Impacts of Maize Breeding Research in Latin America, 1966-1997

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International Maize and
Wheat Improvement Center

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Abstract: This report documents the number and types of maize varieties and hybrids released by public breeding programs between 1966 and 1997, describes the varieties and hybrids marketed by public seed agencies and private companies in Latin America in 1997, analyzes recent trends in commercial maize seed sales, estimates the area planted to improved maize germplasm in 1996, and discusses factors that have influenced adoption. The authors find that the primary locus of maize breeding research has shifted to the private sector, the private sector now dominates commercial maize seed production, and the maize seed industry in Latin America has become increasingly concentrated. Although the area planted to improved maize germplasm continues to increase, adoption has been uneven. The use of CIMMYT materials has been extensive in public as well as private sector breeding programs, and total area sown to CIMMYT-related materials continues to increase.

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Executive Summary

This report, the latest in an occasional series of maize and wheat impacts studies published by the International Maize and Wheat Improvement Center (CIMMYT), presents an updated picture of the impacts of maize breeding research in Latin America.

It documents the numbers and types of maize varieties and hybrids released by public breeding programs between 1966 and 1996, describes the varieties and hybrids being marketed by public seed agencies and private companies in Latin America in 1997, analyzes recent trends in commercial maize seed sales, estimates the area planted to improved germplasm in 1996, and discusses factors that have influenced adoption.

The data presented in this report were collected through interviews with representatives from public research institutes, government seed agencies, and private seed companies located throughout Latin America. An initial survey was conducted in 1992; findings were published in the report entitled *Impacts of International Maize Breeding Research in the Developing World, 1966-1990* (López-Pereira and Morris 1994). A second, more extensive survey conducted in 1997 involved comprehensive interviews with representatives from 36 public maize seed organizations and 172 private seed companies in 18 countries. Information was collected from virtually every organization in Latin America that engaged in maize breeding and maize seed production; collectively, the organizations that participated in the survey accounted for approximately 97% of the commercial maize seed sold in Latin America in 1996.

Major findings of this research are summarized in the following paragraphs.

The primary locus of maize breeding research has shifted to the private sector.

During the past decade, the primary locus of maize breeding research in Latin America has shifted from government research organizations to private seed companies. Private-sector research and development (R&D) expenditures have increased steadily, while support to public maize breeding organizations has declined. The level of private investment now significantly exceeds the level of public investment.

Commercial maize seed production is now dominated by private companies.

The decline in public-sector support for maize research has been accompanied by a gradual disengagement of the state from commercial seed production activities. During the 1980s and 1990s, many money-losing government seed agencies were privatized or shut down, and those that remain account for an insignificant proportion of the total market for seed. State disengagement from seed production has been accompanied by an equivalent expansion of the private seed industry. Private companies now dominate the market for maize seed in virtually every country in Latin America, except for the countries in the Caribbean region.

The maize seed industry has become increasingly concentrated.

The emergence of a flourishing private maize seed industry in Latin America has been characterized by steady consolidation, as large multinational seed companies have swallowed up many small local seed companies through acquisitions and mergers. The maize seed industry in Latin America is today highly concentrated; in most countries, the three largest seed companies control 75% or more of the total market share.

The area planted to improved germplasm continues to expand.

The area planted to improved germplasm in Latin America continues to expand. In 1996, nearly 14 million ha were planted to improved varieties and hybrids (equivalent to about 48% of the total area planted to maize). This represents a significant increase from 1990, when just under 10 million ha were planted to improved varieties and hybrids (equivalent to about 43% of the total maize area).

The pattern of adoption of improved germplasm has been uneven.

Use of improved germplasm has increased throughout Latin America as a whole, but the pattern of adoption has been uneven. Use of improved germplasm is concentrated in areas where maize is a commercial crop; meanwhile, in regions characterized by subsistence-oriented agriculture, most farmers continue to grow local varieties. The area planted to improved varieties and hybrids remains particularly modest in some of the poorest countries and regions within Latin America, including Mexico (20.3%), Central America (21.8%), and the Caribbean (31.3%).

Use of hybrids has increased dramatically relative to use of improved open-pollinated varieties (OPVs).

The rise of the private seed industry has been reflected in a pronounced shift in the types of materials planted in farmers' fields. The area planted to hybrids has increased, while the area planted to improved OPVs has declined. By 1996, the area planted to hybrids already far exceeded the area planted to improved OPVs. Despite warnings that only large-scale commercial producers would adopt hybrid technologies, in many countries small-scale producers have successfully adopted hybrids.

CIMMYT materials have been used extensively by public breeding programs.

Public maize breeding programs have made extensive use of CIMMYT materials. From 1966 to 1997, approximately 55% of all varieties and hybrids released by public breeding programs contained CIMMYT germplasm. Contrary to expectations, this percentage has increased over time. However, the way in which CIMMYT germplasm is used has changed. Public-sector breeders have increasingly tended to subject CIMMYT materials to additional cycles of selection before using them to form finished cultivars.

CIMMYT materials have been used extensively by private-sector breeders.

Private-sector breeders also have made extensive use of CIMMYT materials. Although detailed information about the genetic background of proprietary hybrids is not always available, we estimate that 75% of all seed sold by private companies in Latin America in 1996 contained CIMMYT-derived germplasm. The way CIMMYT materials are used tends to vary by type of seed company. Small local seed companies often make direct use of CIMMYT lines in forming hybrids. Large companies with strong breeding programs (including most multinationals) also use CIMMYT lines directly, but more frequently they use CIMMYT materials as source germplasm for developing their own inbred lines.

The total area planted to CIMMYT-derived OPVs and hybrids continues to increase.

The area planted to improved OPVs and hybrids that contain CIMMYT germplasm in their ancestry continues to increase. In 1996, CIMMYT-derived cultivars were planted on approximately 10.6 million ha, representing over 36% of the total maize area in Latin America and over 75% of the area planted to improved germplasm. Use of CIMMYT-derived cultivars is concentrated in lowland tropical environments.

Adoption of improved germplasm depends on many factors.

Adoption of improved germplasm is influenced by many factors, only some of which pertain to the characteristics of the germplasm itself. Generally speaking, adoption of improved germplasm is higher in countries where it is profitable for farmers to adopt improved OPVs and hybrids and for companies to produce and sell seed. Policy makers therefore must be realistic about researchers' ability to bring about desired changes in farm-level productivity. Improved germplasm is needed to raise productivity, but improved germplasm in and of itself is not sufficient. Other things are also required, including adequate economic incentives, appropriate institutional structures, and a favorable policy environment.

Acknowledgments

The information presented in this report was assembled with help from numerous individuals and organizations engaged in maize breeding research, commercial seed production, or both activities. Although it is not possible to mention all of them by name, we would like to express our appreciation to the hundreds of researchers and seed company representatives who participated in the survey.

Miguel López-Pereira conducted all of the interviews, with occasional assistance from Michael Morris. Logistical support, especially help in arranging contacts with seed company representatives, was provided by numerous CIMMYT colleagues, including Hugo Córdova and David Beck in Mexico, Gustavo Sain and Monica Zurek in Costa Rica, Jorge Bolaños in Guatemala, Hector Baretto in Honduras, Carlos De Leon and Luis Narro in Colombia, Patrick Wall in Bolivia, and Man Mohan Kohli in Uruguay.

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Introduction

Objectives of the study

During the early 1990s, researchers at the International Maize and Wheat Improvement Center (CIMMYT) conducted a major study documenting the global impacts of international maize breeding research. The results of that study, published in 1994 in a CIMMYT monograph entitled *Impacts of International Maize Breeding Research in the Developing World, 1966-1990*, provided a wealth of information about the germplasm outputs of maize breeding efforts in developing countries and sketched out a compelling picture of the widespread diffusion of improved maize varieties and hybrids (López-Pereira and Morris 1994). In subsequent years, the data generated by CIMMYT's global maize impacts study came to recognized as definitive and were widely used for a broad range of research investment and research management activities.

