Research Center, Japan			30	30
United Kingdom				0
United Nations Development Programme		2,397		2,397
United States Agency for International Development	3,943	94	24	4,061
United States Department of Agriculture		77	26	103
World Bank	4,400			4,400
Miscellaneous research grants			14	14
Total income from grants	**17,234**	**10,026**	**1,767**	**29,053**

Trustees and Principal Staff (as of August 1997)

Trustees

[1] *Ex officio* position

Principal Staff

Office of the Director General

Timothy G. Reeves, Australia, Director General
Roger Rowe, USA, Deputy Director General of Research[4]
Claudio Cafati, Chile, Deputy Director General of Administration and Finance
Gregorio Martínez V., Mexico, Government and Public Affairs Officer
Peter J. Ninnes, Australia, Executive Officer, Research Management[3]
Lucy Gilchrist S., Chile, Head, Seed Health Unit
Norman E. Borlaug, USA, Consultant

General Administration

Linda Ainsworth, USA, Head, Visitor and Conference Services
Krista Baldini, USA, Manager, Human Resources
Hugo Alvarez V., Mexico, Administrative Manager
Martha Duarte, Mexico, Finance Manager
Salvador Fragoso, Mexico, Payroll and Taxes Supervisor
María Garay A., Mexico, Head, Food and Housing
Gilberto Hernández V., Mexico, Training Coordinator
Héctor Maciel, Mexico, Accounting Manager
Domingo Moreno, Mexico, Head, Telecommunications
Roberto Rodríguez, Mexico, Head, Workshop
Eduardo de la Rosa, Mexico, Head, Building Maintenance
Rorika Rueda, Mexico, Accounts Payable Supervisor[4]
Germán Tapia, Mexico, Warehouse Supervisor
Manuel Terrazas M., Mexico, Treasury Supervisor
Miguel Zetina, Mexico, Computer Users Support Supervisor

External Relations Program

Tiffin D. Harris, USA, Director
Anne Starks Acosta, USA, Donor Relations Officer
Leslie Rose, USA, Public Awareness Officer[4]
Jonathan Woolley, UK, Consultant[3]

Publications and Communications

Kelly A. Cassaday, USA, Manager
G. Michael Listman, USA, Writer/Editor
Timothy McBride, USA, Writer/Editor[2]
Alma L. McNab, Honduras, Writer/Editor and Translations Coordinator
Miguel Mellado E., Mexico, Publications Production

Information Technology Unit

Edith Hesse, Austria, Manager
Jesús Vargas G., Mexico, Systems and Operations
Guillermo Ibarra B., Mexico, PC Support and Integration
Rafael Herrera M., Mexico, Software Development
Carlos López, Mexico, Software Systems
Héctor Sánchez V., Mexico, Project Leader, Wheat Systems

Library

Corinne de Gracia, Mexico, Head
Fernando García P., Mexico, Electronic Information Specialist
John Woolston, Canada, Visiting Scientist

Maize Program

Gregory Edmeades, New Zealand, Interim Director[3]
Delbert Hess, USA, Director[2]
Richard Wedderburn, Barbados, Associate Director
David Beck, USA, Breeder
David Bergvinson, Canada, Entomologist
Javier Betrán, Spain, Breeder
Hugo Córdova, El Salvador, Breeder
Daniel Jeffers, USA, Pathologist
Shivaji Pandey, India, Breeder
Ganesan Srinivasan, India, Breeder, International Testing/Highland Maize
Suketoshi Taba, Japan, Breeder, Germplasm Bank
Martha Willcox, USA, Breeder/ Applications of Biotechnology[4]
Gonzalo Granados R., Mexico, Consultant
Felix San Vicente, Venezuela, Consultant

Andean Region (staff based in Colombia)

Benoit Clerget, Switzerland, Breeder[1]
Carlos de León G., Mexico, Pathologist
Luis Narro, Peru, Breeder

Asia (staff based in Thailand)

Surinder Vasal, India, Breeder
James Lothrop, USA, Breeder
Danilo Baldos, Philippines, Agronomist/ Coordinator, Crop Management Training/NRG

Eastern Africa

Joel K. Ransom, USA, Agronomist (based in Kenya)
Alpha O. Diallo, Breeder (based in Kenya)
Anthony Esilaba, Kenya, Regional Research Fellow (based in Ethiopia)[3]

Central America and the Caribbean (staff based in Guatemala)

