

Diversity

to Heal the Earth and Feed its

People



 **CIMMYT**
Annual Report 2001-2002 Annual Report

A Message from the Director General

In my new role as CIMMYT's Director General, I am pleased to present this report on our latest research. We have called our report *Diversity to Heal the Earth and Feed its People* to emphasize the immense value of diversity in sustaining people and the environment. The pages that follow describe the many forms of diversity that are essential to our work: genetic diversity in plants, agricultural system diversity, a varied range of research partnerships, a global research program addressing the needs of more than 100 nations, and a multinational, multicultural team of researchers based throughout the developing world.

As plant breeders, we have an abiding respect for genetic diversity, because it is the medium with which we work. Many of the stories in this report emphasize why it is vital to use new sources of diversity, such as sources of resistance to diseases and pests, tolerance to drought, and other characteristics that enable plants to withstand difficult agricultural conditions. The stories also highlight the many ways in which we are seeking diversity: by looking within the genomes of plant species, searching among the myriad collections of seed in our genebank, evaluating many thousands of experimental strains of maize and wheat, and working with farmers to preserve traditional maize and wheat varieties.

As specialists in the management of agricultural systems and natural resources, we know that agriculture cannot be sustained without diversity in cropping systems. Our research on conservation agriculture, climate change, and soil fertility reflects a holistic approach that extends beyond particular maize and wheat cropping practices to address the resource constraints and conservation needs of entire agricultural systems.

As social scientists, our effort to set research priorities is based on an analysis of the myriad factors that influence the potential for agricultural research to improve livelihoods, from the global to the local level. Nations and individuals alike pursue different paths to development, as shown in this report. These very different perspectives must be understood if CIMMYT is to make enlightened choices about its own contribution to development.

Finally, given the magnitude of the problems facing agriculture in developing countries, it is no surprise that research to solve those problems must rely on a broad spectrum of partners. To be effective rather than a mere formality, a research coalition must be able to benefit from the diverse perspectives of its partners.

It must foster the kind of participation that yields new opportunities to innovate and creates an intense human commitment to taking new paths toward a shared goal. This report provides examples of many such alliances and shows how they are having an impact in rural communities.

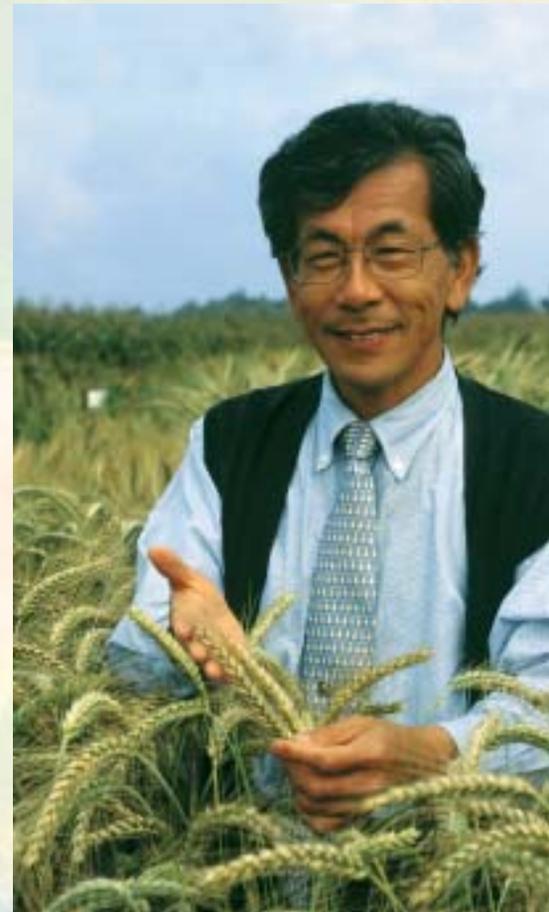
Another point that is implicit throughout this report is that diversity of any kind—whether we are speaking of genetic diversity or the diversity of our research community—is most useful in the service of a unifying vision. As we go to press with this report, we are initiating the development of a new vision and strategy for our research center. Today, when the world is sharply divided over how to sustain its people and its natural resources, it is more important than ever for CIMMYT to develop a clear vision of its mission over the next 10 to 20 years and to articulate a flexible, proactive strategy for making that vision a reality. Our new strategy, developed through extensive consultation within and outside our research center, will lay the foundation for the institutional changes that will enable us to serve the poor constructively and responsibly in the years to come. Let me describe some of the challenges that will have a decisive effect on CIMMYT's future role in development.



- The primary challenge is that food security will remain a serious concern in many parts of the world for the foreseeable future. Poverty, hunger, and malnutrition continue to affect more than one billion people. For many of these people, especially in Africa, poverty and hunger have worsened despite global overproduction of staple grains. As long as a major part of humankind cannot satisfy the most basic food needs, there can be no social peace.
- Maize and wheat will remain extremely important sources of food and income for poor people, and the productivity of maize and wheat cropping systems must be sustained.
- The increasing interdependence of nations has important economic, technological, and cultural implications that must be reflected in CIMMYT's strategies and activities.
- New research tools—particularly in genetics and bioinformatics—are revolutionizing approaches to agricultural research and development.
- It is widely acknowledged that farmers are the arbiters of what will and will not work in their agricultural systems, and research must be planned and conducted with their participation.
- The implementation of new international agreements regarding the ownership and control of global plant genetic resources, and the strengthening of intellectual property rights (IPRs) relating to the products of public and private plant breeding programs, are already altering the ways in which the public sector conducts agricultural research.
- Climate change is affecting farming environments severely, especially in developing countries. In the absence of agricultural alternatives, rural poverty and rural-urban migration will only intensify.
- A final consideration is that the mechanisms for funding public international research are changing. The extent to which governments are willing to support development assistance over the coming years, the issues that governments will wish to champion, and the willingness of non-traditional donors to turn greater attention to issues of global importance are all open questions. In the very near future, the CGIAR's recently instituted Challenge Programs will have significant implications for the way that all CGIAR Centers, including CIMMYT, fund and conduct research.

This list could be longer and more detailed, but I merely wish to give an indication of the kinds of issues that we must examine to ensure that our research remains relevant well into the future.

Perhaps the most fundamental assumption we need to make in planning for the future is that volatility and change are the only certainties that await us. How we choose to respond to the great changes and great needs in developing countries will affect the lives of millions of people, and we take our responsibility to future generations extremely seriously. Although we know that CIMMYT cannot be all things to all people and to the environment, we know that our research can be one very important thing: sustenance for people, for their communities and economies, and for the natural resources that support us all.



M. Iwanaga

Dr. Masa Iwanaga
Director General



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Acronyms and Abbreviations

ABC	Applied Biotechnology Center, CIMMYT
ADB	Asian Development Bank
AMBIONET	Asian Maize Biotechnology Network
Bt	<i>Bacillus thuringiensis</i>
CIAT	International Tropical Agriculture Center
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement, France
CONABIO	Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Mexico
Danida	Danish International Development Assistance
GIS	Geographic information systems
GTZ	Gesellschaft für Technische Zusammenarbeit, Germany
IDRC	International Development Research Centre, Canada
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
INIFAP	Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico
INRA	Institut National de la Recherche Agronomique
IRD	Institut de Recherche pour le Développement, France
IRMA	Insect Resistant Maize for Africa
IRRI	International Rice Research Institute
KARI	Kenya Agricultural Research Institute
NARO	National Agricultural Research Organization, Uganda
NARS	National agricultural research system
NGO	Non-governmental organization
NRG	Natural Resources Group
OPV	Open-pollinated variety
QPM	Quality protein maize
QTL	Quantitative trait loci
SADC	Southern Africa Development Community
SADLF	Southern Africa Drought and Low Soil Fertility Project
SPIA	Standing Panel on Impact Assessment, CGIAR
SSR	Single sequence repeat
TATRO	Technology Adoption through Research Organizations
USAID	United States Agency for International Development

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Diversity

to Support Rural Communities





COMMUNITY

Seed Production: Can Farmers Supply
Themselves and Earn a Profit?

With support from the Rockefeller Foundation, CIMMYT works with community action groups and national research programs in Uganda and Kenya, helping farmers produce and market quality seed of improved maize varieties they select.

"I see children in the classroom who are malnourished, and here we are trying to pump something into their heads! You don't teach a child who is starving." Paul Okongo, schoolteacher and farmer in Ochur Village, wanted to assist children and widows in his community. In 1993 he, his wife Joyce, and several village women founded Technology Adoption through Research Organizations (TATRO), a local group whose chief aim is to improve women's conditions by involving them in agricultural development and small agribusinesses. The association has logged so many accomplishments that Ochur is commonly referred to as "TATRO."

Their participation in the CIMMYT-Rockefeller seed production project* is one element in a plan that includes crop diversification, seed production and marketing, and information dissemination. TATRO farmers, who are beginning to produce seed of improved maize varieties, hope to supply seed for their own needs and profit by selling the rest to other farmers. An innovation that could help is a communal seed storage bank, which allows participants to deposit and withdraw seed as needed.

Maize in East Africa: A Litany of Limitations

Maize is the major staple in Kenya and increasingly important in Uganda. Expanding populations are pushing up the demand for maize by 3% or more each year. "Average per capita consumption is 100 kilograms of maize a year, but one person can eat as much as 200 kilograms," says Moses Siambi, a researcher seconded to the seed project from the Kenya Agricultural Research Institute (KARI). "In a bad year farmers may harvest as little as 180 kilograms of grain per hectare. The average farm family has eight or more members and less than two hectares."

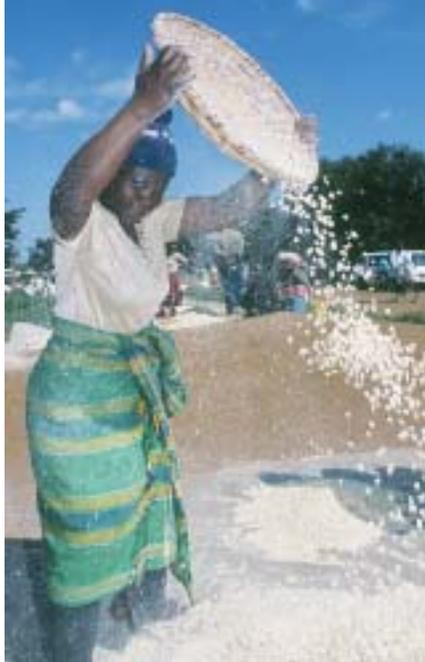
What keeps yields down? Agriculture is rainfed and conducted within complex, labor-intensive cropping systems beset by frequent droughts, diseases, field and storage pests, weeds, the parasitic flowering plant *Striga*, and poor soil fertility. As if this were not enough, 65% of Kenya's populace lives in the Lake Victoria Basin, one of the regions most severely affected by HIV/AIDS worldwide. The disease breaks up households and leaves little labor for fieldwork.

The lack of effective seed production and distribution systems limits the spread of improved maize and farming practices in eastern Africa, according to Stephen Mugo, CIMMYT maize breeder and coordinator of the seed project. "Improved varieties raised yields in the past and could do so again," he says, "but only about one-fifth of the region's farmers grow improved varieties." Even when farmers have cash to spare, they have trouble finding quality seed of varieties that fit their needs, despite the many suppliers.

The project sought to familiarize farmers with the range of improved varieties available. Researchers grew two "mother" trials, each comprising 20-30 varieties or hybrids, in each participating village; 7-12 farmers per village grew "baby" trials, with each farmer sowing four of the same varieties grown in the mother trial. "The baby trials were laid out in a four-square design, with one variety in each square," says Siambi. "Farmers could stand in the center of the field and judge performance at a glance." The mother trials were sown with and without fertilizer. "The dramatic differences in performance showed farmers the importance of fertilizer," says Siambi. "This is a major accomplishment, because conventional wisdom in the region is that inorganic fertilizers hurt the soil."

* "Strengthening Maize Seed Supply Systems for Small-Scale Farmers in Western Kenya and Uganda."

In 2001, two varieties from CIMMYT's stress tolerance breeding work for southern Africa—SADVILA and SADVILB—topped the trials in Kenya, beating out even leading hybrids included in the trials for comparison. Farmers in some villages have already begun producing seed of the varieties. The project is increasing foundation seed so others can do the same.



Community seed production helps women earn income and gain some control over the resources they generate.

Uganda: Women Propel Community Development

"In Uganda improved seed or inputs are not readily available in villages," says George Bigirwa, head of maize research for the National Agricultural Research Organization (NARO) and seed project coordinator in Uganda. "But in the last five years farmers have had greater access to credit, inputs can be imported duty-free, and the government has encouraged the establishment of farmer associations." Governments in both Kenya and Uganda are promoting gender equity to foster development and improve the quality of rural life. Community groups play a key role.

One such group, the Bakusekamajja Women's Development Farmers Association in Iganga District in eastern Uganda, participates enthusiastically in the seed project. The association marshals the efforts of more than 450 local farmers. Founder Grace Bakaira first mobilized a handful of women in 1986, organizing training in handicrafts and growing vegetables, but now she catalyzes a range of community and agricultural development activities involving entire families. "People wanted to organize," she says. "It's easier to solicit support collectively from NGOs and government agencies."

In an approach like that of TATRO, Bakusekamajja helps women undertake activities that bring money to the family and provide women with some control over resources they generate.

Bakusekamajja began seed production in the mid-1990s. The group has committees for planting, harvesting, and marketing seed. It sells seed of Longe 1 (a cross of Kawanda Composite and CIMMYT population 49) to members at the equivalent of US\$ 0.50 per kilogram—about 20–40% cheaper than commercial hybrids.

According to CIMMYT maize breeder and seed production expert David Beck, the project gives Bakusekamajja technical support but also learns from the group's success. "Elements I see include dynamic leadership by Grace Bakaira and her associates, excellent organization, good communication, close partnering with technical organizations such as NARO, good choice of a variety, and careful attention to the details required to produce quality seed," Beck says. "Last but not least, there is a special bond among members that I can only describe as 'divine.' "

Seeking Markets

A common concern voiced by farmers is that of securing markets for grain and, eventually, seed. In its next phase, the project will address the seed market issue. Bakaira recognizes collective organization as a key strategy: "Rather than attempting to sell seed individually, farmers need to pool their seed and seek an external market." Quality is crucial: producers of seed must

guarantee its genetic purity and ability to germinate. Ensuring purity means separating seed production plots either in distance or time from the pollen of other maize plants. Germination depends in part on proper storage and treatment. "If farmers grow seed properly and harvest and treat it correctly, maybe farmers elsewhere will want to purchase it," says Bakaira.

Not all farmers have the means or the inclination to produce and market quality seed, but those who do could improve their livelihoods. "We hope the seed reaches farmers who desire quality seed but cannot afford to buy it from companies that operate at high cost," says Mugo.

Partners in Kenya have included KARI; NGOs such as Catholic Relief Services (CRS) through the Catholic Diocese of Homabay, the Sustainable Community-Oriented Development Programme (SCODP), and CARE-Kenya; many seed companies (Faida Seeds, Lagrotech, Western Seed Company, Kenya Seed Company, Pioneer, and Monsanto); and village schools. In Uganda, the project has worked through NARO, NGOs (IDEA, UNFA), Pannar Seed Co., FICA, Faida Seed, and Western Seed, among others.



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As Incomes Grow in CHINA, What Happens to Maize Production?



**CIMMYT
economist Erika
Meng traversed
China in 2002 to**

examine the effects of increased incomes and changing diets on maize production. While surveying farmers—men and women, rich and poor—in six provinces, she and her colleagues at the Center for Chinese Agricultural Policy, Chinese Academy of Sciences, encountered a spectrum of economic, environmental, cultural, and political variables affecting maize production.

Through her photographs, Meng narrates some general impressions of farmers' practices and concerns.

1 Interview group: “I was always a bit surprised that villagers participated so openly in interviews. This was partly because of an innate sense of hospitality, and partly because of responsibility to village or county officials who asked them to help us. And with the increased general openness, there are fewer reasons not to be frank. Informal discussions like this would have been much more difficult several years ago.

“We tried to make them as comfortable as possible and tried to go beyond agriculture. We asked about all kinds of constraints or problems they were having. They would bring up different topics, such as education costs, rural/urban gaps, and lack of promised compensation for replacing staple food crops with trees to prevent erosion.

2 Buying versus saving seed: “This is a large regional grain exchange in Shandong Province for farmers and traders from the surrounding area. Because of changes in the Chinese seed industry and overall seed



system, organizations are increasingly required to come up with their own funding for research and salaries. Many are now selling seed to raise funds. The focus is overwhelmingly on hybrid varieties due to the need to replace seed annually.

“There has not been a lot of emphasis in the Chinese research system on open-pollinated varieties [OPVs], but in Guangxi, a relatively poor province in southwestern China, people in many villages still eat maize as the primary staple and use it for livestock feed. A considerable percentage of the maize area is still planted with OPVs. Many farmers there felt the hybrids were not suitable for their often marginal growing conditions.”



3 Maize for livestock feed: “Most of the livestock in China continues to be raised on household farms like this one. Large-scale farms for cattle and pig production are still not common. In most of the country, farmers produce maize primarily to feed their animals and will often store it outside or in containers such as these homemade bins.”

Challenges to maize production, northeastern China: “In the northeast, where maize and soybeans are the main crops, the livestock industry hasn’t developed as much as in warmer parts of the country. Heat for the animals has just been too expensive. Maize is more important as an income source. The northeast faces some unique challenges: the local market is fairly saturated, with part of the problem caused by transportation infrastructure. But moving maize from the northeast to other parts of China has often been more expensive than importing it from outside. With China’s entry into the World Trade Organization, domestic subsidies and other means of protection will be phased out, and the domestic market will open up to foreign production. There is no question that there will be a maize influx.

“There are currently limited possibilities for utilization in the northeast and limited crop diversification possibilities because of climatic constraints. A big question is what is going to happen to farmers and production in that region.”

4 Farmers have very different opportunities: “Normally, they would already have planted maize between the rows of wheat shown here, but this was an exceptionally dry season and farmers were still waiting to plant. In many regions, farmers lay sheet plastic over the seedlings to trap moisture, and increase the temperature. The price of the plastic varied greatly from region to region, and not all farmers were able to use this technique.

“Also, maize usually lost out in the competition for flat land to rice and higher value crops. Farmers use terracing to get as high up on the hillsides as they can—sometimes terraces are as narrow as 4–5 rows of maize.

“It’s important to remember that even within one village farmers are going to have different opportunities and different transactions costs.”

5 Using every inch of land: “This is a field in Sichuan, in the southwest. It’s incredibly diverse there and very fertile. Farmers use every inch of the land. Because Sichuan is one of the most

populated provinces, the per capita arable land is one of the lowest in the country, but they get everything possible from it. Wheat is intercropped with vegetables and then maize with the wheat. What you see here are mulberry trees for silkworms. They can harvest five or more crops a year from one field!

“We would drive along and even see maize squeezed between rocks on the hillside next to the road.”

