A Sampling of

CIMMYT Impacts, 1999

New Global and Regional Studies

Sustainable Maize and Wheat Systems for the Poor

Introduction

CIMMYT and its partners engage in one of the world's most ambitious humanitarian endeavors: together, we form a global wheat and maize improvement system that seeks to better the lives of millions of poor farmers and consumers in developing countries.

Maize and wheat are staple foods and important sources of income virtually everywhere in the developing world. Together, these two crops provide about one-fourth of the food calories consumed in developing countries. Because these crops are so critical to the survival of so many people, we believe it is imperative to conduct regular, rigorous studies to monitor the progress of maize and wheat research.

This latest issue of *A Sampling of CIMMYT Impacts* provides four new global and regional perspectives on research impacts:

- **The Global Wheat Impacts Study: Overview and Preliminary Findings**
- **The Global Maize Impacts Study: Overview and Preliminary Findings from Latin America**
- **Impacts in Eastern Africa: Results of Recent Studies**
- **Sustainable Production through Reduced Tillage in Maize and Wheat Systems**

Global and regional perspectives on crop improvement research

The global wheat study provides the latest information on wheat research impacts in all regions of the developing world. It conclusively documents that recent achievements in wheat improvement are among the most impressive research accomplishments seen anywhere in the world. The maize study provides information for Latin America (studies on Africa and Asia are forthcoming). It demonstrates that commonly held notions about the roles of public- and private-sector research in the region must be reconsidered if farmers are to gain greater access to improved maize. Together, these studies highlight the importance of—and continuing need for—truly international, collaborative maize and wheat improvement systems.

Regional perspectives on technology adoption and impact

Our effort to assess impact does not end with global studies or focus only on crop improvement research. As the other two articles in this publication demonstrate, impact assessment is a demanding process for a great number of our researchers and partners—especially farmers, whose time and efforts to collaborate with us are invaluable. An important aspect of these impact assessments is that they help us to develop methods—and train others—to conduct more effective analyses, particularly of more complex crop and resource management technologies. In this publication we examine results of recent impact studies in Eastern Africa and of research on reduced tillage technologies in Latin America and Asia.

Future impacts

An important message of the studies presented here is that they are forward-looking, in the sense that the information they provide helps to orient future research. They give us insight into which factors are likely to advance or attenuate the effectiveness of research in a multitude of changing circumstances—declining funding for many national research programs; the frequent lack of farmer support services; the absence or presence of the private sector in research; and the emergence of new forms of intellectual property protection. Such insights are extremely important, because researchers are not working towards a vision of what farmers need today; they are anticipating farmers' needs more than five to twenty years from now. The lasting contribution of impact studies is to help us understand how we can work today to make food security a reality for all people in the years to come.

The Global Wheat Impacts Study: Overview and Preliminary Findings

Objectives of CIMMYT's Global Wheat Impacts Work

Our study of the global impacts of international wheat research is designed to achieve five objectives: to document the use of CIMMYT-related and other improved wheat germplasm; document the farm-level adoption of improved wheat germplasm; identify factors that affect adoption of modern varieties (MVs); generate information for research priority setting; and provide information to raise awareness of the importance and benefits of international wheat research.

Coverage

To conduct the study, we sent questionnaires to all 41 countries in the developing world that produce 20,000 t or more of wheat annually (the nations of Central Asia and the Caucasus were not included). We received responses from 36 countries, representing just under 99% of all wheat production in the developing world. Coverage by region is shown in Table 1.

Table 1. Regional coverage for the global wheat impacts study

Region	Coverage (% of total wheat production)
Asia	99.7
West Asia and North Africa	94.3
Sub-Saharan Africa	98.3
Latin America	Nearly 100

Global Wheat Research Efforts by National Agricultural Research Systems (NARSs)

In both the earlier study of Bohn and Byerlee (1993) and this one, research intensity measured by scientists per million tons of wheat production tends to *fall* with increasing wheat production. This appears to be an empirical regularity. Actual *numbers* of scientists involved in wheat improvement research must be treated with considerable caution, given the difficulties of measuring with a more impersonal questionnaire and the difficulties in including other scientists (e.g., researchers in universities) who conduct research related to wheat improvement.

Impact fact: In 1991-97, virtually 90% of the spring bread wheats released in developing countries had CIMMYT ancestry.

In terms of *number of scientists per million metric tons of wheat production*, wheat research intensity seems to be slightly *greater* than reported by Bohn and Byerlee: 6.2 scientists per million tons across the developing world in 1997 compared to 5.3 in 1992–93 (Figure 1).

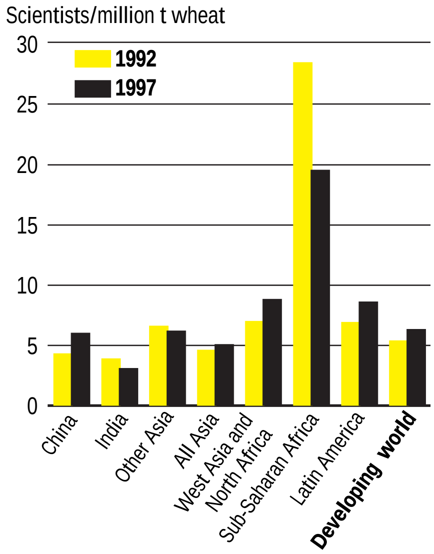

Figure 1. Wheat improvement scientists per million tons of wheat production, developing countries.

This difference is largely caused by a greater number of wheat improvement scientists reported for China in 1997; with China excluded, the 1992–93 and 1997 figures are almost identical. Furthermore, research by the International Food Policy Research Institute (IFPRI) and International Service for National Agricultural Research (ISNAR) suggests that financial support to agricultural research in many national research systems has fallen in recent years. This trend has been masked at the aggregate level by continued support to research in strong research systems in large countries such as China and India. Wheat improvement by national research systems appears to be increasingly dualistic, with large countries such as China and India continuing to support such research, at the same time that funding in many smaller research systems is declining.

Releases of Wheat Varieties

The rate at which wheat varieties are released, as measured by the number of varieties released per million hectares of wheat per year, appears to have *increased* in recent years in several regions, including West Asia/North Africa (WANA) and Sub-Saharan Africa.