Following the completion of the initial study in 1994, CIMMYT made a commitment to update and extend its global maize impacts database roughly every five years. Regular updating was considered important given the extremely rapid rate of technological change that characterizes the global maize economy. Extending the database was considered necessary given the lack of success achieved during the initial study at collecting detailed and comprehensive information from the private sector.

Efforts to update and extend the maize impacts database were initiated in 1997. Given the great scope of the data collection task, the global study was divided into three regional studies—one each for Latin America, Sub-Saharan Africa, and Asia. This report presents the results of the first of the three regional studies, whose basic objectives remain largely unchanged from the initial global maize impacts study:

- to estimate the level of public- and private-sector investment in maize breeding research in developing countries;
- to document the germplasm outputs of public and private maize breeding programs in developing countries;
- to document the use of CIMMYT materials by public and private maize breeding programs in developing countries; and
- to estimate the rate of farm-level adoption of improved maize germplasm in developing countries.

An additional objective of the current studies—made possible by the availability of the baseline data collected in 1992—is to assess the nature and extent of the changes taking place in the organization and performance of the global maize seed industry.

Sources of information

In addition to drawing on the original impacts data collected in 1992, this report presents new information collected in 1997 through an extensive survey of Latin American maize seed organizations. The survey covered 18 countries, including all of the region's leading maize producers (Table 1).[1]

Compared to the 1992 survey, the 1997 survey collected far more data from the private sector. Detailed questionnaires were completed by the directors of 36 public maize seed organizations (breeding programs and seed production agencies), as well as by representatives of 172 private companies. Virtually all of these respondents were personally interviewed; only in rare cases was the information collected indirectly (e.g., by mail or by relying on secondary sources). The sample included almost all of the public and private organizations in Latin America that currently engage in maize breeding; collectively, these organizations produced about 97% of the commercial maize seed sold in Latin America in 1996. Given the size of the sample, the information presented in this report provides an extremely comprehensive and highly accurate picture of the impacts of maize research in Latin America.

Table 1. Coverage of the 1997 Latin America maize impacts survey

	Public organizations surveyed	Private companies surveyed	Maize seed sales, 1996 (000 t)	Percent of formal maize seed market
Central America	**7**	**39**	**5.4**	**90**
Costa Rica	1	4	0.1	100
El Salvador	1	6	2.1	91
Guatemala	1	5	1.5	86
Honduras	2	13	1.0	95
Nicaragua	1	9	0.5	95
Panama	1	2	0.3	90
Caribbean	**3**	**4**	**2.4**	**95**
Cuba	1	0	1.6	100
Dominican Republic	1	2	0.5	100
Haiti	1	2	0.3	65
Mexico	**11**	**18**	**32.6**	**97**
Central America, Caribbean, and Mexico	**21**	**61**	**40.5**	**96**
Andean Zone	**11**	**63**	**21.1**	**96**
Bolivia	5	15	2.6	88
Colombia	1	9	3.2	95
Ecuador	2	7	2.8	96
Peru	2	15	1.6	88
Venezuela	1	17	10.9	100
Southern Cone	**4**	**48**	**219.4**	**98**
Argentina	1	14	64.9	94
Brazil	1	24	151.8	99
Chile	–	–	–	–
Paraguay	2	10	2.7	93
Uruguay	–	–	–	–
South America	**15**	**111**	**240.6**	**98**
Latin America	**36**	**172**	**281.0**	**97**

Source: Calculated by the authors.

Definitions of key terms

Before proceeding, it is necessary to clarify a number of key terms. By convention, the products of scientific maize breeding programs, whether open-pollinated varieties (OPVs) or hybrids, are referred to as *improved materials*, reflecting the fact that their characteristics have systematically been altered in ways that bring economic benefits to those who grow them. Although use of the term *improved* is appropriate in this context, an unfortunate consequence of the convention is that the traditional varieties grown by farmers (referred to interchangeably in this report as *landraces* or *local varieties*) often end up being considered *unimproved*. This is clearly incorrect. Landraces have been subjected to numerous cycles of improvement at the hands of farmers, many of whom are skilled at identifying superior germplasm and expert at selecting individual plants that embody desired traits. Farmers' selection procedures in many ways resemble the selection procedures used in formal

1 Chile, which features around 100,000 ha of maize area, was not included in the survey. The omission is relatively unimportant, however, because maize in Chile is grown in temperate environments that are not targeted by CIMMYT's breeding program.

plant breeding programs, and although scientific breeding methods may allow progress to be achieved more rapidly in breeders' plots than in farmers' fields, the gains made by farmers over thousands of years have been enormous.

In addition to failing to acknowledge that local varieties are also improved, use of the term *improved materials* to refer only to cultivars produced by formal breeding programs has another unfortunate consequence. Maize varieties and hybrids undergo a continual process of genetic change in farmers' fields. In the case of varieties and hybrids that were originally developed by formal breeding programs, this phenomenon is sometimes referred to as "genetic deterioration" or "genetic depreciation," with the process being described as one in which improved materials become "contaminated" by exposure to external sources of pollen. Use of such negative terms is misleading and may in fact incorrectly characterize what is actually happening. Although genetic change is undesirable when farmers would prefer to preserve the characteristics of the original germplasm, in many instances genetic change occurs as cultivars become better adapted to local production conditions and/or consumption preferences. In other words, what some plant breeders refer to with the perjorative term "genetic deterioration" may in fact be a positive phenomenon from the point of view of farmers. Thus, the process is more appropriately described with less value-laden terms, for example, as the "rustification" or "local adaptation" of improved materials (Wood and Lenné 1997).

In this report, the term *improved materials* refers to the varieties and hybrids produced by formal plant breeding programs. This usage is not meant to imply that local varieties are in any sense unimproved.

The Maize Economy of Latin America

Maize growing environments

Maize is the dominant cereal in Latin America, grown in a wide range of production environments, at altitudes ranging from sea level to over 3,000 m elevation, under temperatures ranging from extremely cool to very hot, under moisture regimes ranging from extremely wet to semi-arid, on terrain ranging from completely flat to precipitously steep, in many different types of soil, and using a wide range of production technologies.

No universally recognized system exists for classifying maize production environments. The closest thing to a standardized classification system has been developed by CIMMYT, which holds the global mandate for maize germplasm improvement in developing countries. CIMMYT recognizes four major maize production environments, known as *mega-environments*: (1) lowland tropics, (2) subtropics/mid-altitude zones, (3) tropical highlands, and (4) temperate zones. These mega-environments, which are defined primarily in terms of climatic factors (e.g., mean temperature during the maize growing season, elevation above sea level, daylength), theoretically are characterized by their relative within-class uniformity. Since the growth habits of maize plants are influenced by complex interactions among many different climatic factors, however, it is not always clear exactly where one mega-environment ends and the next begins.

In considering the relative importance of the four mega-environments, it is important to note that approximately 85% of the maize produced in Latin America is grown in non-temperate production environments; only about 15% is grown in temperate environments, mainly in southern Brazil, Argentina, and Chile (Table 2). The marked difference between non-temperate and temperate maize-growing environments has important implications for the flow of improved germplasm. Maize varieties and hybrids that perform well in temperate regions generally cannot be introduced directly into non-temperate regions without undergoing extensive additional adaptation breeding. For this reason, most of the improved OPVs and hybrids developed for use in industrialized countries (including the vast majority of the commercial hybrids developed by private seed companies) are of little direct use for most of the farmers in Latin America.

Production trends

Maize production statistics for Latin America are summarized in Table 3. The aggregate country-level data conceal considerable variation in production and consumption methods.

