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 Naltel, 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.

MAYAN
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/whatiscimmyt/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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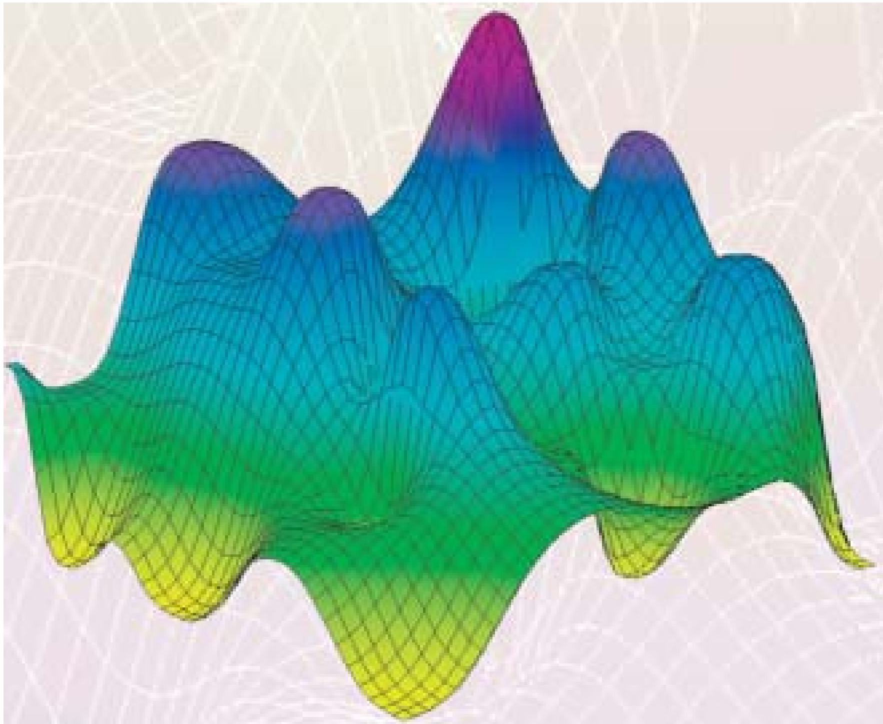
QU-CIM: Breeding Real Wheat from Virtual Wheat



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 connot 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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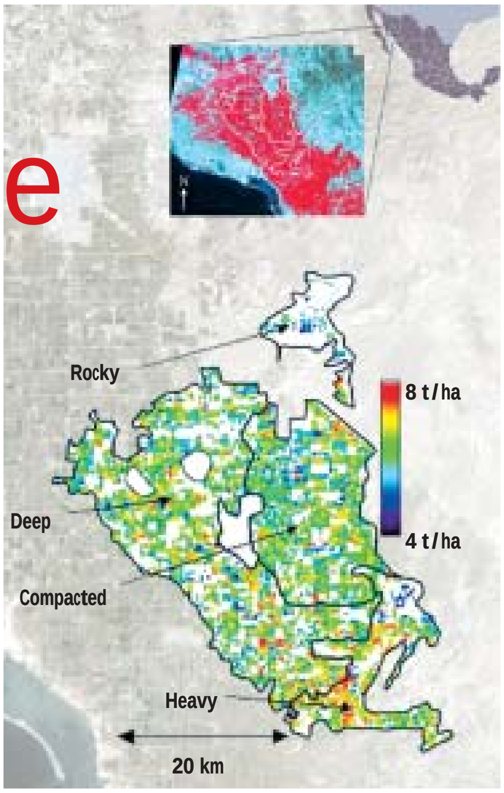
Managing Agriculture
to Manage

Climate Change



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

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.

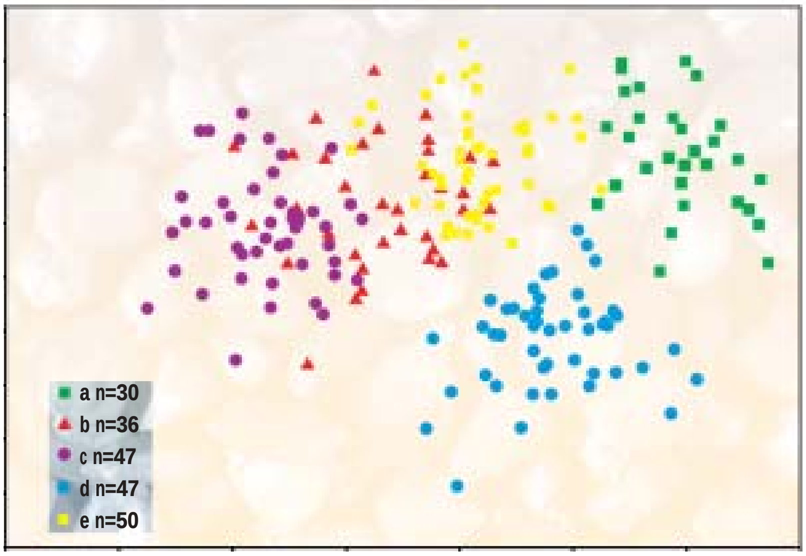
When CIMMYT's predecessor organization began work in the 1940s on improved maize for developing countries, its first step was to gather seed of diverse landraces from fields, markets, and farm households throughout Latin America. This seed was classified by race, the ecology where it was best adapted (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.

Taba 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," Taba 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 Taba 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

Taba 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 Taba 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 Taba, 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.