The rate of release of varieties over the past 30+ years has been much higher in both Latin America and Sub-Saharan Africa than in the rest of the developing world. These higher rates of release *may* be associated with smaller wheat areas, greater diversity in mega-environments, and greater participation of the private sector in wheat improvement.

Nearly all spring bread wheats released by NARSs in developing countries are now semidwarf types. In the latest period (1991–97), of all spring bread wheats released by NARSs, 56% were CIMMYT crosses, sometimes with reselection by the national research program; 28% were NARS crosses with at least one CIMMYT parent; 5% were NARS crosses with at least some known CIMMYT ancestry; 8% were NARS semidwarfs with other ancestry; and 3% were tall varieties (Figure 2).

In winter/facultative bread wheats, in 1991–97, of all releases by NARS, 19% were CIMMYT crosses; 13% were NARS crosses with at least one CIMMYT parent; 9% were NARS crosses with known CIMMYT ancestry; 41% were NARS semidwarfs with other ancestry; and 18% were tall varieties (Figure 3). The number of winter/facultative wheat releases has been considerably higher in 1991–97 than in earlier periods, particularly in WANA. The percentage of winter/facultative NARS releases that contain CIMMYT germplasm has also been

Impact fact: In 1991-97, 98% of the spring durum wheats released in developing countries had CIMMYT ancestry.

considerably higher in 1991–97 than in earlier periods. Non-CIMMYT winter/facultative semidwarfs were mainly Chinese releases.

Compared with spring bread wheats, an even greater proportion of spring durum wheats released by NARSs contain CIMMYT germplasm. Over 1991–97, of all releases, 77% were CIMMYT crosses; 19% were NARS crosses with at least one CIMMYT parent; 2% were NARS crosses with known CIMMYT ancestry; and 2% were tall varieties (Figure 4).

Farmers' Adoption of Improved Wheat Varieties

Just over 80% of the wheat area in the developing world is planted to semidwarf varieties. Sixty-two percent of the total wheat area is planted to CIMMYT-related varieties, including varieties with earlier CIMMYT ancestry.

The proportion of wheat area planted to CIMMYT-related material is greater for spring bread wheat and spring durum wheat than for winter or facultative wheat types (Figures 5, 6, and 7). For spring bread wheat, 59% of total area is planted to CIMMYT crosses or varieties with at least one CIMMYT parent, and 79% of total area is planted to all CIMMYT-related varieties; for spring durum wheat, 69% of total area is planted to CIMMYT crosses or varieties with at least one CIMMYT parent. In spring durum wheat, the area planted to all CIMMYT-related varieties is almost

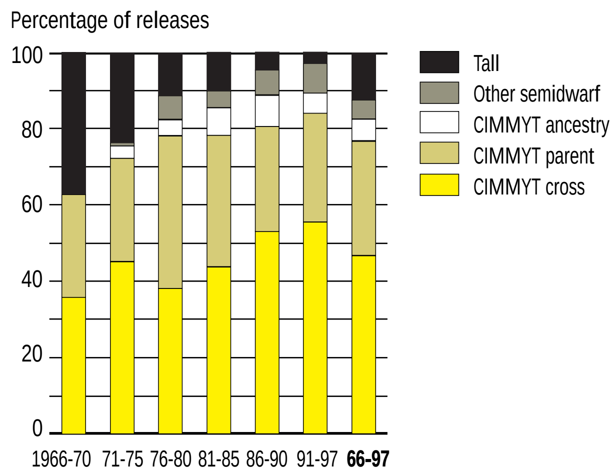

Figure 2. Spring bread wheat releases by time period, developing countries.

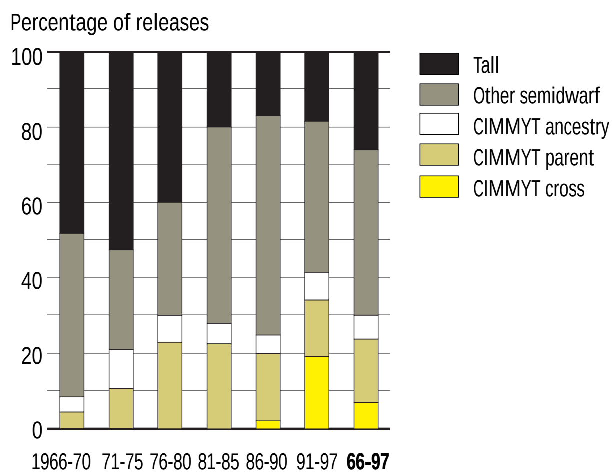

Figure 3. Winter/facultative bread wheat releases by time period, developing countries.

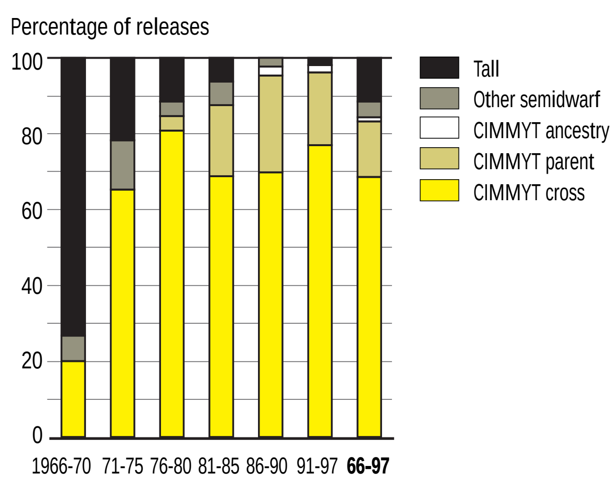

Figure 4. Spring durum wheat releases by time period, developing countries.

Impact fact: Developing country farmers plant CIMMYT-related wheats on 79% of the spring bread wheat area. In some parts of the world, this percentage is even higher.

identical to this figure, since few programs using CIMMYT durum materials incorporate CIMMYT germplasm at earlier stages in the breeding process. In winter/facultative wheat, only 9% of the total area is planted to CIMMYT crosses or varieties with one or two CIMMYT parents, and 24% of the total area is planted to all CIMMYT-related varieties.