6 Planting maize for food: “In many parts of China, people refuse to eat maize. One of my colleagues in these surveys grew up in the fifties. Almost all his family had to eat was steamed maize buns. That’s all. To this day he won’t eat anything having to do with maize.

“Some villages we visited in Guangxi had recently switched from consuming predominantly maize to consuming more rice. Part of it has to do with increasing economic status: rice is considered to be a higher-class food than maize. However, in cities, people have begun to eat sweet maize almost as a kind of gourmet snack.”

Note: CIMMYT appreciates the contributions of Elizabeth Fox, US Congressional Hunger Fellow, in preparing this photo essay.



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CONSERVATION AGRICULTURE:

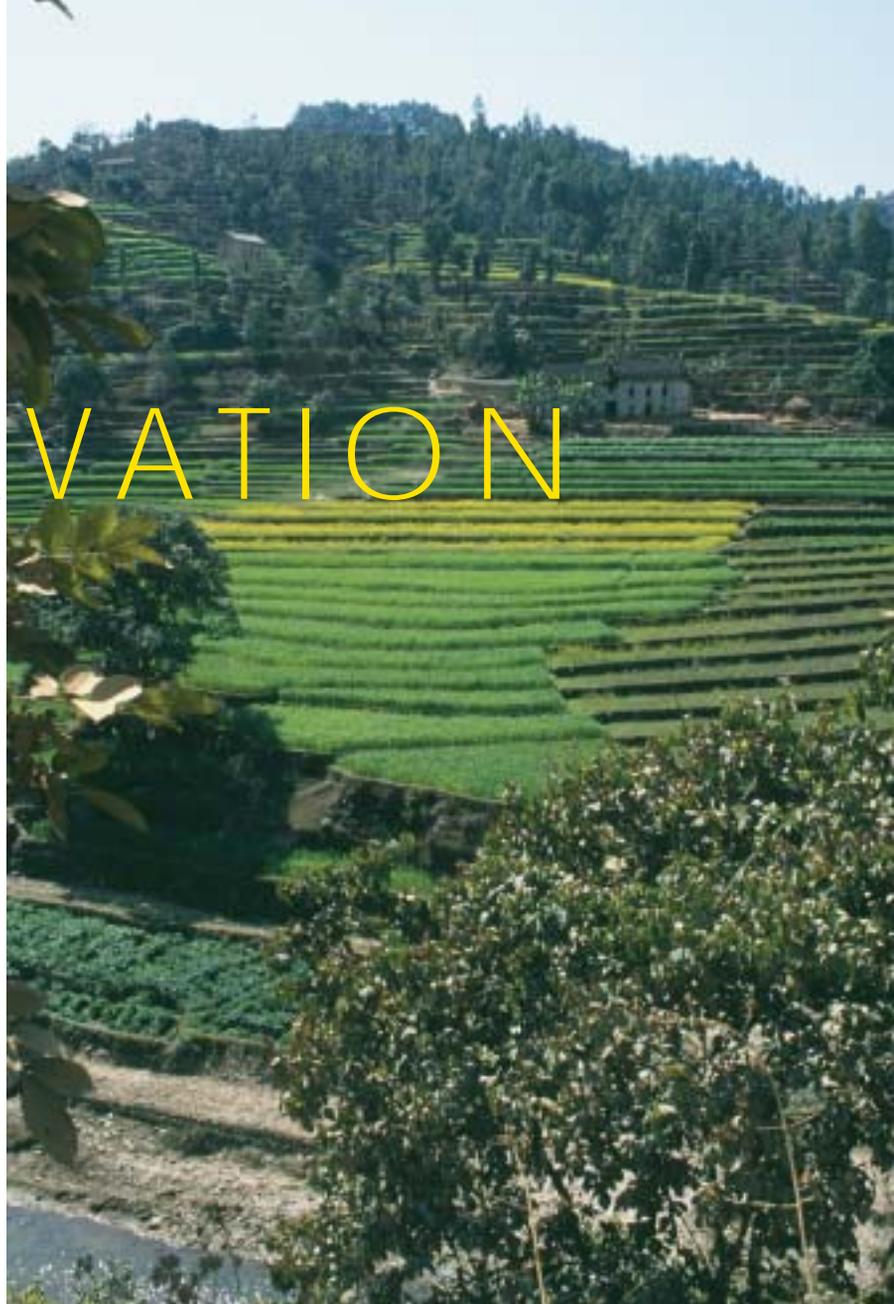
Feeding the World without Consuming Natural Resources

Bucking Tradition

“We’re not talking about small changes. Conservation agriculture represents a total departure from conventional farming,” says Patrick Wall, agronomist and coordinator of CIMMYT’s global program on conservation agriculture.

Conservation agriculture can be described as the retention of crop residues and use of rotations and, sometimes, green manure cover crops.

The learning curve for conservation agriculture can be steep, especially for farmers with limited access to information outside their own communities. Subsistence farmers will not risk using a new practice unless they are sure it addresses their problems. CIMMYT agronomist Peter Hobbs, who has worked with resource-conserving technologies in South Asia, understands farmers’ skepticism. “At a site in Haryana State, India,” he recalls, “a neighbor who saw his friend using zero-tillage brought a bag of wheat to his house, saying, ‘You have destroyed your land.



Conservation agriculture would seem like a natural choice for subsistence farmers in developing countries, but few practice it. What’s holding them back?

Here is some food you will be needing to feed your family.' But once the neighbor saw the harvest, he also wanted to experiment with zero-tillage."

This story illustrates that farmers who buy into a conservation practice also become its most convincing advocates. In Bolivia, where Wall and his colleagues promoted conservation agriculture, farmer-to-farmer interactions were crucial. "We didn't convince farmers to go into zero-tillage—other farmers did that. We brought in farmers from around the region to tell local farmers about their experiences and success," he says. "Later, once the local farmers had acquired experience, we worked with them to develop a manual called *By Farmers for Farmers*."

Participatory Routes to Success

For conservation agriculture to work, a diverse group—researchers, farmers, input supply companies, extensionists, and farm implement manufacturers—must share ideas and products. "Many public research and extension institutions were not set up to participate in such innovation networks," says CIMMYT economist Javier Ekboir. "They want to follow the traditional process of testing all aspects of a technology before passing it to extension and farmers."

"Rather than being the prime movers of change, researchers must come in behind it and solve the problems that emerge, supporting continuous adaptation and follow-up," says Wall.

Successful promotion of conservation agriculture has also depended on individuals or organizations who ensure that farmers receive the information and support to assess conservation agriculture and adopt it, if they desire. "These catalytic agents sometimes are local scientists or extension workers who move forward without support from their own organizations. They bring participatory research methods, promote the exchange of information, provide access to products from advanced research institutes, and mobilize funding," says Ekboir.

Finally, Hobbs observes that access to affordable, suitable, locally manufactured equipment for seeding directly into residues is crucial for conservation agriculture to spread. "Without it, farmers can't even begin to experiment," he says.

For more information on adapting zero-tillage to the needs of smallholders in developing countries, see CIMMYT's *2000-2001 World Wheat Overview and Outlook*.



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Accomplishments

Conservation agriculture means many things to many people, but a key tenet is sustainability. In almost all cases, this means managing mulches to conserve soil organic matter. Other cropping systems that conserve other vital resources—water, fuel—or reduce greenhouse gas emissions represent a move toward sustainability. CIMMYT has supported the spread of conservation agriculture in various ways. This brief selection of examples gives an idea:

- In the late 1970s and early 1980s, CIMMYT agronomists taught developing country researchers about zero-tillage systems in a course at CIMMYT headquarters.
- Since the early 1980s, CIMMYT and local researchers have fostered participatory approaches and expanded partnerships that led zero-tillage to be used in wheat production on some 207,000 hectares in South Asia by 2002. The practice saves 75% or more fuel, obtains better yields, uses about half the herbicide, and requires at least 10% less water—equivalent to 1 million liters less on a hectare of land.
- During 1994–2001, CIMMYT helped promote zero-tillage and crop rotations in Bolivia by working with local partners to organize a network of research institutions, farmer associations, and progressive farmers. By 2000, farmers were using the new practices on 300,000 hectares in the eastern lowlands.

CIMMYT's Work in Conservation Agriculture

- In 1994, CIMMYT formed a network to help Malawian and Zimbabwean maize farmers make their poor soils more productive. The network recently expanded its efforts to Mozambique and Zambia and will now cover policy issues relating to soil fertility.

Hopes and Hard Work

As coordinator of research on conservation agriculture at CIMMYT, Wall will work with partners worldwide, including CIMMYT wheat agronomist Kenneth Sayre, an expert in the cultivation of cereals on raised soil beds and agricultural machinery for conservation agriculture.

In Mexico, a project initiated in 2001 by agronomist Bernard Triomphe will foster wide adoption of conservation agriculture in the Bajío region, where intensive, irrigated maize-sorghum cropping faces a serious water shortage. The work is supported by the French research agency CIRAD (Centre de coopération internationale en recherche agronomique pour le développement) and involves Mexican institutions and farmers.

“In South Asia,” says Wall, “we have to find ways to increase the amount of crop residue left on the soil surface. In the rice-wheat system, we have to manage rice using resource-conserving principles like those being adopted for wheat, and expand into other cropping systems.”

As for sub-Saharan Africa, Wall considers the very dry areas particularly worrisome. “Drought is a major problem, but water-use efficiency—the ratio of rainfall converted into crop production—is also important. Well over 50% of the rainfall runs off fields. Finally, unless farmers begin to leave residues to restore soil organic matter, agriculture there will not be sustainable.”

Wall concludes that zero-tillage is functioning well in a broad range of conditions, but says researchers still don't know how to make it work in a few spots. “One is under dry conditions where you can't

produce enough crop residues,” he explains. “Another is where there are drainage problems, and zero-tillage can make them worse. Finally, it's tough to get the system going in very degraded areas with a long history of conventional tillage.”



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How can we stop scorched-earth policies in agriculture?





Drought Relief, Seed Relief in Sight

A devastating combination of events, orchestrated by nature and by human beings, is forcing an estimated 14 million people into starvation in southern Africa.

Farmers See Results

Erratic rainfall and drought are recurring problems in southern Africa, which is why the Swiss Agency for Development and Cooperation and the Rockefeller Foundation funded the Southern African Drought and Low Soil Fertility Project (SADLF), involving CIMMYT and national agricultural research programs of the Southern Africa Development Community (SADC) region.

“The SADLF project was initiated in 1996, and now we’re seeing the first benefits,” says Masa Iwanaga, CIMMYT’s director general. Stress-tolerant, open-pollinated varieties (ZM421, ZM521, and ZM621) from the project have been released in Malawi, South Africa, Tanzania, and Zimbabwe, and they are also being used in Angola and Mozambique. In trials grown from Ethiopia to South Africa in 1999, ZM521 produced an average 34% more grain than other improved varieties farmers currently grow.

Since 2000, CIMMYT and partners from national programs and NGOs have channeled more than 70 tons of seed of these varieties into community-based seed production in Angola, Malawi, Mozambique, South Africa, Tanzania, Zambia, and Zimbabwe. The varieties are spreading (see “Project Partners Affirm Impact,” p. 15). More than 500 tons of commercial seed of these varieties has been produced so far—enough to plant 25,000–30,000 hectares.

The project is testing a newer generation of drought-tolerant, open-pollinated varieties whose productivity exceeds that of ZM421, ZM521, and ZM621 by 15%.

Hybrids on the Horizon

More than 2.5 million hectares are planted each year to hybrid maize in eastern and southern Africa (excluding South Africa). Most hybrid seed is produced by private companies and grown by smallholders. SADLF developed several hybrids that produce over 50% more grain at the 1 ton per hectare yield level—the typical yield in many farmers’ fields—and continue to exceed the best check hybrids from private companies by an average of 1 ton per hectare, up to the 10 ton per hectare level (measured from 35 trials conducted across eastern and southern Africa in 2001).

Maize affected by drought.



Agriculture without Choice

Every year, each of the nearly 150 million people in the SADC region consumes on average 91 kilograms of maize and earns only US\$ 230 (excluding South Africa).

Throughout eastern and southern Africa, annual maize production averaged 16.2 million tons over the past 20 years, barely resulting in food self-sufficiency. During the same period, production levels fluctuated between 7.3 and 22.4 million tons—indicating just how variable and uncertain maize production can be. Nevertheless, farmers' choice to grow maize is economically rational, and substituting another crop for maize is not likely to increase food security.

Over 100 million people in the SADC region live in rural areas, in large households that farm 0.5–3.0 hectares. The average yield for maize region-wide is 1.2 tons per hectare, but in drought-affected years or on widespread, infertile areas, farmers obtain less. Farmers are trapped in low-input, low-risk, but low-productivity cropping systems because they are trying to deal with an unstable climate, declining soil fertility, rising population pressure, high input costs, and poor credit systems.

At the farm level, poor productivity limits incomes, nutrition, health, and education. At the national level, the impoverishment of agriculture is reflected in a poorly developed agricultural input sector, grain imports, food aid, unstable maize prices, and recurring hunger.

Better Choices for Seed Relief

The SADLF project's goal—to provide smallholder farmers with more appropriate stress-tolerant maize varieties—relies on a system in which *any* breeding program in the SADC region (CIMMYT, national programs, private companies) can test its maize for qualities important to resource-poor farmers. These include tolerance to drought and poor soils (low nitrogen, acidic, low phosphorus) and resistance to diseases and insect pests. Maize is tested in researcher-managed regional trials as well as farmer-participatory on-farm trials (called "Mother-Baby" trials), which are a collaborative effort between national agricultural research and extension programs, NGOs, and farmers.

Ministries of agriculture, NGOs, and private seed companies use the trial results to provide farmers with better varieties. Because of the drought, thousands of tons of maize seed are currently being made available to farmers by agencies such as World Vision, Catholic Relief Services, Africare, and CARE International. Marianne Bänziger, a maize physiologist based in Zimbabwe who leads the SADLF effort, points out that the trial results can help relief agencies make better decisions about which varieties to supply. "The right choice can result in a yield increase of 20–35% for recipient farmers," she says.

"For drought relief in the Southern Province of Zambia, GTZ will support the purchase of only those varieties that have been previously tried and selected by farmers," reports Ortwin Neuendorf of the GTZ/Small Scale Seeds Project, Zimbabwe.



Environmental Impact

"Maize varieties that yield better under stress will not be sustainable if they take a toll on the environment," says Bänziger. As stress conditions increase, maize plants increasingly fail to produce a cob, but they still use nutrients and water. Stress-tolerant maize varieties are efficient: they put those resources into grain production, but the overall uptake of water and nitrogen remains virtually the same.

The environment may also benefit indirectly when farmers experience better harvests. With less fear of crop failure, farmers may be more inclined to invest in their maize crop and purchase fertilizer, or take other steps to improve soil fertility and conserve water. Because of the high risk of drought, many farmers plant more maize area than needed to be sure their families will not suffer hunger if rainfall is poor. Drought-tolerant maize varieties ensure improved food security on a smaller area. Farmers can allocate more land and labor to legumes and cash crops, thereby improving incomes and soil quality.



Forestalling Famine

The project brings together more than 30 core participants, 50 institutions, and 1,000 farmers in approximately 100 farming communities. Today the national maize breeding programs in Angola, Botswana, Malawi, Mozambique, South Africa, Tanzania, Zambia, and Zimbabwe, as well as the CIMMYT-Zimbabwe program, annually screen thousands of maize cultivars for drought tolerance. Through regional collaboration, the other SADC countries gain access to the best of these cultivars. As awareness of this successful breeding strategy has spread, several private seed companies recently initiated similar strategies.

“Our job is to give farmers an option where rainfall is erratic and socioeconomic factors restrict access to fertilizers,” says Iwanaga. “This project will not give up until farming families can access seed of varieties that will make them less vulnerable in the future.”

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Project Partners Affirm Impact

The largest impact of SADLF on the Malawi Maize Program has been the release of...ZM421, ZM521, and ZM621. Demand is more than the supply of these varieties. At present all the breeder seed for these varieties has been sold to farmers, and farmers are still looking for more breeder and foundation seed.

–**Gresham W. Nlhane**, Ministry of Agriculture, Malawi

Farmers have sold seed throughout the area and neighboring wards and districts. There is strong demand for the ZM521 variety that appears to be better adapted to drought than other varieties.... They reported that during the vegetative crop development stages, there was a serious drought that lasted over six weeks. Most varieties succumbed but with the little rain in February the CIMMYT varieties picked up to such an extent that most people doubted that they were ever severely water stressed.

–**Temba M. Musa**, GTZ/Small Scale Seeds Project, reporting on Limpopo Province-Based Local Seed Provision Systems in the Northern Province, South Africa

The biggest impact will definitely be the adoption of the improved stress-tolerant varieties, which will improve food security and incomes of the resource-poor farmers in the country.

–**Zubeda O. Mduruma**, Maize Program Coordinator, Tanzania

The ZM421, 521, and 621 series of open-pollinated varieties have been released and multiplied throughout their area of adaptation, and farmers are today benefiting from this investment and harvesting more maize under the marginal growing conditions that are common to the region.

–**Joseph D. DeVries**, Associate Director, Food Security, Rockefeller Foundation

SADLF is a success story on grounds of...innovative approaches in farmer participatory research, combining traditional and modern knowledge. Results...will contribute to the stabilization of farmer income and food security.

–**Thomas Zeller**, Deputy Head of Division, East and Southern Africa Division, Swiss Agency for Development and Cooperation

Small-scale farmers should always have an opportunity of viewing and trying new and improved varieties. This project seems to be a perfect vehicle for that.

–**Richard Ramugondo**, Department of Agriculture of the Northern Province, South Africa

Central Asian Nations:

Different Paths to Development

Since the Soviet Union collapsed in 1991, the former Soviet republics have chosen different strategies to meet their new national objectives, including their priorities for wheat production.

CIMMYT, which works with all of the Central Asian republics, realized that detailed information was needed on the wheat economy to chart an appropriate course for collaborative research. In late 2001, CIMMYT economist Erika Meng spent two months in Kazakhstan, Tajikistan, Uzbekistan, and Kyrgyzstan, collecting information on current and future wheat productivity, wheat competitiveness, and potential regional research links.

“In each country, I tried to obtain information on policy directions and priorities for agriculture and then to get a better understanding of the role of wheat in the agricultural sector,” Meng explains. “We needed information on the priorities for wheat research, the level of interaction between scientists and farmers, and the inputs and information available to farmers. We also lacked a lot of basic statistical data. In addition, I tried to collect information on marketing and transportation infrastructure, the overall institutional environment, and irrigation facilities.”

Some of her findings are briefly outlined here.

Kazakhstan

Relatively low government involvement and financial support exist for the agricultural sector in Kazakhstan, the largest Central Asian wheat producer. Kazakhstan’s economy declined sharply after independence, and its economic woes were later compounded by drought and recession in Russia, an important export market.