Throughout most of Mexico, Central America, and the Caribbean, as well as parts of the Andean countries, maize is an important food staple grown by a large part of the rural population for home use. Except for a small commercial farming sector, most maize production systems in these countries are characterized by their small scale, their complexity, and their heavy reliance on animal traction and especially human labor. Maize is often grown in association with beans, squash, peppers, cassava, and other food crops destined for home consumption, and many farmers use little or no chemical fertilizer or pesticides. Use of improved varieties is frequently limited, either because farmers lack access to reliable sources of affordable seed or because they prefer to grow traditional maize varieties developed to meet specific food and feed requirements.

Further to the south, the picture is different. In southern Brazil, Argentina, and Chile, maize is primarily a cash crop grown by large-scale commercial producers using extensive mechanization and (where profitable) high levels of purchased inputs. Use of improved varieties and especially hybrids is extensive. Many of the maize production environments found in this latter group of countries feature a temperate climate, so growers have directly adopted commercial hybrids and improved management practices imported from North America and Europe.

Table 2. Estimated distribution of maize production by ecological zone, Latin America, late 1990s (000 ha)

	Lowland tropical	Subtropical/ mid-altitude	Highland	Temperate	Total
Central America	**1,555.4**	**49.7**	**36.5**	**0.0**	**1,641.6**
Costa Rica	14.5	0.0	0.0	0.0	14.5
El Salvador	293.3	0.0	0.0	0.0	293.3
Guatemala	492.8	36.5	36.5	0.0	565.8
Honduras	403.9	13.2	0.0	0.0	417.1
Nicaragua	277.8	0.0	0.0	0.0	277.8
Panama	73.1	0.0	0.0	0.0	73.1
Caribbean	**365.8**	**0.0**	**0.0**	**0.0**	**365.8**
Cuba	74.0	0.0	0.0	0.0	74.0
Dominican Republic	41.5	0.0	0.0	0.0	41.5
Haiti	250.3	0.0	0.0	0.0	250.3
Mexico	**3,000.0**	**1,553.6**	**3,042.9**	**0.0**	**7,596.5**
Central America, Caribbean, and Mexico	**4,921.2**	**1,603.4**	**3,079.4**	**0.0**	**9,603.9**
Andean Zone	**1,363.2**	**414.9**	**539.3**	**0.0**	**2,317.4**
Bolivia	106.0	41.6	145.5	0.0	293.0
Colombia	331.9	262.9	47.1	0.0	642.0
Ecuador	258.6	110.4	181.3	0.0	550.4
Peru	223.3	0.0	165.3	0.0	388.7
Venezuela	443.3	0.0	0.0	0.0	443.3
Southern Cone	**9,903.5**	**4,325.5**	**0.0**	**2,728.5**	**16,957.4**
Argentina	214.5	0.0	0.0	2,574.2	2,788.7
Brazil	9,333.8	4,325.5	0.0	0.0	13,659.3
Chile	0.0	0.0	0.0	103.1	103.1
Paraguay	355.2	0.0	0.0	0.0	355.2
Uruguay	0.0	0.0	0.0	51.2	51.2
South America	**11,266.7**	**4,740.4**	**539.3**	**2,728.5**	**19,274.8**
Latin America	**19,187.9**	**6,343.7**	**3,618.6**	**2,728.5**	**28,878.7**

Source: Estimated by the authors based on CIMMYT Maize Program (1988) and FAO (1998).

Table 3. Maize production and net imports, Latin America, 1995-97

	Area (million ha)	Yield (t/ha)	Production (million t)	Net imports[a] (million t)
Central America	**1.64**	**1.76**	**2.90**	**0.78**
Costa Rica	0.02	1.74	0.03	0.31
El Salvador	0.29	2.20	0.64	0.14
Guatemala	0.57	1.96	1.11	0.14
Honduras	0.42	1.63	0.68	0.04
Nicaragua	0.28	1.16	0.32	0.02
Panama	0.07	1.50	0.11	0.13
Caribbean	**0.37**	**0.90**	**0.33**	**0.82**
Cuba	0.07	1.17	0.09	0.13
Dominican Republic	0.04	1.04	0.04	0.67
Haiti	0.25	0.80	0.20	0.02
Mexico	**7.60**	**2.30**	**17.49**	**1.83**
Central America, Caribbean, and Mexico	**9.60**	**2.19**	**21.04**	**3.43**
Andean Zone	**2.32**	**1.80**	**4.16**	**2.73**
Bolivia	0.29	2.07	0.61	0.00
Colombia	0.64	1.61	1.03	0.92
Ecuador	0.55	1.10	0.60	-0.02
Peru	0.39	2.04	0.79	0.82
Venezuela	0.44	2.53	1.12	1.01
Southern Cone	**16.96**	**2.88**	**48.77**	**-3.27**
Argentina	2.79	4.35	12.13	-5.01
Brazil	13.66	2.55	34.80	1.34
Chile	0.10	8.49	0.88	0.41
Paraguay	0.36	2.38	0.85	-0.09
Uruguay	0.05	2.26	0.12	0.08
South America	**19.27**	**2.75**	**52.92**	**-0.54**
Latin America	**28.88**	**2.56**	**73.97**	**2.89**

Source: FAO (1998).
a 1993-95.

Compared to other regions of the world, the performance of the Latin American maize economy has been mixed (Table 4). During the 1960s, 1970s, and 1980s, maize yields in Latin America grew more slowly than maize yields in developing countries generally; yield growth in Latin America consistently trailed yield growth in Asia but for the most part outpaced yield growth in Sub-Saharan Africa. During the 1990s, the rankings reversed themselves; up through 1997, maize yields grew faster in Sub-Saharan Africa than in all other developing regions, and Asia lagged behind. The relatively favorable performance of the Latin American maize sector during the 1990s can be attributed to extremely rapid productivity growth achieved in the Southern Cone as growers reacted to sharp increases in global maize prices; productivity growth in Mexico, Central America, and the Andean Zone has been much more modest.

Table 4. Growth in maize yields, by region, 1961-97 (% average annual growth)

	1961-70	1971-80	1981-90	1991-97
Latin America	**1.98**	**2.12**	**0.30**	**3.10**
Mexico and Central America	2.23	3.35	0.30	1.46
Andean Zone	1.36	1.84	0.68	1.61
Southern Cone	1.66	1.45	0.33	3.92
Sub-Saharan Africa	**1.09**	**1.16**	**0.93**	**3.57**
South, East, and Southeast Asia	**4.19**	**3.87**	**2.93**	**1.69**
Developing countries	**2.91**	**3.11**	**1.66**	**2.27**
Industrialized countries	**3.11**	**1.77**	**1.14**	**1.73**

Source: Calculated by the authors using data from FAO (1998).

CONSUMPTION TRENDS

Unlike other leading cereals that are mainly consumed as human food, such as wheat and rice, maize is a multipurpose crop that is eaten by humans, fed to animals, or used as a raw input into industry. Maize consumption statistics for Latin America reflect marked differences between countries in the relative importance of each of these end uses (Table 5). Maize is the leading food staple in Mexico, Central America, and parts of the Andean Zone, but most maize produced in the Southern Cone countries is used as animal feed or for industrial purposes.