Landraces are sown on 15% of the total winter or facultative wheat area and 23% of the spring durum area, but landraces are found on only 2% of the spring bread wheat area.

Reference

Bohn, A., and D. Byerlee. 1993. The wheat breeding industry in developing countries: An analysis of investments and impacts. Part 1 of *1992/93 CIMMYT World Wheat Facts and Trends.* Singapore: CIMMYT.

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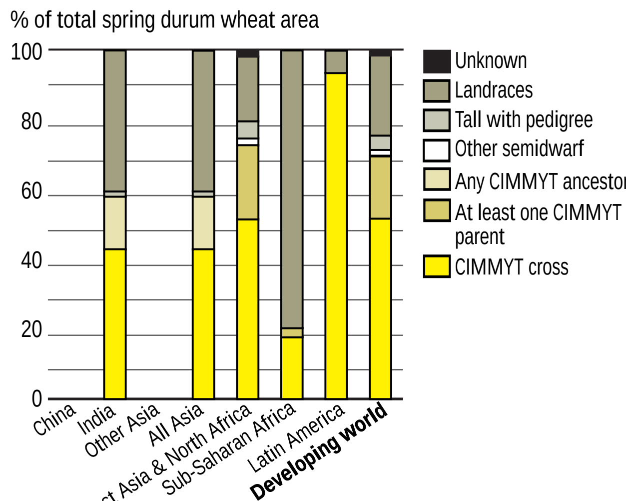

Figure 6. Area planted to spring durum wheat in developing countries, 1997.

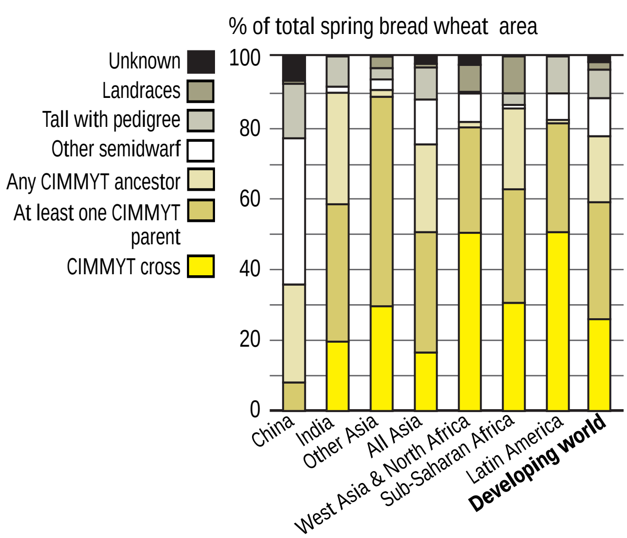

Figure 5. Area planted to spring bread wheat in developing countries, 1997.

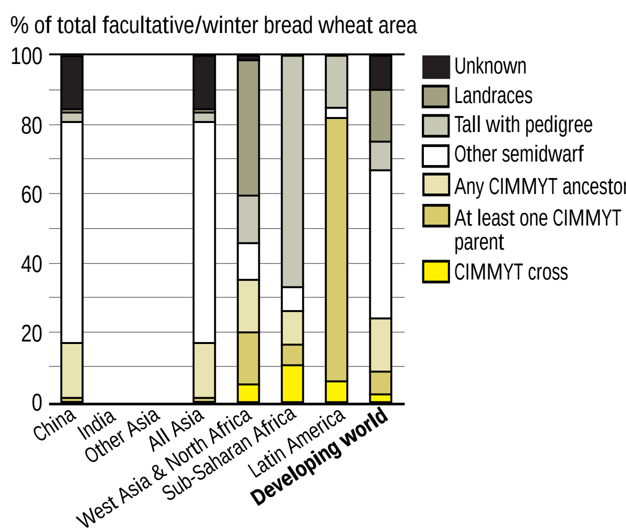

Figure 7. Area planted to facultative/winter bread wheat, developing countries, 1997.

Maize Impacts

The Global Maize Impacts Study: Overview and Preliminary Findings from Latin America

Objectives of CIMMYT's Global Maize Impacts Work

Our study of the global impacts of international maize breeding research is designed to achieve several objectives: document the use of CIMMYT-related maize germplasm; document the farm-level adoption of CIMMYT-related maize germplasm; identify factors that affect adoption of modern varieties (MVs); monitor the performance of national maize seed industries; generate information for priority setting; and provide information to raise awareness of the importance and benefits of international maize research.

The global maize impacts study is composed of three regional studies. The study for Latin America has been completed (preliminary results are presented here), and studies for Sub-Saharan Africa and Asia are underway. To complement the global effort, numerous country-level case studies of MV adoption have been published (for an overview of recent studies from eastern Africa, see page 7), and more are planned.

Special Challenges Associated with Maize Impacts Studies

Documenting the impacts of maize breeding research involves a number of special challenges. Several technical measurement issues must be considered: How do we define "improved germplasm" when we know that a lot of outcrossing goes on in farmers' fields? How do we estimate the area planted to improved germplasm? How do we quantify productivity gains attributable to MV adoption? How do we allocate credit among different breeding programs for productivity gains attained through breeding?

Practical issues must also be addressed. With more and more maize breeding taking place in the private sector, access to data is becoming more complicated. In conducting maize research impacts studies, CIMMYT researchers must determine how to obtain reliable pedigree information for MVs; information about the use of CIMMYT-related germplasm; and reliable information about private-sector seed sales. Many data disclosure/ confidentiality issues mediate access to this information. It is important to ensure the confidentiality of data provided by respondents and to maintain a policy related to the disclosure and distribution of raw data.

Impact fact: Private seed companies have made little effort to target subsistence farmers—the vast majority of Latin American maize producers. Public-sector research for these farmers

Preliminary Results from Latin America

The Latin American Maize Impacts Study has generated detailed information about the area planted to MVs (Table 1) and the use of CIMMYT maize germplasm (Table 2) in Latin America. It has also generated information about sales of seed of open-pollinated varieties vs. hybrids (Figure 1) and sales of publicly produced vs. privately produced seed (Figure 2). Although the complete study will be published later in 1999, preliminary results have already provided valuable information for maize researchers and policy makers. One of the most salient points to emerge is that some widely held assumptions about the roles and scope of private- and public-sector breeding and seed production may need to be revised. It is becoming increasingly clear that continued support for public maize breeding research will be required if the needs of small-scale and semi-subsistence farmers are to be met.