Jorge Bolaños, Nicaragua, Agronomist
Jerome Fournier, Switzerland, Agronomist/ NRG Associate

Southern Africa (staff based in Zimbabwe)

Marianne Bänziger, Switzerland, Physiologist
David Jewell, Australia, Breeder
Kevin Pixley, USA, Breeder
Stephen Waddington, UK, Agronomist/ NRG Associate
Batson Zambezi, Malawi, Breeder

Ghana

Roberto F. Soza, Chile, Agronomist[2]

Associate Scientists

Miguel Barandiarán, Peru, Breeder
Harish Kumar, India, Entomologist[4]
Anne Elings, Netherlands, Physiologist
Byung-Ryeol Sung, South Korea, Breeder

Pre- and Postdoctoral Fellows

Salvador Castellanos, Guatemala, Breeder
Priscilla Henríquez, El Salvador, Entomologist[2]
Jan Hirabayashi, USA, Entomologist[4]
Scott McLean, USA, Breeder[2]
Sai Kumar Ramanujam, India, Breeder[4]
Felix San Vicente, Venezuela, Breeder[4]

Visiting Scientists

Jan Bocansky, Yugoslavia, Breeder
Jaime Carvajal, Bolivia, Breeder
Javier Eddy Flores, Bolivia, Breeder
Shambhu Nath Mishra, India, Breeder
Ricardo Mora, Mexico, Breeder
Lawrence Mshana, Tanzania, Breeder
Stephen Mugo Ngure, Kenya, Breeder
George Ombhako, Kenya, Breeder
Edison Silva, Ecuador, Breeder
Zhang Shukuan, China, Breeder
Satish K. Sudan, India, Breeder
Legesse Woulde, Ethiopia, Breeder
Habtamu Zelleke, Ethiopia, Breeder

Wheat Program

Sanjaya Rajaram, India, Director
H. Jesse Dubin, USA, Associate Director
Arnoldo Amaya, Mexico, Executive Administrative Officer
Paul Fox, Australia, Manager, International Nurseries
Guillermo Fuentes D., Mexico, Pathologist (Bunts/Smuts)
Lucy Gilchrist S., Chile, Pathologist (Fusarium/Septoria)
Maarten van Ginkel, Netherlands, Head, Bread Wheat Breeding
Gunther Manske, Germany, Physiologist[4]
Mohamed Mergoum, Morocco, Head, Triticale Breeding
A. Mujeeb-Kazi, USA, Head, Wide Crosses
Iván Ortiz-Monasterio, Mexico, Agronomist
Roberto J. Peña, Mexico, Head, Industrial Quality
Wolfgang H. Pfeiffer, Germany, Head, Durum Wheat Breeding
Matthew P. Reynolds, UK, Head, Physiology
Kenneth D. Sayre, USA, Head, Crop Management
Ravi P. Singh, India, Geneticist/Pathologist (Rust)
Bent Skovmand, Denmark, Head, Wheat Germplasm Bank, and Genetic Resources
Richard Trethowan, Australia, Bread Wheat Breeder[3]
Reynaldo L. Villareal, Philippines, Head, Germplasm Improvement Training
Hugo Vivar, Ecuador, Head, ICARDA/ CIMMYT Barley Program
Maximino Alcalá, Mexico, Consultant[3]

Eastern Africa (staff based in Ethiopia)

Thomas S. Payne, USA, Breeder
Douglas G. Tanner, Canada, Agronomist

Southern Africa

George Varughese, India, Leader, Maize/ Wheat Network (based in Zimbabwe)

South America

Man Mohan Kohli, India, Breeder (based in Uruguay)
Patrick C. Wall, Ireland, Agronomist/NRG Associate (based in Bolivia)

South Asia (staff based in Nepal)

Etienne Duveiller, Belgium, Pathologist
Guillermo Ortiz Ferrara, Mexico, Breeder
Eugene E. Saari, USA, Pathologist/Breeder[4]

Bangladesh

Craig A. Meisner, USA, Agronomist/NRG Associate

West Asia/North Africa (WANA)
Syria

Osman S. Abdalla, Sudan, Bread Wheat Breeder
M. Miloudi Nachit, Germany, Durum Wheat Breeder

