ACRONYMS AND ABBREVIATIONS

ACIAR  Australian Centre for International Agricultural Research
ADB  Asian Development Bank
BARC  Bangladesh Agricultural Research Institute
BRDB  Bangladesh Rural Development Board
CAC  Central Asia and the Caucasus
CGIAR  Consultative Group on International Agricultural Research
CIMMYT  Centro Internacional de Mejoramiento de Maíz y Trigo
CIRAD  Centre de Coopération Internationale en Recherche Agronomique pour le Développement [France]
EC  European Commission
EMBRAPA  Empresa Brasileira de Pesquisa Agropecuária [Brazil]
EST  Expressed sequence tag
FAW  Fall armyworm
GIS  Geographic information systems
GTZ  Deutsche Gesellschaft für Technische Zusammenarbeit [Germany]
ICARDA  International Center for Agricultural Research in the Dry Areas
ICRISAT  International Center for Research in the Semi-Arid Tropics
IFAD  International Fund for Agricultural Development
IFPRI  International Food Policy Research Institute
INIFAP  Instituto Nacional de Investigaciones Forestales y Agropecuarias [Mexico]
IRD  Institut de Recherche pour le Développement
IRMA  Instituto Regional de Mejoramiento de Maíces para América Latina
IRRI  International Rice Research Institute
ITEC  International Triticeae EST Consortium
JIRCA  Japan International Research Center for Agricultural Sciences
KARI  Kenya Agricultural Research Institute
MAS  Marker-assisted selection
NARS  National agricultural research system
NRC  National Research Council
NGO  Non-governmental organization
PRA  Participatory rural assessment
PRM  Programa Regional de Maíz [Central America]
QPM  Quality protein maize
RWC  Rice-Wheat Consortium for the Indo-Gangetic Plains
SADLF  Southern Africa Drought and Low Soil Fertility Project
SCB  Sugarcane borer
SDC  Swiss Agency for Development and Cooperation
SWCB  southwestern corn borer
UNDP  United Nations Development Programme
USAID  United States Agency for International Development
WRC  Wheat Research Centre [Bangladesh]

Credits

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OUR MISSION
CIMMYT is an international, non-profit, agricultural research and training center dedicated to helping the poor in low-income countries. We help alleviate poverty by increasing the profitability, productivity, and sustainability of maize and wheat farming systems.

FOCUS
Work concentrates on maize and wheat, two crops vitally important to food security. These crops provide about one-fourth of the total food calories consumed in low-income countries, are critical staples for poor people, and are an important source of income for poor farmers.

PARTNERS
Our researchers work with colleagues in national agricultural research programs, universities, and other centers of excellence around the world; in the donor community; and in extension and non-governmental organizations.

ACTIVITIES
• Development and worldwide distribution of higher yielding maize and wheat with built-in genetic resistance to important 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.
• Development of new knowledge about maize and wheat.
• Development of more effective research methods.
• Training of many kinds.
• Consulting on technical issues.

IMPACT
• CIMMYT-related wheat varieties are planted on more than 64 million hectares in low-income countries, representing more than three-fourths of the area planted to modern wheat varieties in those countries.
• Nearly 14 million hectares in non-temperate environments of developing countries are planted to CIMMYT-related maize varieties, which is nearly half of the area planted to modern maize varieties in those environments.
• Between 1987 and 1998, CIMMYT delivered nearly 40,000 shipments of wheat seed and more than 20,000 shipments of maize seed to researchers in developing and developed countries. These shipments, which included improved materials developed by CIMMYT breeders and accessions from our germplasm banks, represented a valuable source of genetic resources for public and private research organizations.
• More than 9,000 researchers from around the world have benefited from CIMMYT’s training efforts. CIMMYT alumni now lead major breeding programs, public and private, throughout the world.
• Our information products and research networks improve the efficiency of researchers in more than 100 countries.

FUNDING
CIMMYT wishes to thank the many governments and organizations that help us fulfill our mission (see p. 69 of this report). We owe a special debt of gratitude to those who support our core activities. The impacts described in this publication would have been impossible to achieve without that support.

LOCATION
Activities and impact extend throughout the world via 17 regional offices. Headquarters are in Mexico. See contact information, back cover.

NEWLY UPDATED WEBSITE
We have redesigned our website to give you more news and technical information. Visit us at www.cimmyt.org.
A **Message** from the **Director General**

**At CIMMYT, our daily commitment is to focus the best agricultural science on improved human and environmental well-being. This report describes the people and places that compel us to succeed in our work, the range of research partners who share our goals, and the many other elements that constitute a year in the life of CIMMYT.**

**World Food Prize for Fighting Malnutrition**

Last year in my message for the annual report, I described a visit to China’s poorest province, where quality protein maize (QPM) had changed peoples’ lives. (Quality protein maize contains nearly twice as much usable protein as other maize grown in the tropics.) This year it gives me great pleasure to congratulate the two chief architects of QPM, researchers Surinder K. Vasal and Evangelina Villegas, who have just won the World Food Prize for their work. Well done Sam and Eva!

The story of these two CIMMYT researchers is told later in this report, but the bottom line is that they developed an effective means for poor people to fight malnutrition, which kills almost five million children under five every year. The World Food Prize is a striking reminder of the impact that can be achieved by investing core funds in research. The time, care, and commitment that produced QPM are now yielding results in human lives. What better return on investment can there be?

**Partners Who Share Our Commitment**

The growing success with QPM exemplifies qualities seen in all of our work: first-class, exciting research and strong, genuine alliances with a diverse range of partners to ensure impact. To make better products available more quickly to farmers, and to gain access to the very best research technologies, we have established a range of well-thought-out partnerships.

We have built “upstream” partnerships with advanced research institutions, public and private. Because such partnerships require great clarity on issues of intellectual property, we have developed an intellectual property policy with the primary objective of ensuring that intellectual property generated through CIMMYT remains in the public arena. We believe that technology must serve the wider needs of all people. It cannot exist as an instrument of exclusion, especially at the expense of the poor.

To deliver “pro-poor” technologies quickly and efficiently to those who need them, we have also entered into a broad range of “downstream” partnerships with extension agencies, non-governmental organizations (NGOs), and seed companies—large and small—which are best placed to work with farmers in adapting and adopting technology.

Our consistent companions in all of our partnerships continue to be the national agricultural research systems, which, depending on their own strengths and priorities, can be involved anywhere along the research-adoption continuum.
RESEARCH ACHIEVEMENTS: Maize for Africa and the World

This report covers many facets of our maize work; here, I would like to emphasize two interrelated ones: our work in Africa and our work related to water-use efficiency.

We believe that our program for maize in Africa is the best that we have ever had anywhere. The drought-tolerant CIMMYT varieties developed in southern Africa will have a life-saving impact, not only in Africa but most likely everywhere in the developing world. Like QPM, this work has benefited from years of painstaking basic research, in this case dedicated to understanding the physiological basis of drought tolerance. That foundation research yielded innovative breeding strategies that are breaking the “drought barrier” for African farmers. Researchers have identified maize cultivars that yield far better under smallholders’ conditions (characterized by drought stress and infertile soils) than any other maize available. Experimental cultivars have shown yield advantages of 50–75% over commercial cultivars under stress conditions.

These research results become more meaningful when seen in the context of the farm communities that participate in the research. Last April, I was privileged to visit Zvimba in Zimbabwe, where the local rural school is heavily involved in the drought research. The students introduced us to the trial site and also sang for us. It was telling that their songs were about hunger, poverty, and inequality—a reminder of grim realities. The fact that together we are making progress against these problems was best summed up by Chief Chirau, who said, “CIMMYT people came to talk to our farmers, but then they came back and have stayed. If I were a rich man I would build a house for Dr. de Meyer [one of the CIMMYT researchers] so he could stay here forever and help my people.”

Bred for tolerance to drought and poor soils, disease and pest resistance, better protein, and other superior nutritional characteristics, our maize varieties for Africa are a hardy guarantee of food security and better nutrition for poor people. By reducing the impact of agriculture on Africa’s fragile ecosystems, CIMMYT maize is also a guarantee of environmental security.

RESEARCH ACHIEVEMENTS: Water and Wheat Worldwide

Across much of the developing world, wheat and other crops grown under irrigation must contend with increasing water scarcity. Likewise, crops produced in rainfed systems must be bred and managed to withstand drought. In conducting the field interviews for this report, we repeatedly heard how people are seeking to cope with water shortages. Often they are succeeding, thanks to CIMMYT and its partners. With our Asian partners, we continue to have tremendous success with conservation tillage and bed planting systems, which have substantial advantages for input-use efficiency: water savings of 30–40% are reported!! Awareness of the importance of conservation tillage is building across South Asia as adoption increases ten-fold each year. This research is reaching the crucial stage at which continuing investment is needed to maintain the momentum.

CIMMYT is also raising the water-use efficiency of wheats for irrigated and marginal environments. A new research protocol at CIMMYT challenges early
generations of experimental wheats with two irrigations instead of the usual four or five. A range of lines appear to yield about the same under the reduced moisture regime as under the full regime. These wheats are the forerunners of the varieties that will secure irrigated wheat production in the water-scarce environments of the future.

What about marginal environments? A growing body of evidence indicates that CIMMYT wheats are now adopted extensively in marginal areas. New sources of drought tolerance should further extend the utility of CIMMYT wheats in these areas. These sources—derived from wild relatives of wheat—have resulted in experimental varieties that yield up to 2 tons per hectare when other material is dying from drought. As climate change becomes less of a theory and more of a reality for the world’s poor farmers, these varieties will become critical elements of production systems.

NEW AND PROVEN Science for Local and Global Impact

In all of this research, new science (such as functional genomics, marker-assisted selection, wide hybridization, and transformation) is allied with proven methodologies to reinforce the quality and efficiency of our research. Many examples of this kind of research are contained in the pages that follow.

Finally, I would like to point out that this report illustrates how our researchers and partners, with their considerable understanding of local conditions and policies at the field level, have woven this local understanding into a wider research strategy for coping with the tremendous changes affecting agriculture in the South. The foresight and dedication of our staff and their colleagues are giving farmers around the world a safety net in times of change.

CHANGES, CHALLENGES, AND Commitments

Farmers are not the only people for whom change is a fact of life, of course, and as I complete my initial five years as CIMMYT’s Director General, I have had time to reflect on what CIMMYT has accomplished during that period. It has been a time of transformation and challenge, but I believe that the Center is in very good shape thanks to the efforts of everyone at CIMMYT. Our science has never been better; our partnerships never stronger; and our resourcing has improved significantly.

I also believe that over the past five years we have created a fairer, more equitable workplace for internationally and nationally recruited staff, through better staff classification systems and promotion procedures. Multi-source assessment for staff will further improve the work environment. In fact, a recent review of our project-based management system identified multi-source assessment as one of the critical factors of success.

Like the work environment, the funding environment has also experienced change in the past five years. I believe that we have adapted well and have successfully diversified our base of support. In 2000, CIMMYT has received about 7% of its funding from targeted research agreements with advanced research institutes, private and public. Contributions from the CGIAR members in the South now constitute 4% of Center income. Finally, funding from non-traditional (in other words, non-CGIAR) sources provides 17% of the budget, with non-CGIAR foundations contributing around half of that amount.

Because we are all too aware that no condition is permanent, we know that we must continue to lead, to strive, and above all to change as the challenges and opportunities of the 21st century arise. There can be no time for complacency when 40,000 people die every day from hunger and malnutrition. We must all press on with urgency, whether our time at CIMMYT is five years, five months, or 25 years. My colleagues and I remain convinced that it is a privilege to work at this research center. When I think about what defines CIMMYT, it is this: superb technology, superb partnerships, superb participation, and, above all, superb people.

The context in which we work is changing dramatically, but one thing that will not change is our commitment to the people for whom we work—the resource-poor—and the people with whom we work—our partners—and our strong resolve to have a large, lasting, global impact.

Prof. Tim othy G. Reeves
Director General
In 1963, scientists at Purdue University were studying a set of seemingly commonplace Andean maize races and found something quite out of the ordinary. One sample contained a peculiar gene that significantly increased grain levels of lysine and tryptophan—amino acids that are essential building blocks for proteins in humans, poultry, and pigs. Named “opaque-2” because it gave kernels a chalky appearance, the gene also conferred low yields and susceptibility to many pests and diseases. For these and other reasons, after years of breeding efforts, publicity, and hope, farmers still showed little interest in opaque-2 maize varieties and researchers in many quarters began to write off the discovery. Not in CIMMYT, however. In 1970, the Center hired a young postdoctoral scientist from India to work with its cereal protein quality lab and develop a useful product based on the opaque-2 gene. Over the next 20 years, with strong support from the United Nations Development Programme (UNDP), Surinder K. Vasal would team up with Mexican cereal chemist Evangelina Villegas, using novel field and lab techniques to overcome opaque-2’s drawbacks. Lacking biotech tools, Vasal capitalized on traditional breeding techniques to incorporate a series of special genes that countered the unwanted side-effects of opaque-2. To ensure that the value-added protein trait was not lost, Villegas and her lab group painstakingly measured amino acid content in the protein of some 20,000 maize grain samples each year. It was 12 long years before they began to believe they would accomplish their goal, according to Villegas. “Around 1982–83, through the use of modifier genes, we saw the real possibility of completely changing the appearance of the opaque-2 kernel, improving yield, and working on the other problems, while maintaining protein quality,” she says.

**New Maize for A New Era**

Their new product was named “quality protein maize” (QPM) by former Maize Program director Ernest W. Sprague, a firm believer in its potential usefulness. Quality protein maize looks, grows, and tastes like normal maize, but it contains nearly double the lysine and tryptophan...
and a generally more balanced amino acid content that greatly enhances its nutritive value. A CIMMYT study found that QPM can contribute to reducing protein deficiencies, particularly in young children. In studies by others in Colombia, Guatemala, Peru, and, more recently, Ghana, malnourished children were restored to health on controlled diets using QPM. Nutritional studies with pigs, poultry, and other animals have all shown a significant advantage from use of QPM in animal feeds.

**The Global Spread of QPM**

During the late 1980s and 1990s, CIMMYT breeders Magni Bjarnason and Kevin Pixley built on Villegas’ and Vasal’s work to develop high yielding QPM varieties. Sasakawa Global 2000, an international organization that works to spread improved farm technology in Africa, promoted QPM in Ghana and several other African nations. The Brazilian research organization, EMBRAPA, developed and marketed QPM varieties. Most recently, CIMMYT breeder Hugo Córdova and his colleagues have developed high yielding QPM hybrids and tested and promoted them worldwide, with funding from the Nippon Foundation. “The yield advantage of new QPM hybrids—as much as 10% over local commercial hybrids, on average, and often more—has caught the eye of breeders and policymakers in many developing countries,” Córdova says.

“We believe we’re witnessing a revolution unfolding,” says CIMMYT director general Timothy Reeves. In 1999, he saw how a government program based on QPM had increased the food security and incomes of many families in Guizhou, China’s poorest province. “Several farmers there told me they had often been without food supplies for two or three months each year and literally had to scrape, beg, borrow for scraps and the occasional root or tuber,” Reeves says. “When QPM arrived, it not only helped with their own nutrition and income but also allowed them to start raising a sow or two. The turnaround in their lives was remarkable and all resulted from the new maize.”

**A Prestigious Award**

Established in 1986, the World Food Prize is awarded annually to individuals who have advanced human development by improving the quality, quantity, or availability of food in the world. The Prize, sponsored since 1990 by businessman and philanthropist John Ruan, includes a cash award of US$ 250,000.

The first woman ever to receive the World Food Prize, Villegas said that she was initially surprised. “I’m grateful and happy to be co-recipient of this award, but the most important thing is that it will raise people’s awareness about combating malnutrition. In hospitals in Ghana I saw children dying because they didn’t have enough quality food. This made a tremendous impact on me; you feel powerless to do anything for them. I know QPM will not solve all the world’s nutrition problems, but it will help.”

For Vasal, now leader of CIMMYT’s Asian regional maize program, the award caps a large list of honors in a long career dedicated to producing better maize varieties for developing country farmers. He credits Villegas and her team, though, for their central role in the accomplishment of QPM. “Without the biochemical laboratory, this breakthrough would not have been possible,” he says. “Finally, Bill Mashler, who worked at UNDP at that time, and former CIMMYT deputy director general, Keith Finlay, also provided key support for our work on QPM.”

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Wheat to Feed the “Hidden Hunger”

Millions of children die every year from “hidden hunger” caused by the unsatisfied need for minerals and vitamins. Three-fourths of them show few outward signs of the nutrient deficiencies that are killing them. Global concern about micronutrients is increasing. What about global support to end the problem?

Elements such as iron and zinc are called micronutrients because people need them in minute amounts. If these minute amounts are lacking, however, the consequences can be disastrous. Iron deficiency can cause anemia, especially in women and children, cognitive and learning problems in young children, and impaired work productivity in adults. Zinc-deficient women may suffer more complications and mortality during childbirth, while children may present retarded growth and skeletal deformities. The problem is most severe in developing countries.
GETTING AT HIDDEN HUNGER IN DEVELOPING COUNTRIES

Traditional strategies for preventing micronutrient deficiencies in developing countries have focused on health education programs, long-term vitamin supplementation, and the fortification of important foods. Although often successful in the industrialized world, these approaches tend to be costly and unsustainable in developing countries. Grain that is bred to be naturally rich in micronutrients may be a complementary, inexpensive, and sustainable means of preventing malnutrition.*

Cereal grains such as wheat, maize, and rice furnish the energy that people need to survive. Cereal grains are not good sources of micronutrients, but, at least in wheat, there is good reason to believe that levels of iron and zinc can be increased through plant breeding. If micronutrient-rich wheat were widely available in developing countries, the malnourished poor who eat wheat every day would automatically receive iron and zinc without having to take supplements or purchase more expensive foods.