Table 5. Maize consumption, Latin America, 1992-94

	Consumption (million t)	Consumption per capita (kg)	Percent used for:		
			Food	Feed	Other
Central America	3.57	117.1	68	25	7
Costa Rica	0.27	81.7	22	71	7
El Salvador	0.70	130.1	66	28	6
Guatemala	1.47	146.5	75	18	7
Honduras	0.61	115.1	79	12	9
Nicaragua	0.28	71.9	82	7	11
Panama	0.24	92.9	36	61	3
Caribbean	1.09	43.0	16	79	5
Cuba	0.20	18.3	0	94	6
Dominican Republic	0.67	88.7	8	88	4
Haiti	0.22	31.8	52	40	8
Mexico	18.46	209.8	60	25	15
Central America, Caribbean, and Mexico	23.11	178.8	59	28	14
Andean Zone	5.95	61.8	53	32	15
Bolivia	0.37	51.7	56	38	6
Colombia	1.83	53.1	68	29	3
Ecuador	0.55	50.5	16	5	79
Peru	1.40	61.5	20	72	8
Venezuela	1.80	86.1	74	13	13
Southern Cone	39.79	189.4	10	79	11
Argentina	5.61	165.7	3	85	12
Brazil	32.28	208.6	10	78	12
Chile	1.28	93.0	7	89	4
Paraguay	0.43	92.8	44	36	20
Uruguay	0.20	61.8	32	53	15
South America	45.74	149.3	15	73	12
Latin America	68.86	158.1	30	58	12

Source: FAO (1998).

Maize Research Investment in Latin America

Organization of the maize research system

Before examining the impacts of maize breeding research in Latin America, it is useful briefly to consider the organization of the region's research system. The improved OPVs and hybrids that eventually make their way into farmers' fields are products of an international breeding system that includes one publicly supported international research center (CIMMYT); dozens of public breeding programs operating at the national, regional, state, or district level; and hundreds of private seed companies, both national companies and multinationals. Information about the organization and performance of this international research system is available elsewhere, so it will not be described in detail here (see López-Pereira, Clancy, and Morris 1992; López-Pereira and Filipello 1994; López-Pereira and Morris 1994).

As a charter member of the Consultative Group on International Agricultural Research (CGIAR), CIMMYT holds a global mandate for maize research and in this capacity plays a leading role in Latin American maize breeding efforts. Working in collaboration with other organizations, both public and private, CIMMYT develops, tests, and distributes improved maize germplasm. Contrary to the widely held view, CIMMYT's goal is not to produce finished materials; for this reason, CIMMYT does not release named varieties and hybrids intended for direct use by farmers. Instead, CIMMYT distributes intermediate products designed to be used as inputs into public and private breeding programs; typically these consist of improved materials with high yield potential, good agronomic characteristics, resistance to important diseases and pests, and (in the case of inbred lines) good combining ability. CIMMYT's maize breeding efforts thus are concentrated at the "upstream" end of the research continuum.

CIMMYT distributes materials (both materials that have been worked on by CIMMYT breeders as well as materials obtained from external sources) through two main channels. The primary germplasm distribution channel is the system of international trials, which consists of sets of materials sent to local cooperators for evaluation under controlled levels of management; in return for reporting performance data back to CIMMYT, the cooperators are free to incorporate any material selected out of the trials into their own breeding programs. A second germplasm distribution channel consists of seed shipments sent from the Wellhausen-Anderson Plant Genetic Resources Center, a state-of-the-art storage facility in which more than 10,000 maize accessions are permanently maintained.

POLICIES AFFECTING NATIONAL MAIZE SEED INDUSTRIES

Although the basic organization of the international maize breeding system in Latin America dates back to the time when CIMMYT was established in the mid-1960s, the roles of different institutional players have changed over the years. The public research institutes and seed agencies that once dominated maize breeding and seed production have seen their role gradually diminish in the face of fierce competition from the private sector, to the degree that in many countries the public sector no longer participates actively in seed production and/or seed marketing (Table 6). Even indirect regulation of seed industry activities has been relaxed, with the elimination of restrictions on seed trade and the removal of seed price controls (Table 6).

Table 6. Maize seed industry policies, Latin America, late 1990s

	Public-sector maize seed production?	Commercial seed imports permitted?	Mandatory maize seed certification?	Official seed price controls?
Central America				
Costa Rica	N	Y	Y	N
El Salvador	N	Y	Y	N
Guatemala	Y	Y	Y	N
Honduras	N	Y	Y	N
Nicaragua	N	Y	Y	N
Panama	N	Y	Y	N
Caribbean				
Cuba	Y	N	Y	Y
Dominican Republic	Y	Y	N	N
Haiti	Y	Y	Y	N
Mexico	**Y**	**Y**	**N**	**N**
Andean Zone				
Bolivia	Y	Y	Y	N
Colombia	N	Y	Y	N
Ecuador	Y	Y	Y	N
Peru	Y	Y	N	N
Venezuela	N	Y	Y	N
Southern Cone				
Argentina	N	Y	N	N
Brazil	N	N	Y	N
Chile	-	-	-	-
Paraguay	Y	Y	Y	N
Uruguay	-	-	-	-

Source: CIMMYT maize impacts survey.

The emergence of flourishing private maize seed industries in many Latin American countries can be attributed to a complex set of technical, economic, and institutional factors that will not be examined in detail in this report.[2] In view of the current heated debate over the role played by intellectual property rights in stimulating private investment in seed research, it seems worth mentioning, however, that only seven countries in Latin America are signatories to the UPOV (International Union for the Protection of New Varieties of Plants) agreement. This suggests that relatively few countries in the region have enacted effective systems of plant varietal protection (Table 7).

Table 7. Intellectual property rights regimes, Latin America, late 1990s

	UPOV signatory?	PVP laws in effect?	Plant patents allowed?	Varietal registration required?
Central America				
Costa Rica	N	N	N	N
El Salvador	N	N	N	N
Guatemala	N	N	N	N
Honduras	N	N	N	N
Nicaragua	N	N	N	N
Panama	N	N	N	N
Caribbean				
Cuba	N	Y	Y	N
Dominican Republic	N	N	N	Y
Haiti	N	N	N	N
Mexico	**Y**	**Y**	**N**	**Y**
Andean Zone				
Bolivia	N	Y	N	N
Colombia	Y	N	N	N
Ecuador	Y	N	N	N
Peru	N	N	N	Y
Venezuela	N	N	N	N
Southern Cone				
Argentina	Y	Y	Y	N
Brazil	N	Y	N	N
Chile	Y			
Paraguay	Y	Y	N	N
Uruguay	Y			

Source: CIMMYT maize impacts survey.

2 For a discussion of the evolutionary growth process that characterizes the development of national seed industries, see Morris and Smale (1997).

CURRENT STRUCTURE OF NATIONAL MAIZE SEED INDUSTRIES

Table 8 presents information on the numbers and types of organizations that conducted maize breeding research, produced maize seed, and/or marketed maize seed in Latin America in 1996. The data appearing in Table 8 almost certainly understate the true size of the regional maize seed industry, because even though a concerted effort was made to identify all relevant organizations, some probably were overlooked. Also, in some cases it was difficult to classify individual organizations (e.g., when a company was registered as a national company but maintained formal links with a multinational corporation); for this reason, the numbers appearing in each category should be considered approximate.

Table 8. Numbers of maize seed organizations, Latin America, 1996

	Public seed agencies	Private seed companies			
		Domestic producers	Multinational producers	Seed importers	NGOs
Central America	**8**	**31**	**12**	**25**	**73**
Costa Rica	3	3	1	0	7
El Salvador	1	4	0	5	10
Guatemala	1	11	6	4	22
Honduras	1	4	5	6	16
Nicaragua	1	6	0	6	13
Panama	1	3	0	4	8
Caribbean	**5**	**4**	**0**	**6**	**15**
Cuba	2	0	0	1	3
Dominican Republic	1	1	0	3	5
Haiti	2	3	0	2	7
Mexico	**4**	**50**	**5**	**52**	**111**
Central America, Caribbean, and Mexico	**17**	**85**	**17**	**83**	**202**
Andean Zone	**7**	**61**	**9**	**42**	**119**
Bolivia	2	16	1	14	33
Colombia	1	14	3	0	18
Ecuador	2	9	0	3	14
Peru	1	10	0	21	32
Venezuela	1	12	5	4	22
Southern Cone	**8**	**83**	**13**	**10**	**114**
Argentina	1	19	7	2	29
Brazil	6	48	5	5	64
Chile					
Paraguay	1	16	1	3	21
Uruguay					
South America	**15**	**144**	**22**	**52**	**233**
Latin America	**32**	**229**	**39**	**135**	**432**

Source: CIMMYT maize impacts survey.