Approximately 98% of all commercial maize seed sold in Latin America in 1997 was sold by private companies. Of this seed, approximately 75% was seed of proprietary hybrids whose pedigrees contained CIMMYT-derived germplasm. These data suggest that it is simply not accurate to contend that the private sector is poised to take over international maize breeding. Private-sector maize breeders continue to rely heavily on CIMMYT-derived germplasm.

In 1997, about 48% of the total area planted to maize in Latin America was planted to improved OPVs and hybrids; the remaining 52% was planted to local varieties. In Mexico and Central America, only 20% of the total area planted to maize was planted to improved OPVs and hybrids; fully 80% of the maize area in this region was still planted to local varieties. Evidently private seed companies are making little effort to target subsistence and semi-subsistence farmers, who constitute the vast majority of maize producers in Latin America. Instead, the seed companies are competing with one another for market share within the relatively small commercial farming sector. The obvious lack of interest from private companies in the subsistence and semi-subsistence farming sectors, coupled with the recent decline in strength of many national research programs in Latin America, underscores the need for continuing public investment in maize breeding research and in the production and distribution of seed of open-pollinated varieties.

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Table 1. Adoption of maize MVs, Latin America, 1996

	Maize area (M ha)	Land-races (%)	Improved: OPVs (%)	Improved: Hybrids (%)
Mexico	7.9	79.7	1.1	19.2
Central America	1.6	78.3	3.3	18.5
Andean Zone	2.3	55.6	8.2	36.2
Southern Cone	17.0	37.1	6.1	56.8
Total	**29.1**	**52.1**	**5.0**	**42.9**

Table 2. Use of CIMMYT germplasm, Latin America, 1996

	Area planted to CIMMYT-derived: OPVs	Area planted to CIMMYT-derived: Hybrids	% of maize area	% of MV area
Mexico	64	1,363	18.1	89.1
Central America	54	291	21.1	96.9
Andean Zone	174	806	43.4	97.6
Southern Cone	711	6,969	45.3	72.0
Total	**1,072**	**9,513**	**36.3**	**75.8**

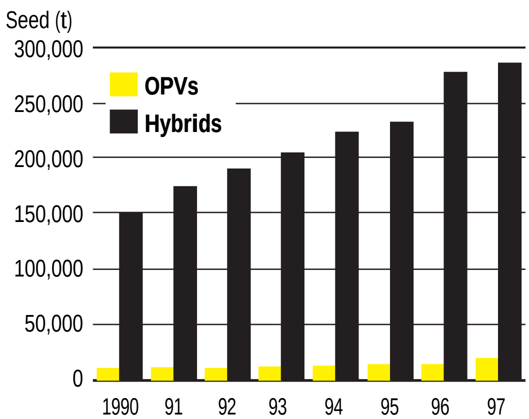

Figure 1. Sales of seed of improved open-pollinated maize varieties (OPVs) and hybrids, Latin America.

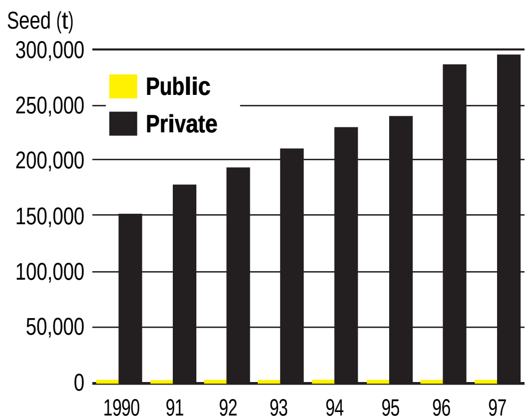

Figure 2. Public vs. private seed sales, Latin America.

Impacts in Eastern Africa: Results of Recent Studies

Thirty studies produced under a project to strengthen economics and policy research in eastern Africa (sponsored by the European Union) will serve as a comprehensive reference on two issues of prime importance to eastern African national research programs and the farmers they serve: 1) current adoption of improved maize and wheat varieties and related technology, especially soil fertility practices; and 2) factors that positively and negatively influence adoption of these technologies, especially the role of gender; seed supply systems; farmers' seed management practices; extension; and credit and input supply policies. Taken together, these studies offer a clearer picture of research impact throughout the region. Highlights of some studies completed to date follow.

Ethiopia

A study of farmers' wheat seed sources and seed management in Chilalo Awraja sought to clarify farmers' seed acquisition and transfer mechanisms and explore associated problems, as well as to document the status of previously released bread wheat varieties with respect to the purity and viability of seed.

Wheat area in Chilalo Awraja doubled from 1992 to 1995, mainly as a result of farmers' adoption of the varieties Dashen and Pavon-76. A new variety stays in production without problems for only four years. Vulnerability to disease is farmers' chief reason for disadopting a variety, followed by susceptibility to frost, declining yields, and availability of better varieties.

Farmers' main source of wheat seed was seed retained from the previous harvest, although when farmers first plant a new wheat variety, their main sources of seed are the Ministry of Agriculture and the Ethiopian Seed Enterprise. The farmer's proximity to the seed source positively influenced adoption of new wheat varieties, as did the farmer's contact with extension in the preceding year.

In 1995/96, the majority of farmers used seed saved from the previous harvest. According to farmers, the major problems associated with recycling seed are lower yields (21.9%), loss of disease resistance (34.1%), and weed problems (42.1%). Fifty-seven percent of the farmers interviewed store their seed separately from grain intended for home consumption, 19% have separate fields for seed, 21% thresh seed separately from grain, and 87% clean seed at planting.