CAN WHEAT PACK MORE NUTRITIONAL Power?

To raise the micronutrient content in wheat grain, researchers first need to explore whether some wheats, or wild species related to wheat, have higher levels of iron and zinc than others. Preliminary studies conducted at CIMMYT–Mexico, CIMMYT–Turkey, and the University of Adelaide in Australia** have suggested that this variability in micronutrient levels does exist, especially in wild relatives and wheat landraces. Since only 1% of the materials available at CIMMYT have been tested, much more variability is likely to be found.

Another positive finding is that increased micronutrient content in wheat is not linked to lower wheat yields. There is a good possibility of breeding wheat varieties that will produce high quantities of micronutrient-rich grain.

Breeders also need to consider that there may be sufficient micronutrients in the grain, but they may be present in forms that are not available to human beings. Ivan Ortiz-Monasterio, CIMMYT wheat agronomist, points out that micronutrients must be available not only in plants but in soils. “Soils often contain high amounts of minerals, but they aren’t available to crop plants,” he says. “If plants can’t take iron and zinc from the soil, the grain they produce won’t have enough of these nutrients either.” Breeders will have to improve the efficiency with which wheat extracts these nutrients from soil, and—just as importantly—the efficiency with which it stores them in the grain.

If researchers develop wheat varieties that deliver more minerals in their grain, agricultural productivity will improve, because plants, like people, need micronutrients. Seed with high concentrations of micronutrients produces more viable and vigorous seedlings. Wheat varieties that are better at taking minerals from the soil have better disease resistance, nutrition, and yields, particularly in mineral-deficient soils in arid regions.

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** These studies formed part of the CGIAR Micronutrients Project, organized and coordinated by H. Bouis at the International Food Policy Research Institute (IFPRI).
PLANT BREEDING AS A PUBLIC Health STRATEGY

Maarten van Ginkel and Richard Trethowan, CIMMYT bread wheat breeders, raise some important points related to breeding wheat with higher levels of micronutrients. “Farmers growing the micronutrient-rich wheats will get higher yields and use fewer chemicals to control diseases,” points out van Ginkel. Adds Trethowan, “Once the genes that increase grain micronutrient content are incorporated into all our wheats, the costs of continuing to breed these wheats will be no different than the costs of breeding ‘normal’ wheats.”

Because wheat is the most widely consumed crop in the world, the impact on nutrition could be extensive. In the long run, a breeding program may cost less and reach more people than most nutrition programs—another reason why plant breeding could be a sound public health strategy.

Finally, it is increasingly clear that better-nourished, healthier people have higher incomes and contribute more to national income growth.* A more direct route to better nutrition could bring considerable economic benefits.

Many people have come to recognize that “hidden hunger” is less visible than hunger in famine zones but that it is just as serious. The new awareness that plant breeding may help improve nutrition (see story on the World Food Prize for quality protein maize, p. 6) should help mobilize resources for research in this important area. The CGIAR Micronutrients Project provided seed money for CIMMYT’s preliminary studies on breeding for increased micronutrient content in wheat, but a far greater commitment is needed if this important work is to continue.

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Reducing Plants’ Thirst at the Molecular Level

In southern Africa, CIMMYT and its partners have developed maize that withstands drought and infertile soils because of an innovative breeding approach based on more than 12 years of research in maize physiology at CIMMYT–Mexico. In this approach, cited extensively in the scientific literature, maize is bred under carefully managed drought and nitrogen stress. The breeding procedures are described in a new manual, *Breeding for Drought and Nitrogen Stress Tolerance in Maize.*

The search for creative breeding approaches has not stopped there. In 1999, maize physiologist Marianne Bänziger traveled to CIMMYT–Mexico for a strategic planning workshop on how to use molecular tools to help crops withstand drought. Experts from around the world discussed drought tolerance in five major cereal crops (maize, rice, wheat, sorghum, and millet) and developed a workplan for using molecular approaches to reduce drought losses in farmers’ fields.

“The workshop was very encouraging as it highlighted the progress achieved in different crops and disciplines,” observes Bänziger. “It left many of us thinking that by working together we can really tackle the problem of improving the drought tolerance of our main staple crops.”

Though some believe that drought tolerance may be too complex to attain through molecular approaches, Bänziger points out that, in maize, time after time breeders have found that the same genomic regions are linked to an important component of drought tolerance: the anthesis-silking interval. “We have high expectations that we may identify more universal genomic regions for drought tolerance in maize and use a fairly inexpensive molecular marker approach to speed up our selection process,” she says. For a breeder this means greater breeding progress in less time and easier incorporation of drought tolerance into different germplasm backgrounds.

CIMMYT molecular geneticist Jean-Marcel Ribaut, who organized the workshop, concurs with Bänziger. In addition to molecular genetics, Ribaut says, genetic engineering can also make valuable contributions to the pursuit of drought tolerance. For example, genetic engineering can be used to confirm the effect of a candidate gene—a gene that is thought likely to confer a given trait. Once plant response pathways have been identified and the genes involved with them characterized, the expression of these genes can be modified, he says. Building on this information, scientists can come to a better understanding of the physiological and biochemical pathways involved in drought responses and produce crop lines with improved resistance or tolerance to drought.

For more information:
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** Funded by the Rockefeller Foundation. See *Molecular Approaches for the Genetic Improvement of Cereals for Stable Production in Water-Limited Environments* (CIMMYT, 2000).
In one of the largest sets of farmer-participatory trials ever established in southern Africa, farmers have found a powerful forum to communicate about the kind of maize seed they need.

In rural communities across Zimbabwe, a new kind of research trial engages smallholder farmers in decisions that will help them obtain the kinds of maize cultivars they want to grow. Comments by Stan Tapererwa, District Agricultural Extension Officer of Zimbabwe’s national extension service (AGRITEX), reflect the widespread excitement and interest that the approach, known as “mother-baby” trials, has generated. “Extension officers feel highly honored to be involved with these trials and they are taking it as a part of their core business—unlike in the past, when they were just on-lookers and only got involved when new varieties had been released.”

“WE HAVE EXPERIENCED AS A COMMUNITY THAT WE CAN HAVE AN ACTIVE INVOLVEMENT IN RESEARCH AND DEVELOPMENT. THAT IS HOW IT SHOULD BE HAPPENING.”

Developing and Testing Drought-Tolerant Maize

Through the Southern Africa Drought and Low Soil Fertility (SADLF) Project, supported by the Swiss Agency for Development and Cooperation (SDC) and more recently the Rockefeller Foundation, CIMMYT researchers Marianne Bänziger and Julien de Meyer and their colleagues in southern Africa have been developing maize that produces more grain under severe drought and low soil fertility. The breeding methodology itself is farmer-centered (for news on breeding methods, see “Reducing Plants’ Thirst,” p.11).
“We take the two most common and challenging nemeses of subsistence agriculture in the region—drought and low nitrogen conditions—and replicate them in a controlled way on our breeding stations,” says Bänziger. Selecting in this way, they have developed two open-pollinated varieties, ZM421 and ZM521, that yield 30–50% more than current maize varieties under drought and low soil fertility. Experimental hybrids under development show even more dramatic gains.

Following Through with a Farmer Focus

Bänziger and de Meyer had the maize seed. What they then needed was a reliable way to test the performance and acceptance of their stress-tolerant maize under resource-poor farmers’ conditions and to ensure that seed became available. They hit upon a novel and cost-effective model devised by Sieglinde Snapp, of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), for on-farm testing of practices to improve soil fertility. As adapted by the CIMMYT–Zimbabwe team, the model involves complementary sets of experiments grown by researchers and farmers within farm communities.

For each researcher-designed “mother” trial, there are 6–12 “baby” trials within walking or bicycling distance. The mother trial contains promising maize cultivars for testing under both optimal and farmer-representative conditions. It is located near the center of the community and managed by a local counterpart—a teacher of agriculture, an extension officer, or a member of an NGO. Baby trials typically comprise four of the cultivars in the mother trial and are sown and managed exclusively by farmers. “This method allows 50 to 200 or more farmers in a country to assess a subset of the most promising new maize varieties,” explains de Meyer. “Farmers and researchers use results from both types of trial to assess a variety’s suitability for different environments and its acceptability to farmers.”

The mother-baby model is a decentralized approach to on-farm research that greatly improves the timeliness of sowing, trial supervision, and contact with farmers. The local partner provides established links to the community and intrinsic knowledge of farmers’ concerns. Farmers who grow baby trials are usually selected by the community and receive seed free of charge in color-coded bags. Stones painted with the same colors come with the seed. Farmers place these stones in the field as they start sowing, making it easy for everyone to keep track of specific trial entries. “This system has been the key to timely and decentralized planting of baby trials by virtually hundreds of smallholders,” says de Meyer. Trial results are distributed to all partners and farmers involved, as well as through the extension system and the press.

Widespread Participation

In 2000, 37 mother trials and more than 280 baby trials were planted all over Zimbabwe. Collaborating partners in the trials included NGOs, such as CARE International, the Southern African Unit for Local Resource Development, and the International Technology Development Group; community development associations, such as the Horseshoe Farmer Association in northern Zimbabwe, which links commercial farmers with smallholders to improve agriculture; AGRITEX; secondary schools; and national research stations. The demand for trials by collaborating research and extension staff and particularly NGOs was so great that researchers ran out of seed. By all indications, other countries in southern Africa will establish similar testing systems in 2000–2001.
Ingredients of Success

Bänziger identifies several key elements in the mother-baby model that make it particularly useful for testing and disseminating stress-tolerant maize. “Farmers and their entire communities observe commercial and experimental varieties and hybrids in their own fields and in the mother trials, and tell researchers, extension, seed companies, and others what they think,” she explains. The participation of secondary schools has been particularly valuable for conducting the mother trial. Students plant and care for the trial, compare results under different levels of fertilizer and under conditions that prevail in most farmers’ fields, and involve their parents and the wider community in what they are learning. According to one teacher, the empowering effect has been noticeable: “We have experienced as a school and as a community that we can have an active involvement in research and development. This is how it should be happening.”

In addition, farmers can now make informed choices about purchasing commercial varieties and hybrids. “We have seen smallholder farmers asking for seed of the best released cultivar of last year’s trials. Because half of the trial entries are experimental and the other half are recent releases, this means adoption occurs while research is conducted and decisions are made on future releases,” says Tapererwa. A farmer from Mushawasha in Masvingo District reinforces this by saying, “In a shop you cannot buy small quantities of maize seed from several varieties, just to try them out. Growing baby trials with several farmers in our own community makes it possible to see how varieties perform under our conditions.”

Finally, NGOs are keen to link community-based seed production schemes to a mother-baby testing scheme. “We benefit from results of cutting-edge research, knowledge on new varieties, and very practically the seed of relevant varieties already packed as a trial,” says Mr. V. Zvarevashe of Care International. “Also, our field officers receive training in field experimentation.”

The Message: LOUD AND CLEAR

Because interest in the trials is so high, Bänziger, de Meyer, and their partners are exploring ways of making these trials available more widely in southern Africa. Representatives from national agricultural research programs, extension, and NGOs from neighboring countries have been visiting and discussing the trials during a travelling workshop. The feedback of the group was clear: “The concept of mother-baby trials is logical, desirable, and exciting. Its great advantage is that farmers start adoption while new technologies are verified. This greatly reduces the lag-phase between research and impact, adoption rates will likely increase, and smallholder farmers and extension are bound into a natural flow of new research products. The approach guarantees a high return to investment due to cost-sharing and synergy among partners.”

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New Methods Pinpoint Drought-Tolerant Durum Wheats

A durum wheat carrying the unlikely name of “Sooty-Rascon” has surprised researchers with its outstanding performance in an experiment comparing how wheats tolerate drought at different stages of their growth cycle.

Sooty-Rascon came out best in three of four different kinds of drought imposed on the tested wheats, and in the top 10% in the fourth. It produced at least 3.4 tons per hectare regardless of drought severity, a yield that would please most farmers in dry environments.

The primary use of durum wheat in most of the world is to make pasta, but in West Asia and North Africa, durum is a staple crop. Bread, couscous, and other local foods made from durum wheat make up the basic diet of a large portion of the population. Durum is often grown in less-than-ideal environments where water is scarce, and thus it must be capable of tolerating drought.

Simulating Drought Precisely—Drip by Drip

Breeding wheat for arid environments requires simulating drought in experimental fields. In the Yaqui Valley, Sonora, Mexico, site of the CIMMYT Wheat Program’s principal wheat research station, different degrees of drought were achieved using flood, or furrow, irrigation. However, this method does not result in a true replication of all drought conditions, since the water filters into the ground, where it remains even after the superficial soil layers have dried out. Wheat plants can grow their roots long enough to reach the water stored there.

Casting about for alternatives that might work better than restricted flood irrigation, researchers decided to try drip irrigation, famously used by Israeli farmers to “make the desert bloom.” With this system, it is possible to apply the exact amount of water to the soil surface, without flooding the subsoil. The precision irrigation allows responses to drought in the experimental wheats to be differentiated more clearly.

How Accurate Is Simulated Drought?

To try out the new system, scientists set up an experiment comparing four situations: no drought, drought early in the season, drought late in the season, and drought throughout the season. They also included a field with flood irrigation to see how the new system compares with the old.

Choosing the test wheats was important. “The wheats included in the experiment have been extensively tested in many environments all over the world,” says Richard Trethowan, the wheat breeder who heads the work on drought. “Data from those environments will allow us to compare how the wheat varieties behaved in our experiment with how they behave in different conditions all over the world.”

The end result will allow CIMMYT breeders to tailor wheats to specific drought-stressed regions, providing farmers with varieties they can rely on to produce well year after year, even in the dry environments of West Asia and North Africa.

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As India’s population passes the one billion mark, farmers are discovering cropping practices that not only produce more food and profits but also save water and help curtail global warming. The practices are promoted by the Rice-Wheat Consortium for the Indo-Gangetic Plains (RWC).

“Where will the food to feed all these people come from?” Peter Hobbs, agronomist with CIMMYT’s Natural Resources Group and RWC co-facilitator, gestures toward teeming fellow travelers on foot, bicycle, wagon, motorbike, tractor, or in cars. All share a one-and-a-half lane road crossing Haryana State, in northern India. The beat-up jeep he rides jostles and jars noisily as it negotiates potholes and oncoming traffic. “Say you decide to import a million tons of cheap grain. If you use ten-ton lorries, then you’d need a fleet of 100,000 trucks plying these roads for hundreds of miles to deliver it. Maybe a better option would be to look at the deficit areas and increase productivity there.”

Hobbs is a man on a mission, with no time to lose. He communicates that urgency when the national researchers escorting him through Haryana stop to show him another of the trials they are conducting in farmers’ fields. Questioning, joking, cajoling, he and the RWC facilitator, Raj Gupta, drive home an important message to their colleagues. Researchers can no longer spend years dotting “i”s and crossing “t”s on research stations, but must quickly place promising options in farmers’ hands for testing, and then provide backstopping. “Everywhere you go, people are asking how we can produce more food and save resources,” Hobbs says. “As scientists, we have to try new ideas; we can’t just continue business as usual.”
**Business—Not as Usual**

Hobbs and Gupta smile often on this Haryana tour because business is not as usual. Zero tillage is catching on.

Farmers on some 8,000 hectares in Haryana have chosen to sow their wheat seed directly into recently harvested rice fields, instead of performing weeks of costly, laborious plowing and planking. This zero tillage practice is particularly apt for northwestern India and for Pakistan—high production areas where tractors are used widely and cutting costs is vital. Nearly all practitioners report similar benefits from the new technology: at least 10% less water used; fewer weeds; around 75% diesel savings; reduced labor and tractor maintenance costs; and higher yields from timely planting of the wheat crop.

Even when small numbers of farmers use reduced tillage methods, they can do a lot for the environment, from conserving scarce water supplies to easing the effects of global warming. By changing to zero tillage on just one hectare of land, a farmer can save as much as one million liters of irrigation water and 98 liters of diesel. For diesel, using a conversion factor of 2.6 kilograms of carbon dioxide produced per liter of fuel burned, the savings represent a reduction in carbon dioxide emissions (a major cause of global warming) of about a quarter ton per hectare.

These benefits increase dramatically if extended across even a portion of the rice-wheat region’s 12 million hectares. Adoption of zero tillage on, say, 5 million hectares would represent a savings of 5 billion cubic meters of water each year. That would fill a lake 10 kilometers long, 5 kilometers wide, and 100 meters deep. In addition, annual diesel fuel savings would come to 0.5 billion liters, equivalent to a reduction of nearly 1.3 million tons in \( \text{CO}_2 \) emissions each year.

Consortium scientists from several national organizations and advanced research institutes are also working with farmers to cut down on the burning of crop residues, which amount to as much as 10 tons of residue per hectare, producing some 13 tons of carbon dioxide. Eliminating burning on just 2 million hectares would reduce the huge flux of yearly \( \text{CO}_2 \) emissions by 17 million tons. Leaving stubble on the field, rather than burning it or plowing it under, also furnishes a habitat for beneficial insects that help control crop pests.

**Zero Till: A Lot to Like**

“How can one argue with a practice that does all that?” Hobbs asks. Meanwhile, agricultural engineers and local machine shops are scrambling to meet the rising demand for affordable, reliable, zero tillage seed drills. This essential tractor attachment opens a series of shallow ruts in standing rice stubble, drops in seed and fertilizer, and then covers the seed, all in one pass.