“The use of agricultural inputs has risen somewhat in the last two years but remains low in wheat production. And the basic infrastructure for technical information and markets lags behind,” explains Meng. High debt levels and recent land tenure changes that limit the size of landholdings and the duration of land rights contracts could also influence farmers’ behavior. “Another interesting development is the consolidation of market power by a group of large, vertically integrated grain companies,” says Meng.



Tajikistan

Tajikistan is still recovering from civil war in the mid-1990s. Only 6% of the land in this mountainous country is arable, and resource constraints are felt quickly. Agriculture is the largest economic sector.

The civil war took a great toll: its effects are evident in the economy and infrastructure. “While political stability seems to be improving, recent drought in parts of the country has undermined people’s ability to recover,” says Meng.

Wheat, the most important food crop for households, is grown largely to satisfy subsistence needs. Given the pressing need for suitable varieties and seed, the main focus of national research institutions, international organizations, and NGOs has been to identify varieties and to multiply and distribute seed.

Despite the importance given to wheat production in national priorities, at the local level it often loses in the competition for land and other resources (particularly water) to cotton, the country’s main crop before independence and one of its few export commodities.

Uzbekistan

Food security, interpreted largely as food self-sufficiency, is one of the most important government policies in Uzbekistan, where consumption needs are approximately 3 million tons of grain for food and 1.5 million tons for feed. The Uzbek government is heavily involved in all aspects of wheat production, from recommending varieties to producing and ensuring supplies of seed and fertilizer

“In Uzbekistan irrigated land was largely allocated to cotton before independence, and wheat was grown almost exclusively on rainfed land,” comments Meng. Given the priority placed on food security since independence, a concerted effort was made to increase irrigated wheat area. Wheat area is now mostly irrigated and has held steady at approximately 1.4 million hectares. Yields are about 2.6 tons per hectare.

Kyrgyzstan

In the last five years, wheat area in Kyrgyzstan increased from slightly over 193,000 hectares to 480,000 hectares, with yields of around 2.4 tons per hectare. Kyrgyzstan differs from Tajikistan and Uzbekistan in that national wheat research was better established before independence. Kyrgyzstan is also the only Central Asian country that is a member of the World Trade Organization and the International Union for the Protection of New Varieties of Plants.

“It was the only country I visited where plant breeders’ rights, patents for crop varieties, and royalties featured prominently in discussions with scientists,” Meng says. “There is great interest in the development and commercialization of an international seed industry, but they still have a ways to go.”

Evolving Roles for Research Economists

Meng also found that the roles of economists in some Central Asian research institutes are still evolving. “Past economics research was not particularly independent and was largely carried out to be in line with government policies. The trend is shifting towards more objective research, but political pressure is still quite strong in some places. There is also some reluctance to make data available to outsiders and not much of a tradition of collaboration and sharing research results,” Meng says.

These aspects of economics research are likely to change as a program of regional collaboration develops. “It will be a long-term process,” says Meng, “since changes can be accomplished only through more interaction and communication within and outside the region, and through an increased familiarity with new economic and political principles.”



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Triticale, the result of a researcher-made cross between wheat and rye, is not widely sown, or even widely known, though it has been around since the 19th century, and CIMMYT has worked on it for more than 30 years. Originally promoted as a new grain for human consumption, triticale has made little headway against more established crops. Livestock are happy to change their eating habits, however, and triticale is coming into its own for its adaptability as a feed and forage crop in difficult growing environments.



TRITICALE

Helps Farmers Diversify

Is This Unusual Crop Coming into its Own?

Triticale is excellent in baked goods and flat breads, but its present appeal is that it gives farmers numerous options for feeding dairy and beef cattle, sheep, pigs, and poultry. Since triticale is tolerant to drought, frost, and problem soils, it can be grown in seasons and places where other crops will not grow so well, sometimes making it the only source of animal feed. In such adverse conditions, triticale yields more biomass (stems and leaves) and also more grain than competing crops.

A good source of protein and energy, triticale is sown on more than 3 million hectares worldwide. As scientists and farmers discover its versatility, it is gaining ground in several countries, including Mexico, Poland, China, Belarus, Germany, and Australia. Despite these advances, the crop could be better known in other countries where farmers would benefit greatly from it.

Diversifying the Menu—and the Farming System

CIMMYT has developed different types of triticale for different uses. Grazing varieties produce a lot of biomass and can sprout several times after being grazed by livestock.* Other varieties can be cut for forage, left to grow again, and go on to produce grain. Still others produce highly nutritious grain for animal feed. Dual-purpose triticales can be grazed and/or grown for feed and forage,

particularly in environments with relatively long periods during which few other sources of animal feed are available.

These special-purpose varieties are gaining acceptance. For example, a group of farmers in Mexico's Yaqui Valley is enthusiastic about growing triticale instead of durum wheat for feeding pigs. They will sow more land to triticale next season. This strategy will also diversify their farming system, which is 80% wheat. This preponderance of wheat places the wheat crop at high risk for diseases such as the rusts. More rust resistant than wheat, triticale also competes better with weeds. Farmers do not have to spend money controlling weeds and rust.

Dairy farmers in Cuatro Ciénegas, Coahuila, Mexico, have implemented a novel system for grazing young milk cows. In a large, round triticale field, a structure is set up that divides the field into segments like a pie and keeps the cows grazing in one section at a time. The structure is advanced as the crop is grazed. The system relies on a triticale variety bred especially for grazing. The cows graze the entire field, section by section, four or five times over a six-month period, and the crop persistently comes back up after being grazed.

In the northern Mexican state of Chihuahua, farmers grow oats for winter forage, but the crop is sometimes damaged by frost. In view of its cold tolerance, triticale is being tested as an alternative to oats by the CIRENA research group (a training, research, and extension organization of Mexico's Ministry of Education), with CIMMYT's

help. CIRENA is also active in another part of the state, where Mennonite farmers grow oats for forage in the summer. Researchers are trying triticale to see how it fares in such droughty conditions. Results so far have been excellent: triticale produces 100% more biomass than oats and—an unexpected advantage—on less water. Farmers can feed their livestock and cope with the dwindling water supply.

Meeting Local Needs

CIMMYT has bred triticales useful to national research programs in low-income countries seeking to adapt triticale to local conditions. In Bangladesh, for example, dairy farmers sow triticale for grain to feed their milk cows: it produces more grain than wheat in places where water is scarce. In the Ecuadorian highlands, where the climate is particularly harsh and barley is the leading food cereal, triticale is sown mostly by small-scale farmers looking to broaden the options for feeding their families.



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* Triticale sprouts again because livestock are put to graze on it when the plant's growing point is still below the soil surface.

Safe Haven for Insects

Helps Protect Farmers' Crops



There is something different about Margaret Mulaa's trial plots at the National Agricultural Research Center in Kitale, Kenya. The trial seems more like a botanical collection or an ornamental garden, featuring Guinea grass, napier grass, Giant Panicum, and Sudan grass, not to mention local and exotic sorghum varieties. Mulaa is happy when she discovers insects, particularly stem borers, devouring her plants. What's going on?

Seeking Refugia

The Insect Resistant Maize for Africa (IRMA) Project, a collaboration between CIMMYT and KARI, funded by the Syngenta Foundation for Sustainable Agriculture, uses biotechnology and conventional breeding to develop maize resistant to stem borers, one of the most devastating pests in Africa. Mulaa, a KARI entomologist, and her CIMMYT counterpart, entomologist David Bergvinson, seek plants that might serve as refugia in a system for limiting insect resistance to Bt maize, a genetically engineered plant that represents one of the best hopes for controlling stem borers.

Although Bt maize differs from other pesticide technologies because it produces its own pesticide rather than requiring spray applications, it shares a vulnerability common to plant protection measures: the target pest can build up resistance. To prevent this from happening, farmers in developed countries must plant a significant proportion of their fields (e.g., 20%) to varieties that are susceptible to the target pests. These *refugia* provide a safe haven where insects that would otherwise succumb to the Bt toxin can reproduce. The resulting populations of susceptible insects mate with the few resistant insects that evolve and greatly slow the development of pest populations resistant to the Bt toxin (or any other form of insect resistance controlled by a single gene). Refugia are a central component of a broader insect resistance management strategy, which includes integrated pest management and the combination of multiple sources of insect resistance in the maize plant.

Different Cropping Systems, Different Refugia

Mulaa and Bergvinson must develop economically viable management strategies suited to small- and large-scale cropping systems in Kenya's five major maize growing regions.



The most demanding clients of refugia are not farmers but insects. Each borer species has its own characteristics and life cycle. The borers must find the refugia plants attractive for oviposition (egg laying); the plants must then support larval development and provide a favorable environment for the borers to complete their life cycle. Further complicating matters, the stem borers must develop at about the same rate on the refugia plants as in the maize crop, to synchronize their mating.

Given all this complexity, why not ask farmers to plant susceptible maize, as in developed countries? Although this approach might work for large-scale growers, the economics work against resource-poor smallholders, the majority of Kenya's farmers. For large-scale farmers, identifying and planting alternative refugia could significantly reduce the area needed for susceptible maize, thereby increasing overall yields.

Plants with Insect Appeal

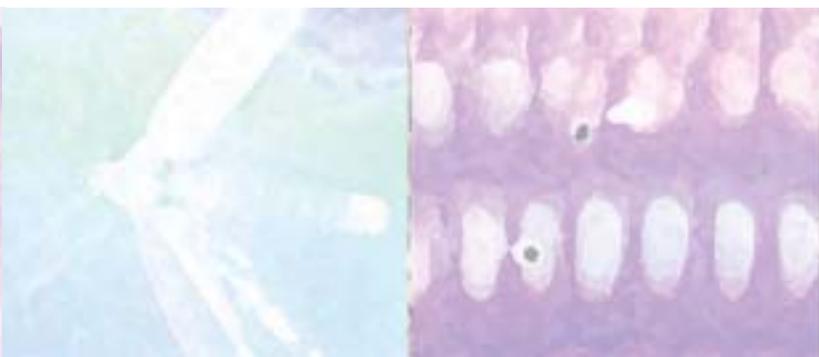
Mulaa multiplied prospective refugia plants at Kitale in 2000. The next year, 30 alternative hosts for stem borers were evaluated in experiment station trials in four of the five maize growing regions. Sorghum,

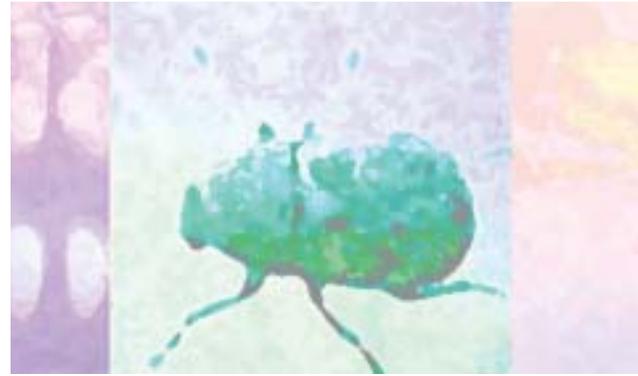
particularly local varieties, had the highest borer damage rating and number of exit holes (which indicate larval survival). Columbus grass and Sudan grass appeared effective as refugia but were not economic. Napier grasses supported oviposition and provided good economic returns but did not excel for larval development.

Laboratory bioassays were also undertaken in 2001, using the most common stem borer species, to determine larval survival and development, as well as fecundity, on a range of hosts. Specific sorghum varieties, maize hybrids, and forage grasses supported stem borer survival and development well. The results are being verified and integrated with experiment station data.

Devising the right refugia for each category of farmers is a challenge. Farmer surveys are being completed in the highland area of Kitale, the lowland tropics (Mtwapa), and the midaltitude dry zone (Katamani). The midaltitude transitional zone (Kakemega) and the midaltitude moist zone (Embu) will be surveyed in 2003. These surveys will provide estimates of refugia species and area in these zones.

This sorghum variety being examined by researchers Margaret Mulaa and Stephen Mugo could prolong the resistance of new maize varieties to insect pests in Kenya.





Tale of Two Farmers

Two Kitale-area farmers reflect the extremes that refugia strategies must cover

Collins Omunga (top photo) has more than 600 hectares in the highlands in Trans-Nzoia District. His primary income is derived from maize and livestock. He has a Certificate of Agriculture and has been building his farm operation for more than 30 years. He already grows napier for livestock feed and erosion control on about 18 hectares and has no doubt about its economic value.

In a bad year, Omunga reckons 20% of his maize crop is lost, and he is ready to try something effective against borers. He does not believe that managing a refugia presents a significant obstacle. "Farmers are eager to adopt new technologies," he says. "Knowledge is spreading, as you can see by the wide adoption of hybrid maize and fertilizer. But there are some 'lazy' farmers out there," he concedes, "and they might be more problematic."

Mulaa takes issue with the characterization of "lazy" farmers. "There are some very small landholders," she says, "farming half an acre or even less,

that are not diversified and only plant maize. For this group, we are considering establishing some kind of rotating communal refugia."

Not far away, Samson Nyabero (bottom photo) works his six hectares. The diversity found on his farm heartens Mulaa. Aside from some small fruit plots, he grows maize and, most positively, sorghum, finger millet, and napier, all potentially effective refugia. He says in a bad year he loses 30–40% of his maize to stem borers. Nyabero does not like to buy pesticide because it is often "bogus" or sold after its "effective date." The timing and number of applications also pose constraints. He too saw little problem adjusting his crop practices if it would allow his crop to repel stem borers.

Mulaa is encouraged by what she has seen on the Kitale farms, but she recognizes that more research is needed before firm recommendations can be made. Even so, the development of a well-tailored strategy for managing insect resistance should just be a matter of time.



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Diversity

To Sustain Future Generations



An Inspired Experiment

It is a story Rufino Chi has told often and probably will tell for some time to come, judging from the animated responses from farmers every time Nalxoy is mentioned. Nalxoy is the product of a cross between PR7822, a CIMMYT maize population, and Naltet, a traditional maize grown by indigenous farmers in Yucatán, Mexico.

Nalxoy is the brainchild of Chi, a Mayan farmer from the village of Xoy, Yucatán. Chi did not know that the seed he acquired in 1983 from long-time friend and agronomist, Luis Dzib, was from CIMMYT. He knew only what Dzib told him, that it was good and gave high yields, and decided to try it on his field.

M A Y A N

Farmer Breeds Popular Maize Variety

*Mayan farmer and breeder Rufino Chi:
“I want to help my brothers so people can have food for their families and stay on their farms.”*





“I took the seed and planted it. It had very good yields, gave good-sized cobs and grain, but was very susceptible to pests. The stems were also not strong,” said Chi. “I thought, why not cross this maize with Nal-tel? Nal-tel gave more maize per plant, the husk was hard and strong, and the grain was resistant to pests. The advantages of one balance out the disadvantages of the other. I crossed them and came up with this variety.”

Chi continued growing the maize and after two years convinced Dzib to try it on his experimental field in Becanchén, Yucatán.

“Rufino came to me in 1985 and told me about Nalxoy and its yield—1,500 kilograms per hectare compared to 750 with other varieties he used,” recalls Dzib. “He wanted me to plant this maize. At first I was skeptical but began to grow the maize and record its yield and attributes. At the same time, Rufino’s father, brothers, and community members continued experimenting with the maize in their fields.”

The Word, and the Seed, Spread

The variety Chi developed in 1983 had yellow grain. In 1998, he began experimenting again and obtained white-grained Nalxoy. Both yellow and white Nalxoy were tried in farmers’ fields in Xoy and other municipalities. Word of the maize spread.

“Farmers learned about Nalxoy from other farmers and came to buy seed. Some farmers from Chiapas came one year. They returned a year later and asked for more seed. I met a farmer in Campeche who bought 10 kilos. When I went to Quintana Roo, they asked me about Nalxoy and took 16 kilos,” says Chi.

Nalxoy, by now known for its adaptability and high yields, also became part of non-governmental and research programs in the area.

“It was diffused to several communities in south and central Yucatán and in Quintana Roo,” says Dzib. Soon more farmers were asking for seed.

“When We Don’t Have Maize, We Have Nothing”

Yucatán has a large indigenous population and some of the poorest and most marginalized communities in the country. High migration rates, poor education, lack of basic social security, and very low incomes are common. Most farmers depend on maize for food. Conditions under which farmers grow the crop are difficult.

“The soils are poor in many areas, and we either have too much rain or it is very dry,” says Dzib. “Nalxoy’s leaves curl in when it doesn’t rain. As soon as it starts raining, Nalxoy starts growing. The plant may be shorter and yield less, but it *will* give a harvest. With Nalxoy, farmers have greater food security.”

“When we don’t have maize, we have nothing. We have to go out to work to feed the family,” says Daniel Castillo, a farmer from Tahdziú, one of the poorest communities in the area. “We need maize for the whole year. This maize”—he points to Nalxoy—“is good. It is more tolerant, we can grow it with other crops, and it yields more. Now we don’t grow any other maize.” Abel Escoffie, Director of the Instituto Nacional Indigenista (INI, the National Institute of Indigenous Peoples) in José María Morelos, Quintana Roo, shares the sentiment. “It’s a good maize and we have great hopes for it. Most of the maize

we have here is very susceptible to pests and doesn’t tolerate drought. If we can improve it further, it will be marvelous,” he says.

“Maize Is Important for Indigenous Communities”

For Chi, Nalxoy has not only brought greater food security for his village, but also greater cohesion among indigenous communities. “Through this work, farmers are getting closer. We can learn from each other and become better organized,” he says. “Maize is very important for indigenous communities. They are poor and undernourished.”

The experience of Rufino Chi shows that poor, small-scale farmers often have their own pathways for adopting improved maize, believes CIMMYT social scientist Mauricio Bellon. Bellon was excited when he heard about Nalxoy because it supported CIMMYT research on “creolization”—the process through which farmers change improved maize to suit their needs.

“Small-scale farmers benefit from improved maize through different pathways, not necessarily from directly adopting an improved variety,” says Bellon. “Even though CIMMYT did not intentionally provide the maize for farmers to transform, Nalxoy came about because the improved maize clearly had some valuable characteristics. We need to evaluate experiences such as this and assess whether we can build on them and serve people better.”



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Ensuring the Survival of Sacramental Wheats

Some of the first wheats to reach Mexico, so-called sacramental wheats offer a glimpse into the past—and possibly the future—of wheat.

A “Snapshot” of a 16th Century Wheat

Brought to Mexico in the 16th century by Spanish monks, sacramental wheats provided grain for making the host, an unleavened wafer consecrated during the Roman Catholic Mass (hence the name sacramental). Mexico’s indigenous people had a grain of their own—maize—but for religious reasons the host must be made of wheat. The monks gave the Indians wheat to sow after their maize harvest. Consequently, “wheat spread as fast in Mexico as the Catholic religion did,” says Bent Skovmand, head of the CIMMYT wheat genebank.

Conditions in some regions where those wheats were sown, such as the Altos de Mixteca in the state of Oaxaca, which is very dry, are far from ideal for growing wheat. Nonetheless, sacramental wheats have been grown there through the centuries and can be found in farmers’ fields to this day. They are thought to be directly descended from the wheats introduced by the monks in 1540.