Wheat seed was tested in the field and the laboratory. Seed samples were analyzed for viability, purity, off-types, and grain size. Except for Tikur Sinde, all of the varieties met the minimum germination requirement of 85% seed set, which is the Ethiopian standard for certified seed. Most seed samples met the Ethiopian purity standards for commercial seed (95% pure) and certified seed (97% pure). Fields planted with seed from Arsi Agricultural Development Enterprise and Ethiopian Seed Enterprise had fewer weeds than fields planted with farmers' own seed or seed obtained from other farmers. The average percentage of off-types in farmers' wheat fields was about 3.5%, which is higher than the percentage permitted in Ethiopian standards for certified and commercial seed (0.1–0.5%). The highest thousand-kernel weight was recorded for the variety Israel, followed by Batu.

CIMMYT Partners: *Regassa Ensermu and Mohammed Hassena, Kulumsa Research Center.*

Kenya

Kenyan researchers assessed the adoption of seed and fertilizer packages and the role of credit in smallholder maize production in Kakamega and Vihiga Districts. Their study focused on documenting maize farmers' current circumstances and practices, identifying factors affecting adoption of seed-fertilizer technology, and identifying farmers' sources and use of credit to purchase seed and fertilizer.

Impact fact: In 2 areas in Kenya, about half of the farmers surveyed grew improved maize.

About half of the sample farmers grew improved maize varieties. Hybrid maize yields 1.5 t/ha on average compared to 1 t/ha for local maize varieties. Adoption of improved maize is positively influenced by district, livestock ownership, use of hired labor, and extension contacts. Many farmers stopped growing hybrids over 1992–96, mainly because of high seed prices. More of the adopters of improved maize (45.6%) used chemical fertilizer compared to non-adopters (23.1%). Adoption of chemical fertilizer is positively influenced by district, livestock ownership, and membership in an organization. The use of manure negatively affects the adoption of fertilizer. The main constraint to use of fertilizer is its high price. The role of credit is not significant in technology adoption. Only 5% of the sample farmers used credit to purchase either chemical fertilizer or improved maize seed.

CIMMYT Partners: *Beatrice Salasya, M. Odendo, and J.J. Odenya; Regional Research Center, Kakamega.*

Uganda

In Iganga District, Uganda, a research team gathered information on farmers' current agricultural practices, particularly maize production practices and the constraints on adoption of new maize technology. This information was used to form an assessment of factors affecting adoption of maize production technologies, define recommendations based on the resource endowments and specific decision factors of target groups of farmers, and propose possible solutions to problems.

The research team found that about 43% of the sample farmers grew improved maize. Adopters of improved maize were slightly older, owned larger farms, were more educated, used more hired labor, participated more in farmers' groups as well as non-farm employment, had more access to extension services, and sold more maize. Men were more likely than women to adopt improved maize. Adopters and non-adopters did not differ appreciably in their access to credit, household size, farming experience, maize area, and livestock ownership. Virtually none of the farmers used recommended fertilizers and herbicides. A small proportion of the sample farmers had access to farm credit to purchase these inputs, but farmers cited lack of awareness as the main reason for not using inputs. Farmers' reasons for adopting the preferred improved maize variety, Longe 1, were (in descending order of importance) early maturity, high yield, and filled cobs. Farmers who did not grow Longe 1 preferred Kawanda Composite A for its large grains, sweetness, and taste. Farmers' education, the use of hired labor, and membership in an organization positively influenced the adoption of improved maize seed. Land ownership had a negative impact on the adoption of improved maize seed.

CIMMYT Partners: *William Nanyeenya and Mary Mutetikka, National Agricultural Research Organization.*

Tanzania

A nationwide study of the economic impact of maize research in Tanzania quantified the impact of maize research between 1974 and 1994, with the ultimate objectives of formulating maize research priorities and deriving policy recommendations that could lead to improved adoption of maize technologies.

The estimated rate of return on the investments in maize research and development was 19%. Total maize area in 1994 was 1.65 million hectares; 42% was planted to landraces, 22% was planted to improved open-pollinated varieties (OPVs), and 36% was planted to hybrids. Farmers adopted the improved technologies in a stepwise fashion, whereby they first adopted inexpensive technologies (such as row planting) and only later adopted more expensive technologies (such as chemical controls for pests and diseases). Lack of information and credit have been cited by farmers as constraints to adoption. Extension services should be strengthened and appropriate policy measures should be promoted to provide credit for inputs.

CIMMYT Partners: *Tanzania National Research Program/CIMMYT/SACCAR*

Gender-Related Studies

In Ada, Lume, and Gimbichu Woredas of the Central Highlands of Ethiopia, researchers investigated whether there were gender differentials in the adoption of improved wheat varieties. They documented that the proportion of male-headed households (30%) that adopted improved wheat varieties was significantly higher than the proportion of female-headed households (14%). In male-headed households, farm size and extension contact significantly and positively influenced the adoption of improved varieties. In female-headed households, farm size and owning a radio had significant and positive effects on the probability of adopting improved varieties.

Impact fact: In the Southern Highlands of Tanzania, adoption of improved maize was strongly influenced by the gender of the household head.

Another project, this one in the Mbeya Region of the Southern Highlands of Tanzania, examined whether there were gender differentials in adoption of improved maize production technologies. As was the case in Ethiopia, researchers in Tanzania found that the proportion of male-headed households (84%) that adopted improved maize varieties was significantly higher than the proportion of female-headed households (62%). The factors that most strongly influenced adoption of improved maize varieties were the gender of the household head, number of extension contacts, and hired labor (the latter two showed positive effects).

Gender differentials in the adoption of improved maize technologies were also studied in Iganga District, eastern Uganda. In this case, the adoption of improved maize varieties was 19% for both male- and female-headed households. In female-headed households, age (negatively) and farm size (positively) significantly affected the adoption of improved maize. In male-headed households, hired labor had a positive and significant effect on the probability of adopting improved maize varieties.

Additional Studies of Farmers' Seed Sources and Seed Management

An analysis of farmers' wheat seed sources and seed management in major wheat producing areas of Ethiopia indicated that the formal seed sector produces and distributes only 15% of the wheat seed in the country. The popular improved wheat varieties are Dashen, Enkoy, and Pavon-76, but they have been affected by either stem rust or stripe rust. The weighted average age of varieties is 11–13 years, indicating that farmers replace current varieties with new ones only after more than a decade has passed.