Consortium researcher R.K. Malik of Haryana Agricultural University works with farmers to test and spread zero tillage. He says farmers here first adopted zero tillage out of desperation, when a herbicide-resistant biotype of the weed *Phalaris minor* began ravaging fields. “If you had been here three or four years ago; it was such a sad story! Farmers were ready to give up their wheat crop because of *Phalaris*. I saw zero tillage at CIMMYT in Mexico in 1995 and was convinced its savings would allow farmers to buy the new herbicides needed. At first none of the other researchers believed in us, but now they have begun believing in a big way.” Malik sees the trust gained among researchers and farmers as opening doors to promoting other worthwhile practices.

“Agricultural research requires innovation. You have to be continuously changing, trying new things based on what farmers need. The approach should be like that of the private sector—you have to understand your product and know how and when to launch it. Doing this requires work in farmers’ fields and use of their feedback.”
**Raised Beds Elevate Efficiency**

Another option that Malik and his associates are testing with farmers is that of planting crops on raised soil beds, a practice pioneered by Mexican seed producers and wheat farmers. In this technique, two or three rows of seed are sown into long, flat soil beds about 10 cm high and 70 cm wide. A narrow furrow between each bed carries irrigation water and allows tractor entry for operations such as weeding. The system saves even more water (30%) than zero tillage and multiplies fertilizer use efficiency, among other virtues.

CIMMYT wheat agronomist Ken Sayre brought bed planting to suitable parts of South Asia through the RWC. It is gaining popularity in Pakistan (see “Pakistan Puts Aside the Plow,” p. 19). Sayre is helping agricultural engineers and machine shops to develop appropriate implements for bed planting and zero tillage.

“In rice-wheat areas, raised beds work best in partially reclaimed alkali soils and other low-lying areas where waterlogging or weeds are problems or, conversely, where there is a need to increase water-use efficiency dramatically,” Sayre explains. His dream is to develop a system whereby rice can be grown on beds, allowing the use of zero tillage on raised, permanent crop beds. According to Gupta, as of July 2000, several farmers in Karnal and Uttar Pradesh are already taking the lead in growing rice on beds. Researchers in India and Pakistan have kept each other informed of progress and potential research ideas through a recent RWC-sponsored traveling seminar.

**A Platform for Environmentally Appropriate Agriculture**

“We keep repeating ‘reduce tillage, reduce tillage!’ “ Hobbs says. “Some people say we talk too much about it, but it’s the platform for many other improvements.” As time goes on, farmers in increasing numbers are deciding they agree.
Pakistan Puts Aside the Plow

Speaking on why zero tillage was not adopted sooner for wheat in Pakistan, despite successful experiments in the mid-1980s, Mushtaq Ahmad Gill, director general of On-Farm Water Management, Punjab Province, Pakistan, combines boardroom terminology with a crusader’s zeal. “Zero tillage was not promoted properly to the real clientele: the average Pakistani wheat farmer,” he says. “We decided that, instead of only working for the farmers—that is, doing the trials—now we would work with farmers.” This meant that farmers not only did the trials themselves, but paid for them and for the use of equipment.

Forty Percent Water Savings

Through this approach and because benefits are good, in a few short years zero tillage has spread to nearly 5,000 hectares in Pakistan. One of its chief selling points is a 25–40% water savings. “Freshwater resources are depleting, and many farmers are forced to irrigate with saline water now,” Gill says. Part of the package Gill and his team promote involves laser leveling of farmland and proper layout of fields and irrigation channels, practices that further enhance water-use efficiency. Finally, the group has promoted farmers’ access to equipment and encouraged actual purchases. “Our method is to work one season in a village, providing the equipment, and then tell them, ‘Okay, if you like the seed drill, go buy it,’ and give them the address of a supplier. Then we move on to other villages,” Gill explains.

According to agronomist and Gill associate, Hafiz Mujeeb-Ur-Rehman, from 1998 to 2000 drill purchases shot up from only 13 to 113. Gill says the price—around US$ 600—has held steady or actually dropped, because new suppliers are entering the market.

With Tillage, Less Is More

Getting to this point has been a battle for Gill. Skepticism among researchers and extension workers still runs high, their main worry being the stem borer, an insect pest that overwinters in the rice stubble. According to studies, though, other organisms in the stubble serve as a natural check on borer numbers. Even farmers, who had long used as many as ten tractor passes to sow wheat, were initially reluctant to commit precious resources to a seemingly outlandish practice.
“There is a saying in Pakistan: ‘The more you till, the more you get,’ ” Gill says. “Farmers worried that wheat would not sprout in rice stubble, that there would be weeds and borers, even that the stubble itself would sprout again. When we proposed to plant a small demonstration on one farmer’s field, he agreed, but when we began to work, the relatives came by and demanded that we stop. Eventually, though, we managed to get one acre in, and as soon as farmers saw how it germinated, they were after us to plant any remaining land they had.”

**Getting INTO BEDS IN A HURRY**

Convinced of the utility of raised beds for wheat during a visit to Ludhiana, India, in 1998, Gill decided to go straight to his now-friendly clients—the farmers. “We asked for help from Peter Hobbs of CIMMYT, who got a bed planter airlifted through the RWC to our manufacturers. We tried the practice at 5 or 6 sites during 1998–99, and it worked! So, the following season we arranged trials on 63 sites in 8 districts of Punjab Province. Village data from these plantings show a 30% water savings, a 17% yield gain, a similar increase in fertilizer-use efficiency, and savings in herbicides of four dollars per hectare. When farmers saw the results, they got motivated.”

**Farmers as ENTREPRENEURIAL RESOURCE Managers**

According to Gill, resource management is the key to future food security in Pakistan. “There are 3.5 million new Pakistanis per year—12,000 daily—demanding food, a place to live, water, a better environment. All this in a country like ours means we have to increase our resource productivity: produce more food with less land, less water, less energy, less fertilizer. This is our vision.”

He emphasizes that improved tillage techniques will not work well in isolation—fields must be properly surveyed, designed, and leveled. Also, equipment should be simple, locally manufactured, and within farmers’ means. “Future research and development here will rest largely with private enterprise, farmer organizations, and entrepreneurs, instead of governments. We hope that our client farmers will also work as salepersons of these technologies.”

Finally, Gill says that resource conserving tillage practices would not have spread in Pakistan without support from the RWC and CIMMYT. “The Consortium has been a prime mover. They have arranged traveling seminars, the supply of equipment, visits of farmers and technicians, communication materials. Peter Hobbs motivated us to take things off the shelf, and Ken Sayre has helped refine bed planting equipment and practices.” Gill also cites Ashraf Chaudhary of Massey University, New Zealand, and the New Zealand Overseas Development Agency, as providing crucial, continual support.

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Breaking New Ground in Breeding Wheat for Disease Resistance

Take a technological breakthrough, add a fortuitous break, and you may get the ingredients for another breakthrough. Can a gene that makes rice immune to rust, the worst disease of wheat, point the way to new strategies for wheat to fight disease?

Last year, Alessandro Pellegrineschi, a cell biologist with CIMMYT, considerably raised the transformation rate of wheat—the percentage of wheat plant clones that successfully incorporate a new gene and associated traits through genetic engineering.*

Transformation rates are critical to the successful use of genetic engineering for plant improvement. Low rates greatly reduce the likelihood of producing a viable plant with a selected gene and trait. High rates produce more viable plants and give researchers and breeders more materials with which to experiment.

A Breakthrough in Efficiency

By mid-1999, Pellegrineschi had taken wheat transformation efficiency rates from an average of 0.2% to 0.9–1.0%, a five-fold increase. He did this by making incremental improvements in the transformation protocol, such as using “cleaner” DNA, optimizing selection standards for embryos, and identifying key environmental conditions for the mother plants of the embryos used in the transformation process.

Although encouraged by his results, Pellegrineschi was far from satisfied. His goal was a 5% transformation rate. “Shooting” 1,200 wheat embryos with a 5% transformation rate every week would produce 60 transformations, enough to test one gene construct and produce at least one viable plant capable of transferring the trait to its progeny. Over the course of a year, this would allow scientists to insert more than 50 different genes into plants—providing a lot of new material for breeders.

Twelve months after setting his target, Pellegrineschi and his team far exceeded their ambitious aim. Wheat transformation rates of 6–7% are now the norm at CIMMYT, and some elite lines exhibit average transformation rates between 10 and 15%. “The biosafety greenhouses are full,” says the researcher, “so we can now focus on other issues.”

A FORTUITOUS BREAK

Lee Jang-Yong had just attended a seminar in early 1999 at CIMMYT by the Deputy Director General of the Korean National Institute of Agricultural Science and Technology, an institute under the umbrella organization of Lee’s sponsor, the Rural Development Administration. Eun Moo-Young had given a presentation in which he touched upon a gene in rice—the receptor-like protein kinase gene—that might help explain rice’s immunity to rust diseases.

Interest in Eun’s aside about the gene was fairly low. CIMMYT develops wheat and maize, not rice. As in most advanced research institutes, in CIMMYT at that time genetic engineering for wheat was more promise than reality. The large size of the wheat genome and a lack of knowledge about the response of the plant in tissue culture severely constrained advances.

While the gene faded off the radar screens of some in the audience, it sparked an interest in Lee. He followed up on the matter with Eun, who agreed to provide the gene to CIMMYT for research. Lee knew of no successful transfer of a gene from rice to wheat before, and in fact he was not sure if anyone had even tried it. But because Lee was working in that special international mix of scientists and expertise which one finds at CIMMYT, he knew of Pellegrineschi’s accomplishments in boosting wheat transformation rates and decided to approach him.

As Pellegrineschi recalls, “Lee told me he had this interesting rice gene and he thought it could be important for developing rust resistance in wheat. I hadn’t heard of the gene before. Lee created a gene construct here at CIMMYT and we quickly kicked off some transformation work.”

The initial results were striking. Plants were infected with one of the more virulent races of rust found in Mexico. The transformed plants showed “only spots of necrosis, reflecting only a modest infection,” compared with highly lethal infections on the control plants. Pellegrineschi and Lee were ebullient over their results but also recognized their own limitations in this area. They were not comfortable with their disease inoculation skills, and neither researcher considered himself a pathologist by any means. It was time to call in another expert.

CIMMYT’s GENETIC ENGINEERING STRATEGY

In developing the tenets of its genetic engineering strategy for wheat and maize, CIMMYT has emphasized the needs of its partners at the national level and the usefulness and safety of its products at the farmer level. The points stated below guide the efforts of the Center’s genetic engineering program.

♦ Plant varieties that are genetically engineered by CIMMYT are developed in concert with a national program partner to meet a delineated need.

♦ CIMMYT provides only transformed plants that carry “clean” events, meaning that only the gene of interest is inserted into the final product.

♦ No transformed plants that carry selectable markers, such as herbicide or antibiotic resistance, are provided to national programs.

♦ CIMMYT’s focus on possible genes for transfer is on plant and bacterial genes.

♦ CIMMYT works only in countries that have biosafety legislation or regulations.

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A **Breakthrough** for **Wheat Disease Resistance**?

“I was very excited to see the results,” says CIMMYT wheat pathologist Ravi Singh, “because it’s the first time I’ve seen before my eyes that transformation can provide this kind of resistance.”

Singh, who has studied rust for 20 years, is quick to point out that while the gene comes from rice, which exhibits immunity to rust, he thinks it unlikely that it will confer the same level of resistance to wheat. He explains that there are two types of rust resistance: hypersensitive or race-specific resistance, which is based on a “major gene,” and non-race-specific or “slow rusting” resistance, which relies on the accumulated effects of numerous minor genes.

In race-specific resistance, a gene elicits a response to a specific race(s) of rust and fights it by killing the tissue in the immediate area of the infection, thus denying the pathogen a source of food (rust feeds only on live tissue). While this sort of resistance sounds ideal, it holds up only for three to five years. Slow rusting resistance, on the other hand, allows the rust pathogen to continue feeding on live cells but fights it within the cells, meaning that infection is reduced to a level that does not seriously damage the plant or reduce yields. This type of resistance is not subject to breaking down, although crop losses can be significant when a rust epidemic is severe.

Singh, who is now conducting more elaborate tests with the transgenic plants, says that they exhibit resistance responses closely resembling race-specific responses, so he doubts that this single gene represents a magic bullet (with truly novel characteristics) against the disease. Nevertheless, more experimentation is needed to confirm this supposition, and even if the gene turns out to be race-specific, it could still be a valuable asset when stacked or pyramided with other major or slow-rusting genes within a wheat line.

The real breakthrough with great potential impact, according to Singh, lies in the process itself. “A lot of effort in conventional breeding goes into looking for and transferring alleles and genes. The exciting aspect of this [wheat transformation process] is the fact that if we can identify something in rice that can be expressed in wheat, we can now investigate moving other genes with known functions into wheat. Traits such as heat tolerance, or resistance to fusarium head scab in durum wheat, would be invaluable.”

Experiments and research strategies are already in place to determine if the rice gene can help produce resistance to a wide diversity of rust races as well as a host of other wheat diseases, including fusarium, yellow rust, helminthosporium, and septoria. “We are producing adequate supplies of seed and plan to test more widely,” says Singh. “It looks like this will be quite an exciting year.”

**Researchers at the Right Place, Right Time**

Lee and Pellegrineschi share that sentiment and are quick to attribute the advance to the international research environment of CIMMYT. Lee notes that little work on wheat is carried out in Korea, and none of it employs transformation. “Even with this gene in hand,” he observes, “it is pretty unlikely that anyone would have thought of using it with wheat.”

“It was the right place and the right time,” Pellegrineschi says with a grin. “Our two projects crossed inside CIMMYT, and that’s why we’ve been able to have this rapid progress. Working back in our labs at home—in two different institutions in two distant parts of the world—it would have taken a long time to achieve this, and actually, it might never have happened. Now we have immediate collaboration and something to show for it. This doesn’t happen just anywhere.”

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Without Protection from Insects, No Field of Dreams for Kenyan Maize Producers

As a young boy, Stephen Mugo worked in his father’s small maize plot on the southern slopes of Mt. Kenya. With care, that land fed the family and its dreams, paying the school fees and allowing Mugo’s parents to build up a village shop. Even so, farming had its risks, particularly the havoc that insects could wreak on the maize field and the family’s daily life.

“The stem borers would hit the crop around knee-high stage, inflicting damage that, if not checked, would mean very little yield,” Mugo recalls. “At harvest, during seasons of heavy infestation, we had to stoop to recover plants that had lodged on the ground, and the maize would often be rotten.”

“When my parents could afford it, they would purchase DDT powder in bright yellow packets, and we would spend hours applying the dust into the funnel of every single maize plant. We were unaware of the dangers we faced and did not use any protective measures. And as we all know, DDT has long since been banned.”
Still Working Against Insects, But on a Larger Field

Thirty years later, Mugo still seeks to banish destructive insects, but his dream to raise maize production is now played out on fields across Kenya. As CIMMYT maize breeder and coordinator for the Insect Resistant Maize in Africa Project (IRMA), a collaborative effort between the Kenya Agricultural Research Institute (KARI) and CIMMYT, Mugo works to produce maize that can resist these insects on its own.

A Project with a Purpose

A variety of insect pests eat through Kenya’s maize crop, but stem borers are among the most pernicious. Once inside a maize stalk, borers are impervious to conventional insecticide applications and cannot be removed by hand. Damage estimates vary from year to year, ranging from 15 to 40% of the national maize crop. Some smallholders lose entire fields to the pests. Several insecticides widely used against borers were pulled off the market due to safety concerns. How can farmers possibly cope?

Scientists from KARI and CIMMYT designed the IRMA Project to address the problem. Over five years, they will use conventional and biotechnological means to develop insect-resistant maize for major Kenyan production systems and insect pests. They will also:

- establish procedures to provide insect-resistant maize to resource-poor farmers;
- assess the impact of insect-resistant maize in Kenyan agricultural systems;
- transfer skills and technologies to KARI and Kenya to develop, evaluate, disseminate, and monitor insect-resistant maize; and
- plan, monitor, and document project processes and achievements for dissemination to other developing countries, particularly in East Africa.
MULTIDISCIPLINARY Partnerships FIND THE RIGHT APPROACH

The IRMA Project calls on CIMMYT and KARI expertise in maize breeding, agricultural economics, biotechnology, entomology, and communications. To develop solutions that are right for Kenya, researchers are gathering baseline data and soliciting input from farmers and other key stakeholders. In 2000 they initiated participatory rural appraisals (PRAs), yield loss assessments, an analysis of the maize market in Kenya, and environmental impact assessments (particularly in regard to non-target insects, potential stem borer parasitoids and predators, and soil ecology).

In the rural appraisals, CIMMYT economist Hugo de Groote and KARI economists collect information on what farmers like in a maize variety and what they think about insect pest problems. These baseline data will help researchers assess IRMA’s economic impact. The PRAs also provide information on agronomic and consumer characteristics that will help breeders produce varieties tailored to Kenya’s agricultural zones. To economize on time and effort, crop yield loss assessments are conducted in a representative subset of the PRA locations.

Entomologist Josephine Songa of KARI, meanwhile, is investigating a very different population—the insects and soil organisms residing in the fields of Mtwapwa and Kakamega, two of the five maize-growing regions where crop loss assessments will be made. Songa, working with KARI scientists and extension staff, set a variety of traps to capture the flying and crawling insects typically found in farmers’ fields. Research and extension staff regularly collect the catch in these traps, thus obtaining the baseline data for assessing impact on insect populations at a later date. Soil cores will be drilled at the respective sites at four stages of maize growth, and the range and density of organisms in the samples will be analyzed, again serving as a baseline for later assessments.