Turkey

Hans-Joachim Braun, Germany, Breeder
Alexei Morgounov, Russia, Breeder

Associate Scientists

Sarah Fennell, UK, Geneticist
Arne Hede, Denmark, Geneticist
Monique Henry, France, Virologist
Masanori Inagaki, Japan, Cytogeneticist

---

1 Appointed in 1996
2 Left CIMMYT in 1996
3 Appointed in 1997
4 Left CIMMYT in 1997

Postdoctoral Fellows

Janny van Beem, Colombia, Physiologist
Belgin Çukadar-Olmedo, Turkey, Breeder

Visiting Scientist

Nigatu Tadesse, USA, Geneticist[3]

Graduate Students

Ligia Ayala, Ecuador, Molecular Geneticist[1]
Heidi Mickelson, USA, Breeder[2]
Henning Müller, Germany, Agronomist[2]

Economics Program

Prabhu Pingali, India, Director
Mauricio Bellon, Mexico, Human Ecologist[3]
Paul W. Heisey, USA, Economist
Michael Morris, USA, Economist
Melinda Smale, USA, Economist
Ma. Luisa Rodríguez, Mexico, Program Administrator

Central America and the Caribbean (staff based in Costa Rica)

Gustavo E. Sain, Argentina, Economist/ NRG Associate
Monika Zurek, Germany, Economist (Associate Scientist)[3]

Eastern and Southern Africa (staff based in Ethiopia)

Wilfred M. Mwangi, Kenya, Economist
Hugo Verkuijl, Netherlands, Economist (Associate Scientist)

Zimbabwe

Mulugetta Mekuria, Ethiopia, Economist[3]

Rockefeller Foundation Visiting Research Fellow

Erika Meng, USA, Economist[3]

Associate Scientist

Damien Jourdain, France, Economist[3]

Affiliate Scientists

John Brennan, Australia, Economist
David Cleveland, USA, Economist
Marianne van Dorp, Netherlands, Economist
Cheryl Doss, USA, Economist
David Godden, Australia, Economist
Douglas Gollin, USA, Economist
Jikun Huang, China, Economist
Miguel Angel López, Honduras, Economist
Dominique Louette, France, Economist
James MacMillan, Canada, Economist[3]
Mitch Renkow, USA, Economist
Scott Rozelle, USA, Economist
Daniela Soleri, USA, Economist
Gregory Traxler, USA, Economist

Research Associates

Dagoberto Flores, Mexico, Field Researcher
Maximina Lantican, Philippines, Economist
Naresh Pradhan, Nepal, Economist
Elizabeth Rice, USA, Economist[4]
Jean Risopoulos, Belgium, Economist
Manisha Shah, USA, Economist

Natural Resources Group

Larry Harrington, USA, Director
Peter Grace, Australia, Soil Scientist[3]
Jeff White, USA, GIS/Modeling Specialist
Adriana Rodríguez, Mexico, GIS Technician[3]
Ma. Luisa Rodríguez, Mexico, Program Administrator

Central America and the Caribbean (staff based in Honduras)

Héctor J. Barreto, Colombia, Agronomist (joint CIMMYT/CIAT staff)

South Asia (staff based in Nepal)

Peter R. Hobbs, UK, Agronomist

Associate Scientists

Olaf Erenstein, Netherlands, Economist[4]
Dewi Hartkamp, Netherlands, GIS/ Modeling Specialist
Eric Scopel, France, Agronomist

Consultants

David Hodson, UK, GIS Specialist
Joost Lieshout, Netherlands, Database Manager
Monica Mezzalama, Italy, Plant Pathologist
Jonathan Woolley, UK, Agronomist

Applied Biotechnology Center

David Hoisington, USA, Director
Ognian Bohorov, Bulgaria, Scientific Services Officer
Natasha Bohorova, Bulgaria, Cell Biologist, Genetic Engineering
Diego González-de-León, Mexico, Geneticist, Molecular Genetics
Mireille Khairallah, Lebanon, Geneticist, Molecular Geneticist
Jean Marcel Ribaut, Switzerland, Geneticist, Molecular Geneticist
Wanggen Zhang, China, Molecular Biologist, Genetic Engineering

Associate Scientists

Robert Bird, USA, Archeobotanist[2]
Sarah Fennell, UK, Geneticist, Genetic Engineering
Paul Julstrom, USA, Biosafety Greenhouse Specialist[2]
Scott McLean, USA, Geneticist, Genetic Engineering[3]