In Kenya, a study of farmers' wheat seed management and varietal adoption found that the formal sector produces and distributes 22% of the wheat seed in the country. The popular improved wheat varieties are Kwale and Mbuni (released in 1987), whereas the more recent (1994) releases Duma, Mbege, and Ngamia are grown by only 2% of the farmers.

A similar study in Kenya's semiarid areas focused on maize seed. The formal sector produces and distributes 33% of the maize seed in these areas. About 38% of the farmers said they purchased improved maize varieties, while 62% bought local maize varieties. Poor seed quality and unavailability of seed were the main constraints to purchasing seed of improved maize varieties.

For more information, contact:
w.mwangi@cgiar.org or h.verkuijl@cgiar.org. For full text of studies conducted under this project, see "Strengthening Economics and Policy Research," at www.cimmyt.cgiar.org/Research/Economics/Index.htm.

Sustainable Production through Reduced Tillage in Maize and Wheat Systems

Reduced tillage practices offer maize and wheat farmers in developing countries an ecologically and economically sound way to increase productivity, conserve natural resources (including water and nutrients), and reduce risk over the long term. CIMMYT has served as a catalyst for different kinds of research on reduced tillage with national program partners throughout the world. What these researchers have accomplished is impressive. They have worked in the field with farmers, amassing considerable experience with reduced tillage in a range of settings. They have developed alternative approaches to tillage and crop residue management, started to quantify the biophysical performance of these different options, fostered farmer participatory research to tailor the most attractive options to farmers' circumstances, and they have anticipated (through modeling) and measured (through monitoring) longer-term consequences for productivity and sustainability. By virtue of this experience, national programs have identified tillage, rotation, and fertilizer strategies that should be truly sustainable over the long term. Not only will farmers realize the yield potential of improved cultivars; farmers will reduce their production costs. As a result, farmers and consumers should benefit from reduced food costs, improved food security, and a reduction in poverty.

In this brief, we will focus on impacts in parts of Latin America and South Asia. We conduct many other kinds of strategic agronomic research with partner organizations throughout the world, although we cannot describe every initiative here. For more specific information see *People and Partnerships*, our latest Medium-Term Plan (available in print and on our web site <www.cimmyt.cgiar.org>).

Research in Latin America

In many areas of Latin America, reduced tillage practices could be extremely valuable, especially for poor smallholders (for two Central American success stories, see the box, page 16). A growing number of studies in Latin America are forming the basis for a broader understanding of issues and potential options for reduced tillage in maize and wheat production systems. Major activities to date include researcher-managed on-station and on-farm tillage and bed planting research in Mexico; tillage systems for rainfall use efficiency in Bolivia; and simulation modeling.

Impact fact: Bed planting enables Mexican farmers to save 30% on production costs and yields substantial environmental benefits.

Reduced tillage technology for irrigated environments: Sustainable "bed" planting. A reduced tillage system developed by farmers and researchers in Mexico's Yaqui Valley is showing its potential in the Yaqui Valley and other irrigated wheat production environments. In this system, a crop is grown on raised beds that are divided by furrows for irrigation. No soil inversion tillage is used on the beds. Crop residues are chopped and left on the surface of the beds.

The system has several advantages for farmers and the environment, including:

- Nitrogen can be applied when and where the wheat plants can use it most efficiently. Yields improve, and nitrogen losses into the environment are significantly reduced.
- Water conservation improves. As water for agriculture becomes more scarce in the years to come, water conservation practices will become more important for farmers. Researchers in South Asia report a **30% savings** in water use with bed planting.
- Weeds can be controlled by cultivating between the beds—reducing costs and the need for herbicide.
- Residues are returned to the soil without burning, which is beneficial to the environment.
- The beds can be used cycle after cycle. Farmers avoid the financial and environmental costs of making repeated passes with a conventional plow during land preparation.

Prototype machinery specifically for this bed planting system has been designed and tested in Mexico and in Asia. The prototypes are modifications of standard agricultural equipment and are expected to be affordable for poor farmers.

Mexican farmers reportedly save 30% on their production costs when they use the bed planting system. Some 10,000 farmers are thought to use the system in Mexico, and the number of farmers who are using bed planting is growing in South Asia (see below) and China as well.

Tillage trials in Central Mexico. A sustainability trial initiated in 1991 at CIMMYT's headquarters research station provides evidence of the benefits of conservation tillage in maize and wheat farming systems and the processes underlying success. As discovered in similar work by CIMMYT in other parts of Mexico, the prerequisite for success is the combination of conservation tillage and crop residue retention after harvest. A consistent 25% yield advantage has been found for the 1996, 1997, and 1998 cycles for cereal rotations under conservation tillage (Figure 1).

In addition to evidence of added soil organic matter, trial data suggest an increased presence of fluorescent psuedomonads (microbes that are useful in the biological control of soilborne pathogens) and decreased incidence of root rot in zero-tillage/residue-retention systems.

Conservation tillage reduces runoff of valuable water. A **five-fold increase in water infiltration** under conservation tillage compared to more traditional tillage is evident in another trial at CIMMYT headquarters (Figure 2).

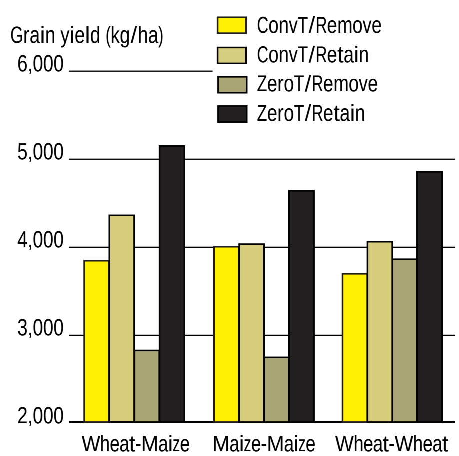

Figure 1. Grain yield (kg/ha) in cereal crop rotations under conventional and zero tillage and retention or removal of crop residues, El Batán, Mexico, 1996–98.