Because wheat is not normally sown in places such as the Altos de Mixteca, the sacramental wheats probably were never crossed with other wheat varieties, leaving their genetic heritage essentially intact.

The potential value of these wheats lies in the fact that so few of their type are known, especially in the Americas. If present-day sacramental wheats are representative of the ones introduced by the Spaniards, they might tell us much about Iberian wheats in the 16th century. They may reveal, for example, whether the taste and other baking qualities of wheat have actually improved in the centuries that have passed since they arrived in Oaxaca. Comments Skovmand, “The farmers who grow sacramental wheats claim they taste much better than modern varieties.”

When Traditions Die, Biodiversity Can Die, Too

One of the important functions of a genebank is to conserve samples of as many different types of a plant species as possible. Of special concern are plants at risk of disappearing, such as those that will be flooded out of existence when a dam reservoir is filled, or lost when the farmers who plant them die or migrate to the cities. Sacramental wheats, grown by very few farmers in Oaxaca, are considered to be among the latter.

A few years ago, Skovmand heard of these and other rare wheats and decided it was important to collect samples for conservation. He obtained funding from CONABIO, Mexico’s Organization for the Study of Biodiversity, to conduct wheat-gathering expeditions in 23 Mexican states. As a result, 10,000 new samples collected in 249 sites in 19 states were added to our collection. Duplicate samples were deposited in the germplasm bank of Mexico’s Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP, the national agricultural research program) in Chapingo, Mexico.

Sacramental wheats are not the only wheats among the new collections that have long been sown for special purposes in Mexico. Two farmer varieties from the state of Michoacán, for example, are grown exclusively for their straw, which is woven into ornaments.

The obvious risk to these and other rare varieties is that their survival depends on the small groups of people who grow them and who might one day abandon their traditional way of life. If such varieties are stored in a genebank, they and their genetic endowment should be available indefinitely. Perhaps one day breeders seeking to raise grain production in marginal environments will find what they seek in 16th century wheats.



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Transgenic Maize in MEXICO: Facts, Fears, and Research Needs

In late 2001, Nature (414: 541-542) published a controversial report that farmers were growing transgenic maize in Mexico and that, as a result, traditional Mexican maize landraces had become transgenic.

Mexico's maize landraces (strains developed over millennia by farmers) are considered a world treasure. The diversity they represent, like their cultural value, is priceless. The *Nature* report that Mexico's landraces were transgenic elicited a visceral response from people who feared that an important resource was lost forever. The report also elicited a strong response from scientists, some of whom felt that the research described in *Nature* did not support the conclusions that were drawn.

As an international research institution based in Mexico and charged with holding maize genetic resources in trust for humanity, CIMMYT was drawn into the controversy amid contentions that landraces in its genebank were transgenic.

The Situation in CIMMYT's Genebank

In fact, there is no evidence that any of the Mexican landraces in the Wellhausen-Anderson Genetic Resources Center (CIMMYT's genebank) carry the most common promoter associated with transgenic plants—cauliflower mosaic virus 35S (CaMV 35S). CIMMYT has screened more than 150 Mexican landraces and

has failed to find the presence of CaMV 35S. CIMMYT continues to screen landrace accessions collected after 1996, when commercial transgenic maize was first released for commercial use.

Several precautions are taken with the landraces held and distributed by CIMMYT. No new maize seed is added to the collection of landraces held in trust for humanity without being tested for transgenic material. To the extent possible, only accessions collected before 1996 are provided to our partners, unless the accessions have been screened for the general presence of transgenes (e.g., CaMV 35S) or unless the recipient guarantees that such screening will be done.

Seed cannot be held in cold storage in genebanks forever; periodically it must be taken out, tested to ensure that it still germinates, and planted to renew the stock of seed needed to meet research needs. When maize seed from the bank is regenerated in the field, researchers use controlled hand-pollination to ensure that the plants do not cross with plants of any other variety. To further ensure that all extraneous pollen is kept out, buffer zones protect the regeneration plots.



“Agriculture can have objectives other than producing high-yielding crops for export. Preserving landraces can be one such objective.”

Once the regenerated seeds are safely in the genebank, CIMMYT follows strict identification procedures to prevent them from getting mixed with other seed. They are held under secure conditions and managed through unique computerized identifiers. The seed samples must conform to so-called “passport data” on seed type and color. Requests for seed are processed according to the seed passport information.

The Situation in Farmers’ Fields

It is easier to determine what is occurring in a genebank, where seed is kept under rigorously controlled conditions, than to determine what is happening in farmers’ fields. If transgenes are present in Mexican landraces, what are the probable effects in farmers’ fields, on genetic diversity, and on the wild relatives of maize? CIMMYT researchers have some idea of the effects (see “Are Mexico’s Indigenous Maize Varieties at Risk?”, opposite), but their hypotheses must be confirmed. It is urgent to pursue several scientific inquiries.

First, to determine which factors influence the diffusion of genes (including transgenes) into maize landraces and what the potential impacts might be, researchers need more knowledge of smallholders’ management and seed selection practices. Related questions should also be addressed: How does this diffusion process affect the livelihoods of small-scale maize

farmers? Can this process and its impacts be managed? If so, how?

Second, a centralized database on maize landraces of Mexico and the rest of the world must be created. It would contain information on agronomic and grain quality traits and, when feasible, genetic information. It would provide baseline information on diversity, be useful for breeding programs, and have other practical applications. For example, in the dispute on patenting high oil-content maize, no data were readily available to show that Mexican landraces with high oil content were cultivated prior to the patent applications. If we lack this kind of information, the value of biodiversity is reduced.

Third, if genes from new crops and crop products—transgenic or otherwise—should not be freely distributed but nevertheless make their way into the environment, what are the options for controlling or reversing their diffusion in farmers’ fields? It is critical to have more information on factors affecting gene flow in maize and how they might be harnessed to reverse, contain, or ameliorate the impact of the diffusion of a deleterious or unwanted gene. *Research in this area should be given high priority.*

Finally, over the long term, how might modern varieties and farmer management practices affect the genetic diversity of teosinte, the closest wild relative of maize? More in-depth studies are needed to answer this question.

A Wake-Up Call for More Research

“As pressure increases to participate in the global economy, it is easy to forget that agriculture can play many roles,” says Masa Iwanaga, CIMMYT’s director general. “Agriculture can have objectives other than producing high-yielding crops for export. Preserving traditional landraces in their centers of origin may be one such objective. The present concern in Mexico has reminded the world that we need to understand and assist the farmers who are the guardians of maize biodiversity.”

“Mexican smallholders have fostered maize genetic diversity very efficiently for thousands of years,” comments Mauricio Bellon, a CIMMYT social scientist who has intensively studied farmers’ management of maize diversity. “The questions about transgenic maize have shown the many challenges these farmers face. Can they support their families just by growing landraces? Many farmers who grow these landraces are old, and their knowledge is dying with them. Will their children have incentives to continue the tradition?”

“The issues surrounding the maintenance of genetic diversity in the center of origin of maize are not simple, so it is not surprising that there are so many questions to answer,” says Iwanaga. “The important point is that if no one funds research to answer these questions, the consequences will be serious for Mexico and the rest of the world.”



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CIMMYT statements on transgenic maize in Mexico, including details of genebank screening: http://www.cimmyt.mx/whaticimmyt/transgenic_index.htm

Are Mexico's INDIGENOUS Maize Varieties at Risk?

Mexican farmers safeguard some of the world's most important maize biodiversity. What do we know about how they maintain landraces? What might happen if transgenic maize finds its way into their fields?



Maize Landraces: Always Evolving

A widely held misconception about maize landraces is that they do not change. In fact, the landraces found even in remote areas of Mexico today are not the same as the maize found in the same location hundreds of years ago. Maize is an open-pollinating species. Individual maize plants readily exchange genes with other maize plants growing nearby, a characteristic that farmers recognized long ago as a way to adapt varieties to their own needs. Today's farmers in Oaxaca, Mexico, for example, readily notice when their maize has been inbred over too many generations and lost vigor. Some will say the maize "gets tired" (*"se cansa"*) and will seek other varieties to mix with it.

In short, diversity in farmers' fields is not a static condition, but a dynamic process maintained by an influx of new genes, together with farmer selection. Likewise, landraces themselves are constantly evolving, while farmers maintain the traits that they desire.

Do Single-Gene Traits Displace Genetic Diversity?

What happens when a characteristic controlled by a single gene, such as transgenic, Bt-based insect resistance, is introduced into the genetic background of an established variety?

Current knowledge and theory in maize genetics suggest that there should be little impact on genetic diversity. Most genes in maize are independent, meaning that they will diffuse independently through a maize population rather than remain linked to other genes in that population. Suppose a modern yellow-grained variety carrying a transgene, such as Bt, is planted in a field in Mexico with a traditional white-grained landrace. After a few generations, there would be plants with yellow grain and the transgene, white grain and the transgene, yellow grain and no transgene, and white grain and no transgene.

Although the gene would have introgressed into some plants, diversity would not decrease. In fact, one could argue that overall genetic diversity would increase. *Whether this increased diversity is desirable is a very different issue.*

What Could Happen in Real Maize Fields?

What actually happens in maize fields in Oaxaca and other Mexican states? It is critical to remember that maize varieties are subject both to environmental selection and human management practices, which greatly influence whether a gene (and trait) is lost or fixed and at what frequency it occurs.

Tracking the effects of environmental selection is relatively straightforward compared to assessing the impact of farmers' management practices. If a transgene confers a trait that works

against a plant's survival, plants carrying that gene will be eliminated from the gene pool through natural selection. If no environmental selection pressure acts on the gene, population genetics models indicate that the gene will be fixed at the frequency at which it was introduced, or it will be lost over time. Finally, if the gene confers a selective advantage, it will increase and spread through the population. Again, since the transgenic maize varieties now being commercially grown use single-gene traits, in none of these cases should overall genetic diversity be decreased. There are implications, however, for the rate of diffusion (or conversely, containment) of transgenes.

Perhaps the most influential and least understood influence on genetic diversity and the "maintenance" of landraces is farmers' management practices, particularly the practices farmers use to choose seed for planting. The ancestors of today's Oaxacan farmers, who developed maize from a weedy grass to a robust food crop, probably used these practices, which encourage the flow of genes among different varieties of maize. If today's smallholders had access to transgenic varieties, and if they perceived those varieties to be valuable, they might foster their diffusion into their local maize populations. Clearly this is a complex process that merits much research.

What Could Happen to Wild Relatives of Maize?

Finally, there is the question of potential impacts on the wild relatives of maize, *Tripsacum* and teosinte. It is very difficult to produce maize x *Tripsacum* hybrids, although CIMMYT has produced some using sophisticated laboratory techniques. The only known naturally occurring maize x *Tripsacum* hybrid is "Guatemala

grass," a vigorous but sterile forage that can be propagated only vegetatively.

Mexican annual teosintes are the closest relatives of maize. Maize genes can flow easily into teosinte, but the long history of maize and teosinte sharing the same fields in Mesoamerica has not produced a "swamping" of the teosinte by maize, suggesting that some genetic mechanisms may be at work to maintain the genetic integrity of teosinte.

Given the difficulty of creating maize x *Tripsacum* hybrids, it seems extremely unlikely that transgenes would introgress into the *Tripsacum* genus. Introgression into teosinte would be much more likely, and the same principles related to natural and farmer selection cited earlier should apply. In short, one would not expect to see a negative impact on diversity *per se*, but only limited research has been conducted to date on this aspect of gene flow.

Validating the Hypotheses

This brief look at some of the underlying issues related to transgenes and Mexican landraces has focused mostly on potential impacts on genetic diversity. The observations are drawn from basic models and will need to be validated through targeted experiments. Clearly the potential impacts of an introgression of a transgene would also extend to the environment, farmers' welfare, marketplace concerns such as consumer acceptance, intellectual property considerations, and the regulatory sphere. These issues should be taken up in appropriate fora.

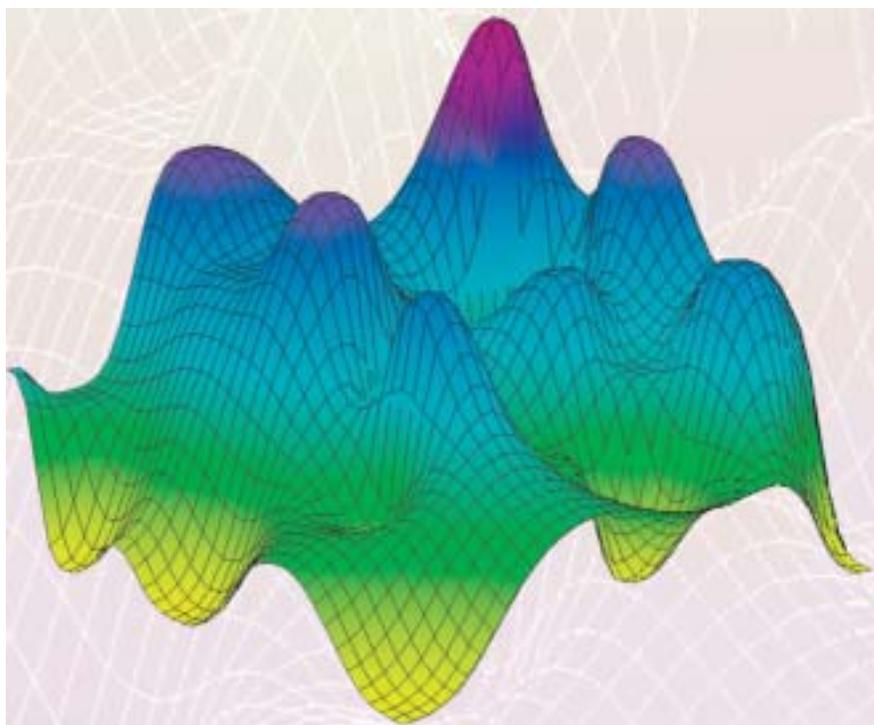


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QU - CIM:

Breeding Real Wheat from Virtual Wheat



High points in wheat breeding: Breeders cross different wheats and select among their progeny to generate improved wheats that have inherited all the good traits of both parents. As per the basic laws of inheritance, the highest peak in this graphic “adaptation landscape” represents the progeny that has all desired traits from both parents, the next highest represents the one that has fewer of these traits, and so on down to the lower peaks. The QU-CIM simulation module will help breeders reach the highest peak more efficiently.

In the works at CIMMYT and at Australia’s University of Queensland is a computer tool so sophisticated that it can help wheat breeders make some of the toughest decisions they face when developing a variety.

QU-CIM, a computer tool designed specifically for simulating CIMMYT’s wheat breeding program, “can help us work better, faster, and more economically,” points out Maarten van Ginkel, who breeds bread wheat for irrigated and high rainfall environments and leads the QU-CIM effort on the CIMMYT side. “It can save labor, land, and money.” When finished, it will be applicable to other crops and other plant breeding programs, including those in developing countries.

CIMMYT’s bread wheat breeding program was chosen for the QU-CIM project because, according to Ian De Lacy, a biometrician and expert on database management, “the program has 53 years of accumulated breeding data and is one of the most important and successful plant breeding programs in the world.” De Lacy is one of the researchers fine-tuning QU-CIM to respond to real-life breeding situations.

Australia's Grains Research and Development Corporation (GRDC) funds the work on QU-CIM, which is based on QU-GENE, a simulation platform developed at the University of Queensland. It can integrate enormous amounts of genetics-based data from widely different sources, process them in many ways, and produce alternative theoretical (but realistic) scenarios that breeders can draw on to make a decision.

Choices that Make or Break a Breeding Program

Jiangkang Wang, a postdoctoral fellow at CIMMYT, feeds the system the information it needs to simulate the breeding program. "My biggest challenge is to describe the field-based breeding process in a genetic language the computer can understand," says Wang. A first experiment is underway in which QU-CIM compares two selection schemes applied by CIMMYT wheat breeders to achieve the same objective. The program will indicate which strategy works best depending on the breeding materials and goals that are fed into it.

The laws of genetics put forth by Mendel more than 130 years ago underpin the simulation module, which also contains genetic equations developed over the past century. To work, the simulator draws upon data from many sources, including CIMMYT's International Wheat Information System (IWIS) and geographic information systems. QU-CIM will also link to the Agricultural Production System Simulator (APSIM), a collection of biological, physical, system control, and other modules that interact to simulate the operation of a farming system. These links will endow the simulation module with knowledge of the genetic and other relationships affecting wheat, plus wheat's performance in real farming situations.

One of the module's strengths is that it accommodates the combined effects of different genes that affect the same trait at the same time, which is often the case. "Breeders know that the effect of putting genes together is not simple, like $1 + 1 = 2$. There's a synergy at work here that sometimes causes $1 + 1$ to equal much more than 2, and sometimes less," explains van Ginkel. Positive synergy can produce huge genetic gains, but apart from relying on experience and intuition, breeders have to conduct tedious, large-scale genetic studies on a few lines at a time to predict how and when this synergy might happen. With QU-CIM they can quickly discover how to achieve the synergistic effects they seek.

QU-CIM can also indicate when it is cost-effective and/or efficient to use a specific technology at a specific stage in the breeding process. For example, using molecular markers to identify plants with valuable traits early in the breeding process might seem appropriate, but at that stage the number of plants to be tested is still very great, as is the cost of testing. It might make more sense to apply the technology at a later stage, when the population of experimental plants has been pared down to a more economical number. But by that time the gene of interest may have been bred out of the population, or nearly so, which is also undesirable. What is a breeder to do? Apply the module to see how the two scenarios play out, and then make a more informed decision.

Simulating Environments and Environmental Variability

QU-CIM does not give breeders just one set of growing conditions in which to run tests, but generates different versions of an artificial environment to simulate conditions in different years and run, say, 100 breeding cycles to see what the outcome would be. Why is this useful?

Consider following example. In North Africa four out of five years are dry. Farmers sow their wheat, and if they see the year will be very dry, they will not let the crop grow to harvest because the grain yield will be very low; instead they allow their livestock to graze on it. For that they need a wheat variety that produces lots of stems and leaves and appeals to the animals. But the variety also has to produce a lot of grain (and not fall over under the added weight), since farmers want to reap an abundant harvest one year out of five, when rainfall is adequate. In wetter years, more disease is present in the fields, so the variety has to be disease resistant. In this complex scenario, the simulation module would aid in setting breeding priorities by running many breeding cycles while weighing the importance of different traits depending on the variations in the environment where the variety will be grown.

Bringing Down Breeding Costs

QU-CIM could bring down breeding costs by reducing the number of crosses breeders make to reach a particular goal, identifying the best breeding method to use, or determining the most cost-effective, efficient time to use it. It would also compare the cost of the input to the cost of the corresponding output to determine whether applying a given technology makes sense. With QU-CIM, wheat breeders will more easily and economically help countries meet their farmers' needs.



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In Situ Maize Conservation in OAXACA, Mexico: What Have We Learned?



The loss of maize landraces may have detrimental consequences, not only for the conservation of genetic resources but for the welfare of farmers who grow them.