Despite these caveats, the data appearing in Table 8 are informative, especially when they are compared to the results of an earlier CIMMYT survey conducted in 1993 (López-Pereira and Filipello 1994). Throughout the region, the public sector continues to maintain an active presence in the maize seed industry, although in many countries this presence has been reduced to a single organization. Often this single public organization is a research institute, rather than a seed production agency; as will become evident when commercial seed sales data are discussed, in many countries the public sector no longer participates directly in seed production activities.

Across Latin America, the role of the public sector is now overshadowed by the private sector, which judging from the numbers of seed companies continues to expand rapidly. The number of multinational seed companies has not changed appreciably since the 1993 survey, but the number of national companies more than doubled. In interpreting these figures, it is important to keep in mind that the activities carried out by individual companies can vary. In contrast to multinational seed companies, almost all of which engage in the full range of research, seed production, and seed distribution, many national seed companies do not maintain their own research programs; rather, they restrict themselves to producing and selling seed.

The dramatic expansion of the private seed industry has been matched in the participatory sector, as the proliferation of private seed companies has been accompanied by similar rapid growth in the number of non-governmental seed organizations. Although this category is not always well defined, generally speaking it includes small, not-for-profit organizations dedicated to the production of maize seed at the community level. In many cases these participatory seed organizations are established as part of integrated rural development projects in an attempt to meet localized demand for improved seed. These participatory organizations virtually never conduct research and almost always restrict themselves to producing seed of public varieties and hybrids.

INVESTMENT IN MAIZE BREEDING RESEARCH

Tables 9 and 10 present information on the numbers and distribution of scientists engaged in maize breeding research in 1996. Marked regional differences are apparent in the relative numbers of maize breeders employed in the public and private sectors.[3] In Mexico, Central America, and the Caribbean, the number of public-sector breeders exceeded that of private-sector breeders, indicating that maize breeding research remained concentrated in the public sector. The situation was quite different in South America, however; both in the Andean Zone and in the Southern Cone, the number of private-sector maize breeders exceeded the number of public-sector breeders. These findings are consistent with the view that private investment flows have been attracted toward more commercial seed markets.

Table 9. Public sector maize research indicators, Latin America, 1996

	Public organizations engaged in maize breeding	Public-sector scientists engaged in maize breeding	Public-sector scientists per million ha planted to maize	Public-sector scientists per million t maize produced
Central America	**7**	**22.5**	**13.7**	**7.8**
Costa Rica	1	3.0	225.5	119.9
El Salvador	1	2.0	6.8	3.2
Guatemala	1	7.0	12.2	6.2
Honduras	2	5.0	12.3	7.6
Nicaragua	1	3.0	10.7	9.0
Panama	1	2.5	34.2	22.8
Caribbean	**3**	**6.0**	**16.1**	**18.1**
Cuba	1	2.0	27.0	23.5
Dominican Republic	1	2.0	46.9	46.7
Haiti	1	2.0	7.8	9.8
Mexico	**11**	**130.6**	**16.8**	**7.3**
Central America, Caribbean, and Mexico	**21**	**159.1**	**16.2**	**7.6**
Andean Zone	**10**	**47.25**	**20.2**	**11.4**
Bolivia	5	6.0	20.9	9.8
Colombia	1	4.0	6.1	3.8
Ecuador	1	6.25	11.0	10.5
Peru	2	16.0	39.9	19.7
Venezuela	1	15.0	34.9	14.3
Southern Cone	**8**	**84.1**	**5.2**	**1.9**
Argentina	1	25.0	9.6	2.4
Brazil	6	54.6	4.1	1.7
Chile	-	-	-	-
Paraguay	1	4.5	13.9	6.9
Uruguay	-	-	-	-
South America	**18**	**131.3**	**7.0**	**2.8**
Latin America	**39**	**290.4**	**10.2**	**4.3**

Source: CIMMYT maize impacts survey.

Table 10. Private sector maize research indicators, Latin America, 1996

	Private organizations engaged in maize breeding	Private-sector scientists engaged in maize breeding	Private-sector scientists per million ha planted to maize	Private-sector scientists per million t maize produced
Central America	**9**	**9.3**	**5.6**	**3.2**
Costa Rica	1	0.6	45.1	24.0
El Salvador	1	0.3	0.9	0.4
Guatemala	3	7.5	13.04	6.6
Honduras	3	0.7	1.72	1.1
Nicaragua	0	0.0	0.0	0.0
Panama	1	0.2	2.9	1.9
Caribbean	**1**	**3.5**	**9.4**	**10.6**
Cuba	0	0.0	0.0	0.0
Dominican Republic	0	0.0	0.0	0.0
Haiti	1	3.5	13.6	17.2
Mexico	**24**	**43.0**	**5.5**	**2.4**
Central America, Caribbean, and Mexico	**34**	**55.7**	**5.7**	**2.7**
Andean Zone	**23**	**51.9**	**22.2**	**12.6**
Bolivia	5	5.3	18.5	8.6
Colombia	7	17.5	26.8	16.6
Ecuador	2	2.6	4.6	4.4
Peru	2	6.9	17.1	8.5
Venezuela	7	19.7	45.7	18.7
Southern Cone	**35**	**101.9**	**6.3**	**2.4**
Argentina	16	35.5	13.7	3.4
Brazil	19	66.4	5.0	2.1
Chile	–	–	–	–
Paraguay	0	0.0	0.0	0.0
Uruguay	–	–	–	–
South America	**58**	**153.8**	**8.3**	**3.3**
Latin America	**92**	**209.5**	**7.4**	**3.1**

Source: CIMMYT maize impacts survey.

3 The category referred to here as *maize breeders* includes not only breeders but also other scientists engaged in germplasm improvement research, such as physiologists, pathologists, and entomologists.

Simply comparing the numbers of maize breeders employed in the public and private sectors may provide a misleading measure of the relative strength of investment if the cost of supporting a breeder differs significantly between the two sectors. Table 11 shows the estimated cost of supporting a senior maize breeder in 1996. The data have been broken into two components: (1) salary and benefits, and (2) operating budget. Survey respondents (especially those working in public organizations) often had difficulty estimating all of the relevant overhead expenses associated with supporting public research personnel, so these figures should be considered conservative. Also, they may not be directly comparable with other published series on research costs. Despite these limitations, however, the data in Table 11 suggest that in every region the cost of supporting a senior maize breeder was considerably higher in the private sector than in the public sector. While the salary-and-benefits estimates for public-sector breeders may have failed to capture some administrative expenses, there is no reason to believe that the operating budgets would have been estimated differently between the two categories. The data thus suggest that public-sector scientists lack operating resources compared to their counterparts in the private sector.