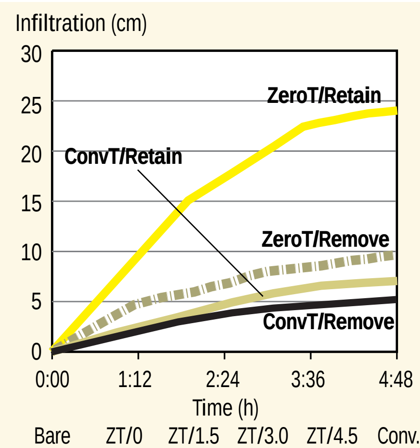

Figure 2. Water infiltration rate under conventional and zero tillage and retention or removal of crop residues, El Batán, Mexico.

Research on rainfed maize systems in Mexico. Similar evidence of the advantages of conservation tillage has been documented by CIMMYT researchers at La Tinaja, a low rainfall site in Jalisco, Mexico. Since 1994, CIMMYT, INIFAP (Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico), and CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement, France) have studied the potential benefits and drawbacks of conservation tillage within the Mexican context. (The economic analysis of conservation tillage practices, which is not described here because of space limitations, is an integral part of this research.)

The general benefits of conservation tillage and improved crop residue management on system sustainability and natural resource protection are clearly significant. The principal physical parameter modified over time through conservation tillage is general infiltration of water into the soil. After five years, infiltration velocity is always 50–80% more than with other tillage techniques. Increased soil surface porosity is linked with the vigorous activity of mesofauna under conservation tillage. In the presence of the fresh organic matter on the surface and the suppression of soil movement, the earthworm population alone increases five- to ten-fold, depending on the amount of residue retained. Another major benefit of the technology, which is often a rationale for using conservation tillage, is that soil erosion is reduced on the order of 50–80% compared to traditional tillage with disks.

After five years of conservation tillage, the reduction in erosion, combined with the effects of returning crop residues to the cropping system, resulted in a significant increase in soil organic matter in the upper part of the soil profile (0–5 cm), representing an additional sequestration of 0.7–1.0 t carbon per hectare per year on average during the first five years in the top 0–20 cm. The C sequestration and indirect effects on global warming are less dramatic perhaps than in systems without biomass exportation (such as forests), but they are very impressive for cereal cropping.

Impact fact: Researchers in South Asia report a 30% savings in water use with bed planting.

Bolivia: Tillage systems for rainfall use efficiency. In Bolivia, where moisture stress is the major limitation to wheat productivity, the potential for reduced tillage technology is being studied in two contrasting settings: the high inter-Andean valleys, where small-scale farmers (2–5 ha) produce one crop of wheat each year in monoculture or in rotation with potatoes, faba beans, peas, and/or barley; and the lowlands, where wheat is grown on large, mechanized farms in the winter in a double-crop system with summer soybeans.

The national programs (IBTA and CIAT) and CIMMYT have redirected the research agenda toward practices that increase rainfall use efficiency. Although the principles of moisture conservation are the same in the highlands and the lowlands, the practical solutions differ because of the great variation in farm size, availability of capital, and farmers' ability to assume risk.

Research in the highland areas concentrates on evaluation of straw cover to increase rainfall use efficiency. Results are extremely encouraging: crop residue retention generally increases yields and reduces risk—two important objectives for Bolivia's small-scale, subsistence farmers. Farmers show marked interest in returning crop residues to the fields after sowing, despite the alternate use of the straw for animal feed. Researchers also participate in a project to develop a small, animal-drawn, no-till seed drill for sowing cereals into surface residues. Initial results with the drill are very positive.

In the lowlands, research concentrates on increasing rainfall use efficiency in wheat-based systems through zero tillage and crop rotations, as well as on identifying and solving problems that may arise in the fields of farmers using these conservation systems. The area under zero tillage has grown rapidly in the last five years, and now approximately 25% of the area seeded to annual crops is untilled. So far, the chief impact of zero tillage has been to reduce costs and allow farmers to seed more of their land at the optimum time. Research indicates a large interaction between zero tillage and crop rotations, though few lowland farmers use rotations. The incorporation of a crop rotation into the zero tillage practice should have a major impact on crop productivity.

Simulation modeling. Crop and soil simulation models will play a key role in integrating the wealth of information being generated at CIMMYT on the processes that underlie reduced tillage. Much modeling work has been done through national research programs. In addition, CIMMYT's Natural Resources Group has developed a tillage routine for the DSSAT models that accurately simulates the impact of different tillage practices on soil nutrition, water, and maize yields. The model generates plausible series of long-term maize yields under reduced tillage in the Mexican highlands, showing yields to be more stable, despite variable rainfall, and less reliant on fertilizer sources of nitrogen, than yields obtained under conventional tillage (Figure 3).

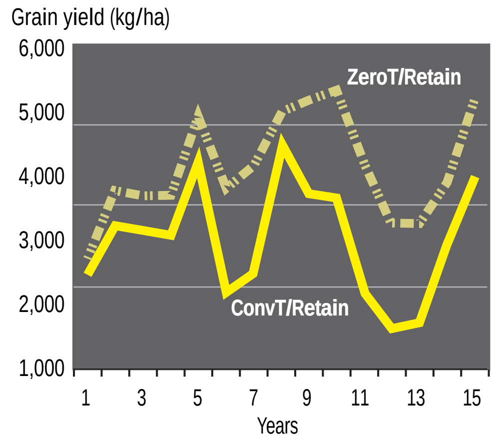

Figure 3. Projected long-term maize grain yields (kg/ha) under traditional and conservation tillage, with retention of crop residues, Mexico.

Impact in South Asia

One example of a wide area where reduced tillage options are beginning to have an impact is South Asia, where researchers are evaluating the potential of several practices to foster a more productive, sustainable, and socially equitable agriculture. All of the practices are aimed at establishing wheat after rice in rice-wheat systems in the Indo-Gangetic Plains. All of them slash tillage costs, enable farmers to sow much earlier,[1] improve water and nutrient use efficiency, improve wheat yields—and sometimes make space in the cropping pattern for a third crop. This research is being carried out in conjunction with the **Rice-Wheat Consortium for the Indo-Gangetic Plains** (a CGIAR Ecoregional Program), comprised of national research programs in the region, relevant international centers, and selected universities in the North.