An exploratory experiment to determine the effectiveness of *Bacillus thuringiensis* (Bt) genes against Kenyan stem borers became the proving ground for project researchers to navigate through, and comply with, important regulatory procedures. The project applied to import fresh leaf tissue from transformed Bt maize plants. The importation of such materials is rigorously reviewed. Following approval by the KARI Institutional Biosafety Committee, the application was forwarded to the Kenya National Biosafety Committee (NBC). It is anticipated that the NBC will authorize the Kenya Plant Health Inspectorate Service to issue the import permit later in 2000. Importing only leaf tissue, not live plants or maize cobs, means that there is no possibility of inadvertently releasing transformed seed.

In the exploratory experiment, local stem borers will be offered a “free lunch” of the leaves under tightly controlled conditions to determine the effectiveness of various Bt gene constructs against the pests. CIMMYT entomologist David Bergvinson is overseeing the bioassay work, which will help guide the development of resistance genes in the CIMMYT biotech lab in Mexico.
MEETING KENYA’S Needs

At the heart of the project is the development of integrated pest management strategies and superior host plant resistance. Conventional and novel sources of resistance are being sought, including resistance based on Bt genes.

Bt, a naturally occurring soil bacterium, produces proteins that are lethal to many borers. There are no known negative effects on human or animal health, and organic farmers in many parts of the world use Bt in spray form. Because its main action is specific to the larvae of moth species that feed on maize, its impact on non-target insects is thought to be considerably less than the effects of wide-spectrum chemical insecticides.

Cell biologist Natasha Bohorova and her CIMMYT team have inserted synthetic versions of several Bt genes into tropical maize. Cry1B and cry1Ac genes were transformed into a tropical maize background. This maize resists southwestern corn borer (SWCB), sugarcane borer (SCB), and fall armyworm (FAW). A synthetic cry1E gene and a translational fusion cry1B-1Ab gene were also introduced into tropical maize and have shown resistance to FAW, SWCB, and SCB.

Because insect populations evolve to withstand conventional and transgenic pesticides, measures must be taken to extend maize plant resistance. The IRMA approach is to “stack” or “pyramid” a number of Bt genes together with conventional resistance mechanisms to make it much harder for stem borers to evolve an effective response. In addition, management strategies such as refugia are being studied to help thwart the emergence of Bt resistance.

Researchers will identify and develop gene constructs that contain no herbicide or antibiotic markers. Maize varieties produced by the IRMA Project will carry only “clean” or “purified” Bt genes, circumventing concerns about unforeseen impacts on the environment or human health. While this approach costs more and takes longer, IRMA researchers are committed to addressing all reasonable issues that emerge regarding this technology.

Meanwhile, Mugo and his KARI counterparts are busy identifying the maize that will carry the novel resistance genes. They are looking at numerous elite open-pollinated varieties, inbred lines, and hybrids from CIMMYT, KARI, the Africa Maize Stress Project, and the private sector. They seek plants with traits such as drought escape/tolerance; tolerance of low nitrogen; resistance to Striga, turcicum leaf blight, and gray leaf spot; high yields; and a basic level of stem borer resistance.

FULL STEAM Ahead

“KARI and CIMMYT are taking this on full steam and are totally committed,” says David Hoisington, director of the CIMMYT Applied Biotechnology Center and the IRMA Project. Looking forward to next year, Hoisington affirms that CIMMYT plans to finish inserting all the individual genes of interest into a general maize background. The timeline also calls for completing a biosafety greenhouse in 2001, which will allow IRMA breeders to begin moving the resistance genes into Kenyan maize.

“The first time through these steps is always tough,” Hoisington concedes. “But hurdle by hurdle, we’re moving towards testing the project’s first varieties and—ultimately—towards seeing Kenyan maize farmers produce more for everyone.”

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Since 1990, a joint project between CIMMYT and the French Institut de Recherche pour le Développement (IRD), formerly ORSTOM, has focused on understanding the mysteries of apomixis, the asexual reproduction of plants through seed, and how the trait might be transferred to maize. The scope and complexity of the challenge cannot be overstated.

In a move aimed at accelerating progress in this potentially revolutionary area, CIMMYT and IRD formally entered into an important research collaboration with three seed companies (Pioneer Hi-Bred International, Groupe Limagrain, and Novartis Seeds) during the latter part of 1999.

The five-year agreement is aimed at further understanding apomixis, which is the natural ability of some plants to reproduce offspring identical to the mother plant through asexual reproduction. In the plant kingdom, more than 400 species, most with little or no agronomic potential, possess this apomictic characteristic. Greater knowledge about this natural plant mechanism could provide the basis for its transfer to some of the most commonly grown agricultural crops, for instance, hybrid maize.

For the agreement’s seed-producing partners, enhanced knowledge of apomixis might create new options for improved multiplication and quality of seeds. For CIMMYT and IRD, the transfer of apomixis to maize offers the long-term possibility of delivering superior hybrid crop traits—such as disease resistance and higher yields—to the resource-poor farmers of the world through the inherent reproductive characteristics of apomictic plants.

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To choose wisely among the many tools of the breeding trade, CIMMYT researchers need to answer that question. A judicious choice could lower the cost and speed the pace of plant breeding, bringing millions of dollars in additional benefits to farmers and consumers.

Plant breeding at CIMMYT is well positioned to benefit from the wave of innovation brought by biotechnology, including marker-assisted selection (MAS) of breeding materials. As biotechnology comes into its own at CIMMYT, the time has come to take a fresh look at the costs of conventional and molecular-based breeding schemes, their relative advantages and disadvantages, and optimal strategies for achieving different breeding objectives. This is a formidable task, but it is integral to conducting research efficiently.
SELECTING A REAL CASE FOR Analysis

Kate Dreher, a research associate, and Michael Morris, an economist—both with the CIMMYT Economics Program—organized a study that examined the costs of various breeding schemes designed to transfer a single gene/single trait into maize. The study relied on the expertise of Applied Biotechnology Center (ABC) staff Mireille Khairallah and Jean-Marcel Ribaut, and Maize Program staff Shivaji Pandey and Ganesan Srinivasan.

In setting up the study, Dreher and Morris met with Maize Program and ABC researchers to identify examples of breeding projects that incorporated disparate parameters, such as the transfer of a single gene versus multiple genes, or the detection of important traits earlier rather than later in the breeding process.

Dreher, Morris, and the other researchers were interested in breeding projects already underway at CIMMYT because they wished to obtain actual, rather than simulated, cost data. For two reasons, the group decided to focus on projects related to quality protein maize (QPM).* First, CIMMYT was already using molecular markers to introduce the quality protein trait into experimental maize lines. Second, the conversion of “normal” maize lines into QPM lines involved selecting for only a single trait, the quality protein trait, which made QPM a relatively straightforward example for an initial cost study.

The case study concentrated on:

• generating detailed information about the costs of conducting conventional breeding operations and of implementing MAS procedures at CIMMYT’s facilities in Mexico;
• determining the cost-effectiveness of using MAS for particular breeding applications, specifically QPM; and
• providing insights into the potential cost-effectiveness of future applications of MAS.

The analysis proceeded in three stages. First, field and laboratory operations involved in conventional and MAS breeding were identified and costed out. Dreher observed and questioned researchers and lab technicians as they went through each stage of their work, from start to finish, to gather specific information on the costs involved.

Second, CIMMYT maize breeders and molecular geneticists were asked to design representative breeding schemes for QPM line conversion, and four hypothetical, stylized breeding schemes were selected. Two of the schemes relied solely on conventional breeding methods and phenotypic evaluation, and two incorporated MAS.

Third, the laboratory and field parameters put forth in each breeding scheme were used to calculate the total cost of implementing that particular scheme.

* Quality protein maize, which was developed through conventional breeding processes, has the nutritional advantage of containing twice the amount of two essential amino acids, tryptophan and lysine, as normal maize. See p. 6.
THE DEVIL IS IN THE DETAILS

Although they are still analyzing the results of the study, Dreher and Morris have come to several preliminary conclusions, the most salient being that the relative cost-effectiveness of various conventional and MAS schemes depends on the detailed circumstances of each particular application. Decisions about whether to incorporate MAS into a breeding scheme are likely to require a case-by-case analysis.

When phenotypic screening is simple (in other words, when it is relatively easy to determine whether a given plant variety possesses a given trait, such as a certain grain color), conventional breeding is, and will continue to be, extremely cost-effective. Conversely, when phenotypic screening is expensive, technically difficult, or even impossible, MAS will often be advantageous, according to Dreher.

“Nematode resistance or tolerance is a case in point,” she says. “Most cereal nematodes are insidious, below-ground pathogens that are difficult to diagnose and quantify. Determining a variety’s resistance through conventional selection techniques requires sampling, extracting, and counting the nematodes, extrapolating the results, and diagnosing the effects on the variety—a process that is costly, labor intensive, and only moderately reliable. In this case, if we have molecular markers that are linked to the gene (or genes) that confer resistance or tolerance, MAS offers an alternative that is simple, direct, and very reliable.

“Or take the case of maize streak virus,” Dreher continues. “CIMMYT can’t screen for it here in Mexico, because strict quarantine regulations rightly prohibit the introduction of the disease into the country. Molecular markers are the only choice for conducting such work at headquarters.”

TIME IS STILL MONEY

Aside from cost, another important factor affecting efficiency—time—is addressed in the study. Marker-assisted selection often allows breeders to cut down on the number of seasons needed to produce a desired product. For farmers and seed companies, the benefits of developing and releasing a new variety more rapidly can be significant, as indicated in a study by the International Rice Research Institute (IRRI) and Chum Phae Rice Experiment Station, Thailand.* The study concluded that additional benefits of more than US$ 18 million were realized over the life of a particular rice variety because the variety was released two years earlier than usual.

“Even if we assume a high-end MAS scheme that might run a few thousand dollars more than a conventional scheme,” Morris notes, “the extra cost pales in comparison to the additional benefit to our clients when a variety becomes available sooner to farmers.”

Although data analysis is continuing, the study has already produced concrete results. “Kate Dreher spent a huge amount of time around the labs and in the field costing out day-to-day procedures that usually don’t get reviewed at that level of detail,” says Morris. “For station and lab management, these data are very useful. In addition they provide the kind of solid information needed by our national program partners to put together biotech project proposals based on real figures.”

Finally, Morris adds, the analytical tools (linked spreadsheets) developed by Dreher will allow researchers and managers to conduct additional detailed case studies aimed at increasing the efficiency of breeding schemes for CIMMYT and national program scientists alike.

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These hardy grasses are not only wheat’s relatives; they are its ancestors. Spontaneous crossing among different species gave rise to primitive wheats that human beings started planting and selecting thousands of years ago. As wheat became domesticated, it acquired the ability to yield more and bigger grain, but it lost a good part of its ancestors’ hard-won genetic protection.

Realizing the wealth of useful traits in wheat’s wild relatives, Abdul Mujeeb-Kazi, head of the Wheat Wide Crosses Unit, used an elegant and effective strategy to transfer those traits into improved bread wheat, the most commonly used wheat. This painstaking research, which Mujeeb-Kazi has conducted for more than 15 years, involves crossing durum wheat with a wild relative to replicate the original cross that gave rise to bread wheat in nature about 10,000 years ago. The CIMMYT program has been far more successful than other programs in applying this technique, and the “synthetic” wheats it produces have inherited the genetic protection that served their undomesticated parents so well.


**Drawing Diversity into Modern Varieties**

The process does not stop there. Mujeeb-Kazi’s synthetic wheats are crossed with high yielding, improved wheats to produce descendants that yield well and possess combinations of traits to withstand tough conditions in varied growing environments.

“In places where there’s a good bit of rainfall, for example, wheats face diseases such as rust, septoria, leaf and spot blotch, fusarium scab, and powdery mildew,” says Mujeeb-Kazi. “The wheats we’ve developed show genetic resistance to six or seven diseases at the same time, plus tolerance to such problems as salinity, waterlogging, and drought. This gives them a huge advantage in most environments where wheat is grown.”

These materials also have a much broader, and different, genetic diversity than their “normal” counterparts. In farmers’ fields this translates into more stable yields. As genetic diversity—and its many advantages—become increasingly important in modern cropping systems, the value of Mujeeb-Kazi’s work is increasingly evident.

CIMMYT’s Wellhausen-Anderson Plant Genetic Resources Center houses about 500 species of wheat’s wild relatives that were gathered in many different places, from several Middle Eastern countries to Turkey to China. When choosing wild relatives to use in his crosses, Mujeeb-Kazi is careful to select species that originated in different places so that their genetic heritage will vary. To confirm genetic differences, parents and progenies are undergoing DNA fingerprinting at CIMMYT’s Applied Biotechnology Center. Fingerprinting will also reveal whether the resistance and other traits the descendants carry were indeed inherited from their “wild” parent.

**Sharing the Inherited Wealth**

“We’ve developed 95 elite synthetic wheats that are available to any researcher, especially in the developing world,” says Mujeeb. “We’ve placed a list on the websites of Kansas State University and CIMMYT that includes very detailed descriptors of each line.”

These synthetics have multiple disease resistance and thus fit the needs of national agricultural research systems in the developing world, which are incorporating them into their breeding programs. These materials are being used extensively by countries such as India, Pakistan, China, and Turkey, plus the Southern Cone countries of South America. From these materials the programs will develop varieties that will withstand diseases and other stresses to produce good yields for farmers, year in and year out.

* (See http://www.KSU.edu/wgre/germplasm/synthetics.html).

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SCIENCE FOR equity
Asia’s maize economy is poised to change greatly, and very soon. “Some time in the next two decades, demand for maize in developing countries will surpass demand for wheat and rice,” says Mark Rosegrant of the International Food Policy Research Institute (IFPRI). “The effects of this growing demand will be seen most clearly in Asia, which will account for 60% of the global increase in maize consumption.” Rosegrant estimates that demand for maize, which was 138 million tons in 1993, will reach 243 million tons by 2020. China alone could witness a 94% increase in maize demand over this period. Much of this increased demand comes from Asia’s burgeoning livestock industry, and it cannot be met by maize imports alone.

“Imports will increase, but so will domestic production,” says Prabhu Pingali, director of CIMMYT’s Economics Program. “It is unlikely that most countries will make an ‘either/or’ choice on this matter.”

Across Asia, the expansion in maize production that has occurred during the last decade was concentrated in the marginal uplands. In all probability, that is where maize production will expand in the future. Even relatively isolated communities in marginal areas—the hilly or less productive regions, where rainfall supplies the only water for crop production and agricultural research has been limited—are likely to feel the effects of the growing demand for maize.

“The question that concerns us is whether this trend will bring more turbulence or affluence into the lives of poor people in upland areas,” says Ganesh Thapa, regional economist for Asia with the International Fund for Agricultural Development (IFAD). “Demand for maize in Asia has serious implications in marginal upland environments. It can influence the sustainability of agriculture and affect food security in the poorest households.”

Known for its support of innovative projects such as the Grameen Bank loan program for poor women, IFAD has just started funding a three-year project to understand the question posed by Thapa. The project, which focuses specifically on the implications of intensified maize production in Asia, is coordinated by CIMMYT and involves a network of researchers from China, India, Indonesia, Nepal, the Philippines, Thailand, Vietnam, IFPRI, and Stanford University.

This network is already in place and has proven to be very productive," says Pingali. "Most of us have worked together for several years on socioeconomic issues related to maize in Asia." The group has just finished a comprehensive assessment of the impacts of maize research in Asia.* At their third annual meeting in Ho Chi Minh City, Vietnam, they devised a workplan for the new project. (The workshop also gave network members the opportunity to observe maize production in Vietnam firsthand and learn how it has changed in the past decade; see p. 60.)

Resource persons at the workshop included economists and maize researchers from CIMMYT’s regional programs and headquarters, as well as economists from IFAD and India’s Institute of Economic Growth.

Planning for Productivity

By planning carefully and devising appropriate policies, governments can ease the adjustment to the new maize supply and demand situation. To plan well, decision makers in the research and policy arenas need accurate information on maize farming systems in upland areas, and they need practical recommendations for intensifying maize production without depleting natural resources.

"Over the next three years, those of us in the project will conduct several related studies. These studies will be the basis of concise recommendations for policymakers and research managers," says Kamal Paudyal, an agricultural economist from Nepal.

Knowledge of Local Maize Systems

Work will begin with participatory rural appraisals (PRAs) in marginal upland areas and mountainous regions, such as northeastern India, the mid-hills of Nepal, and Mindanao in the Philippines. Network members will identify a standard procedure for all PRAs to gather detailed information on the local constraints to growth in maize productivity.

"The PRAs will also provide other kinds of data," observes project member Benchaphun Shinawatra-Ekasingh of Chiang Mai University’s Multiple
Cropping Center. “That includes data for assessing the environmental risks that accompany the intensification of maize cropping systems and data to understand the potential equity effects of intensification.” The equity assessment will pay close attention to differences in women’s and men’s access to resources and information.

**National and Global Influences on Maize Systems**

Policy analysis is the second major activity in the project. “To learn how policy might affect the intensification of maize systems in upland areas, we need to review many kinds of policies, extending from crop- and region-specific policies all the way to national and global macroeconomic and trade policies,” explains Walter Falcon, a project participant who co-directs Stanford University’s Center for Environmental Science and Policy and chairs CIMMYT’s Board of Trustees.