Table 11. Cost of supporting a senior maize breeder, Latin America, 1996 (US$)

	Public sector		Private sector	
	Salary and benefits	Operating budget	Salary and benefits	Operating budget
Central America	**12,250**	**8,341**	**25,173**	**19,233**
Costa Rica	16,800	16,800	100,000	66,667
El Salvador	10,360	4,455	11,422	13,706
Guatemala	7,924	4,132	15,951	10,781
Honduras	12,000	11,656	21,220	20,804
Nicaragua	7,222	8,000	-	-
Panama	19,200	5,000	16,800	4,853
Caribbean	**7,899**	**5,550**	**13,000**	**8,750**
Cuba	4,071	4,071	-	-
Dominican Republic	11,325	5,082	-	-
Haiti	8,300	7,500	13,000	8,750
Mexico	**16,081**	**11,867**	**37,125**	**42,652**
Central America, Caribbean, and Mexico	**11,328**	**7,856**	**30,706**	**33,030**
Andean Zone	**15,411**	**17,957**	**25,989**	**22,990**
Bolivia	13,500	30,000	40,400	38,000
Colombia	21,945	21,945	30,886	25,374
Ecuador	12,541	7,838	16,723	12,090
Peru	11,100	20,000	14,833	12,750
Venezuela	19,971	10,000	24,700	23,257
Southern Cone	**27,057**	**25,000**	**75,236**	**101,479**
Argentina	35,500	40,000	67,923	99,769
Brazil	36,000	20,000	83,159	103,331
Chile	-	-	-	-
Paraguay	9,670	15,000	-	-
Uruguay	-	-	-	-
South America	**19,978**	**20,598**	**48,374**	**58,667**
Latin America	**15,084**	**13,520**	**42,414**	**49,343**

Source: CIMMYT maize impacts survey.

Products of Latin American Maize Breeding Programs

The principal output of maize breeding programs is improved germplasm, so the first step in documenting the impacts of maize breeding research in Latin America is to compile a complete inventory of germplasm products. Of course, the fact that a particular breeding program has produced a lot of germplasm products in and of itself does not constitute evidence of impact, since it must additionally be shown that these products are finding their way into farmers' fields and contributing to increased productivity at the farm level. But if a particular breeding program is not producing germplasm products, it is safe to say that the program is not having any impact.

During the original CIMMYT maize impacts survey carried out in 1992, detailed descriptive data were collected on the physical characteristics and genetic background of approximately 850 maize varieties and hybrids released in developing countries between 1966 and 1990. Of these, approximately 480 had been released in Latin America, including about 340 released by public breeding programs and about 140 released by private seed companies. Because relatively few private seed companies participated in the 1990 survey, the coverage of public-sector releases was much more comprehensive than that of private-sector releases.

Following the completion of the 1997 maize impacts survey, the varietal releases database was updated and expanded. All public varieties and hybrids released since 1990 were added to the original database, as were a few older (pre-1990) releases that had been missed during the earlier survey. The original list of private-sector releases was similarly updated, and it was greatly expanded as a result of the concerted effort to survey as many of the leading private seed companies as possible.

In interpreting the data on varietal releases presented in the following sections, it is important to remember that the coverage of public- and private-sector materials is not exactly the same. Public breeding programs were asked to provide information about all varieties and hybrids released since 1966, but in the case of private companies this was considered impractical. Many private seed companies that existed during the 1960s and 1970s are no longer in business, and it is simply not possible to obtain information on varieties and hybrids released by defunct companies. Furthermore, few of the currently active companies that date back to the 1960s and 1970s are able to provide information about materials they were selling 20 or 30 years ago. For these reasons, the private seed companies contacted during the 1997 survey were asked to provide information only about the varieties and hybrids they were currently selling; in most cases these consisted of relatively new hybrids released during the 1990s.

PUBLIC-SECTOR RELEASES

Types of materials. Data on the numbers and types of materials released by public maize breeding programs in Latin America between 1966 and 1997 are shown in Table 12. All told, public breeding programs released 675 cultivars during this period, including 427 varieties and 248 hybrids.

The rate at which cultivars were released by public breeding programs varied through time. The rate of releases rose steadily during the 1960s and 1970s before peaking during the mid-1980s; since then, it has remained fairly constant (Figure 1).

Summarizing across the entire 1966-97 period, varieties significantly outnumbered hybrids among public-sector releases, although this pattern was less pronounced in some countries (Costa Rica, Venezuela) and was actually reversed in two instances (Mexico, El Salvador). The proportion of hybrids released by public breeding programs has increased steadily through time, however, and during the most recent period for which data are available, more hybrids were released than varieties in many countries (Figure 2).

Table 12. Types and numbers of maize cultivars released by public breeding programs, Latin America, 1966-97

	Improved OPVs	Hybrids	Total MVs	MVs per million ha maize
Central America	**83**	**44**	**127**	**77.3**
Costa Rica	11	7	18	1,353.0
El Salvador	3	12	15	51.1
Guatemala	20	13	39	67.8
Honduras	15	5	20	49.2
Nicaragua	19	2	21	74.8
Panama	9	5	14	191.4
Caribbean	**18**	**3**	**21**	**74.8**
Cuba	6	3	9	121.6
Dominican Republic	6	0	6	140.8
Haiti	6	0	6	23.3
Mexico	**104**	**118**	**222**	**28.5**
Central America, Caribbean, and Mexico	**205**	**165**	**370**	**37.8**
Andean Zone	**140**	**53**	**193**	**82.5**
Bolivia	54	5	59	205.9
Colombia	28	18	46	70.5
Ecuador	22	3	25	43.9
Peru	19	11	30	84.8
Venezuela	17	16	33	76.7
Southern Cone	**82**	**30**	**112**	**6.9**
Argentina	27	17	44	16.9
Brazil	39	13	52	3.9
Chile	–	–	–	–
Paraguay	16	0	16	49.3
Uruguay	–	–	–	–
South America	**222**	**83**	**305**	**16.4**
Latin America	**427**	**248**	**675**	**23.6**

Source: CIMMYT maize impacts survey.

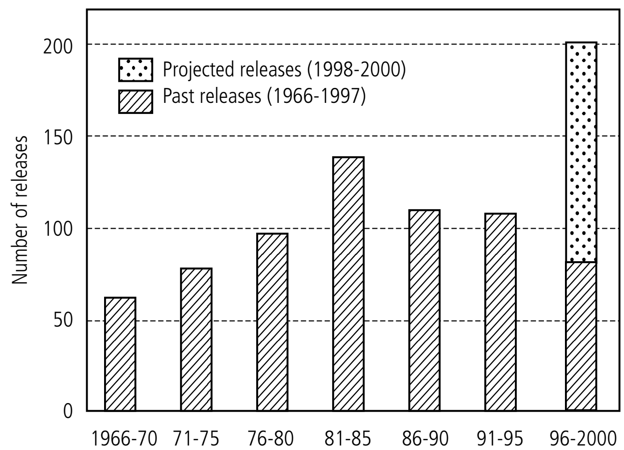


Figure 1. Rate of varietal releases by public maize breeding programs, Latin America, 1966-2000.

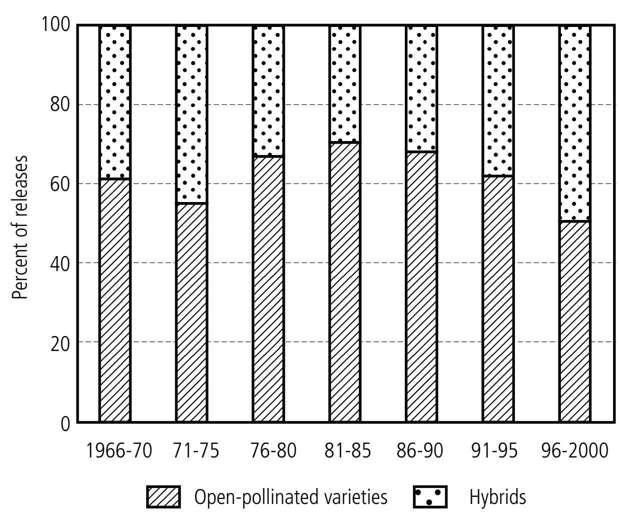


Figure 2. Types of cultivars released by public maize breeding programs, Latin America, 1966-97.