The tillage practices are:

- Chinese Hand Tractors with implements capable of drilling wheat and other crops into standing rice stubble in a single pass (suitable for resource-poor farmers in the eastern Indo-Gangetic Plains).
- Zero-till, surface seeding practices requiring no machinery or implements (suitable for even the poorest farmers).
- Inverted-T, zero-till seed drills for four-wheel tractors (suitable for farmers in the western Indo-Gangetic Plains).

1 For every day that wheat planting is delayed after the best sowing date, yields fall by 1.0–1.5%.

- Bed planting systems, which make use of permanent raised beds for growing crops, will enable farmers to retain crop residues and carry out more precise and ecologically appropriate water, nutrient, and weed control (also suitable for farmers in the western Indo-Gangetic Plains).

Where needed, prototype equipment has been developed by national program researchers, and CIMMYT has imported still other equipment prototypes into South Asia. With our partners in national programs, we have trained farmers in the use and maintenance of this new equipment. By working on this technology with farmers, researchers have empowered farming communities to make a realistic assessment of the ups and downs, and the costs and benefits, of the new tillage practices.

Chinese Hand Tractor. The impact of reduced tillage research is particularly impressive in Bangladesh. Even where the Chinese Hand Tractor seed drill is unavailable or has not been introduced to farmers, the Hand Tractor alone is used widely as a rotovator. Growing numbers of farmers have substituted 1–2 rotovations (done over 2–3 days) for the more traditional 6–8 passes with a local plow (requiring 2–3 weeks). As a result, most wheat is sown on time rather than several weeks late, which was common in the past.

Years of demonstrating and testing this tillage technology—developed in concert with farmers, with careful attention to their requirements—have made sustainable production increases possible on some of the world's poorest farms. The rotovator technology is used on 70% of the wheat area in Bangladesh; percentages are even higher in some regions of the country. In the most productive wheat region of the country, the northwest, more than 80% of farmers use the technology. A recent survey by the Bangladesh Wheat Research Centre and CIMMYT in southern Bangladesh, one of the nation's poorest areas, found that 74% of the wheat area is now cultivated using the Chinese Hand Tractor/Tiller. Another survey in southwestern Bangladesh found that 70% of farmers used the technology.

Impact fact: In southern Bangladesh, one of the nation's poorest areas, 74% of the wheat area is now planted using reduced tillage technology developed by national programs and CIMMYT.

This technology is also having a considerable impact on production costs in the small fields of poor farmers in eastern India and Nepal. In these parts of South Asia, the Hand Tractor is used not only as a rotovator but with a range of attachments. The seed drill allows wheat to be planted (in rows and at a uniform depth) in one pass after the rice harvest, thus reducing turnaround time and planting costs. The reaper attachment eliminates the drudgery of harvesting the crop. The tractor itself can be used to power irrigation pumps, threshers, and cleaners, and it can transport farm produce and other items.

Surface seeding and zero tillage. Surface seeding–zero tillage practices are important in Nepal, eastern India, and Bangladesh, especially where waterlogging and heavy soils are a problem. At some test sites in Nepal in the last cropping season, surface seeding made the difference between a yield of 4 t/ha and absolutely no yield at all. Fields were too wet for farmers to use conventional tillage practices, so they could not even sow their crops. Surface seeding, in contrast, enabled farmers to plant directly onto saturated soils.

Zero tillage enables farmers to conserve water, because the practice makes it easier for farmers to flood the fields with water when the fields are not plowed. Because wheat is planted earlier in zero-tillage systems, at a time when there is more moisture in the soil, farmers also use less water for the first irrigation of the wheat crop. Researchers working on zero tillage practices are also examining the benefits of leaving crop residues on the soil surface as mulch, and results have been encouraging.

Impacts of Conservation Tillage in El Salvador and Panama

Guaymango, El Salvador, an area of 5,000 ha, has a maize-sorghum cropping system in which farmers stopped burning crop residues and used them as mulch, adopted hybrid maize, and applied modest levels of fertilizer. These interventions gradually increased maize yields from 1.0 to 4.0 t/ha from the 1970s to the 1990s, while improving soil characteristics and properties. Guaymango has become the focal point for the promotion of soil conservation practices to thousands of farmers, extension workers, and NGOs, through direct visits, farmer-to-farmer dissemination of technology, and also by sponsoring Guaymango's yearly "Conservation Tillage Fair."

In **Azuero, Panama**—an area that had 10,000 ha of mechanized maize production and a serious soil erosion problem—CIMMYT and IDIAP, the national research program, initiated an on-farm research course on conservation tillage in 1985. CIMMYT also donated the first minimum tillage planter to IDIAP (the first time that such technology had been available in the area). By 1996, because of IDIAP's research and extension efforts, there was almost 60% adoption of conservation tillage in Azuero, and adoption was still growing. The benefits of the technology include reduced costs for farmers, reduced weed infestation, reduced herbicide use, and soil conservation.

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Inverted-T seed drill and bed planting. Farmers in northwestern India and in Pakistan have started to use the inverted-T seed drill and bed planting. The advantages of bed planting, described earlier, should have a considerable impact in South Asia, where nearly 25 million hectares of irrigated wheat are grown. Aside from conserving water and increasing the efficiency of fertilizer use, the bed planting system allows farmers to implement an integrated weed management approach to control *Phalaris minor.* This weed is an increasingly worrying problem in the Indo-Gangetic Plains and other major wheat-growing areas of the developing world.

In both Haryana, India, and Pakistan in the most recent crop cycle, more than 350 farmers planted 1,000 ha of zero-tilled wheat. Yields improved and production costs fell by US$ 60/ha. It is anticipated that next year the technology may be used on about 10,000 ha. The availability of equipment and spare parts, as well as close collaboration with farmers and local equipment manufacturers in the use and maintenance of machinery, are critical for success.

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CIMMYT supports Future Harvest, a public awareness campaign that builds understanding about the importance of agricultural issues and international agricultural research. Future Harvest links respected research institutions, influential public figures, and leading agricultural scientists to underscore the wider social benefits of improved agriculture—peace, prosperity, environmental renewal, health, and the alleviation of human suffering (www.futureharvest.org).

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