The relationship between lost landraces and diminished farmer welfare was a key finding from a five-year study funded by Canada's International Development Research Centre (IDRC). Researchers aimed to identify and evaluate interventions that would help smallholders in the Central Valleys of Oaxaca, Mexico, to conserve the diversity of maize landraces in the area. The study was undertaken by CIMMYT and the Oaxaca division of INIFAP, Mexico's national agricultural research program.

Farmers Demand Diversity

"Even when farmers want to continue growing landraces, diversity can be lost," says Mauricio Bellon, the CIMMYT social scientist who headed the study. "It's not easy for farmers to obtain seed of landraces they want to grow or to cross with their own varieties. A farmer has to know who has the variety he or she seeks, if the seed is good, and if it will do well in

the field. Then the farmer has to negotiate to acquire the seed—maybe not through a cash payment but through some sort of commitment to the seed seller."

The Oaxaca study revealed that helping smallholders identify the traditional varieties they want and providing them with seed of those landraces at lowered costs is one of the most important contributions institutions can make to genetic resource conservation and rural development.

The starting point for helping farmers to access and conserve diversity was to systematically collect and evaluate the biodiversity of landrace populations in six communities. The objective was not simply to review local landraces' agricultural or physical characteristics or genetic diversity, but to involve farmers.

"The challenge is to identify landraces that contribute to conserving genetic diversity and are



“If we don’t understand how farmers manage genetic resources, we cannot understand the effects of introducing new maize varieties.”

also of interest to farmers,” says Bellon. “If we can do that, and establish mechanisms for farmers to obtain seed and information, farmers will sow landraces, and maintain the evolutionary processes that are essential to conserving diversity.”

Farmers’ Strategies for Gaining Diversity

Researchers could not help farmers conserve genetic resources until they learned how farmers actually managed those resources. Julien Berthaud, a molecular cytogeneticist at CIMMYT, affiliated with the Institut de Recherche pour le Développement (IRD), says that farmers’ management of landraces shows a high level of gene flow. Gene flow can be described as the movement of genes in and out of the population of maize landraces in the study communities—with obvious implications for the diversity of those populations. Gene flow can occur through human intervention (e.g., the acquisition or exchange of seed) as well as natural intervention (e.g., pollen dispersed by insects and wind).

“There is gene flow through seed exchange among farmers in the same community, and through varieties bought in local and regional markets or within communities,” he says. “There is also a flow of genes over long distances, for example among distinct races of maize at more than 200 kilometers. This flow promotes the maintenance of a full genetic base and greater resistance to stresses of all kinds.”

Farmers in Oaxaca gain greater diversity by managing their landraces in three ways: by adding new varieties to their inventory, by crossing distinct varieties, and by selecting for particular

characteristics in the varieties they grow. “The third strategy is used in farmer participatory breeding,” says Bellon. “But to support farmers’ conservation and use of diversity, we cannot limit ourselves to one strategy.”

Community Dynamics Matter

Nearly 1,000 farmers (654 men and 343 women) from six communities participated in the study, which included a survey that gathered socioeconomic and agricultural data, the collection of 152 representative samples of maize landraces in the region, an agronomic evaluation in scientist-designed and farmer-managed trials, a participatory exercise to identify a subset of landraces that captured the diversity in the larger collection, and the development of 17 “elite” landraces. Farmers participated in 30 training sessions on topics ranging from basic principles of maize reproduction and breeding to seed selection in the household and field, and seed and grain storage.

These kinds of studies are extremely important for understanding how communities maintain diversity in the maize they grow.

“If we don’t understand how farmers presently manage genetic resources, we cannot really understand the effects of introducing new maize varieties,” says Bellon. This question is extremely important, given recent developments in Oaxaca (see “Transgenic Maize in Mexico,” p. 27). “Much more research needs to be done,” cautions Berthaud.



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Managing Agriculture to Manage Climate Change

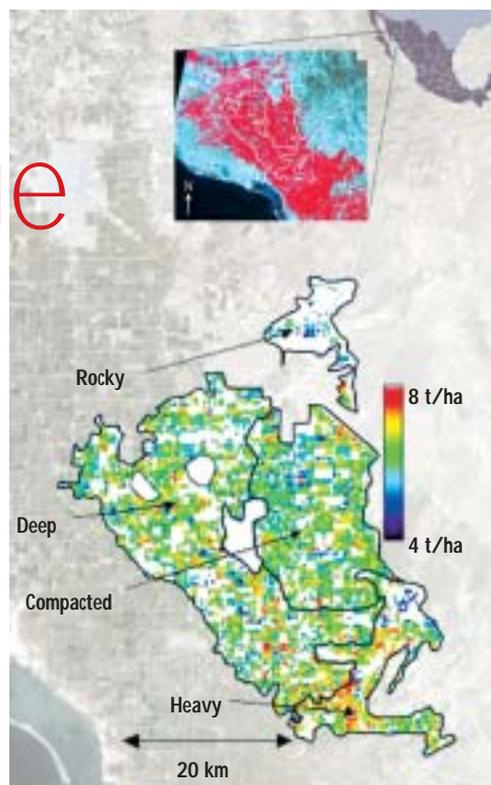
How Will Climate Change Affect Intensive Farming?

CIMMYT scientists, with researchers at Stanford University's Department of Geological Science and Environmental Studies, have concluded that farmers are not totally at the mercy of climate change. They arrived at this conclusion through satellite observations of Mexico's Yaqui Valley. Conducted in three successive years, the observations confirmed that farmers could reduce the negative impact of weather on their crops by using appropriate farming practices.

The Yaqui Valley is ideal for studying the long-term effects of an intensive farming system on neighboring environments and the implications for global warming.* Since agricultural conditions in the Valley are representative of the irrigated environments that produce 40% of the developing world's wheat, study results will be applicable in those environments. This is extremely useful, considering that those environments will have to produce 90% or more of the grain needed to feed a population slated to increase steadily over the next 25 years.

As crop production intensifies, ecological damage and the emission of greenhouse gases will have to be brought under control. The results reported here—namely that certain farming practices are not only more benign for the ecology, but help sustain farm production in the face of climate change—should motivate farmers to adopt those practices.

* See *Nature* 418:812-814.



Soil types in the Yaqui Valley, Mexico: Farmers who have cared for the soil are less likely to be harmed by climate change.

Protecting the Environment by Protecting Agriculture

Researchers conducting this study chose four main soil types in the Yaqui Valley, and in each year they looked at average wheat yields from those soils. The three years of satellite observation showed great contrasts. The first was one of the warmest on record, the last was one of the coolest, and the other was intermediate. In a relatively short time, researchers could learn how wheat yields in the four soil types were affected by different climatic conditions, something that otherwise could have taken many years.

Based on these findings, the research team concluded that farmers on good soils are little affected even by marked climate changes, whereas farmers who have low-quality or degraded soils are more affected. Developing cropping practices that improve soil quality is thus critical not only for increasing yields, but also for diminishing vulnerability to climate change and avoiding soil erosion.

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Treasures in the Attic: Finding the Diversity Stored in the Maize

GENEBANK

CIMMYT and its partners have increased their efforts in “prebreeding”—accessing and refining raw diversity to make it breeder-friendly.

When CIMMYT’s predecessor organization began work in the 1940s on improved maize for developing countries, its first step was to gather seed of diverse landraces from fields, markets, and farm households throughout Latin America. This seed was classified by race, the ecology where it was best adapted (that is, the lowland tropics or midaltitude, subtropical, or highland areas), grain type, and color. Each class was later used to form a genetic pool to which appropriate material from other sources—say, US or developing country breeding programs—was added.

Breeders from CIMMYT and partner organizations have drawn on these pools to develop hundreds of productive maize cultivars sown in the tropics and subtropics. “The pools are the foundation of our entire breeding program,” says Suketoshi Taba, head of maize genetic resources and prebreeding at CIMMYT. “They link the enormous diversity of genebank seed collections to improved varieties, which return this diversity to farmers’ fields in a more productive form.”

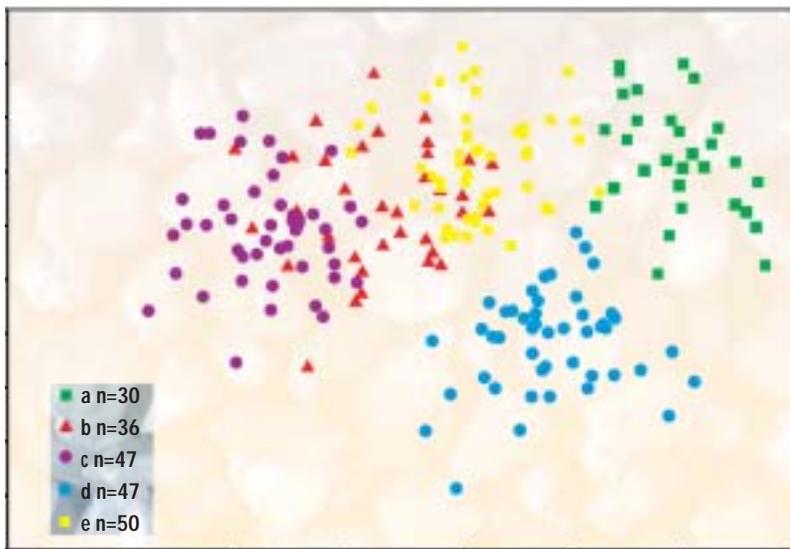
Reinventing Gene Pools

Taba and his team have lately renovated the pools. They enrich them continually with genetic diversity from varied sources—the genebank, partners’ breeding stocks, and collections from farmers, to name a few. “We see the gene pools as evolutionary maize populations for

the future, a merging point for many useful maize genotypes,” says Taba. “In the pools, potentially useful diversity gets refined and made available for advanced breeding.”

The genebank is a valuable source of useful traits for pools, but with 23,000 or more registered seed collections—called accessions—it is also akin to grandma’s attic: you need to look through many boxes to find its treasures. Taba’s group has employed sophisticated statistical analysis and models to distill useful, accessible subsets from bank contents and farmers’ seed. These “core subsets” are carefully chosen to embody most of a specific race’s diversity and to feature useful traits, such as high yield or disease resistance. Core subsets are virtual groupings, rather than actual collections of seed. They are linked both to agronomic data and to records on the original accessions, so users can locate specific maize types or traits and, ultimately, the seed itself.





CIMMYT maize pools are genetically diverse, but their components still fall into discrete groups that researchers are trying to break up and mix together. The clustering shown here for genotypes in Pool 25—all tropical, late-maturing, yellow maize of flint kernel type—was done using data for important agronomic traits. The key gives the number of genotypes in each cluster.

Tabá and his team use the subsets as “samplers” of diversity, crossing them with elite inbred lines to identify genotypes that possess useful landrace genes without typical landrace weaknesses. The best products are added to the pools.

Breaking Ties that Bind

The group also works with the 32 pools to enhance desirable characteristics and weed out unwanted ones. “Yield, for instance, is not a dominant trait. It results from many recessive alleles—forms of the same gene—working together,” Tabá explains. “You’re trying to gather the best alleles for each of maybe 30 or 50 traits, so that their small effects accumulate.”

Because of the way genome segments are broken up and recombined in reproduction, genes that are nearer to each other on a chromosome are more likely to be passed on as a single block to succeeding generations; they are said to be “linked.” As a result, in diversity’s banquet, desirable qualities are often served along with unwelcome side dishes of inferior traits.

“Pools are composed of different race accessions, each with characteristic linkages—that’s what makes them races,” says Duncan Kirubi, CIMMYT adjunct scientist who has worked in prebreeding. “We try to break the normal linkages and create new ones that render useful traits more accessible to breeders.” He and Tabá apply statistical analyses that allow clear visualization of pool components (see figure). Those least alike genetically can be crossed to endow pools with new combinations that contain higher fractions of favorable traits. The researchers also break up close-knit subgroups to remix pool contents, and they are beginning to use DNA fingerprinting to assess and monitor diversity in pools. Finally, they have classified the pools into heterotic groups, which are pairings that can be used to develop productive hybrids.

Breeding Maize with Farmers

Tabá and his associates are perfecting a method that combines *in situ* conservation and farmer participatory breeding of maize landraces, while enriching and taking advantage of gene pools. (*In situ* conservation of cultivated crop

species, such as maize, is the conservation of genetic resources in farmers’ fields rather than in genebanks.) According to Matthew Krakowsky, a postdoctoral fellow at CIMMYT, the first step is cataloguing the genotypes grown in a center of diversity for a particular landrace. “We analyze what farmers have, pinpoint the genotypes they want to improve, and cross them with our improved materials to enhance them,” he says.

For example, in 1997 Tabá and researchers from INIFAP, Mexico’s national agricultural research program, began work with farmers in the Central Valleys of Oaxaca, where varieties bred by researchers have had little impact. They focused on improving Bolita, a drought-tolerant landrace that farmers especially appreciate for its tortilla-making quality. Initial efforts resulted in refined versions of key Bolita types, and farmers throughout the Central Valleys are purchasing Bolita seed.

The researchers will now take a selection of the best genotypes from the area and from Bolita core subsets developed with farmers, cross them with plants from improved pools, and cross the resulting progeny again with the original landrace samples. The first cross with pools will contribute improved traits; the final backcrossing to the landrace ensures conservation of the original landrace type—that is, the grain quality and appearance that farmers like. “This approach also gives us access to valuable traits from the landrace,” says Krakowsky. According to Tabá, similar methods may be perfected and extended to many landraces grown in Latin America.



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It's probably the first and the only tortillería of its kind in Mexico. Tortillería Itanoní, a small "mom and pop" operation run in the city of Oaxaca, Mexico, by Amado Ramírez Leyva and his wife, sells high-quality tortillas prepared the traditional way from maize landraces in the Central Valleys of Oaxaca.

TORTILLERÍA

Preserves Local Traditions

"The tortillería is a model that we hope will be replicated elsewhere," says Amado Ramírez. "Customers who buy the tortillas will know what the tortilla is made of, where the maize came from, and the specific characteristics of the maize with which the tortilla is made."

Itanoní, which means "maize flower" in the Mixteca language, is part of an effort by Ramírez to revive the unique cultural and culinary practices of Oaxaca. He obtained much of his information about maize landraces during field days organized by CIMMYT and INIFAP, Mexico's national agricultural research program, as part of a project in which farmers and scientists worked together to conserve maize genetic diversity.

"The most important aspect of our work is the information given to consumers about the value and quality of the tortillas that they consume," says Ramírez.

Ramírez believes that his marketing strategy will bring economic benefits for farmers. "If people develop an appreciation for the tortillas made from this maize," he says, "farmers will have a viable market to sell their maize. At the same time, there will be a deeper appreciation for the biodiversity and traditions of this region."



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Visitors to the city of Oaxaca will find Tortillería Itanoní at No. 512, Belisario Domínguez.

Diversity

to Foster Scientific Innovation



STRIGA:

Search for a Long-Term Solution

Agronomists classify it as the parasitic weed *Striga hermonthica*. Economists report that it inflicts yield losses ranging from 20 to 80%, and that across sub-Saharan Africa it robs US\$ 1 billion in lost productivity from more than 100 million people, most living on subsistence or smallholder homesteads. Maize farmers in Western Kenya simply and distainfully curse it as “witchweed.” One thing they all agree on is that this scourge, which exhibits a remarkable resistance to conventional controls, is on the rise—both in terms of area affected and intensity of infestation.

CIMMYT’s Applied Biotechnology Center (ABC), together with the Department of Animal and Plant Sciences at the University of Sheffield, is looking for solutions. Funded by the Rockefeller Foundation, scientists from the two institutions are looking for unconventional sources of resistance to *Striga*. Leading CIMMYT’s efforts is molecular geneticist/physiologist Sarah Hearne.

Since 1999, Hearne says, CIMMYT has screened accessions of *Tripsacum* and teosinte (wild relatives of maize) for resistance to *Striga*. The screens revealed that apomictic tetraploid *Tripsacum* is very resistant. Results with teosinte were not as encouraging, although three accessions showed some potential. Jane Ininda, of the Kenya Agricultural Research Institute (KARI), will screen many more teosinte accessions, representing a full range of diversity, later in 2002.

Maize-*Tripsacum* hybrids, generated by the CIMMYT-Institut de Recherche pour le Développement (IRD) apomixis project, have also

stirred a lot of interest (see p. 42). These plants have various combinations of maize and *Tripsacum* chromosomes. Hearne began screening these hybrids in early 2002, and 60 are being grown and infected with *Striga* in root observation chambers at Sheffield to evaluate resistance and observe the form it takes. Once resistant lines are identified, Hearne says, it should be possible to determine the chromosomes responsible for *Striga* resistance by comparing the levels of resistance in the lines and the chromosomes they are known to carry. “If the trait is located on a lot of chromosomes,” she says, “it’s going to be very difficult to introduce the trait using conventional breeding—it probably won’t happen. But if it is located on a single chromosome, we could potentially move the gene or genes controlling the resistance into maize.”

Hearne is also trying to identify the basis of *Striga* resistance in *Tripsacum* by comparing differences in gene and protein expression between resistant *Tripsacum* and susceptible maize. The

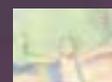
protein research is conducted in collaboration with Christophe Brigidou of IRD. If researchers identify candidate gene(s) responsible for resistance, it may be possible to introduce resistance into maize using a transgenic approach.

Finally, Hearne is looking at the use of genes tagged by Mutator, a so-called transposable element that jumps into genes that control plant functions and turns them off. “For instance, if you had a gene for red pigmentation in the grain and the Mutator jumped into that gene, you would cease to have that pigmentation. We’re applying that same principle in the search for *Striga* resistance, in that there may be a regulatory gene that prevents maize from activating defenses against the weed.”

During 1998–99, about 8,000 Mutator-tagged maize lines were screened under controlled experimental conditions. About 80 showed some level of resistance. Since then, that group has been narrowed to about 20 entries, says Hearne. One looks particularly promising. Once the gene is characterized, researchers will attempt to cross it into adapted material and check its performance.

Although it will be a few years before results of this work reaches farmers’ fields, Hearne is optimistic that new knowledge about plant responses to *Striga*, and some of the research products, will provide long-lasting resistance to the parasitic weed and grant relief to many generations of African farmers.

**An underground epidemic:
Farmers can lose 80% of their
maize crop to *Striga*.**



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A Bridge to BIOFORTIFIED Wheat

Filling empty stomachs, the priority when people are starving, is not enough in the long term: people need food with the nutrients they require to lead healthy and productive lives.

An estimated 3 billion people in the world who do not go hungry nonetheless suffer the debilitating effects of unhealthy diets. People who eat mostly cereal-based foods can lack such essential nutrients as iron, zinc, and vitamin A. Some developing countries overcome this deficiency by distributing supplements to the population and/or fortifying food with nutrients. Some of these programs have been successful, but they are expensive.

Biofortified™ Crops

An excellent means of complementing these programs would be to breed crop varieties with increased levels of minerals and vitamins. Biofortified crops could benefit malnourished populations cheaply and sustainably.