Adjunct Scientists

Godfree Chigeza, Zimbabwe, SIRDC/ Zimbabwe, Breeder, Molecular Genetics[3]
Baldwin Chipangura, Zimbabwe, SIRDC/ Zimbabwe, Biotechnologist, Molecular Genetics[3]
Olivier Leblanc, France, ORSTOM/France, Geneticist, Apomixis Project[3]
Zachary Muthamia, Kenya, KARI/Kenya, Breeder, Molecular Genetics[3]
Kahiu Ngugi, Kenya, KARI/Kenya, Biotechnologist, Molecular Genetics[3]
Yves Savidan, France, ORSTOM/France, Leader, Apomixis Project[2]
Antonio Serratos, Mexico, INIFAP/Mexico, Molecular Biologist, Apomixis Project[1]

Postdoctoral Fellows

Daniel Grimanelli, France, Geneticist, Apomixis Project
Xueyi Hu, China, Geneticist, Molecular Genetics[2]
Enrico Perotti, Italy, Molecular Biologist, Apomixis

Graduate Students

Ligia Ayala, Ecuador, Molecular Genetics[1]
Elsa Espinosa, Mexico, Apomixis
Susanne Groh, Germany, Quantitative Geneticist[4]
Héctor Guillén, Mexico, Molecular Genetics
Ramiro Hernández, Mexico, Genetic Engineering[3]
John Larsen, Canada, Molecular Genetics[1]
Daisy Pérez, Cuba, Molecular Genetics[1]
Alix Pernet, France, Molecular Genetics[4]

Biometrics

José Crossa, Uruguay, Head
Chiangjian Jiang, China, Biometrician
Jorge Franco, Uruguay, Consultant
Mateo Vargas, Mexico, Consultant

Experiment Stations

Francisco Magallanes, Mexico, Field Superintendent, El Batán
José A. Miranda, Mexico, Field Superintendent, Toluca
Rodrigo Rascón, Mexico, Field Superintendent, Cd. Obregón
Abelardo Salazar, Mexico, Field Superintendent, Poza Rica
Alejandro López, Mexico, Field Superintendent, Tlaltizapán

General Laboratories

Jaime López C., Mexico, Supervisor, Soils and Plant Nutrition Laboratory

---

1 Appointed in 1996
2 Left CIMMYT in 1996
3 Appointed in 1997
4 Left CIMMYT in 1997

CIMMYT Contact Addresses

Mexico (Headquarters)
CIMMYT
Lisboa 27
Apdo. Postal 6-641
06600 México, D.F., México
Email: cimmyt@alphac.cimmyt.mx
Fax (International): (52-5) 726 7558/9
Fax (in Mexico): (91-595) 54424/5
Primary contacts:
Timothy Reeves, Director General
Tiffin D. Harris, Director, External Relations

Bangladesh
CIMMYT
P.O. Box 6057, Gulshan
Dhaka-1212
Bangladesh
Fax: (880-2) 883516
Email: cm@cimmyt.bdmail.net
Primary contact: **Craig Meisner**

Bolivia
CIMMYT
c/o ANAPO
Casilla 2305
Santa Cruz, Bolivia
Fax: (591-3) 427194
Email: cimmyt@mitai.nrs.bolnet.bo
Primary contact: **Patrick C. Wall**

Colombia
CIMMYT
c/o CIAT
Apdo. Aéreo 67-13
Cali, Colombia
Telex: 5769 CIATCO
Fax: (57-2) 4450025
Email: c.deleon@cgnet. com
Primary contact: **Carlos De Leon**

Costa Rica
CIMMYT
Apartado 55
2200 Coronado
San José, Costa Rica
Fax: (506) 2292457
Email: gsain@iica.ac.cr
Primary contact: **Gustavo Sain**

Ethiopia
CIMMYT
P.O. Box 5689
Addis Ababa, Ethiopia
Fax: (251-1) 611892
Email: cimmyt-ethiopia@cgnet.com
Primary contact: **Wilfred Mwangi**

Guatemala
CIMMYT
12 Calle 1-25 Zona 10
Edificio Geminis
Torre Norte, 16 Nivel, Of. 1606
Apdo. Postal 231-A
Guatemala, Guatemala
Fax: (502-2) 3353407
Email: jbolanos@ns.guate.net
Primary contact: **Jorge A. Bolaños**