During the project’s second year, the economists will analyze the objectives of these policies, how they work, and what they cost “in economic terms as well as in terms of budgetary implications for governments,” explains Ashok Gulati of the Institute of Economic Growth.

Roberta Gerpacio, a CIMMYT economist who coordinates the Asia maize socioeconomic network, says that the outcome of this work will be “three or four crucial policy recommendations that target the maize sector of the countries in the study, particularly the upland environments.” The recommendations will be made to senior national policymakers.

In preparation for these activities, project participants will undergo training in policy analysis as well as PRA techniques.

**The Road to Results**

The project’s final component is to outline maize research and development plans that can foster the sustainable intensification of maize production in the upland areas of each country.

Senior researchers, national research directors, IFAD project staff, and others will evaluate national maize research priorities in light of the new information gathered through the project. Maize researchers will validate the constraints identified through the participatory appraisals. Once participants have determined which constraints can be solved through research, they will develop a list of research and development priorities. As Michael Morris, CIMMYT economist and resource person at the planning session, explains, “They’ll do this by considering several factors, including the potential impact of eliminating a particular constraint, the probability of finding a solution to the constraint, and the likelihood that farmers will adopt the solution.”

The product will be a plan for maize research and development that is clearly articulated, meets the priority needs of the populations involved, and has support from the scientific and policy community that will implement it.

**Rural Poverty or Rural Empowerment?**

In most countries, upland cropping systems have received relatively little attention from research and development, which concentrated first on the lowland irrigated zones that yielded most of the surplus food. As the capacity of these high-potential zones is exhausted, however, and as diets diversify out of cereals and the livestock industry grows, the rainfed uplands will play a critical role in securing food and income for Asia’s growing population.

“Uplands should become a priority for many Asian countries,” says Pingali. “And if that’s the case, we assume that it is better to be prepared. Either you create options to strengthen rural people’s welfare and protect the environment, or you create a situation in which agriculture becomes untenable for these people, and they become increasingly marginal members of society.”

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Waiting for a Better Wheat Variety in Uzbekistan

Farmer Nasiba Ikramova lives and works in Baitkurgan Kibray District of the Tashkent Region of Uzbekistan, one of eight countries in Central Asia and the Caucasus. Each year, Ikramova sows 1.8 hectares with seed of a winter wheat variety provided by the government. The wheat is sown in autumn, germinates, and then lies dormant during winter. Come spring, the wheat grows quickly to reach maturity in mid-July.

Ikramova grows wheat with help from the government, which provides seed and brings machinery to the district for sowing and harvesting the crop. In return, Ikramova and her fellow farmers are expected to hand over to the government 4.1 tons per hectare of wheat grain. They may keep and sell any grain that remains. In bad years like this one, little is left for the farmers.

Ikramova, who has three school-aged children, grows plums and apricots in her orchard. The fruit harvest is good this year, which she hopes will make up for the poor wheat crop.

CIMMYT Wheats Shorten Breeding Time, Resist Disease and Drought

The main problem for wheat producers in Baitkurgan Kibray this year is that they have had little rain. Farmers irrigate other crops, but not wheat, so the variety they grow must be able to withstand the lack of water. The government provides a different variety practically every year in an attempt to find one that tolerates drought better and resists diseases during the good years, when there is enough moisture for diseases to develop. The chosen variety also has to grow and mature quickly, since farmers plant another crop after they harvest their wheat. Summer in Uzbekistan is short, and farmers must harvest all crops before 20 September, when the first frost usually hits.
At the Uzbek Research Institute of Plant Industry, Bitore Dzumahanov (see photo), a breeder who heads the Department of Plant Industry, is working hard to develop the wheat variety farmers like Ikramova need to produce more and better wheat. The Institute started cooperating with CIMMYT four years ago. Dzumahanov is currently testing a CIMMYT variety for conditions prevailing in Baitkurgan Kibray, and hopes to have it ready to be released to farmers soon.

The CIMMYT variety needs less water and has good genetic resistance to diseases like yellow rust, which are a problem in the good years, when there’s more rainfall. “What’s really exciting is that the new wheat matures a full 28 days before the varieties farmers plant now,” says Dzumahanov. For other regions such as the Fergana Valley, where soil salinity is a problem, he’s testing a salt-tolerant variety, Sama 8, which he got through Osman Abdalla, a CIMMYT wheat breeder posted at the International Center for Agricultural Research in the Dry Areas (ICARDA), in Syria.

Dzumahanov has received 800 winter wheat lines from the Turkey/CIMMYT/ICARDA International Winter Wheat Improvement Program. He planted them and selected about 300 for seed multiplication and plans to share the seed with researchers at other Uzbek research centers. By using CIMMYT materials, breeders have shortened the time it would take to introduce a new wheat variety from ten years to four.

**Science on Starvation Wages**

Back in the fields, a neighbor of Ikramova’s, Baktiyar Turaev, harvests apples with the help of hired women who work for just one bucketful of apples a day. Surprisingly, this doesn’t seem like too little to Dzumahanov, who comments: “If the women sell the apples, they’ll make more money than I do.” He earns barely US$ 10 a month.

How can he and his family survive on this wage? They don’t. Explains Dzumahanov, “My wife has a few dairy cows. In one week, by selling yogurt made from the cows’ milk, she earns as much money as I earn in one month.” Thanks to her efforts, Dzumahanov is able to remain a researcher out of love for his profession and in the hope that his work conditions will improve.

Dzumahanov’s situation is typical for agricultural researchers all over Central Asia. Funding for agricultural research has been reduced to a minimum, which means starvation wages for scientists, the vast majority of whom have master’s or doctoral degrees. This unfortunate circumstance has prompted many to leave the field. Though the exodus of a certain number of researchers was warranted, the trend has gone too far, leaving some research institutes bereft of their best scientists. Worse, it is keeping young people from entering research.

To shore up the research infrastructure and help reverse the “brain-drain,” several projects are currently underway. A CIMMYT project sponsored by the World Bank’s International Development Fund (IDF) in Kazakhstan focuses on developing national strategies to reform the agricultural research system and build up its capabilities. Another CIMMYT initiative financed by Germany’s Gesellschaft für Technische Zusammenarbeit (GTZ) aims to help Tajikistan’s national program, torn apart by civil war.

The forced flight of well-qualified researchers has contributed greatly to the decline of agricultural productivity. The CIMMYT initiatives and others like them should benefit not only scientists but the economies of the region as well.

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Agricultural production in Nepal is growing at about 5% annually, and the government has reformed the economy to foster development. Still, the sharp Himalayan peaks look down on an ethnically diverse populace of 25 million who hunger for better livelihoods. Roads, irrigation, markets, policies on land ownership and use—all require attention. In agriculture, one imperative is to get useful results into the field, where they can make a difference.

The Rice-Wheat Consortium for the Indo-Gangetic Plains (RWC) is helping in many ways, catalyzing and supporting research throughout South Asia (see p. 16). Resource conserving tillage practices promoted by the RWC in Nepal radically cut the cost, time, and drudgery of sowing wheat after rice, in effect lessening smallholders’ burden.

Rice-wheat is the common cropping pattern in the Tarai, a lowland area in the South that is Nepal’s breadbasket, and on terraced hillsides at lower altitudes in the mountainous band between the Tarai and the Himalayas. According to Ganesh Sah, head of the Agricultural Implements Research Center at Birganj, tilling less not only saves costs but significantly increases wheat yields in a rice-wheat system. “Because rice is grown on puddled soils, preparing to sow wheat can normally take two weeks or more, involve 7 to 12 plow passes, and even require additional irrigation,” Sah says. “By sowing wheat as soon as possible after the rice harvest in the fall, the crop matures before the hot winds of spring, which shrivel undeveloped grains.”

**Cast Your Seed Upon Fertile Soil**

The simplest reduced tillage technique is surface seeding. In this method, farmers simply toss wheat seed onto moist soil immediately before or after rice harvest. The practice is especially suited to poorly drained areas with heavy soils that impede normal tillage. Because it
cuts production costs by fully one-third and requires no implements, even the poorest farmers can practice surface seeding.

Sah says that the practice is being adapted on land once considered unsuited to cropping in the Tarai. “CIMMYT researcher Peter Hobbs saw these poorly drained, low-lying areas and suggested surface seeding as an option,” he explains. “It worked nicely; we got yields of 3.7 tons per hectare. Farmers saw this and began planting themselves.” Hobbs observes that farmers need to apply fertilizer later in the crop cycle to avoid soil nutrient losses, and researchers will need to monitor soil fertility in these areas, but farmers are pleased to have found a way to use land that could not be cropped before.

Sanjay Kumar Gami, senior soil scientist and site coordinator of the Regional Agricultural Research Station at Parwanipur, also helped farmers experiment with the practice on as many as 50 hectares in 1999. Once farmers see the evidence, transfer ensues via lively word-of-mouth repartee, according to Sah. “People in wedding parties from India—who often enter southern Nepal to celebrate—have seen surface-seeded plots and asked farmers how they did it,” he explains. “When the farmers from Nepal told them, they still didn’t believe it!”

Farmer Chotelal Prasad Sah of Benauli Village, Bara District, surface seeded 1.5 hectares near a river for the first time in 1999. He used poor quality seed with no fertilizer, just to see how the practice would work. “Crop establishment was excellent,” he says. “I’m expecting wheat yields of four or five tons per hectare, even after paying laborers their portion of the grain.” In a country where wheat yields average 1.6 tons per hectare, it is easy to understand Sah’s enthusiasm.

In Gargati Village, Hatibangai Township, farmer Rama Shankar Misra surface seeded wheat and mustard into a previously unused riverbed. “In wet soils like these, I wouldn’t be able to plow or plant normally. With direct seeding, I don’t have to work as hard,” Misra says. According to Scott Justice, research affiliate in the CIMMYT Natural Resources Group, use of surface seeding has even raised land prices in some areas. “There’s never been a wheat crop here before, and there’s nothing else anyone could do here, yet Mr. Misra’s going to get a good yield,” Justice says.

To discourage birds from feasting on unprotected seed, agronomist Ghana Shyam Giri, of the Regional Agricultural Research Station at Bhairahawa, came up with a unique “solution”—literally, a slurry of farmyard manure in which seed is soaked before it is placed it on the soil. Farmers have widely adopted the treatment, and birds have left the seed alone.
The story of surface seeding shows how the RWC differs from many research partnerships. It does not see itself as simply “giving” promising options to farmers; instead, it is a partnership in which farmers are welcome to experiment, assume ownership, and share observations. For example, farmers in Benauli talked at length with researchers about the importance of having the right soil moisture before surface seeding. They also observed that denser seeding helps control weeds, and many farmers were tossing wheat seed directly into the rice crop before harvest, giving weeds even less of a chance to sprout.

SMALL-SCALE Machinery FOR SMALLHOLDER FARMERS

The RWC works with farmers to test and adapt another particularly suitable option for smaller holdings: the two-wheel tractor. Widely used in China and Bangladesh, the tractor comes to Nepal with an array of implements, including pumps, threshers, reapers, winnowing fans, and trailers, that make farm work less burdensome and more productive. The tractor and implements cost a fraction of the price of a four-wheel tractor and consume about US$ 13 less diesel per hectare. The tractors also work better in muddy soils and on the relatively small plots typical of Nepal. Finally, the tractors and the till-and-sow attachment allow more timely sowing of wheat after rice. As already mentioned, this boosts yields, saves irrigation water and fuel, and heightens the efficiency with which plants use nutrients.

Because they are not built locally, tractors must be imported, a service that only one Nepalese company currently offers. The basic tractor package of US$ 1,300 is still beyond individual farmers’ means (average annual per capita income in Nepal is US$ 200). Like many of their peers all over the developing world, Karmahawa farmers are waiting anxiously for credit to become available. The banks already have a small farmer development program. “All this is waiting to take off—it just needs a little push,” Justice says. “With loans on favorable terms, farmers should have no trouble paying banks back.”

Justice hopes to popularize small-scale mechanization in Nepal. “Current tillage practices involve back-breaking work. Farmers are happy to find alternatives that reduce labor, yield more, and cost less,” he says. Part of his time is spent coordinating training and other support for tractor maintenance shops. “The first step is learning repairs, but eventually shops will manufacture simple implements.”

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In the late 1970s, CIMMYT and the Swiss Agency for Development and Cooperation (SDC) joined forces to promote the science-based cropping of maize in Central America and the Caribbean. Among other things, SDC support created a stable basis for collaborative research with CIMMYT and its predecessors in the region, which dated from the 1950s. Out of this a more formal regional network—the Programa Regional de Maíz, or PRM—grew and consolidated.

The PRM helped specialists from individual nations to share information and experience effectively across borders. Goals were set and progress monitored for the entire region. Each research program performed specific tasks, based on interest and comparative advantage, avoiding wasteful duplication of effort. Funding disbursements became timely, direct, and based on progress toward easily verifiable benchmarks.

THE REGIONAL MAIZE PROGRAM: DELIVERING VALUE TO FARMERS IN Central America

THE COUNTRIES OF CENTRAL AMERICA AND THE CARIBBEAN HAVE EXPLOITED THE ADVANTAGES OF SPECIALIZATION AND ECONOMIES OF SCALE TO BRING FARMERS LARGE BENEFITS. THEY HAVE DONE THIS BY PARTICIPATING IN RESEARCH NETWORKS—WHICH ARE NOW IN DANGER OF DISAPPEARING.
The network and the collaboration on which it built have brought forth a wealth of improved crop varieties and farming practices. It made agriculture more profitable, helped conserve natural resources and, through more abundant harvests, lowered the cost of food for the poor, benefiting farmers and consumers.

**DO COUNTRIES Gain or Lose by Collaborating?**

In a recent study* to measure the efficiency of cooperation among developing countries in a region, the CIMMYT Economics Program examined the case of the PRM in Central America and the Caribbean. The study addressed two questions. First, are there incentives for governments to cooperate in agricultural research? Second, what are the sources and magnitudes of maize germplasm technology spillovers in the region? In very simple terms, a “technology spillover” occurs when a technology—such as a new maize variety—developed in one location (e.g., a certain country) proves useful in another location (e.g., a neighboring country).

In brief, results provide strong evidence that the PRM is the largest contributor of spillovers among all institutions—public or private—that develop maize varieties for the region (see figure, p. 44), and that network projects have made research much more efficient. For example, the study’s cost-benefit analyses show the PRM invests only six cents for every dollar of impact it achieves.

**IMPROVED VARIETIES Pay Their Way**

Higher yields and tolerance to harsh conditions—drought, pathogens, pests, and poor soils—are the hallmarks of improved varieties released in Central America and the Caribbean through CIMMYT–PRM–national program efforts. The varieties are paying their way. As of 1996, extra grain from improved varieties developed through regional cooperation (and based on CIMMYT seed) provided yearly benefits of US$ 70 million. Nearly 150 such varieties have been released in the region.

“A particular advantage of these varieties is their disease resistance, which helps ensure *stable* yields for subsistence farm households,” says Jorge Bolaños, CIMMYT maize agronomist and technical advisor to the PRM. “Such families have little or no cash income and face hunger after a single crop failure. Protecting their harvests from diseases, even at relatively low yield levels, often contributes more to household income and food security than getting higher yields in disease-free years.”

Resistant varieties also allow farmers to reduce or eliminate fungicide applications. This saves millions of dollars yearly across the region, improves farmers’ health, and helps protect the environment. In the Pacific regions where corn stunt disease once decimated maize crops, up to 70% of the farmers now grow resistant, PRM varieties.

**SEED TO Recover FROM DISASTERS**

Who do you call when disaster strikes? For national maize research programs, the answer is clear: the PRM. In 1989, for example, the PRM completely replaced strategic maize seed reserves lost in Panama during the US invasion, allowing the national maize program to meet farmers’ seed needs in only four months. In the wake of Hurricane Mitch in 1998, the PRM quickly helped replace national stocks of maize washed away in floodwaters.

“The network can do this because its members know which varieties are appropriate for the region, because they have access to the right seed and can quickly produce the amounts needed, and because they enjoy a recognized technical and ‘on-the-ground’ presence in the region,” says Bolaños.

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**Systems to Yield More, Save Resources**

Science can help farmers better orchestrate complex cropping systems in ways that increase output and reduce risks. The PRM participants have studied, adapted, and spread improved crop and land management techniques that are profitable for farmers.

One example is the adoption of conservation tillage. The practice has allowed farmers to raise maize yields from 1.5 to 4.0 tons per hectare, while halting erosion, in an intensive maize-sorghum rotation on the hillsides of El Salvador. Network researchers have refined and spread the practice to other parts of the region. In Azuero, Panama, for instance, at least six of every ten farmers now use reduced tillage to save money, reduce weeds and herbicide use, and conserve soils.

Intercropping with various legumes (“green manures”) has also been fine-tuned, tested, and spread through the PRM. Farmers in many areas use maize-legume systems to improve soil fertility and avoid erosion. Finally, PRM scientists have helped farmers use expensive chemical fertilizers more efficiently.

**Benefits of Understanding Farmers’ Perspectives**

The PRM has raised the profile of agricultural economists and rural sociologists in the region. Socioeconomists helped breeders and agronomists to understand farmers’ needs and learn why specific varieties or practices were adopted or ignored. Through the networks, socioeconomists have tested, refined, and promoted useful principles and methods, among them:

- Viewing farm households and activities as a “system.”
- Assessing varieties and practices under farmers’ actual conditions, rather than on experiment stations.
- Using economic analyses to gauge potential benefits of varieties or practices.