Creating biofortified versions of the main food crops is the idea behind the CGIAR Biofortification Project* funded by Danish International Development Assistance (Danida) and coordinated by the International Food Policy Research Institute (IFPRI) and the International Center for Tropical Agriculture (CIAT), which is also working on raising the micronutrient content in beans and cassava. CIMMYT is working on generating nutrient-enriched maize and wheat. Other CGIAR centers, such as the International Rice Research Institute (IRRI) and the International Potato Center (CIP), are working on their respective crops.

The project relies on the collaboration of the University of Adelaide in Australia and Cornell University in the USA, whose

laboratories are testing for micronutrient and vitamin A content and micronutrient bioavailability (i.e., whether nutrients can be assimilated by humans and animals).

A Bridge to High-Nutrient Genes

Since most improved bread and durum wheat varieties lack high concentrations of iron and zinc in the grain, the search is on for good sources of the genes that control these traits. CIMMYT scientists headed by Ivan Ortiz-Monasterio have been screening materials stored in the CIMMYT genebank for five years now. They have found that wheat's wild relatives carry the highest levels of iron and zinc in the grain. Although grain nutrient levels vary depending on where plants are grown, trials in northwestern Mexico revealed that, compared to an average wheat, some of the best wild relatives had 1.8 times more zinc and 1.5 times more iron in the grain.

How to tap into genes contained in these wild species? The Wheat Wide Crosses Unit has already provided the means: bridge wheats. These wheats act as a "bridge" for transferring favorable genes from wild species to improved bread wheat. In this case, they are generated by crossing a durum wheat with a related wild grass. That is a reproduction of the chance crossing that occurred in nature between those two species and first gave rise to bread wheat about 8,000 years ago.

Bridge wheats (also called synthetic wheats) are true bread wheats and can be crossed readily with high-yielding varieties. Crossing bridge wheats with improved wheat is important because it helps to eliminate negative characteristics. The resulting wheats will be like their improved parents, except for the desired trait from the wild parent (in this case, high iron or zinc content in the grain).

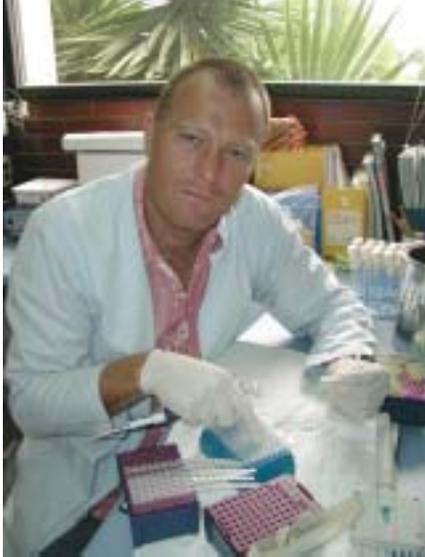
Bread wheat breeders Maarten van Ginkel and Richard Trethowan use bridge wheats as a source of the high iron and zinc traits in their crosses with high-yielding lines. Since the inheritance of high levels of the two micronutrients seems to be linked, breeders can use the same bridge wheats for both traits. The researchers have advanced to the third and fourth generations, which means they are making good progress.

Work on improving the vitamin A content of wheat is just beginning. The materials in the CIMMYT wheat genebank are currently being classified for orange pigmentation, which may indicate high levels of beta-carotene, the precursor of vitamin A.



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* Initially reported as the CGIAR Micronutrients Project in our Annual Report, *CIMMYT in 1999-2000*, pp. 8-10.



APOMIXIS: Why Is It Taking So Long?

“The whole situation with apomixis research reminds me of the 1902 Georges Méliès movie, A Trip to the Moon. In the movie, they simply shot a large bullet from a giant gun at the moon, and after a short time it struck the giant cheese orb. Sixty-seven years later, we actually landed on the moon, but not until we had developed and fully understood a huge range of new technologies, as well as the basic scientific concepts involved. Now, in our apomixis work, we have reached the stage where we understand that our initial approach was too simple, and we need to know more.”

—**Enrico Perotti, apomixis research team member**

Over 13 years ago, the Institut de Recherche pour le Développement (IRD) joined with CIMMYT to initiate work on creating “apomictic” maize. Hopes were high that by crossing maize with its wild apomictic relative *Tripsacum*, researchers could breed a maize plant that would produce clones of itself over generations (see “What Makes Apomixis a Valuable Trait?”, next page).

One need not be familiar with the terminology or the process to recognize the revolutionary potential of apomixis. Hybrid production could be greatly accelerated, breeding for niche environments (small environments with unique conditions) could be economically feasible, and poor farmers could recycle seeds that maintain hybrid characteristics.

Knowledge about apomixis has grown considerably, and so has impatience to develop apomictic maize. So exactly why *has* it taken so long?

The First Approach

“At the beginning,” says research team leader Olivier Leblanc, “we were working on the premise that apomixis is a simple trait and that it should not be overly difficult to

transfer a single-gene trait to maize with the existing technology. We pursued an applied breeding rather than a basic science approach. We weren’t interested in the mechanisms and the molecular basis for the phenomenon. We just needed to find that one and only apomictic specimen that was hiding out there among half a million experimental plants. We never found it.”

Therein lies much of the impatience. In plant breeding, if you identify a source of variability for a given trait, eventually, through step-by-step plant crosses, the desired trait can usually be incorporated into maize varieties or lines. As it turns out, apomixis is complex. It certainly did not yield to a step-by-step procedure.

Does this mean that those years of work were unfruitful? No. In science, as false leads are discarded, efforts are redirected based on the insights obtained, according to David Hoisington, director of CIMMYT’s Applied Biotechnology Center, where the research on apomixis takes place.

“Because we have such a strong team, partnerships, and advances in science,” Hoisington explains, “we can continue our progress toward the ultimate goal, even if we change roads every once in a while.”

The Road Less Traveled

Although the creation of apomictic maize remains the team's clear goal, the route there has changed from a relatively mechanical approach—transferring the apomixis gene(s) directly from *Tripsacum* to maize—to exploring other options that require better understanding of the apomictic process in general.

Most teams working on apomixis, according to Leblanc, are investigating and manipulating the sexual pathways of plants to produce an apomictic outcome. The CIMMYT-IRD team remains committed to using an apomictic plant and a related crop plant. In doing so, they can draw on their long experience with *Tripsacum*, “a truly beautiful model plant for apomixis,” says team member Daniel Grimanelli, “which is an original approach compared to those being pursued by other groups.” They are investigating the cell biology and molecular genetics of the processes behind apomixis, as well as barriers within the maize genome to the transfer of the characteristic.

They also draw support from a consortium formed in 1999 to accelerate progress. The IRD and CIMMYT joined in a five-year agreement with Pioneer Hi-Bred, Groupe Limagrain, and Novartis Seeds (now Syngenta) to bring their diverse strengths to bear on the apomixis challenge. For the CIMMYT-IRD team this means access to useful biological material, databases, information, and experts, as well as additional financial resources.

The team is excited about its new direction. “We’re working on novel approaches and have some nice stuff cooking,” says Leblanc. “But it’s too soon to talk about major achievements. We’re out of the prediction game for good.”



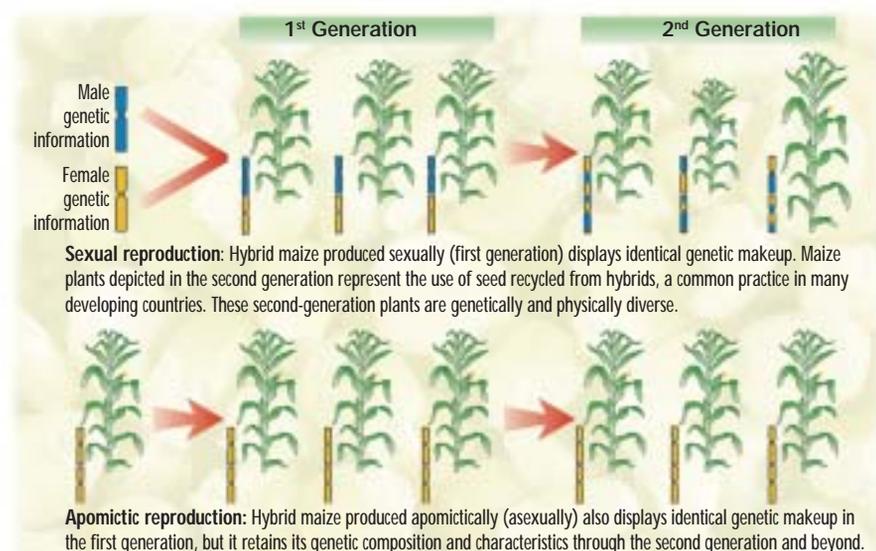
For more information:
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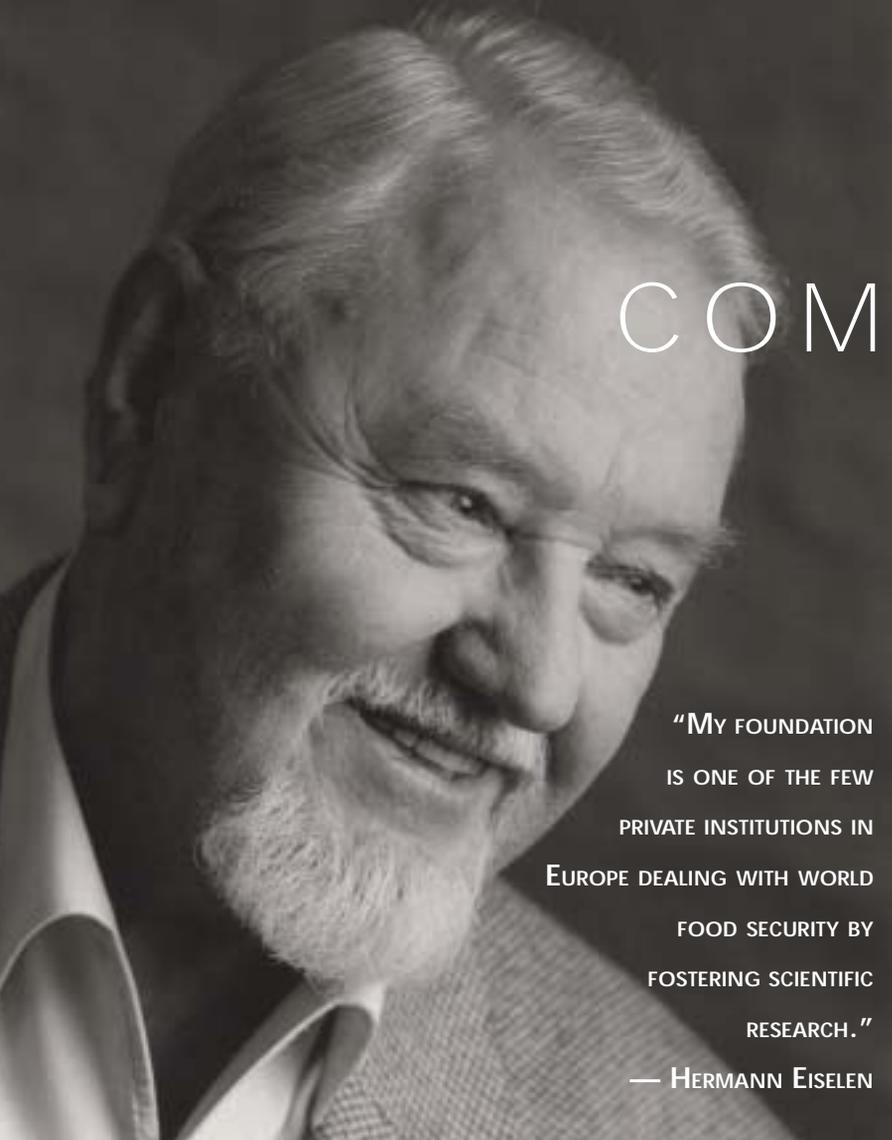
What Makes APOMIXIS a Valuable Trait?

Apomixis—asexual reproduction through seeds—results in plants that are exact clones of the mother plant. The trait occurs naturally and has been identified in more than 400 species of plants, including some varieties of *Tripsacum*, a wild relative of maize. With an apomictic mode of reproduction, exact copies of the chromosomes are transferred from the mother plant to the progeny, making each offspring a clone of its ancestor. This direct transfer of chromosomes (and therefore traits) continues generation after generation.

The implications of transferring the apomixis trait to a major cereal crop such as maize are tremendous. Breeders would be able to greatly reduce the time and expense required to produce new varieties, for example, by instantly “fixing” a desired genetic composition, which normally takes several seasons. Apomixis is of particular interest to CIMMYT because it would make *niche breeding*, the development of cultivars tailored to unique agroecological areas and very specific uses, more economically feasible.

Seed producers would be able to reduce the cost of producing hybrids, which could translate into lower seed prices for farmers. Farmers in developing countries who obtained improved seed carrying the apomixis trait would be able to recycle their seed indefinitely, while maintaining various yield-enhancing properties usually associated with hybrids, which cannot be productively recycled.





Private COMMITMENT Leads to Public Good

"MY FOUNDATION
IS ONE OF THE FEW
PRIVATE INSTITUTIONS IN
EUROPE DEALING WITH WORLD
FOOD SECURITY BY
FOSTERING SCIENTIFIC
RESEARCH."

— HERMANN EISELEN

Molecular geneticist Marilyn Warburton arrived at CIMMYT in 1998 with a goal: to develop large-scale methods for fingerprinting wheat and maize (see "What Is Genetic Fingerprinting?", p. 47). Forty years before that, Hermann Eiselen arrived at what was to be his lifelong mission—a commitment to fighting hunger through research. Their paths crossed through a CIMMYT project on the genetic characterization of wheat.

Large-Scale Genetic Fingerprinting Becomes a Reality

Warburton and David Hoisington, director of CIMMYT's Applied Biotechnology Center (ABC), had several reasons for wanting to conduct large-scale fingerprinting of wheat and maize at CIMMYT. This capability would give researchers new insight into the parentage of thousands of lines, varieties, and landraces used in their work. They would have a new clue as to whether the desirable genes they sought were present. They could incorporate those genes more quickly into new varieties and could ensure that new varieties were genetically diverse. Fingerprinting would also help genebank curators collect and maintain genetic resources more efficiently.

The ABC could screen a few dozen varieties a month. The goal was to screen hundreds. "Given the size of our seed collections," says Warburton, "people were not interested in fingerprinting only a few varieties. We needed to develop high throughput capabilities to respond to CIMMYT's needs."

Funding was quickly procured to develop protocols for maize, mainly from the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), the French Institut National de la Recherche Agronomique (INRA), and PROMAIS (a consortium of private French companies). Support for similar work in wheat was less forthcoming.

Enter Hermann Eiselen, whose family has supported research at the University of Hohenheim, Germany, over the last four decades. Most of this philanthropy has been directed to students interested in applying science to international development, particularly in agricultural sciences and nutrition. Twenty years ago, the family handed these tasks over to the Eiselen Foundation, where Hermann is Chairman of the Board.

Finding the Funding

Through University of Hohenheim professor Albrecht Melchinger, Eiselen learned about CIMMYT's situation and pursued support through GTZ and his own foundation. Eiselen's interest in the wheat project may have been piqued by the fact that his family's fortune came from products for the bread making industry (his affection for bread and baking is evidenced by his family's founding of the Bread Museum in Stuttgart, Germany).

"Biotechnology is one of the key sciences for increasing agricultural production to help alleviate world hunger," says Eiselen. "On my initiative, the German government entered into the first and, to my knowledge, only public-private partnership by the nation in development-oriented agricultural science, this joint project between CIMMYT and the Institute for Plant Breeding in Hohenheim. I am proud that my foundation is one of the few private institutions in Europe dealing with world food security by fostering scientific research, and it is my great desire that other nonprofit organizations do the same."

Capable Hands to Launch a New Project

The three-year project was launched in 2000. Susanne Dreissigacker and Pingzhi Zhang, PhD students at Hohenheim, arrived at CIMMYT to start developing a high throughput fingerprinting method for wheat. It was a daunting task.

"First, we had to identify markers that would allow us to cover the whole genome," Warburton says. "We wanted at least two markers per chromosome arm for each of wheat's 21 chromosomes." Further complicating the job was the fact that the wheat "genome" actually falls into three similar but not identical genomes, meaning that the markers had to be specific to each genome.

"The students and I ran through more than 200 SSR markers. We wound up with nearly 84, the requisite number, though we still had only one marker for a few chromosome arms." The task was complicated by the dearth of good markers in the public domain.

Negotiations with Dupont freed some more effective markers that will be publicly available at the end of the year.

The next step was to identify markers that could be run in the same gel. (If the various markers registered in the same place on the gel, it would be difficult to distinguish one from another.) Finally, software had to be adapted to "score" the markers, which would tell the scientists what gene sequences were present in the tested variety or line.

With the markers selected and the protocols in place, Warburton and the students analyzed hundreds of wheat lines. They looked at important CIMMYT wheats to determine whether genetic diversity was increasing or declining over time. Compared to the 1970s, present-day wheats carry more genetic diversity, indicating that breeders are using new sources of variation and that there is no imminent threat of diminished diversity. Much useful information was obtained, but the biggest impact so far has been on landrace collection and genebank storage strategies (see "Fingerprinting Yields Surprising Findings," p. 46).

Last June, the students returned to Hohenheim to complete their analyses and write their theses. "It's a little sad to lose them and their very capable hands," reflects Warburton, "because now that we've got all the data, the exciting stuff starts. Our relationship evolved from a mentoring situation to a team relationship during those two years. By the end of the second year, they were teaching me a lot and probably knew the sequencer better than anybody in the lab."

Hermann Eiselen could not have hoped for more.



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Fingerprinting Yields SURPRISING FINDINGS on Wheat Diversity

Capturing diversity by collecting and storing wheat landraces is a tricky business. Should collectors go to many fields and obtain a single sample from each? Or should they go to a single field and collect a multitude of samples? Should sampling strategies be the same for regions that are a center of origin as for those that are not? And that's just the beginning. Storage and maintenance strategies also differ based on the variation in each landrace. Genetic fingerprinting can answer these questions.

CIMMYT molecular geneticist Marilyn Warburton and her team looked at about 150 landraces collected from various countries using a range of methods. "Passport data," when available, supplied information about where a sample was collected, how it was collected, and how it was stored. For example, a sample could be collected as a single spike (ear) of grain from one plant, as spikes from several plants from the same field that were conserved separately by the genebank, or as part of a "bulk" of seeds—seeds collected from a number of plants thought to be representative of a given landrace and maintained in the same sample. The analysis reinforced long-held views on collection but, surprisingly, contradicted others.

The team found tremendous genetic differences among landraces grown within a country considered a center of origin for wheat, even if the landraces went by the same name and were collected from adjacent villages. On the other hand, in countries not designated as centers of origin, even landraces going by different names appeared to be very similar genetically.

"These findings tell scientists to focus their collecting in centers of diversity," says Warburton. "While we knew that in theory, we now have the data to back it up."