Ecological adaptation. Data on the ecological adaptation of materials released by public maize breeding programs in Latin America between 1966 and 1997 are shown in Table 13.

Materials adapted to lowland tropical environments have dominated public-sector releases; nearly two-thirds (63%) of the 673 materials whose ecological adaptation is known are adapted to lowland tropical environments. Next in importance among public-sector releases have been materials adapted to subtropical/mid-altitude environments (23%), followed at some distance by materials adapted to highland environments (9%) and materials adapted to temperate environments (4%).

Table 13. Ecological adaptation of maize cultivars released by public breeding programs, Latin America, 1966-97

	Lowland tropical	Subtropical/ mid-altitude	Highland	Temperate
Central America	**111**	**16**	**0**	**0**
Costa Rica	18	0	0	0
El Salvador	15	0	0	0
Guatemala	26	13	0	0
Honduras	19	1	0	0
Nicaragua	19	2	0	0
Panama	14	0	0	0
Caribbean	**20**	**1**	**0**	**0**
Cuba	9	0	0	0
Dominican Republic	6	0	0	0
Haiti	5	1	0	0
Mexico	**98**	**104**	**20**	**0**
Central America, Caribbean, and Mexico	**229**	**121**	**20**	**0**
Andean Zone	**120**	**37**	**39**	**0**
Bolivia	30	13	16	0
Colombia	27	8	11	0
Ecuador	10	13	2	0
Peru	20	3	10	0
Venezuela	33	0	0	0
Southern Cone	**77**	**0**	**0**	**30**
Argentina	9	0	0	30
Brazil	52	0	0	0
Chile	–	–	–	–
Paraguay	16	0	0	0
Uruguay	–	–	–	–
South America	**197**	**37**	**39**	**30**
Latin America	**426**	**158**	**59**	**30**

Source: CIMMYT maize impacts survey.

The proportion of public-sector releases adapted to each mega-environment has varied considerably by sub-region, which is consistent with geographical differences in the distribution of maize production. The proportion of releases adapted to lowland tropical environments is particularly high in Central America and the Caribbean, which is not surprising considering that most maize in Central America and the Caribbean is grown in such environments. In contrast, many of the releases from public breeding programs in the Southern Cone countries are adapted to temperate production conditions, reflecting the fact that a significant amount of maize in these countries is grown in temperate environments. Materials adapted to highland conditions have been released only in Mexico and in the countries of the Andean Zone.

Despite the variability that is apparent at the country and sub-regional levels, for Latin America as a whole the proportion of public-sector releases showing adaptation to each of the four major production environments recognized by CIMMYT is similar to the proportion of maize area located in each environment, indicating a close congruency between the pattern of research outputs and the target environments.

Characteristics. Data on the grain color and texture of materials released by public maize breeding programs in Latin America between 1966 and 1997 are shown in Table 14.

Marked geographical differences are evident in grain color. In Mexico, Central America, and the Caribbean, the vast majority of the materials released by public breeding programs have been white-grained, reflecting strong consumer preferences for white-grained food maize. In contrast, yellow-grained materials have dominated in South America, reflecting the superiority of these materials for feed use.

Geographical differences also are evident in grain texture. In Mexico, Central America, and the Caribbean, the majority of the materials released by public breeding programs have been dent or semi-dent materials, reflecting local consumer preferences for soft-grained food maize that is easier to process (in many rural areas throughout the region, maize is still ground by hand). In contrast, semi-flint and flint materials have dominated in South America; the popularity of these harder-grained materials can be attributed to the fact that they are not only suitable for use as livestock feed but have the added advantage of storing well.

Table 14. Grain characteristics of maize cultivars released by public breeding programs, Latin America, 1966-97

	Grain color		Grain texture				
	White	Yellow[a]	Dent	Semident	Semiflint	Flint	Other[b]
Central America	**81**	**46**	**32**	**52**	**30**	**12**	**0**
Costa Rica	13	5	0	13	4	1	0
El Salvador	12	3	8	5	1	1	0
Guatemala	20	19	2	17	18	1	0
Honduras	15	5	9	9	1	1	0
Nicaragua	20	1	8	6	5	2	0
Panama	1	13	5	2	1	6	0
Caribbean	**0**	**21**	**7**	**2**	**6**	**5**	**0**
Cuba	0	9	0	2	4	3	0
Dominican Republic	0	6	6	0	0	0	0
Haiti	0	6	1	0	2	2	0
Mexico	**213**	**9**	**92**	**69**	**41**	**11**	**0**
Central America, Caribbean, and Mexico	**294**	**76**	**131**	**123**	**77**	**28**	**0**
Andean Zone	**86**	**107 (3)**	**17**	**24**	**54**	**59**	**40**
Bolivia	27	31 (1)	15	15	8	14	7
Colombia	20	26	0	0	13	24	9
Ecuador	8	17	1	0	3	11	10
Peru	9	22 (2)	0	4	9	4	14
Venezuela	22	11	1	5	21	6	3
Southern Cone	**8**	**94 (10)**	**9**	**35**	**24**	**33**	**3**
Argentina	2	42	2	4	13	20	0
Brazil	2	50	5	30	11	3	0
Chile	–	–	–	–	–	–	–
Paraguay	4	2 (10)	2	1	0	10	3
Uruguay	–	–	–	–	–	–	–
South America	**94**	**201 (13)**	**26**	**59**	**78**	**92**	**43**
Latin America	**388**	**277 (13)**	**157**	**182**	**155**	**120**	**43**

Source: CIMMYT maize impacts survey.

a Numbers in parentheses indicate cultivars described as "*colorado*" (meaning "colored").

b Mainly floury types.

Data on the maturity classes of cultivars released by public breeding programs are shown in Table 15. Intermediate and late-maturing materials have dominated public-sector releases; this tendency has been true not only for Latin America as a whole, but for the various sub-regions as well. The preponderance of intermediate- and late-maturing materials is understandable, since materials that take longer to mature usually yield higher. On the other hand, the relatively small number of shorter duration releases may be seen as a cause for concern, given that farmers in drought-prone areas (which account for a significant proportion of Latin America's maize-growing environments) consistently express the need for early maturing materials. Less than 10% of all releases have been classified as early maturing, and less than 2% have been classified as extra-early.

Table 15. Maturity classes of maize cultivars released by public breeding programs, Latin America, 1966-97

	Extra-early	Early	Intermediate	Late	Extra-late
Central America	**2**	**14**	**90**	**8**	**12**
Costa Rica	0	1	14	3	0
El Salvador	0	3	10	1	0
Guatemala	0	1	27	0	11
Honduras	1	5	12	1	1
Nicaragua	1	3	14	3	0
Panama	0	1	13	0	0
Caribbean	**0**	**4**	**16**	**1**	**0**
Cuba	0	2	7	0	0
Dominican Republic	0	0	6	0	0
Haiti	0	2	3	1	0
Mexico	**7**	**30**	**37**	**34**	**112**
Central America, Caribbean, and Mexico	**9**	**48**	**143**	**43**	**124**
Andean Zone	**7**	**15**	**82**	**33**	**54**
Bolivia	5	8	31	13	2
Colombia	1	3	4	2	36
Ecuador	1	2	7	0	15
Peru	0	2	7	18	1
Venezuela	0	0	33	0	0
Southern Cone	**0**	**0**	**18**	**82**	**7**
Argentina	0	0	0	39	0
Brazil	0	0	15	30	7
Chile	–	–	–	–	–
Paraguay	0	0	3	13	0
Uruguay	–	–	–	–	–
South America	**7**	**15**	**100**	**115**	**61**
Latin America	**16**	**63**	**243**	**158**	**185**

Source: CIMMYT maize impacts survey.