“**You see trucks carrying soft drinks to remote villages, but no one delivers seed of improved maize.**”
“These tools are now employed routinely by breeders and agronomists, and help explain the relevance and impact of their work,” explains Gustavo Sain, CIMMYT economist who works with the PRM.

Knowledge: The Impact of “Invisible” Capital

For all their differences, the impacts cited in this document have one, important element in common: they were accomplished by researchers in public and private institutions of countries in Central America and the Caribbean. Working alone or in tandem, these professionals put in long hours away from their families for low pay and under often difficult conditions that have included natural and civil crises. Year after year, the PRM provided crucial opportunities for building skills and careers, and became a pivotal link among these professionals. An expert panel that reviewed the PRM stated, “...The overall effect is reflected in the professionalism of most national researchers, as well as the technical quality of activities that benefit the region’s smallholders.”

A Paradigm for Participation: Will You Join Us?

There is much to be done: only 25% of the region’s farmers regularly purchase fresh seed of improved maize—mostly of hybrids. The remainder plant seed they have saved from a previous harvest—either seed of local, unimproved varieties, or seed of improved maize whose qualities are diluted from generations of re-use and outcrossing. What holds back the purchase of improved seed? Key factors, according to Bolaños, are farmers’ chronic lack of resources and their reluctance to gamble with the few they have.

“Most farmers are loathe to risk what little money they have on an input like improved seed, when much of their crop may be lost to drought, diseases, insect pests, or other constraints,” he says. All of this makes for a relatively unattractive market for commercial seed distributors. “It’s simple economics. You see trucks carrying soft drinks to stores in remote villages, but no one delivers seed of improved maize,” Bolaños remarks.

Even though the region is now poised to build on its achievements through further collaboration, public support for research has eroded. The result is radical cutbacks on staff and a virtual absence of operating funds. “If the trend continues, one can imagine a scenario ten years down the road when Central America and the Caribbean will be forced to import food,” says Bolaños. “Today we import almost 40% of the maize consumed and the figure continues to grow. As rural productivity declines, the massive flight of unemployed farmers would add to the pockets of poverty already existing in cities. It’s hard to imagine that this corresponds to the best interests of the region’s governments.”

When asked what future direction the PRM should take, based on the economic study he co-authored, former CIMMYT research associate Miguel Ignacio Gómez cites recent work by World Bank economist Derek Byerlee. “He published a paper not long ago that suggests a new paradigm for national programs and mentions four key areas,” says Gómez. “First, a more pluralistic structure, with the participation of many institutions. Second, moving toward more competitive ways of funding research. Next, more private participation and, finally, stronger links with international research systems. Because of its ties to CIMMYT, the PRM already has several of these issues resolved.”

With support from SDC, the PRM and two other crop networks from the region are seeking ways to continue their work and that of their partners. Given the results of the CIMMYT economic study and other evidence of impact, they can present a strong case to invest in international agricultural research. The alternative is likely to have a much higher price, much too late.

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CIMMYT’s involvement in Central Asia and the Caucasus (CAC) deepened after the mid-1990s, when the Center initiated research directed at the region’s major wheat production systems and established a regional office in Kazakhstan.* Experimental wheats poured through the channels opened by CIMMYT–Mexico, the International Winter Wheat Improvement Program,** and the CAC countries to reinvigorate wheat research (see “Waiting for a Better Wheat Variety in Uzbekistan,” p. 39).

In conducting research in the region, CIMMYT and its partners must be highly aware of the shifting realities of wheat farming and the political economy. Kazakhstan remains the principal wheat producer in CAC, and recent field visits have documented new wheat production systems and their characteristic challenges.

**From State Farm to Joint Stock Company**

Most of the huge state and collective farms that were the mainstay of agricultural production during the Soviet era were dismantled after 1991, and the people who lived and worked on them were given the right to work individual plots of land. Wheat production in Kazakhstan is concentrated in the immense steppes of the north, where individual farmers working a few hectares of land have little chance of success under current conditions. Many farmers, realizing they could not make it on their own, started banding together to create big farms, but on a profit basis. The resulting enterprises took many forms. One type, the joint stock company, was typically established by people deeding their rights to work individual plots over to the company as an investment. Consequently, these companies operate on vast expanses of land. For example, in Shortandy, the Petrovskoye Co. brought together 28,000 hectares, 23,000 of which are planted to wheat.

The Petrovskoye Co. has 500 shareholder/ workers and is managed by Vladimir Layer, who headed the old collective farm Petrovskoye replaced. Layer is the main shareholder, but profits are shared equitably with the workers, giving them a real stake in the company’s success. In 1999, a good year, the farm produced slightly more than two tons of wheat per hectare for a total of 47,000 tons of grain, which brought in reasonably good profits, but Layer feels they could be a lot higher.

** A project of the Government of Turkey, CIMMYT, and ICARDA.
“Our profits will remain low as long as there is no marketing system that producers can use,” says Layer. “Unfortunately, we have to sell our grain to intermediaries, who make huge profits.” He compares this situation with that in the US, which he visited last year. “If our government supported us by regulating grain marketing, for example, by setting up a distribution hub like the one in Chicago, we could make better profits and perhaps even sell our grain on the international market,” says Layer.

He cites another serious concern. Petrovskoye inherited farm machines from the old collective it replaced. Constant maintenance and repair using spare parts cannibalized from other machines have kept them running until now. The aging machines have to be replaced someday, but Kazakhstan does not manufacture farm machinery, and the company cannot afford to buy even the least expensive models on the international market.

Shareholders or Sharecroppers?
A second type of enterprise is the farmers’ cooperative limited, where the workers have “donated” their land to the cooperative and so are not true shareholders. Larger “centers” often control a number of these cooperatives. Workers are paid mostly in the form of products and services, such as schooling, attention at health clinics, flour, or coal for heating and cooking. The villages where workers and their families live are usually old and rundown, though the center is supposed to maintain them along with the rest of the infrastructure.

The center takes charge of the entire production process, from furnishing seed to marketing products. It makes sure each cooperative has what it needs to operate and makes enough of a profit to buy new machinery when needed. Says the manager of one such cooperative, “The center handles all our problems so the workers can concentrate on producing as much as they can without worrying about anything.” In some people’s view, however, these workers are little better than sharecroppers who have no choice but to work for the cooperatives or, more accurately, the center.

THE SMALL FARM IN AN ERA OF BIG BUSINESS
A third type of agricultural enterprise is the “small” farm (perhaps 500–1,000 hectares) managed by a single farmer with the help of hired hands. Yuriy Omelchenko, who runs such a farm (730 hectares) in Ilizavyetinka, near Astana, the capital of Kazakhstan, got his land from relatives and friends with the agreement that he would share profits with them. He pays his workers according to profits, and they are committed to making the farm as productive as possible.

Omelchenko has his own machinery, which he personally takes a hand in maintaining, since he is a mechanical engineer. One day he will have to buy new machinery but wonders where he will get the money. The rural credit system, a carryover from the Soviet era, has a reputation for favoring large farms, and Kazakhstan still has no agricultural banking system. For small-scale farmers in particular, the lack of access to direct financing is disheartening.
The survival of this farm is more precarious than that of the big outfits, for it is more severely affected by fluctuations in the wheat price and outbreaks of insect pests and diseases. Says Omelchenko: “We have a very small profit margin, about 20 dollars per ton of grain, because we have to sell to intermediaries. Our expenses vary a lot, depending on the price of fuel, spare parts, and seed. If the government doesn’t set up policies to support us, we could disappear.”

**Wheat Research at the Interface between Technology and Policy**

The new flow of experimental wheats throughout CAC has encouraged the development of superior varieties that compete well with local ones. In winter wheat trials conducted in six countries in the region from 1997 to 1999, the highest yielding entry was invariably a CIMMYT wheat. In Tajikistan, a CIMMYT-derived wheat is already under production; all of the other countries in the region are now testing CIMMYT-related wheats at various stages of development. The advanced wheats being tested in Kazakhstan feed the hope that the nation might recover part of its lost production and export market, but is this realistic?

“Though the availability of appropriate technologies is essential to bring about a significant increase in Kazakh wheat production, it is not enough,” says Prabhu Pingali, director of CIMMYT’s Economics Program. “A lot depends on creating production incentives for farmers through adequate policy measures.”

Jim Longmire, consultant to CIMMYT, believes that the potential for sustained recovery in Kazakh wheat production is good, but it will not happen overnight, and production will still vary. “The high-input, energy-intensive farming methods of the Soviet era are gone,” he says. “Policies, research, and agribusiness all need to be redirected toward the new era of low-input, low-cost farming.”

A main objective of CIMMYT’s studies of the CAC region is to become familiar with the economic and political environment within which decisions in the agricultural sector are taken. “For example, the government is no longer involved in ensuring the availability of agricultural inputs or providing production assistance to farmers,” says Erika Meng, a CIMMYT economist who has worked in Central Asia. “It’s largely pulled out of the business of wheat marketing, with some expectation that private traders and companies would step in to create a private grain marketing system. However, this won’t happen without policies to promote the development of economic infrastructure in Kazakhstan.” She adds, “We don’t have much influence over these huge macroeconomic factors, but we need to know what they are to operate better within them.”

For some farmers, the wheat varieties and other agricultural technologies under development may provide the competitive edge needed to negotiate the changing economic and political terrain. “Some initiatives will make an impact quickly,” comments Longmire, “but others—such as restoring degraded steppe soils—will require more time, effort, and insight.” Adequate policies will surely help, as will national strategies to reform research systems originally designed to serve centrally planned economies. In this context, CIMMYT and its partners are committed to doing everything within their power to make wheat production more efficient and stabilize the transition to a new agriculture.

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SCIENCE

outlook
Functional genomics is a major force behind this imminent revolution. Simply defined, functional genomics is a scientific approach that seeks to identify and define the function of genes, and uncover when and how genes work together to produce traits. Current structural genomic approaches (i.e., mapping) generally focus on traits controlled by one or only a few genes, and often they only provide information regarding the location of a gene or genes.

Although obtaining location information is a critical first step, functional genomics goes further to examine the interrelationships and interactions between thousands of genes to determine when and why certain traits are expressed, which sets of genes are specifically responsible for that expression, and under what conditions. This information equips scientists to create varieties with exact combinations of traits. If they can develop varieties that yield as well as possible under any given set of conditions, we will come much closer to meeting the global demand for food.
Global Advances

Recent developments, within and outside of CIMMYT, are bringing functional genomics to the fore. In the global arena, the public release of the gene sequences of wild mustard (*Arabidopsis thaliana*) and rice has made a wealth of information available to scientists. Because the genes that code for scores of plant traits and processes are quite similar across many species, this knowledge can be applied to genetic research on wheat, maize, and other crops. Furthermore, rapid improvements in innovations, such as microarray technology, enable scientists to generate information on thousands of genes and expressed sequences (so-called “expressed sequence tags” or ESTs) in their search for a trait, as opposed to looking at just a few specific “candidate genes.”

Analyzing the mountains of data generated by such technologies falls into the realm of bioinformatics. It requires powerful computational capabilities and highly sophisticated software, networking, and database packages—and the human resources to run them. Such resources, while expensive, are now available.

CIMMYT Advances, Applications, and Challenges

Developments within CIMMYT mirror those in the outside world. During the past year, a unit devoted to bioinformatics was created and incorporated into the Applied Biotechnology Center. On another front, the International Crop Information System (ICIS, developed through the work of national research programs, seven CGIAR centers, and other advanced agricultural research institutes) was released on CD-ROM in early 2000. This product is the foundation for more comprehensive crop data systems.

A gene sequencing facility was established at CIMMYT as well. This facility enabled CIMMYT to contribute more than 1,000 ESTs to the International Triticeae EST Consortium (ITEC, a group of 20 private and public labs, including CIMMYT), which publicly released at least 20,000 wheat gene sequences in July 2000. Whereas a few years ago public institutes had only a handful of sequences to work with, they will now have an abundance. These sequences are the raw material for predicting the possible function of a gene, which can then be substantiated in DNA microarrays. These arrays, in turn, can provide data on when and under what conditions ESTs (or genes) express themselves. Mutagenesis and genetic engineering technology also employ ESTs to further define the function of a particular gene.

The task of tackling a genome is too large for any single institution. Through partnerships and other arrangements with public and private research groups, CIMMYT has gained access to data, expertise, and technologies that enhance its ability to pursue functional genomics.

In 1999, CIMMYT and the International Rice Research Institute (IRRI) launched the “Maize-Rice Functional Genomics Project,” with some initial financial support from the CGIAR’s Technical Advisory Committee. The project seeks to discover the key genes responsible for drought tolerance and to produce molecular tools that will enhance breeding for the requisite trait(s). Another significant step in this direction was the Strategic Planning Workshop on Molecular Approaches for the Genetic Improvement of Cereals in Water Limited Environments (see p. 11).

Whether the ultimate goal is improved drought tolerance, enhanced nutritional composition, or higher yield potential, functional genomics will play an increasingly important role in helping scientists achieve their aims. CIMMYT is committed to harnessing this powerful new approach to provide resource-poor farmers the means to produce not just more food, but better food.

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In the mid-1990s, Bangladeshi wheat researchers posed a basic question: How do you make science-based farming appropriate for and accessible to small-scale wheat growers, who routinely fall outside the reaches of government extension and development organization programs? Those inquiring were from the Bangladesh Agricultural Research Institute’s (BARI’s) Wheat Research Center (WRC), the outfit that lifted wheat from minor status in the early 1970s to its present place as the second most important cereal after rice in Bangladesh. National wheat yields have improved steadily over the years, although they still average 2.2 tons per hectare—nearly 4 tons below the best yields possible.

Researchers suspected that part of the answer lay in reaching a previously ignored group: women. So in 1994–95 the WRC and CIMMYT surveyed 600 women in three major wheat-producing districts. “Contrary to conventional wisdom of the time, we found that most women were knowledgeable, active participants in wheat farming,” says Craig
Wheat in Bangladesh: Testing the Conventional Wisdom

<table>
<thead>
<tr>
<th>Activity</th>
<th>Conventional wisdom</th>
<th>Survey data, Dinajpur</th>
<th>Survey data, Jessore</th>
<th>Survey data, Faridpur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do women work in the field?</td>
<td>Very few</td>
<td>30%</td>
<td>19%</td>
<td>27%</td>
</tr>
<tr>
<td>Do women weed?</td>
<td>A little</td>
<td>61%</td>
<td>18%</td>
<td>22%</td>
</tr>
<tr>
<td>Do women irrigate?</td>
<td>Never</td>
<td>13%</td>
<td>22%</td>
<td>7%</td>
</tr>
<tr>
<td>Do women harvest?</td>
<td>Not much</td>
<td>48%</td>
<td>67%</td>
<td>55%</td>
</tr>
<tr>
<td>Do women supervise in the field?</td>
<td>Never</td>
<td>73%</td>
<td>79%</td>
<td>100%</td>
</tr>
<tr>
<td>Do women thresh?</td>
<td>Mostly</td>
<td>42%</td>
<td>53%</td>
<td>87%</td>
</tr>
<tr>
<td>Do women dry seed?</td>
<td>Mostly</td>
<td>85%</td>
<td>89%</td>
<td>92%</td>
</tr>
<tr>
<td>Do women select and preserve seed?</td>
<td>Mostly</td>
<td>69%</td>
<td>24%</td>
<td>44%</td>
</tr>
</tbody>
</table>

Meisner, CIMMYT agronomist in Bangladesh. “They’d adopted this role partly to support the steady intensification of agriculture in Bangladesh, and partly because men were seeking off-farm employment to round out family earnings.”

Agriculture Affects All Family Members

In any case, analyses suggested that all family members took part in and were affected by agriculture. Furthermore, families had diverse ways of allocating labor to farming. The WRC and CIMMYT devised an experimental model whereby entire families learn together. “The approach respected families’ internal arrangements, rather than dividing training into gender- or task-specific segments,” Meisner says. Female field workers, largely from a non-governmental organization, the Bangladesh Rural Development Board (BRDB), were trained as instructors. In 1995, they conducted simple, participatory seminars using informal training methods with families from their working areas.

Nearly 6,000 persons from more than 1,200 families in eight wheat-producing districts participated. Families received personal invitation cards, making them feel honored and resulting in nearly 100% attendance. Training focused on key pre- and post-harvest management topics: seed germination testing, seed selection, seed rates for sowing, and seed and grain storage. At the end of each seminar, families received a small package of practical implements and a booklet of illustrations for the recommended practices.

Fahmida N. Chowdhury, BRDB organizer and whole-family training instructor, feels the approach makes great sense. “In a farming family, everyone has a different job to do. When all attend training together, each can learn what is important for their particular work. It also makes it easier for a family to plan their work, when everybody has been trained on all aspects of production.”

“Now I Can Manage by Myself”

A woman from Dinajpur Sadar village spoke about her expanded expertise has proven useful. “I thought the training was excellent. I learned about applying fertilizer, proper irrigation, and other things I did not know before. Now I am able to teach others as well. My husband and sons sometimes have to find work outside the village to earn extra income. Now I can manage our family’s wheat production by myself.”

The family format encourages farmer participation and input regarding the practices promoted through training events. For example, farmers provided useful alternate suggestions for testing seed germination. These included placing seed in damp gunny sacks, stalks from banana plants, or hot water. “The latter idea consisted of dropping seeds in hot water for five minutes,” Meisner explains. “Seeds with viable embryos soak up the water more quickly, providing a rough, visual estimate of viability. Subsequent examination by researchers showed this to be a pretty reliable indicator.”
Follow-up studies in 1996 among a randomly selected subset of families who had attended the seminars showed 90–100% adoption of the new practices in general. An economic evaluation by the WRC in Dinajpur District in 1999* revealed direct and indirect on-farm benefits from applying the practices of more than US$ 100 per hectare. This is a significant profit in a country where annual per capita income averages US$ 280, where at least 35% of the population lives in poverty, and where agriculture occupies 65% of the labor force.