However, the team came up with disconcerting results that showed that the amount of variation within a landrace sample did not necessarily correlate with how it was collected—a finding at odds with the conventional wisdom.

"If the sample was collected as a bulk," Warburton explains, "you'd expect to see several different alleles—forms of the same gene—at each marker, but all too frequently we saw only one or two alleles. Either the field where we collected the sample was planted to a single genotype, or some variation was lost after years in storage."

Such samples should not be treated as bulks but rather as a single inbred line. When the sample is regenerated, fewer seeds can be planted. In addition, breeders can be informed that there is limited variation in the line and it can be treated as an inbred.

A few samples collected from a single spike showed a lot of variation. There are several possible explanations for this unexpected result. The sample may have been an outcrossed hybrid (a rare but not impossible occurrence), seeds may have been mixed during some stage of handling, or the passport data were simply incorrect. Regardless of how the variation occurred, wheat breeders or genebank curators should not treat these samples as inbreds. They should treat them as bulks and conserve their diversity.

"This work provided an immediate practical payoff for the genebank," says Bent Skovmand, head of the wheat genebank. "By employing these techniques on a wider scale, we can help people collect and store genetic resources more efficiently, avoid loss of variation, and save money by growing only the number of plants needed to retain the genetic diversity in a particular sample."

What Is Genetic FINGERPRINTING?



Genetic fingerprinting is probably more widely known for its uses in people—where it is used to determine paternity or indicate whether a person was present at a crime scene—than for its uses with plants. However, just like fingerprinting in humans, fingerprinting in plants can clear up a few mysteries.

Known also as “DNA fingerprinting” and “DNA profiling,” fingerprinting in plants is based on the assumption that every individual variety or population has a genetic profile, revealed through its DNA, that is unique to that variety.

Researchers obtain samples of DNA from plant tissue and use several techniques to produce a “fingerprint” that looks like a series of bands of varying size, much like a bar code. The bands for one variety can be compared to bands for other varieties to detect similarities and differences. The more similarities there are, the more related the two varieties are, and the parents of the variety (or sibling varieties sharing the same parents) can be determined.

Although breeders generally have a very good idea of the origins and probable genetic advantages of the varieties or lines they develop, fingerprinting adds greater certainty to their work and helps them to work more rapidly. Closely related lines frequently share the same characteristics; thus, if one line has a favorable performance under certain conditions, lines closely related to it probably will, too. Also, in hybrid breeding, lines that are unrelated generally create better performing hybrids than lines that are related to each other or are very similar genetically. DNA fingerprinting can help breeders decide which varieties to cross with which.

Another problem that can confound plant breeding is that varieties found in several parts of the world (or even the same country or province) can have the same name but may not even be related. Fingerprinting can determine if varieties with the same name are truly genetically identical. This information helps breeders and also helps genebank curators decide which seed to conserve.

IMPACT

Studies: Room for Improvement?



Reaching the right people: International research organizations have documented how their work helps the poor, but are the results of these impact studies making a difference?

The complex and costly nature of good impact assessment studies and the multiplicity of factors that determine their outcome were among the issues discussed during an international conference held in Costa Rica in 2002.

The conference, provocatively entitled, "Impacts of Agricultural Research and Development: Why Has Impact Assessment Research Not Made More of a Difference?", was hosted by the CGIAR's Standing Panel on Impact Assessment (SPIA) and the CIMMYT Economics Program. Leading experts reviewed impact assessment studies, communicated the pivotal role of research and development to policymakers, and shared best practices.

Do We Learn from Our Mistakes?

“Experience suggests that one of the best ways to achieve food security, good environmental stewardship, and sustainable economic development is through the development and application of improved agricultural technologies,” says Prabhu Pingali, director of the CIMMYT Economics Program at the time of conference. He notes that these improved technologies take a long time to develop, and their future availability depends largely on current investments in research.

“If current investments are to be effective, we have to understand the outcomes of past investments,” says Pingali. “This is why our conference focused on ways to make impact assessment more understandable.”

Participants developed principles and strategic guidelines for future impact studies. They examined the multiple purposes of impact assessment—accountability to donors, improving future research, resource mobilization, and public awareness. Mention was also made of the need for multidisciplinary studies that look at a range of impacts.

“People want information that guides them on design, program or project choices, on how to allocate resources across programs or projects, or to demonstrate at the completion of a project that resources were effectively used,” says Alex McCalla, emeritus professor in the Department of Agricultural and Resource Economics at the University of California-Davis and Chair of CIMMYT’s Board of Trustees.

McCalla points out that impact assessment has become more complicated because there are more players with more objectives, and they demand more sophisticated analysis. “Answering questions of impacts for these multiple players with multiple objectives, using complex conceptual models, has made impact assessment more costly,” he says.

Communicating Impacts to Funding Agencies and the Media

Representatives from funding agencies such as GTZ, the International Fund for Agricultural Development (IFAD), and the US Agency for International Development (USAID) outlined issues that concerned donors. They emphasized the need for more credible results, including a more balanced selection of case studies that examine research failures as well as successes.

A media panel included journalists from *The Economist* and *The Hindu* and Barbara Rose, executive director of Future Harvest at the time of conference. The panelists observed that journalists are interested in stories that are relevant to current problems such as environmental degradation, poverty, and global warming. Because myriad issues vie for journalists’ attention, it is critical to target the right audience and media outlet for messages about research impacts.

Immediate Impacts of the Conference

The conference exceeded expectations. “There appeared to be a real openness to rethinking how impact assessment is done at the Future Harvest Centers,” remarks Rose. Archana Godbole from the Applied Environmental Research Foundation in India and Carmen Nieves Mortensen from the Institute of Seed Pathology in Denmark say that they learned a lot. “I have to admit I was surprised to see that even after four long days of meetings, the room was still packed,” says SPIA chair Hans Gregersen.

Instead of issuing a traditional proceedings volume, conference organizers are assembling selected papers for publication in special issues of professional journals. “Special issues reach a much larger audience than proceedings,” says Michael Morris, assistant director of the CIMMYT Economics Program. “They’re externally reviewed and regarded as more substantial publications.”

Special issues are currently being prepared for *Agricultural Economics*, *Quarterly Journal of International Agriculture*, and *Agricultural Systems*. Work has also begun on the development of a web site to promote best practices in impact assessment, disseminate results, foster dialogue between impact assessment practitioners, and demonstrate organizational learning.



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Achieving Uncommon Things: Biotechnology Network in Asia

The first slide appeared on the screen and B.M. Prasanna read it through to the last sentence. “*The purpose of an organization is to enable common men’—and of course we also mean women—‘to do uncommon things.’* These words are from Peter Drucker, the pioneer of management theory,” Prasanna explained, “and they speak directly to why we are here today.”

The occasion was the initiation of Phase II of a project to develop the Asian Maize Biotechnology Network (AMBIONET). The meeting, held in 2002 in Indonesia, involved research teams from the participating countries—Indonesia, Thailand, Philippines, China (two teams), Vietnam, and India—as well as resource persons from CIMMYT headquarters and Antonio “Tony” Perez (interviewed on p. 54) from AMBIONET’s primary financial supporter, the Asian Development Bank (ADB). Other significant donors include CIMMYT and the national agricultural research systems of the research teams.



Individual genius is good, but organized collaboration may be better. AMBIONET team members from Malaysia in the lab with Luz George, project coordinator (back row, left) and Tony Perez of the Asian Development Bank.

Meeting National Needs through Biotechnology

AMBIONET was launched in 1998. Perez and David Hoisington, director of CIMMYT’s Applied Biotechnology Center, envisioned creating a participatory forum that would employ biotechnology to catalyze increased maize productivity in Asia’s developing countries. Collaboration and information sharing would advance the aims of all the teams. CIMMYT would provide technical training, backstopping, and guidance through project coordinator Maria Luz George, based in the Philippines, and scientists at CIMMYT headquarters.

The teams established research objectives to meet national and network needs. One of the objectives, the molecular profiling of maize, has already had considerable impact in China, the world’s second largest maize producer, and in India, a major Asian producer. Shihuang Zhang, the AMBIONET-China country coordinator, reflects that when

the network was initiated, there was considerable debate among Chinese maize breeders about pedigrees and heterotic groups. “Experienced breeders were arguing that we needed maybe 12 or 16 groups or patterns, but this was slowing progress. We went to work with the molecular markers, and today our knowledge about our materials is much better—our breeders work on the basis of 3 groups and 2 patterns, and even more important, they have changed their approach.”

Prasanna tells a similar story. Indian maize breeders were skeptical about molecular genetics. Then along came the Plant Variety Protection Act. Now, says Prasanna, they are interested in fingerprinting their maize lines to firmly establish their identities: “I have more requests than my lab can handle.”

Working on another AMBIONET objective, to use molecular markers to accelerate breeding for traits of interest, teams used molecular data from a cross previously mapped by CIMMYT, combined with phenotypic data produced in five locations in India, Indonesia, Philippines, and Thailand, to identify genes for downy mildew resistance. Five quantitative trait loci (QTL) that significantly influence downy mildew resistance were identified, three of which explain up to 50% of the phenotypic variance for reaction to downy mildew disease. With genetic linkage maps constructed in the AMBIONET-China lab and phenotypic data from Beijing, researchers identified five QTLs conferring resistance to sugarcane mosaic virus, explaining up to 27% of the phenotypic variance. By verifying the presence of these QTLs in their lines and varieties, breeders can be sure that they are developing plants that resist these destructive diseases.

Most gratifying for network coordinator George was simply getting the network up and running well. "Our primary goal, to form an environment where scientists could work together to apply new science to maize production, was realized, but it took some work—about 80 scientists trained at 4 workshops, 12 extended exchange visits, and contributions to 10 graduate degrees. With support from CIMMYT and the national programs, and leadership from the network scientists, we are moving forward." Team leaders discuss their experiences in "AMBIONET: Getting Students into the Lab" (see right) and "AMBIONET: Focus on Thailand," p. 53.

The funding of a second phase was an endorsement of AMBIONET's approach. "One goal for phase two," says George, "is to make the national teams and the network self-sustaining." To make this critical transition, training in grant writing has been assigned high priority. On the scientific side, genetic fingerprinting and mapping activities in support of breeding are targeted to quality protein maize (QPM), drought tolerance, genetic diversity, and resistance to banded leaf and sheath blight (an emerging threat in intensive maize/ rice cropping systems). These objectives too will be supported with training, as will bioinformatics.



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AMBIONET project web site: <http://www.cimmyt.org/ambionet/index.htm>.

AMBIONET: Getting Students into the Lab

Working at the Indian Agricultural Research Institute, B.M. Prasanna is called on to teach as well as conduct research. In the past, students left with an excellent theoretical background but little practical experience. This has changed. "With AMBIONET support, I've trained a number of students on how to employ markers in their research," he says. Students from Vietnam, Iran, and Ethiopia have also worked toward advanced degrees in Prasanna's lab.

During an exchange visit to Prasanna's lab, Shihuang Zhang, AMBIONET-China Country Coordinator, witnessed the effectiveness of this approach. "I saw all these young people in his lab and I thought I should take this back to China. Our universities have many graduate students but they do not have enough money to support research. On the other hand, under recent reforms, my institute is cutting back on paid staff. So we opened our doors and have the students work with us, and in turn we help them prepare their theses. Perhaps this approach is already popular elsewhere, but for China this is very new—and very useful."



A Conversation with **AMBIONET** Donor Representative Antonio "Tony" Perez

As a Principal Agriculturalist with the Asian Development Bank (ADB) for many years, Antonio Perez has seen support ebb and flow for agricultural research, and he has witnessed the impacts on poor farmers. All of this has endowed Perez with a keen sense of what is needed to get results. During a break at the AMBIONET Phase II meeting in April 2002, Perez took a few moments to talk about the project with us.

Q: Dr. Perez, you were present at the creation of AMBIONET. What did you originally envision?

A: What we envisioned was simply to have maize farmers benefit from biotechnology. Because the rice biotechnology network has been so successful, we found a similar opportunity to do the same with maize.

The NARS [national agricultural research systems] were not getting access to biotechnology techniques. They had laboratories, but they did not function well, if at all. Most of them were not getting support from their governments and ministries. This network was meant to build a foundation so that the scientists from the ADB developing member countries can support one another in the future.

All this ties into a central mandate of the ADB—the reduction of poverty. More than 900 million people in Asia still suffer from poverty, most of them in rural areas. We have seen firsthand how something as simple as an improved variety can make a lot

of impact on the income and nutrition of the poor in these areas. When farmers earn some extra money, most often it goes to sending their children to school, a huge factor in helping people lift themselves out of poverty. Bringing biotechnology to bear on the development of improved varieties will lead to improved varieties with various resistances and advantages in terms of consumer characteristics. This is a clear route to getting the benefits of modern science to the poor farmers.

Q: Why did ADB seek out CIMMYT as a partner?

A: The advantage you gain when you bring a CGIAR center such as CIMMYT into a project is that you get a team of scientists from a range of disciplines with the knowledge to backstop the multifaceted activities of a network like AMBIONET. The ADB's focus on networks—backstopped by strong institutions such as CIMMYT—has been evaluated as one of our more successful approaches to agricultural research and development.

Q: Aside from the hard work of the AMBIONET team and CIMMYT's support, what was critical for the network's success?

A: I think those institutions that brought graduate students into their labs and programs really strengthened their outputs and the vitality of the network. They strengthened the overall scientific capacity of their nation at the same time. The lack of this approach remains a concern in some AMBIONET partners, but I believe they will move in this direction. The ADB experience is that whether it's a livestock network or a commodity network, when the universities participate, the payback in terms of quality and quantity of research are tremendous.

Q: Why did ADB decide to support a Phase II for AMBIONET?

A: Obviously we were quite pleased with the progress we saw in Phase I. The capacity building, both human and in terms of facilities, and the coalescence of the team were very encouraging. With those in place, we saw the opportunity to focus on the development of germplasm that will be tailor-made for resource-poor farmers. These are difficult but important areas of research, including resistance to drought, tolerance to low soil fertility, the introduction of quality protein maize, and resistance to emerging diseases such as banded leaf and sheath blight.

With the pool of trained people we now have in the region, we also have the ability to move into functional genomics and bioinformatics. Work in these areas can be broken down into independent components, so it is amenable to a network approach. Because of the expense and scope of this type of research, it will only be through networking that ADB developing countries will be able to fully utilize this new branch of science.

Antonio Perez, much to the regret of the AMBIONET team, retired from his position at ADB in June 2002. He plans, however, to remain active in the field of agricultural research and international development.

AMBIONET: Focus on THAILAND



Shortly after the launch of AMBIONET, Thai maize breeder Pichet Grudloyma (pictured, far right) became a key part of the Thailand team. Two years ago, he was partnered with molecular geneticist Krishnapong Sripongpankul (pictured to the left of Pichet), who works with the Asian Rice Biotechnology Network (also initiated by ADB). Krishnapong's experience with rice could be very useful in developing a marker-assisted selection approach for maize.

Both researchers concluded that they could go well beyond fingerprinting for downy mildew resistance, drought tolerance, and tolerance to low nitrogen in the soil; they could produce recombinant inbred lines that would yield a new generation of hybrids that incorporate those traits. That kind of progress goes a long way toward convincing breeders about the efficacy of the technology.

"Right now," says Pichet, "the breeders spend a lot of time and money on numerous breeding cycles. If we can optimize the marker-assisted selection, we can quickly decide whether to breed a variety further."

"We interact a lot," says Krishnapong. "Though we sit in different places and have different perspectives based on our disciplines, our idea of where we want to go is the same. We both aim to benefit farmers through the Department of Agriculture mandate. It's our job and our duty."

Such talk in a US or European lab might sound contrived. In Thailand this commitment is heartfelt, not just by the AMBIONET-Thailand team, but by the national government, which gives agriculture high priority and sees biotechnology as the way forward. In late 2002, Krishnapong will move to a new lab in the Srinthorn Plant Genetic Resources Building, named after the highly esteemed Royal Princess of Thailand who has championed the use of these technologies.

All the disciplines that use biotechnology will be in a single facility, together with a robust genebank for key crops. The facility will provide high throughput sequencing, lab and bioinformatic support for functional genomics, and with its transformation lab and biocontainment greenhouse, genetic engineering.

CIMMYT Funding Overview

2001-2002

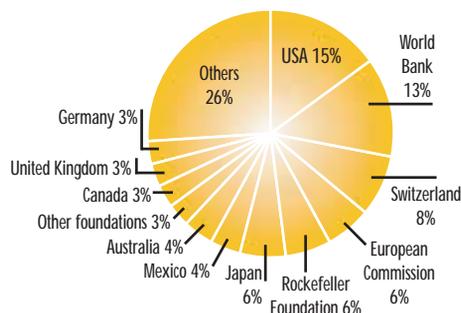


Figure 1. Top 12 investors in CIMMYT, 2001.

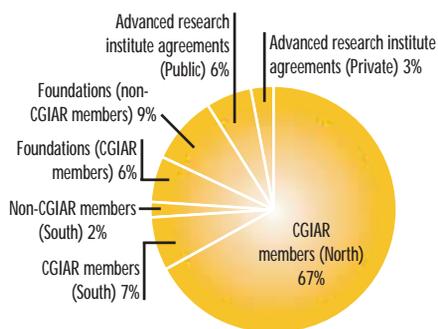


Figure 2. Investors in CIMMYT, 2001.

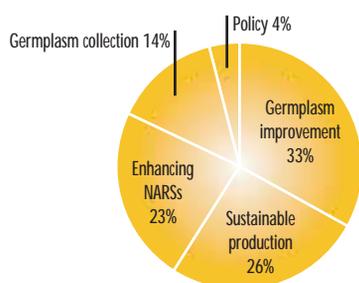


Figure 3. Allocation by CGIAR output, 2001.

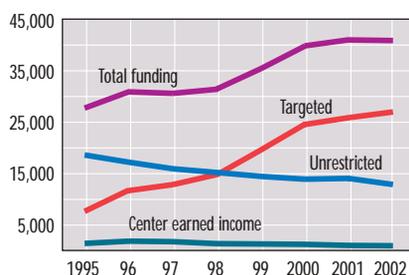


Figure 4. Trends in funding (US\$ 000), 1995-2002.

Funding at a Glance

The governments and agencies that provided the largest share of our funding in 2001 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 (public and private), are presented in Figure 2. To achieve the five research outputs of the CGIAR, CIMMYT allocated its budget as shown in Figure 3.

Sources of income from grants are presented in the Table (p. 56). Targeted funding continues to provide the bulk of CIMMYT's research resources (Figure 4). The trend in core unrestricted funding in relation to targeted contributions continues to provide challenges to the Center, as flexibility is reduced and core research on the management and use of genetic resources becomes harder to support. Full costing of projects is more important than ever, including accurate costing and recovery of indirect costs. Indirect costs are currently running at about 28%, whereas net overhead recovery is slightly less than half this rate.