Honduras
CIMMYT
CIAT-Laderas
c/o IICA-Honduras
Apdo. Postal 1410
Tegucigalpa, DC
CP 11101 Honduras
Fax: (504) 315472
Email: ciathill@hondutel.hn
Primary contact: **Héctor Barreto**

Kenya
CIMMYT
P.O. Box 25171
Nairobi, Kenya
Fax: (254-2) 631499, 630164
Email: j.ransom@cgnet.com
Primary contact: **Joel K. Ransom**

Nepal
CIMMYT
P.O. Box 5186
Kathmandu, Nepal
Fax: (977-1) 419352
Email: cimkat@mos.com.np
Primary contact: **Peter Hobbs**

Syria
CIMMYT
Cereal Improvement Program
ICARDA
P.O. Box 5466
Aleppo, Syria
Fax: (963-21) 213490
Email: m.nachit@cgnet.com
Primary contact: **Miloudi Nachit**

Thailand
CIMMYT
P.O. Box 9-188
Bangkok 10900
Thailand
Fax: (66-2) 5614057
Email: svasal@loxinfo.co.th
Primary contact: **Surinder K. Vasal**

Turkey
CIMMYT
P.K. 39 Emek
Ankara, Turkey
Fax: (90-312) 2878955
Email: cimmyt-turkey@cgnet.com
Primary contact: **Hans-Joachim Braun**

Uruguay
CIMMYT
CC 1217
Montevideo, Uruguay
Fax: (598-2) 928522, 923633
Email: cimmyt@inia.org.uy
Primary contact: **Man Mohan Kohli**

Zimbabwe
CIMMYT
P.O. Box MP 163
Mount Pleasant
Harare, Zimbabwe
Fax: (263-4) 301327
Email: cimmyt-zimbabwe@cgnet.com
Primary contact: **David Jewell**

Bibliographic Information

Correct citation: CIMMYT. 1997. *CIMMYT in 1996-97: Widening the Circle of Partnerships.* Mexico, D.F.: CIMMYT.

AGROVOC descriptors: *Zea mays*; Wheats; Varieties; Genetic resources; Plant breeding; Sustainability; Plant biotechnology; Organization of research; Research projects; Research policies.

Agris category codes: A50, A01.

Dewey decimal classification: 630.

ISSN: 0188-9214

Credits

Writing: Kelly Cassaday, Mike Listman, Alma McNab, and Tiffin D. Harris, with CIMMYT staff.

Design and layout: Miguel Mellado.

Layout assistance: Eliot Sánchez P., Marcelo Ortíz S., G. Antonio Luna., Juan José Joven C., and Ma. Concepción Castro A.

Printed in Mexico.

CIMMYT receives special project funding for specific research activities from the following:

Asian Development Bank
AusAID
Australian Council for International Agricultural Research
Bangladesh
Belgium
Bolivia
Canadian International Development Agency
Colombia
CONACYT, Mexico
Cornell University
DANIDA (Denmark)
European Union
France
Germany
Grains Research and Development Corporation, Australia
INIA - Uruguay
Inter-American Development Bank
International Development Research Centre
International Fund for Agricultural Development
Iran
Japan
Korea
McKnight Foundation
Mexico
Monsanto
NAFINSA
Netherlands
Nippon Foundation
NORAD (Norway)
OPEC Fund for International Development
Patronato, Estado de Sonora, Mexico
Republic of South Africa
Rockefeller Foundation
Spain
Stanford University
SIDA (Sweden)
Switzerland
United Kingdom
United Nations Development Programme
United States Agency for International Development
United States Department of Agriculture
United States National Science Foundation

The Consultative Group on International Agricultural Research (CGIAR)

Primary financial support for CIMMYT's work comes from the 54 members of the Consultative Group on International Agricultural Research (CGIAR). This international consortium, which represents developed and developing countries, is cosponsored by the Food and Agriculture Organization of the United Nations, the World Bank, the United Nations Development Programme, and the United Nations Environment Programme. Through its support to CIMMYT and 15 other international agricultural research centers, the CGIAR promotes sustainable agriculture for food security in developing countries.

“Everything begins and ends in the seed.”

Barrios and Buenrostro,

“El maíz, nuestro sustento,”

***Arqueología Mexicana* V(25): 7.**

International Maize and Wheat Improvement Center
Centro Internacional de Mejoramiento de Maíz y Trigo
Lisboa 27, Apartado Postal 6-641, 06600 México, D.F., México