AN EXPERIMENT FOR THE WORLD’S FUTURE

The whole-family approach has spread to other institutions in Bangladesh, according to Meisner. One is the German Bangladesh Seed Development Project funded by GTZ, which has been using the approach successfully since 1997. Meisner also believes that this and other useful innovations from Bangladesh could have global relevance.

“Bangladesh is not only the experiment for the future of agriculture in the developing world, but may be the experiment for the future of the world,” he explains. “Each square centimeter of arable land here is used 1.9 times a year. Land, water, and other resources are stretched far beyond what we would call sustainable. Plant, animal, and human micronutrient deficiencies are appearing. If we can meet the challenges here, then there is hope for the future. If we fail, then many other areas may also be in danger.”

* E. Baksh, Indicators of Impact on Wheat Production Practices Due to Whole Family Training (BARI-WRC, 1999).
Farmers’ enthusiasm for hybrids has awakened far more rapidly in Vietnam than in many other countries. Much of the dynamism in Vietnamese maize production can be attributed to a vigorous national breeding program that has come into its own just as the free market system, known as doi moi, has encouraged more diversified agriculture.

“Since doi moi began in 1986,” explains Nguyen Tri Khiem, Associate Professor of Economics at Cantho University in southern Vietnam, “farmers have ventured to grow crops other than rice, including maize. Maize is becoming increasingly important for helping Vietnam meet its food production and security objectives.”

Vietnam is primarily a rice-consuming country, but as in most Asian countries, demand for maize is running rampant. Maize constitutes a major portion of people’s diets in rural and mountainous areas, and it is used as a substitute staple when rice runs short. Even more crucial, maize is the primary ingredient in poultry and livestock feed. Large feed plants now line the southern Vietnamese highway that leads from Ho Chi Minh City to Bien Hoa City. They are just one indication of growth in the feed industry.

**Milestones in the Maize Economy**

Throughout Vietnam, average maize yields rose from 1.6 tons per hectare in 1990 to 2.7 tons per hectare in 1998. In more commercial areas, the average exceeded 3 tons by 1998. Tran Hong Uy, who directs Vietnam’s National Maize Research Institute, attributes this achievement to many factors, including the national maize program’s development of competitive varieties and hybrids, better maize production techniques, and farmer training.

It can also be attributed to good collaborative research. Uy estimates that about 70% of the improved maize grown in Vietnam, including hybrids, is related in one way or another to CIMMYT breeding materials.
Ngo Van Giao, Director of the Southern Seed Company, says that farmers growing hybrids obtain 4.2 tons per hectare on average but that yields as high as 9 tons have been reported on farmers’ fields. The Southern Seed Company—one of several public and private seed companies active in the country—meets 60% of the demand for maize seed in southern Vietnam and exports some seed to Laos.

Exports of maize and maize products from Vietnam rose from 247,000 tons in the 1960s to more than 1,200,000 tons in 1995. “The growing domestic maize market, promising export potential, and strong government support clearly have encouraged farmers to pursue and strengthen maize production,” says Roberta Gerpacio of the CIMMYT Economics Program.

The Farm View

Perhaps the best understanding of how maize production has changed in Vietnam comes from farmers themselves. A man and woman interviewed recently in Vinh Tan village in Dong Nai Province, not far from Ho Chi Minh City, have been growing maize on their farm since the mid-1970s. Once they grew local maize varieties; now they plant single-cross hybrid seed purchased from a private seed company and obtain 8–9 tons per hectare. (The average yield in this area in 1991 was 1.8 tons per hectare.)

“We learned how to grow maize from our parents and from our own experiments,” explained the man, justifiably proud of the family’s meticulously tended maize field. The couple sell their maize to local traders, who sell to feed millers. They also keep some maize to raise pigs for sale; the interview was punctuated by the sounds of construction as laborers converted the small piggery into a larger facility.

The feed industry’s rising demand for maize has spurred the Vietnamese government to set new objectives for maize production. By 2005, the government seeks to increase maize area to 1 million hectares, 90% of which will be planted to hybrid maize, and to raise production to 4 million tons. By 2010, the goal is to raise production to 6 million tons by planting hybrids on 95% of an even larger area (1.2 million hectares). Some unirrigated land currently planted to rice will be dedicated to maize production.

CIMMYT Garners Government Recognition

Comments Uy, “The Vietnamese government and Ministry of Agriculture and Rural Development highly appreciate the valuable, vigorous assistance of CIMMYT.” The government awarded CIMMYT its Friendship Medal in 1993 at the Fifth International Maize Meeting in Hanoi.

“Few countries have achieved so much in maize production in such a short time,” states Shivaji Pandey, director of CIMMYT’s Maize Program. In June 2000, Pandey was honored in Hanoi for CIMMYT’s continuing contributions to maize research and production in Vietnam and for its equally important role in human resource development. “Vietnam has a strong maize breeding program, it has highly innovative farmers, and we’ve benefited from good communication over the years,” says Pandey. “Many people have worked very hard for this success.”

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Gene Mapping Sets Course for Wheat Disease Resistance

The Japan International Research Center for Agricultural Sciences (JIRCAS) recognizes the tremendous importance of wheat in the world and has sponsored an Adjunct Scientist at CIMMYT to pursue its improvement. Geneticist Kazuhiro Suenaga has eagerly taken up the challenge. Since early 1998, Suenaga has worked with CIMMYT’s Applied Biotechnology Center on mapping genes from a Japanese wheat variety that provide resistance to fusarium head blight (FHB), known more prosaically as “scab.” Mapping these genes is the equivalent of adding another brick to the foundation needed for building higher levels of resistance to this important disease.

Fighting Billion-Dollar Losses

Losses to FHB have surpassed one billion dollars and one million tons of wheat in large wheat-producing countries. Fungicides provide inadequate protection and are not environmentally sustainable.

To date, Suenaga has identified three quantitative trait loci (QTLs) that contribute to scab resistance. While these findings are encouraging, the geneticist emphasizes their tentative nature. “The problem with fusarium evaluation is that the trial data can vary greatly between seasons and environments,” says Suenaga. “To confirm these results, we’ll need some good wet seasons (prime conditions for scab) and two or three years of replication, preferably at different locations. But I’m hopeful that one or two of these QTLs will turn up again in this year’s trial.”

The three QTLs identified by Suenaga individually account for 10, 15, and 20% of the total variation of FHB resistance. A simple tabulation of these percentages, however, does not provide an accurate picture of their actual influence, because some of their resistance almost certainly overlaps or results from interactions between the genes. Further statistical analysis is planned to ascertain the actual combined effect of the three QTLs, but Suenaga makes a rough calculation that they account for 30–40% of the resistance. Good results, but not yet up to the 60–70% he hopes to achieve by targeting specific gaps in his map construction.

Adding Value to Other Research

The value of this work is greatly amplified when it is considered together with similar wheat/fusarium mapping being conducted on a Chinese variety by a JIRCAS colleague in Japan, on a resistant Brazilian variety (Frontana) by CIMMYT molecular geneticist Mirelle Khairallah, and on other sources.

By comparing maps from these varieties, Suenaga explains, it should be possible to determine whether their respective resistance traits come from the same or different genes. If the sources are the same, there may be little to gain in terms of scab resistance from crossing these varieties. However, if they derive their resistance from different genetic sources, these genes could be pyramided together to create long-lasting resistance that responds to a broad range of environmental conditions.

Recognizing the value of Suenaga’s work, JIRCAS has extended his tenure well into 2001. In addition, he plans to conduct scab resistance mapping work on some synthetic wheats developed by A. Mujeeb-Kazi, head of wheat wide crosses at CIMMYT.

Wheat is not a major crop in Japan. Even so, Japanese expertise is contributing to research that is giving the world’s wheat farmers greater security against an important disease.

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Interspersed with other crops in a farmer’s field near Hami, Xinjiang Uygur Autonomous Region, in northwestern China, the wheat soaks up the sun as it ripens. The tawny fields look like they will yield a good bounty—perhaps six or seven tons per hectare—though the farmer has not invested much in the crop. This is not surprising, since he planted Xin Chun 6, which yields well and tolerates drought and high temperatures.

Set in the middle of a desert, the farming village is lush with vegetation thanks to water from the nearby mountains, which is supplemented with water brought up from the depths of the earth. Encompassed on all sides by tall poplar trees, the fields abound with crops: melons, grapes, vegetables, cotton, maize, and wheat.

Despite the evident abundance, conditions here are tough, and wheat, which is not irrigated, endures dry conditions throughout the growing cycle. Farmers, however, have found the key to successful wheat production: a good, high yielding variety that does well despite the lack of water. Most of them plant Xin Chun 6, which covers 40% of the area sown to wheat in the region.
Four hundred kilometers away, Wu Zhenlu, who developed Xin Chun 6, goes out to inspect his experimental plots. As he makes his way through the fields, he explains that most of the materials are derived from CIMMYT lines, which he has been using to develop his varieties since 1972. The qualities he finds most useful in CIMMYT materials are their short stature, their capacity to adapt to different conditions, and their resistance to diseases such as stem and stripe rusts and powdery mildew.

“Do you know what is really unique about CIMMYT wheats?” asks Wu. “Their combination of high yield potential and good drought tolerance. Drought is the worst problem for wheat production in Xinjiang, so we need this combination.”

Wu has been breeding wheat for 40 years. How did he get started using CIMMYT wheat?

“By chance. When the Chinese Academy of Agricultural Research began exchanging germplasm with CIMMYT in 1972, they sent the seed here to the Xinjiang Academy, and it fell to me to test the lines,” explains Wu. He found CIMMYT materials extremely useful and started crossing them with local wheats right away. Within a few years, he had developed new varieties that had inherited desirable traits from their CIMMYT parents and were adapted to local conditions.

Today the varieties developed by Wu and his team of researchers are preferred by farmers all over Xinjiang Region, especially for their high yield capacity. An outstanding example is Xin Chun 6, which can produce up to 10 tons per hectare under favorable conditions. Its CIMMYT heritage comes from both of its parents. Seventy percent of the spring wheat area in the region is covered with varieties developed by Wu and his team, and all of them have CIMMYT “blood.” The team is currently focusing on improving the grain quality of their wheats by crossing them with good quality CIMMYT lines. They have already identified lines that tolerate drought and rust well and have good grain quality.

A Practical Bent for Breeding

Team leader Wu came to be a breeder fortuitously. His chosen field of study was originally Chinese language and literature. But he soon discovered that he preferred the biological sciences and that he valued doing something that produces tangible results, like breeding does. He learned to breed by doing, and is first and foremost a practical breeder. Showing his practical bent, he says, “A breeder needs to go out to farmers’ fields to see the problems they’re facing, and then think how to solve them.”

Wu also believes in learning from other people’s mistakes and in recognizing their contributions. “You should try to use the newest and best germplasm, which is always based on other researchers’ work. It’s important to acknowledge that you’re building on other people’s contributions.” Finally, Wu believes that a researcher should devote himself body and soul to his work. He hopes to pass his work ethic on to the young breeders who work with him to ensure that farmers in the Xinjiang Region will continue have varieties that outyield Xin Chun 6, long after he has retired.

For more information: Zhonghu He (zhhe@public3.bta.net.cn) Maarten van Ginkel (m.vanginkel@cgiar.org)
CIMMYT Feeds Youth’s Enthusiasm for World Food Issues

Not everyone who visits CIMMYT gets to room next to Norman Borlaug, winner of the 1970 Nobel Peace Prize. But Matthew Feldmann, a visiting student from Harvard University, made the most of it and of his summer at CIMMYT.

Feldmann first came to CIMMYT in the summer of 1998. A paper he wrote on food security in Benin for the World Food Prize Youth Institute landed him an internship sponsored by that organization. He later learned that he would be assigned to CIMMYT. “I was extremely pleased to learn I was going to CIMMYT,” says Feldmann. “I’d been fascinated by the work of Dr. Borlaug and the topic of world food security, and this seemed like a tremendous opportunity.”

An Intern Who Delivers Results

Planning to pursue a degree in economics in college, Feldmann—then 18 years old—chose to work with the CIMMYT Economics Program. “We were a little concerned about this unknown high schooler coming to a new professional environment, and a little worried that we might have to do some hand-holding,” recalls Prabhu Pingali, director of the Economics
Program. Feldmann also harbored some concerns. Would the internship be of the busywork variety that some of his friends had encountered? In the end, both parties’ apprehensions proved unfounded.

Already fluent in Spanish, Feldmann was sent to the Yaqui Valley in northern Mexico to write about how the living standard of farmers had changed since the Green Revolution. The following summer, he co-authored (with Michael Morris of the Economics Program and David Hoisington of the Applied Biotechnology Center) an article entitled “Genetically Modified Organisms: Why All the Controversy?” The piece appeared as the lead article in the first quarter 2000 issue of Choices magazine* and has served as a standard reference in many CIMMYT presentations on the subject.

**Internships Spark Commitment to Agricultural Development**

“These projects were really not make-work projects,” Pingali emphasizes. “These were two big projects that would not have been possible if Matt had not stepped in. We’re looking at this as a long-term investment and hope he continues to work in this area and to interest others with the positive message he puts out about the program and this kind of work.” In fact, since Feldmann’s first summer with CIMMYT, two other World Food Prize interns have followed in his footsteps and worked with maize and biotechnology researchers at CIMMYT.

Feldmann says the challenging projects further opened his eyes to international food issues. Following his summer 2000 internship, during which he produced an annotated bibliography on agricultural impacts assessment, he returned to his university and continued to pursue his goals of obtaining a Ph.D. in economics and eventually working in an international research and policy organization. In the meantime, Pingali is exploring ideas for Feldmann’s next project.

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* Published by the American Agricultural Economics Association.
Resourcing the Research: CIMMYT Financing, 1999–2000

At CIMMYT, the hallmark of a successful funding strategy is that it empowers scientists to pursue socially responsible research and empowers developing countries to use technology to improve human and environmental welfare.

This review of CIMMYT’s financial resource base highlights funding trends, specifies the Center’s major investors, and documents the contributions of public and private agencies, as well as agencies from the North and South, to our work. It also outlines the Center’s research agreements with the private sector.

Funding LEVELS AND TRENDS

Funding for 1999 was US$ 35.407 million (including Center-earned income), consisting of US$ 29.426 million from CGIAR investors and US$ 5.981 million from other sources. Expenditure was US$ 36.733 million. Although 1999 ended without any deficit in operating funds, defaults on core payments necessitated a draw-down of our financial reserves. In 2000–2001, the Center will replenish its reserve through renewed funding and reduced capital expenditure.

The governments and agencies that provided the largest share of our funding in 1999 are shown in Figure 1. The contributions to CIMMYT’s budget by CGIAR member nations, North and South, as well as foundations and advanced research institutes (in the private and public sectors), are presented in Figure 2.

Figure 3 shows how CIMMYT’s research funds were allocated in 1999 towards achieving the five research outputs of the CGIAR.

Over the past several years, targeted funding has grown substantially. Unrestricted funding, the cornerstone of CIMMYT’s research and source of its flexibility, has
continued its slow decline (Figure 4). In 1995, unrestricted funding constituted 71% of our budget; in 2000, it will constitute 39%. Targeted funds accounted for most additional resources in 1999, particularly funding for core special projects. Sources of income from grants are summarized in Table 1, p. 69.

**NEW Alliances for Socially Responsible Research**

The increase in targeted contributions reflects two strategies. First, CIMMYT has made a concerted effort to develop highly focused, strategic partnerships directed at specific major challenges for maize and wheat research in developing countries. Second, to respond in a timely way to new challenges and opportunities, we have adopted a resource mobilization strategy that also includes non-traditional sources of income and research support.

Collaborative alliances are the lifeblood of our research agenda and enable us to channel additional funding to partners in national agricultural research systems. All of these alliances considerably reinforce our mandate and commitment to serve developing countries. Details of our agreements with the private sector are reviewed in “Transparency Is Important,” p. 70.

**A View to the Future**

Our budget estimate for 2000 is US$ 37.5 million. Although this figure is higher than forecast at the start of the year, it is important to note that revenues are still subject to instability brought about by delayed contributions and/or exchange rate fluctuations.

Over the 2001–2003 planning period, we foresee an increase of about 2% per year, in real terms, in the Center’s budget. This increase will permit moderate growth in key areas and some scope to respond to unexpected needs. In our budget projections we are maintaining a conservative approach to exchange rates, which has proven most prudent in recent years.

The Center’s most pressing capital investment need was to identify a research site to replace its Poza Rica Research Station, an important maize breeding site for the lowland tropics. The station was destroyed by floods in October 1999. Research conducted at Poza Rica helped CIMMYT to meet the needs of resource-poor farmers cultivating 55 million hectares of maize in Africa, Asia, and Latin America (about 70% of the maize area in developing countries, excluding Argentina, China, and South Africa).