Funding Trends

Funding for 2001 was US\$ 41.030 million (including Center earned income), of which 80% came from CGIAR investors and 20% from other sources. Expenditure was US\$ 41.3 million.

The budget in 2001 was 4% higher than initially projected for several reasons. First, our research portfolio is highly relevant to the current goals of investors who have traditionally supported international agricultural research. Second, CIMMYT has enhanced efforts to support its research with non-traditional sources of funding. The trend towards diversified sources of income has continued in 2001-2002. CIMMYT's partnerships with foundations and advanced research institutes are expanding.

CIMMYT's alliances with advanced research institutes take the form of partnerships, generally with the public sector in the North and the South. In the case of the former, CIMMYT is interested in alliances that help us to more quickly develop new, appropriate technologies and deliver them to farmers' fields in developing countries. For the latter, we are very cognizant of our role in helping to create an enabling environment for our partners in developing countries. A significant component of CIMMYT's budget in 2001 (almost US\$ 5.5 million) was flow-through funding to our partners in the South; this represents trust in CIMMYT by our partners and trust with our investors.

Similarly, our interactions with the advanced research institutes of the private sector have become stronger. These interactions continue to take the form of "win-win" alliances directed at achieving the following outcomes:

- access to proprietary technologies that enable CIMMYT to deliver research outcomes to developing countries more quickly;
- the facilitated transfer of technology, research products, and other benefits to the resource-poor; and
- the leverage of additional resources brought to bear on challenges in developing countries.

A third reason that the Center's budget was higher in 2001 than initially projected is that CIMMYT has vigorously pursued partnerships that enable scientists from developed countries to work at CIMMYT sites worldwide and make a significant contribution to CIMMYT's research agenda. This approach, known as "in-kind contributions," is perhaps best exemplified by the current contribution from France (CIRAD, IRD, INRA),* but there are a number of other examples. Total income in this category for 2001 amounted to almost US\$ 2 million.

Prospects for 2002-2003

An important factor in the Center's budget and cash flow scenario in 2001 was that the US dollar remained strong against almost all other currencies in the world.

Against this trend, however, the Mexican peso appreciated in value. With 50% of CIMMYT's budget expended in pesos, the Center was forced to produce an effective "efficiency gain" of 5-7%.

The operation of a Center that has two major plant breeding programs continues to pose challenges for financial management, particularly with regard to cash flow and working capital reserves. CIMMYT's level of working capital is lower than that recommended by the CGIAR and an additional injection is needed. We are using alternative options to increase working capital beyond the current level of about 50 days. We have also taken measures internally to optimize the use of capital funds. For example, we have implemented an internally administered cost recovery system for the vehicle fleet.

Given the volatility of traditional funding resources and the increased competition for resources, both inside and outside the CGIAR, CIMMYT's budget estimate for 2003 is likely to be more conservative. More specifically, CIMMYT and other CGIAR Centers will be affected by changing conditions in the World Bank's general support allocation (replacing the matching formula with a fixed contribution based on the past three years' funding outcomes), most probably starting in 2003. In addition, we have not budgeted funds for the implementation of the Challenge Programs.

* CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement), IRD (Institut de Recherche pour le Développement), and INRA (Institut National de la Recherche Agronomique).

Table 1. CIMMYT sources of income from grants by country/entity (US\$ 000s), 2001.

Investor	Grant	Investor	Grant
ADB (Asian Development Bank)	745 ¹	Kenya, Government of	78
Argentina	50	KARI (Kenya Agricultural Research Institute)	78 ²
INTA (Instituto Nacional de Tecnología Agropecuaria)	50 ⁶	Korea, Republic of	140
Australia	1,467	Rural Development Administration	140 ²
AusAID	115 ¹	Mexico	1,592
Australian Centre for International Agricultural Research	640 ¹	SAGAR (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación)	1,137 ²
CRC Molecular Plant Breeding	259 ⁶	Fideicomisos Instituidos en Relación con la Agricultura	45 ³
Grains Research and Development Corporation	448 ⁶	Fundación Guanajuato Produce A.C.	59 ⁵
Southern Cross University	5 ⁶	Fundación Hidalgo	30 ⁵
Austria	160	Fundación Sonora	228 ⁵
Federal Ministry of Finance	160 ¹	Grupo Industrial Bimbo (Industrial Quality in Wheat)	38 ⁷
Azerbaijan	158	ICAMEX (Maize and Wheat Improvement)	54 ⁷
Agency for Support to the Development of the Agricultural Private Sector	158 ³	Miscellaneous Research Grants	149 ⁶
Bangladesh	65	Netherlands	398
Bangladesh Agricultural Research Council	65 ²	Ministry of Foreign Affairs	318 ¹
Belgium	574	DGIS (Directorate General for International Cooperation)	81 ⁶
Ministry of Foreign Affairs, Foreign Trade and International Cooperation	574 ¹	New Zealand	100
Bolivia	449	Ministry of Foreign Affairs and Trade	100 ¹
Protrigo	449 ³	Norway	268
Brazil	100	Royal Norwegian Ministry of Foreign Affairs	268 ¹
EMBRAPA (Brazilian Agricultural Research Corporation)	100 ²	OPEC Fund for International Development	50 ¹
Canada	1,335	Other	717 ⁷
Agriculture and Agri-Food	63 ⁶	Other Foundations	1,337 ⁵
Canadian International Development Agency	1,213 ¹	Peru	60
International Development Research Centre	58 ¹	National Institute of Natural Resources	60 ²
CGIAR	648	Philippines	12
Centro Internacional de Agricultura Tropical	30 ¹	Bureau of Agriculture Research, Department of Agriculture	12 ²
CGIAR Finance Committee*	352 ¹	Portugal	150
International Food Policy Research Institute	154 ¹	Institute for International Scientific and Technological Cooperation	150 ¹
International Livestock Research Institute	20 ¹	Rockefeller Foundation	2,405 ⁴
International Plant Genetic Resources Institute	23 ¹	SCOPE	37 ⁶
Standing Panel on Impact Assessment	68 ¹	South Africa	135
China	424	Agricultural Research Council	41 ⁶
Department of International Cooperation, Ministry of Agriculture	120 ²	National Department of Agriculture	94 ²
CAAS (Chinese Academy of Agricultural Sciences)	293 ⁶	Spain	325
Lamsou Milling Company (Germplasm Enhancement)	11 ⁷	Ministerio de Agricultura, Pesca y Alimentación	223 ²
Colombia	219	Agrovegetal, S.A. (Durum and Bread Wheat Breeding)	102 ⁷
CORPOICA	87 ³	Sweden	352
Ministry of Agriculture and Rural Development	132 ²	Swedish International Development Agency	352 ¹
Denmark	686	Switzerland	3,325
Danish International Development Agency	686 ¹	Swiss Agency for Development and Cooperation	1,680 ¹
European Commission	2,424	Syngenta Foundation for Sustainable Agriculture	1,644 ⁵
Rural Development and Food Security	2,424 ¹	Tajikistan, Republic of	5
Ecuador	23	Farm Privatisation Support Project	5 ³
Promsa	23 ³	Thailand	9
FAO (Food and Agriculture Organization)	21 ¹	Department of Agriculture	9 ²
Ford Foundation	56 ⁴	United Kingdom	1,319
France	1,113	Department for International Development	1,295 ¹
Club Cinq (Wheat Breeding)	153 ⁷	University of Reading	24 ⁶
Ministère de l'Éducation Nationale, de la Recherche et de la Technologie - DRIC (Délégation aux Relations Internationales et à la Coopération)	960 ¹	UNDP (United Nations Development Programme)	505
Germany	1,216	Africa Bureau	413 ¹
Eiselen Foundation	64 ⁵	SEED	93 ¹
Federal Ministry of Economic Cooperation and Development	1,139 ¹	Uruguay	150
University of Hohenheim	13 ⁶	National Institute of Agricultural Research	150 ³
India	181	USA	5,971
Department of Agriculture, Research and Education	161 ²	Carter Center	80 ⁵
Maharashtra Hybrid Seed Co. Ltd. (Wheat Germplasm)	20 ⁷	Cornell University	36 ⁶
Indonesia	69 ²	Hilton Foundation	12 ⁵
IDB (Inter-American Development Bank)	300 ¹	Monsanto Company (Hybrid Wheat)	229 ⁷
IFAD (International Fund for Agricultural Development)	441 ¹	Oklahoma State University	28 ⁶
Iran, Islamic Republic of	227	Pioneer (Training Center)	25 ⁷
Ministry of Agriculture	227 ²	Stanford University	116 ⁶
Japan	2,214	United States Agency for International Development	4,883 ¹
Economic Cooperation Bureau, Ministry of Foreign Affairs	1,814 ¹	United States Department of Agriculture	547 ⁶
JIRCAS (Japan International Research Center for Agricultural Sciences)	112 ¹	University of California	15 ⁶
Nippon Foundation	251 ⁵	World Bank	5,028 ¹
Sasakawa-Global 2000	37 ⁵	Total Grants	39,980 ^{**}

* Activities related to this grant: Rice-Wheat Consortium (214), Maize-rice genomics (55), CAC System-wide Initiative (wheat) (62), and CAC System-wide Initiative (maize) (21).

** Does not include Center income of US\$ 1.050 million.

¹⁾ CGIAR Members (North).

²⁾ CGIAR Members (South).

³⁾ Non-CGIAR members (South).

⁴⁾ Foundations (CGIAR members).

⁵⁾ Foundations (Non-CGIAR members).

⁶⁾ Advanced research institute agreements (Public).

⁷⁾ Advanced research institute agreements (Private).

CIMMYT Worldwide

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 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.
- Research on economic and policy issues in maize and wheat production and research.
- 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.

- Farmers on hundreds of thousands of hectares in developing countries use resource-conserving practices developed and promoted by CIMMYT and its partners.
- 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. 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 our regional offices. Headquarters are in Mexico. See contact information, p. 61.

Visit CIMMYT at www.cimmyt.org.

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

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

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A Map of the World for Wheat Breeding

CIMMYT wheat breeders have a different map of the world than the rest of us.

Their map is a mosaic of growing environments, each with distinct characteristics that influence wheat production.

Most wheat breeders have a fairly narrow scope of operations, but those at CIMMYT breed wheat for the entire developing world. This is a tall order: wheat is grown on about 110 million hectares in more than 70 developing countries, so CIMMYT breeders must understand how factors such as temperature, rainfall, diseases, and pests vary. They need to know which characteristics are essential in wheat varieties intended for specific parts of the world, and they must also understand how individual wheat varieties—and ultimately wheat production—are likely to be affected by growing conditions in the various environments.

In the 1980s, CIMMYT's wheat breeders began to codify their vision of the developing world's wheat growing areas into a standard set of "mega-environments." The mega-environments were defined by crop production factors (temperature, rainfall, sunlight, latitude, elevation, soil characteristics, and diseases), consumer preferences (the color of the grain and how it would be used), and wheat growth habit (see "Habits of Highly Successful Wheat Varieties," inside back cover). Researchers identified six mega-environments for spring wheats and three each for facultative and winter wheat (see table). Most wheat grown in developing countries is spring wheat, though China, Turkey, and parts of Central Asia, for example, have large areas of winter and facultative wheat.

Description of global wheat mega-environments. Climatic criteria are based on conditions during the coolest, warmest, or wettest consecutive three months of the year and annual means or totals.

Mega-environment	Description	Representative sites
Spring Wheat		
ME1: Favorable, irrigated low rainfall. Estimated area: 36 M ha.	Well irrigated, low rainfall regions. Conditions during the cropping season range from temperate to late heat stress, especially with late sowing. Predominantly winter-sown, tropical to subtropical. Rarely, spring-sown cool temperate regions. White-grained types predominate.	Gangetic Valley, India; Indus Valley, Pakistan; Nile Valley, Egypt; Yaqui Valley, Mexico.
ME2: High rainfall. Estimated area: 8 M ha.	Regions where crops experience no or minor moisture deficits.	
ME2A: Highland, summer rain. Estimated area: 2 M ha.	Highland regions of the tropics and subtropics where crops are grown on summer rainfall. Red grain type except white for Ethiopia.	Kulumsa, Ethiopia; Toluca, Mexico.
ME2B: Lowland, winter rain. Estimated area: 6 M ha.	Highland regions of subtropical and warm temperate regions where crops are grown on winter rainfall. Red grain type.	Izmir, Turkey; Pergamino, Argentina.
ME3: High rainfall, acid soil. Estimated area: 2 M ha.	Similar to ME2 but for regions with acid soils. Red grain is generally preferred except in the Himalayas.	Passo Fundo, Brazil; Mpika, Zambia.
ME4: Low rainfall. Estimated area: 14 M ha.	Three types of moisture deficits, based on developmental stage when moisture deficits occur, are recognized as sub-environments.	
ME4A: Winter rain or Mediterranean-type climate. Estimated area: 8 M ha.	Regions with a Mediterranean climate with post-flowering moisture deficits and heat stress typical. Late season frosts may occur. White grain is preferred.	Aleppo, Syria; Settat, Morocco.
ME4B: Winter drought or Southern Cone-type rainfall. Estimated area: 3 M ha.	Associated with pre-flowering moisture deficits. Red grain preferred to reduce sprouting.	Marcos Juárez, Argentina.
ME4C: Stored moisture. Estimated area: 3 M ha.	Sown after monsoon rains, resulting in continuous, Indian Subcontinent-type drought. Only white grain is accepted.	Dharwar, India.
ME5: Warm.		
ME5A: Warm, humid. Estimated area: 8 M ha	Warm, humid, lowland tropical to subtropical regions.	Joydebpur, Bangladesh; Encarnación, Paraguay.
ME5B: Warm, dry. Estimated area: 1 M ha.	Warm, semiarid to arid tropical to subtropical regions.	Kano, Nigeria; Wad Medani, Sudan.
ME6: High latitude (> 45°N or S). Estimated area: 50 M ha.	Cool temperate regions of North America, Europe, and Asia where wheat is spring-sown as winters are too severe for survival of even winter wheat.	
ME6A: High-rainfall.	Humid regions of western and central Europe and of eastern Asia with winter conditions too severe for winter wheat.	Harbin, Heilongjiang, China.
ME6B: Semiarid.	Dry regions of central and eastern Asia and the northern plains of Canada and the USA with winter conditions too severe for winter wheat.	Astana, Kazakhstan.
Facultative Wheat		
ME7: Favorable, moderate cold, irrigated.		Zhenzhou, Henan, China.
ME8: High rainfall (> 500 mm), moderate cold.		Temuco, Chile; Corvallis, Oregon, USA.
ME9: Semi-arid, moderate cold, low rainfall.		Diyarbakir, Turkey; Vernon, Texas, USA.
Winter Wheat		
ME10: Favorable, cold, irrigated.		Beijing, China.
ME11: High rainfall, cold.		Cambridge, UK; Krasnodar, Russia.
ME12: Semi-arid, low rainfall, cold.		Ft. Collins, Colorado; Manhattan, Kansas, USA.



When your job is to breed wheat for the entire developing world, how can you meet specific needs in specific regions?

CIMMYT wheat breeders plan crosses between varieties with the different mega-environments in mind. By focusing on key characteristics for each mega-environment, breeders can reach their objectives more efficiently. For example, farmers in high-rainfall environments need wheat that resists as many as eight diseases, whereas fewer and different diseases are important for their counterparts in droughty areas.

Once the actual breeding process has come to an end, experimental wheats destined for a certain mega-environment are tested under those conditions. They are selected for additional improvement only if they can withstand the particular stresses predominating in that environment. Mega-environments therefore help CIMMYT's breeders set priorities for their research, which is important when they serve such a large area.

The results of this approach have been impressive. CIMMYT-related wheat varieties are planted on more than 64 million hectares in developing countries—more than three-fourths of the area planted to modern wheat varieties in those countries. In other words, CIMMYT wheat breeders have been extremely successful in developing wheat for a multiplicity of environments.

With the advent of geographic information systems (GIS), researchers have gained a means to visualize these important growing environments in greater detail, though it is not a simple matter to map the mega-environments. Jeff White, head of CIMMYT's GIS and Crop Modeling Laboratory, recently revised the mega-environment classification, primarily using climate data (see map, previous page).

"Chasing down mega-environment classifications for each site required several rounds of consultation with wheat scientists," White says. "Not surprisingly, nailing down precise locations was a challenge—names of research sites sometimes bear no relation to nearby towns or cities. But with this database in place, we can address the challenge of delineating the mega-environments as regions based on quantitative criteria for climatic and soil conditions."

The head of bread wheat breeding at CIMMYT, Maarten van Ginkel, worked closely with White to revise the mega-environments. He appreciates the potential of GIS techniques to help breeders develop varieties with the precise traits that farmers and consumers want. "With GIS, we can go beyond classical maps based on political boundaries, rainfall, and temperature. For example, we can visualize the geographical extent of trends in climatic change, projected pathways for wind-borne wheat diseases, human demographic and migration trends that affect wheat consumption, urban-rural zoning developments, and perhaps even new consumer preferences," he says.

Over the past 40 years, CIMMYT's wheat breeders have increasingly refined their breeding goals based on their comprehensive experience of conditions in the developing world. Now GIS techniques offer a way to test some of the assumptions behind their breeding goals. "We want to do more than simply confirm what we already know," says van Ginkel. "I hope that using GIS will teach us some things we do not know, or identify assumptions that are incorrect, so we can become better at what we do."



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Habits of Highly Successful Wheat Varieties

Almost everyone knows about the two main kinds of wheat—bread wheat and durum wheat—but few are aware that wheat also has three distinct growth habits: spring, winter, and facultative. A variety's growth habit limits its survival to certain geographic areas, mostly defined by latitude, which is why growth habit is fundamental to CIMMYT's classification of wheat growing environments.

Spring-habit wheats have a continuous growth cycle with no inactive period. In areas where winters are severe, such as northern Kazakhstan or Canada, wheat is planted in the spring after there is no risk of frost. In areas with very mild winters, such as India or Australia, spring wheat is sown in the autumn and grows through the winter.

Winter-habit wheats evolved to withstand low winter temperatures, such as those that prevail in North Korea or northwestern Europe. To flower, they require exposure to cold during their early growth. Winter wheats are sown in autumn and start to grow before winter sets in, when they become inactive. The plants resume rapid growth in the spring as temperatures rise.

Facultative-habit wheats tolerate cold more than spring wheats and less than winter wheats, but they do not require extended exposure to cold temperatures to reproduce. These wheats are found in transition zones between true spring and winter wheat regions.

Because these types of wheat have become adapted to contrasting climatic conditions, each has developed resistance or tolerance to stresses common in those conditions. These kinds of wheat probably also have distinct genes for high and stable yield. In some cases, the special genetic advantages of one wheat type can be useful in other wheat types. For example, some of CIMMYT's highest-yielding wheats have resulted from crosses between spring and winter wheats that exploited the yielding ability and stress resistances/tolerances of both wheat types. "This breeding approach brings genes together in completely novel combinations," says van Ginkel. "The genes were already widely present, but they were in geographically distinct—and often distant—locations."