A new site was identified by early 2000 and its purchase approved by CIMMYT’s Board of Trustees. Special resources were made available by the CGIAR Finance Committee and the Government of Australia to help CIMMYT acquire the new site. Further funding is required to develop and equip the research facilities there.
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Total grants 34,072 1

1) CGIAR member (North).
2) CGIAR member (South).
3) Foundation (non-CGIAR member).
4) Advanced research institute agreement (Public).
5) Non-CGIAR member (South).
6) Advanced research institute agreement (Private).
7) Foundation (CGIAR member).
8) Not including Center-earned income.
Transparency is Important

As the nature of the CGIAR changes to include more research agreements with advanced research institutes—both public and private—we believe that it is important to be as transparent as possible in these agreements. This is particularly so in relation to agreements with the private sector, because there is sometimes a perception that the potential conflicts between the production of global public goods (CIMMYT/CGIAR) and the objectives of the private sector are insurmountable.

**Project 1: Apomixis**

**CIMMYT objective:** Development, evaluation, and distribution of apomictic hybrid maize to subsistence farmers.

**Partners:** IRD (France); Novartis; Limagrain; Pioneer Hi-Bred Co.

**Duration:** Five years (1999–2004)

**CIMMYT receives:** Access to scientific expertise and proprietary technologies; a paid-up, royalty-free, worldwide, non-exclusive license (with the right to sub-license to non-profit institutions) to provide research products to subsistence farmers.

**Financial support for CIMMYT scientists involved.**

**CIMMYT provides:** Staff and laboratory resources; access to CIMMYT and IRD’s apomixis technology; a paid-up, royalty-free, worldwide, co-exclusive license for research products.

**Project 2: Hybrid Wheat**

**CIMMYT objective:** To evaluate the potential of heterosis in wheat with a view to decision-making on further development of this technology for hybrid wheat production in developing countries around the world.

**Partner:** Monsanto Company

**Duration:** Five years (1998–2002)

**CIMMYT receives:** Access to scientific expertise and proprietary technology (including a hybridizing agent and related information). Financial support for the CIMMYT scientist involved.

**CIMMYT provides:** Staff, laboratory, and field resources; access to scientific expertise and expertise in wheat breeding; access to various lines of CIMMYT wheat (non-designated germplasm), suitable only for hybrid wheat in Mexico.

CIMMYT’s policy on these matters is that we will enter into such agreements only if they enhance CIMMYT’s ability to achieve its mandate of service to the resource-poor and the environment. In simple terms, will a particular agreement help us to more quickly develop new, appropriate technologies and deliver them to farmers’ fields in developing countries? If so, the agreement is what we call a “win-win” alliance, and we can participate.

**Project 3: Durum and Bread Wheat Breeding**

**CIMMYT objective:** To gain access to rainfed wheat variety evaluation in Spain and receive associated feedback on performance and associated expertise to enhance CIMMYT’s contributions to global wheat breeding, with particular reference to enhanced disease resistance, yield, and quality.

**Partner:** AGROVEGETAL, S.A. (Spain)

**Duration:** Five years (1998–2003)

**CIMMYT receives:** Access to germplasm evaluation and research methodologies, information, and other services that contribute to CIMMYT’s global mandate. Financial support is provided to meet the costs and overheads of this project. (All proceeds and benefits from this alliance are used to further CIMMYT’s mandate to assist the resource-poor and in particular are focused on furthering CIMMYT’s contribution to the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture.)

**CIMMYT provides:** Up to 150 lines of durum and bread wheat varieties per year for commercial evaluation. Material is provided in yield, selection, and elite line nurseries. In addition, some segregating populations and designated germplasm may be provided for research purposes only.

**Project 4: Industrial Quality in Wheat**

**CIMMYT objective:** To enhance CIMMYT’s abilities to develop wheat varieties with improved industrial quality adapted to mechanized baking systems.

**Partner:** Grupo Industrial Bimbo, Mexico

**Duration:** Five years (1999–2004)

**CIMMYT receives:** Access to industrial expertise and specialized wheat quality equipment, thereby enhancing CIMMYT’s overall wheat quality research. Financial support and equipment for CIMMYT’s Wheat Quality Laboratory.

**CIMMYT provides:** Field and laboratory evaluation of wheat varieties for enhanced industrial quality in the northwestern and Bajío regions of Mexico. CIMMYT identifies parents, lines, and populations for this evaluation and develops elite germplasm for use by farmers in the Mexican States of Sonora and Guanajuato.

CIMMYT has four important agreements in 1999–2000 with the private sector, which in total provide 3% of CIMMYT’s annual budget. More importantly, however, they provide access to expertise and technologies not normally available. In the interests of transparency, and with due regard to confidentiality, the nature of these agreements is outlined below.
TRUSTEES AND PRINCIPAL STAFF

TRUSTEES

Walter Falcon (USA), Chairman, Board of Trustees, and of the Executive and Finance / Administration Committees, and Co-Director, Center for Environmental Science and Policy, Stanford University

Johan Holmberg (Sweden), Vice-Chairman, Board of Trustees, and Ambassador of the Government of Sweden to Ethiopia

Jorge Kondo López (Mexico), Vice-Chairman, Board of Trustees, and Executive Director, National Institute of Forestry, Agriculture, and Livestock Research

Gary Fowler (USA), Chairman of Program Committee, Board of Trustees, and Associate Professor, Center for International Environment and Development Studies, NORAGRIC, Agricultural University of Norway

Anthony K. G. Eggn (Australia), Chairman of Audit Committee, Board of Trustees, and Wheat Farmer

Romário Arroyo Marroquín (Mexico), Secretary of Agriculture, Livestock, and Rural Development

Rodrigo Avelaño (Mexico), General Director, Agricultural Research, National Institute of Forestry, Agriculture, and Livestock Research

Sérgio Chávaro Loaiza (Mexico), Dean of Agribusness Leadership, Duxx-Monterrey

Robert M. Goodman (USA), Professor of Plant Pathology, University of Wisconsin

Atsushi Hirai (Japan), Laboratory of Plant Molecular Genetics, Graduate School of Agriculture and Life Sciences, University of Tokyo

Carlos Felipe Jaramillo (Colombia), Technical Vice-Minister of Finance, Ministry of Finance

Klaus M. Leisinger (Germany), Executive Director, Novartis Foundation for Sustainable Development

Alexander McGill (Canada), Emeritus Professor, Department of Agricultural and Resource Economics, University of California, Davis

Jesús Moncada de la Fuente (Mexico), Executive Secretary, National Coordination of Produce Foundations

Norah K. Olembo (Kenya), Director, Kenya Industrial Property Office, Ministry of Research, Technical Training, and Technology

Mangala Rai (India), Deputy Director General (Crop Science), Indian Council for Agricultural Research

Timothy G. Reeves (Australia), Director General, CIMMYT

Uraiyan Tan-Kim-Yong (Thailand), Chair, Graduate Program in Man and Environment Management Program, Payao College of Graduate Study, Chiang Mai University, Thailand

John R. Witcombe (UK), Centre for Arid Zone Studies, University of Wales

Xin Zhiyong (China), Director, Institute of Crop Breeding and Cultivation, Chinese Academy of Agricultural Sciences

* Ex officio position.

PRINCIPAL STAFF

Office of the Director General

Timothy G. Reeves, Australia, Director General

Claudia Cadafi, Chile, Deputy Director General, Administration and Finance

Lucy Gilchrist S., Chile, Senior Scientist, Head, Seed Health Unit

Patricia López-M., Mexico, Executive Assistant to the Director General

Gregorio Martínez V., Mexico, Government and Public Affairs Officer

Peter J. Niness, Australia, Senior Executive Officer, Research Management

Consultant

Norman E. Borlau, USA

Maize Program

Shivaji Pandey, India, Director Marianne Bänziger, Switzerland, Senior Scientist, Physiologist (based in Zimbabwe)

David Beck, USA, Senior Scientist, Leader, Highland Maize

David Bergvinson, Canada, Senior Scientist, Entomologist

Jorge Bolaños, Nicaragua, Principal Scientist, Agronomist (based in Guatemala)

Hugo Córdova, El Salvador, Principal Scientist, Breeder / Leader of Tropical Maize

Carlos De Leon, Mexico, Principal Scientist, Pathologist / Breeder / Liaison Officer (based in Colombia)

Alpha O. Diálo, Guinea, Principal Scientist, Breeder / Liaison Officer (based in Kenya)

Dennis Friesen, Canada, Senior Scientist, Agronomist (based in Kenya)

Fernando González, Mexico, Senior Scientist, Breeder (based in Thailand)

Daniel Jeffers, USA, Senior Scientist, Pathologist

Stephen Mugo, Kenya, Associate Scientist, Breeder (based in Kenya)

Luis Narro, Peru, Scientist, Breeder (based in Colombia)

Vipo V. Pixley, USA, Senior Scientist, Breeder / Liaison Officer (based in Zimbabwe)

Joel K. Ransom, USA, Senior Scientist, Agronomist (based in Nepal)

Ganesan Srinivasan, India, Senior Scientist, Leader, Subtropical Maize / Head, International Testing Unit / Interim Associate Director

Suketoshi Taba, Japan, Principal Scientist, Head, Germplasm Bank

Strafford Twumasi-Afriyie, Ghana, Scientist, Breeder (based in Ethiopia)

Surinder K. Vasal, India, Distinguished Scientist, Breeder / Liaison Officer (based in Thailand)

Wheat Program

Bindiganavile Vivek, India, Associate Scientist, Breeder (based in Zimbabwe)

Stephen Waddington, UK, Principal Scientist, Agronomist / NRG Associate (based in Zimbabwe)

Batson Zambezi, Malawi, Scientist, Breeder (based in Zimbabwe)

Adject Scientists

Miguel Barandiarán, Peru, Breeder (based in Peru)

Salvador Castellanos, Guatemala, Breeder (based in Guatemala)

Neeranjan Rajbhandari, Nepal, Agronomist (based in Nepal)

Pre- and Postdoctoral Fellows

Julien de Meyer, Switzerland, Crop Scientist (based in Zimbabwe)

Duncan Kirubi, Kenya, Breeder

Carlos Urrea, Colombia, Breeder

Narciso Vergara, Mexico, Breeder

Consultants/Research Affiliates

Jerome Fournier, Switzerland, Consultant

Zion Gonzalo Ordaz, Mexico, Training Consultant

Sanjaya Rajaram, India, Director Osman S. Abdalla, Sudan, Senior Scientist, Regional Bread Wheat Breeder, West Asia and North Africa (based in Syria)

Arnoldo Amaya, Mexico, Administrative Manager

Hans-Joachim Braun, Germany, Principal Scientist, Head, Winter Wheat Breeding / Liaison Officer (based in Turkey)

Belgin Çakdar, Turkey, Associate Scientist, Hybrid Wheat Breeder

Efién del Toro, Mexico, Administrative Manager

Etienne Duveiller, Belgium, Senior Scientist, Regional Pathologist, South Asia (based in Nepal)

Guillermo Fuentes D., Mexico, Senior Scientist, Pathologist (Bunts / Smuts)

Lucy Gilchrist S., Chile, Senior Scientist, Pathologist (Fusarium / Septoria)

Zhong-Hu He, China, Regional Wheat Coordinator, East Asia (based in China)

Arne Hede, Denmark, Associate Scientist, Head, Triticale Breeding

Monique Henry, France, Scientist, Virologist

Man Mohan Kohli, India, Principal Scientist, Regional Breeder, Southern Corn / Liaison Officer (based in Uruguay)

Jacob Lage, Denmark, Associate Scientist, Breeder

Luz Alicia Mercado, Mexico, Wheat International Nurseries

Mohamed Mergoum, Morocco, Senior Scientist, Wheat Breeder (based in Turkey)

Muratbek Karabayev, Kazakhstan, Senior Scientist, International Liaison Scientist (based in Kazakhstan)

A. Mujeeb-Kazi, USA, Principal Scientist, Head, Wide Crosses
Visiting Scientists and Research Fellows

(for terms of at least 2 months, September 1999 to September 2000)

Frédéric Goulet, France (Natural Resources Group)
German Gutierrez, Mexico, Instituto Politecnico Nacional (Applied Biotechnology Center)
Rebecca Hedland, Australia (Information and Multimedia Services)
Mario Felipe Herrera T., Mexico, Universidad Veracruzana (Applied Biotechnology Center)
Anthony Hunt, Canada, University of Guelph (Wheat Program and Natural Resources Group)
Geoffrey Mbuthia Kamau, Kenya, Kenya Agricultural Research Institute (Maize Program)
Liu Aimin, China, Jiangsu Academy of Agricultural Sciences (Applied Biotechnology Center)
Philippe Lucas, France, DESS (Applied Biotechnology Center)
Anne Medhurst, Australia, University of Melbourne (Applied Biotechnology Center)
Araceli Moniel E., Mexico, Universidad Veracruzana (Applied Biotechnology Center)
Moon Hyeon-Gui, Republic of Korea, National Crop Experiment Station (Maize Program)
Muhammad Yaqub Mujahid, Pakistan, Pakistan Agricultural Research Council (Wheat Program)
Pak Songhak, Democratic People’s Republic of Korea, Institute of Agriculture (Maize Program)
Park Jong-Youl, Republic of Korea, Hongchon Maize Experiment Station (Maize Program)
Pablo Aldo Polci Q., Argentina, Universidad Nacional del Sur (Applied Biotechnology Center)
Quintin Rascon, Mexico, CINVESTAV (Applied Biotechnology Center)
Teresa Esperanza Rosales T., Peru, Universidad Nacional de Trujillo (Applied Biotechnology Center)
Satish Chander Sharma, India, Palampur Agricultural University (Wheat Program)
Leah Shultz, USA, World Food Prize Intern (Applied Biotechnology Center)
Dhalilwal Harcharan Singh, India, Punjab Agricultural University (Applied Biotechnology Center)
Song Kyol Ju, Democratic People’s Republic of Korea, Crop Genetic Resources Institute (Maize Program)
Víctor Félix Vásquez S., Peru, Universidad Nacional de Trujillo (Applied Biotechnology Center)
Dheya Petros Yousif, Iraq, Agricultural and Biological Research Center (Maize Program)
Zhang Fenli, China, Agricultural University of Hebei (Maize Program)

Research Coordinating Committee

Claudio Cafati, Deputy Director General, Administration and Finance
Larry W. Harrington, Director, Natural Resources Group
David Hoisington, Director, Applied Biotechnology and Bioinformatics
Peter J. Ninnis, Senior Executive Officer, Research Management
Shivaji Pandey, Director, Maize Program
Prabhu L. Pingali, Director, Economics Program
Sanjaya Rajaram, Director, Wheat Program
Timothy G. Reeves, Director General

Management Advisory Committee

Krista Baldini, USA, Senior Human Resources Manager
Claudio Cafati, Deputy Director General, Administration and Finance
Martha Duarte, Mexico, Senior Finance Manager
Larry W. Harrington, Director, Natural Resources Group
David Hoisington, Director, Applied Biotechnology and Bioinformatics
Peter J. Ninnis, Senior Executive Officer, Research Management
Shivaji Pandey, Director, Maize Program
Prabhu L. Pingali, Director, Economics Program
Sanjaya Rajaram, Director, Wheat Program
Timothy G. Reeves, Director General

Project Coordinators

(Not that “G” indicates global projects; “R,” regional projects; and “F,” frontier projects.)

Marianne Bänziger: Project 4 (G4), Increasing the Productivity and Sustainability of Maize in the Presence of Stress
Timothy G. Reeves: Project 19 (F5), Genetic Approaches to Reducing Post-harvest Losses
Natasha Bohorova: Project 17 (F3), Using Genetic Engineering to Improve Maize and Wheat for Developing Countries
Jorge Buñolos: Project 13 (R5), Enhancing Maize and Wheat Production Systems in Latin America and the Caribbean
Hans-Joachim Braun: Project 12 (R4), Increasing Cereal Food Production in West Asia and North Africa
Hugo Córdova: Project 2 (G2), Developing Core Germplasm and Integrating Interdisciplinary Approaches for Maize Improvement
Javier Ekboir: Project 20 (F6), Priority Setting and Technology Forecasting for Research Efficiency
Peter R. Hobbs: Project 11 (R3), Sustainable Wheat Production Systems in the Indo-Gangetic Plains
Olivier Leblanc: Project 16 (F2), Apomixis: Equit in Access to Hybrid Vigor for Resource-Poor Farmers
Craig A. Meisner: Project 21 (F7), Learning to More Effectively Confront Problems of Resource Degradation in Maize and Wheat Systems
Alexei Morgounov: Project 14 (R6), Increasing Cereal Food Production in Central Asia and the Caucasus
Michael Morris: Project 7 (G7), Gauging the Productivity, Equity, and Environmental Impact of Modern Maize and Wheat Systems
Iván Ortiz-Manasterio: Project 18 (F4), Improving Human Nutrition by Enhancing Bioavailable Protein and Micronutrient Concentrations in Maize, Wheat, and Triticale
Wolfgang H. Pfeiffer: Project 5 (G5), Increasing Wheat Productivity and Sustainability in Stressed Environments: Abiotic Stress
Matthew P. Reynolds: Project 15 (F1), Increasing the Yield Potential of Wheat
Ravi P. Singh: Project 6 (G6), Increasing Wheat Productivity and Sustainability in Stressed Environments: Biotic Stress
Bent Skovmand: Project 1 (G1), Conservation and Management of Genetic Resources
Maarten van Ginkel: Project 3 (G3), Developing Core Germplasm and Integrating Interdisciplinary Approaches for Wheat Improvement
Surinder K. Vasil: Project 10 (R2), Meeting the Accelerating Demand for Maize Development, Production, and Delivery in South and Southeast Asia and China
Reynaldo L. Villareal: Project 8 (G8), Building Partnerships through Human Resource Development
Stephen Waddington: Project 9 (R1), Improving Food Security in Sub-Saharan Africa