Private-sector (proprietary) materials

In interpreting the following tables and figures showing patterns in private-sector (proprietary) releases, it is important to recall that the data are not directly comparable with those presented earlier showing patterns in public-sector releases. Two main points must be kept in mind:

1. Whereas the information collected from public breeding programs relates to all public varieties and hybrids released between 1966 and 1997, the information collected from private seed companies relates only to materials available on the market in 1997. Usually these consisted of commercial hybrids released during the 1990s. Thus, in the case of private-sector materials the temporal coverage is much more limited.

2. Interpretation of the data relating to private-sector materials is complicated by the fact that commercial hybrids are often introduced simultaneously in several countries (especially hybrids developed by multinational seed companies). This is quite different from what happens with materials developed by public breeding programs, which typically are released only in a single country—usually the country in which they were developed. In attempting to discern patterns in the overall set of private-sector materials, it is therefore difficult to avoid multiple counting, since many private-sector materials appear several times in the database. For this reason, Tables 16-19 present country-level results only. Sub-regional and regional totals are not presented, because these are most affected by the multiple-counting problem.

Types of materials. Data on the numbers and types of proprietary materials available on the market in Latin America in 1997 are shown in Table 16. As expected, the product line of most private seed companies was dominated by hybrids; only in three countries (Mexico, Venezuela, and Haiti) were proprietary OPVs available on the market.

The types of hybrids available on the market differed markedly between countries. Technically more sophisticated hybrids (e.g., single-crosses, three way-crosses) were found almost exclusively in countries with well-developed commercial production sectors, such as Argentina, Brazil, Mexico, and Paraguay. Technically less sophisticated hybrids (e.g., double-crosses, top-crosses, varietal crosses) tended to predominate in countries in which maize production is characterized by small-scale, subsistence-oriented production, including most of the countries in Central America, the Caribbean, and the Andean Zone. But these two categories are not mutually exclusive. Seed companies recognize that the presence of a commercial production sector capable of using more sophisticated technologies does not preclude targeting other segments of the market. For this reason, in all of the countries in which single-cross

Table 16. Types of private-sector (proprietary) maize cultivars available on the market in 1997, Latin America

	Improved	Hybrids				
	OPVs	SC	TWC	DC	Other	Total
Central America						
Costa Rica	0	1	8	4	0	13
El Salvador	0	0	2	5	0	7
Guatemala	0	0	3	8	0	11
Honduras	0	0	11	10	0	21
Nicaragua	0	0	1	4	0	5
Panama	0	1	2	1	0	4
Caribbean						
Cuba	0	0	0	0	0	0
Dominican Republic	0	0	0	0	0	0
Haiti	1	0	0	0	0	1
Mexico	**5**	**46**	**68**	**28**	**8**	**155**
Andean Zone						
Bolivia	0	0	12	4	0	16
Colombia	0	6	13	10	0	29
Ecuador	0	1	3	6	0	10
Peru	0	0	1	7	0	8
Venezuela	9	0	16	40	2	67
Southern Cone						
Argentina	0	67	49	14	0	130
Brazil	0	37	45	37	3	112
Chile	–	–	–	–	–	–
Paraguay	0	25	19	18	1	63
Uruguay	–	–	–	–	–	–

Source: CIMMYT maize impacts survey.

Note: Some varieties and hybrids were being sold in more than one country, so the data do not necessarily refer to *different* cultivars (i.e., the same cultivar may have been counted in more than one country). For this reason, summing the country-level counts will tend to overstate the total number of *different* cultivars on the market. SC = single cross; TWC = three-way cross; and DC = double cross.

and three way-cross hybrids were available, double-cross hybrids and other even less sophisticated types of hybrids were also being sold.

Ecological adaptation. Data on the ecological adaptation of private-sector (proprietary) materials available on the market in Latin America in 1997 are shown in Table 17. In all but two countries, the product lines of private seed companies were dominated by lowland tropical materials. The only exceptions were Argentina (in which temperate materials were by far the most common) and Mexico (in which a significant number of subtropical/highland materials and a small number of highland materials were also available).

Table 17. Ecological adaptation of private-sector (proprietary) maize cultivars available on the market in 1997, Latin America

	Lowland tropical	Subtropical/ mid-altitude	Highland	Temperate
Central America				
Costa Rica	11	1	0	0
El Salvador	7	0	0	0
Guatemala	11	0	0	0
Honduras	18	0	1	0
Nicaragua	5	0	0	0
Panama	4	0	0	0
Caribbean				
Cuba	0	0	0	0
Dominican Republic	0	0	0	0
Haiti	1	0	0	0
Mexico	**84**	**56**	**6**	**1**
Andean Zone				
Bolivia	16	0	0	0
Colombia	29	0	0	0
Ecuador	10	0	0	0
Peru	5	2	0	1
Venezuela	67	0	0	0
Southern Cone				
Argentina	4	0	0	129
Brazil	118	0	0	4
Chile	–	–	–	–
Paraguay	56	0	0	7
Uruguay	–	–	–	–

Source: CIMMYT maize impacts survey.

Note: Some varieties and hybrids were being sold in more than one country, so the data do not necessarily refer to different cultivars (i.e., the same cultivar may have been counted in more than one country). For this reason, summing the country-level counts will tend to overstate the total number of different cultivars on the market.

Even though lowland tropical environments predominate throughout much of Latin America, the number of proprietary cultivars adapted to these environments seems disproportionately large. This suggests one of two possibilities: either private seed companies have concentrated their breeding efforts on lowland tropical environments at the expense of other environments, or, if private-sector breeding efforts have been distributed across the entire range of production environments, relatively few commercial materials have been developed showing good adaptation to subtropical/mid-altitude and highland conditions.

Characteristics. Data on the grain color and texture of private-sector (proprietary) materials available on the market in Latin America in 1997 are shown in Table 18. Private seed companies clearly are

Table 18. Grain characteristics of private-sector (proprietary) maize cultivars available on the market in 1997, Latin America

	Grain color		Grain texture			
	White	Yellow[a]	Dent	Semident	Semiflint	Flint
Central America						
Costa Rica	7	5	2	3	6	1
El Salvador	6	1	1	1	2	3
Guatemala	7	4	2	2	2	5
Honduras	18	1	1	5	6	7
Nicaragua	5	0	0	1	1	2
Panama	1	3	2	2	0	0
Caribbean						
Cuba	0	0	0	0	0	0
Dominican Republic	0	0	0	0	0	0
Haiti	0	1	0	0	0	1
Mexico	**135**	**20**	**7**	**55**	**37**	**52**
Andean Zone						
Bolivia	1	18	7	8	1	0
Colombia	1	15	18	7	1	3
Ecuador	2	8	4	2	2	2
Peru	0	8	5	1	0	2
Venezuela	49	18	6	39	7	15
Southern Cone						
Argentina	1	126	57	24	23	25
Brazil	2	120	28	54	11	27
Chile	–	–	–	–	–	–
Paraguay	0	63	22	25	3	11
Uruguay	–	–	–	–	–	–

Source: CIMMYT maize impacts survey.

Note: Some varieties and hybrids were being sold in more than one country, so the data do not necessarily refer to *different* cultivars (i.e., the same cultivar may have been counted in more than one country). For this reason, summing the country-level counts will tend to overstate the total number of *different* cultivars on the market.

a Including materials described as "*colorado*" (meaning "colored").

sensitive to demand factors, and their product lines reflect the well-known geographical differences in consumer preferences. The majority of the proprietary cultivars available on the market in Mexico, Central America, the Caribbean, and the Andean Zone were white-grained materials suitable for use in preparing local food dishes. In contrast, the materials marketed in the Southern Cone countries were almost exclusively yellow-grained feed materials. Grain texture was quite variable, however, and in most countries a wide range of grain textures was on offer.

Data on the maturity classes of private-sector (proprietary) materials available on the market in Latin America in 1997 are shown in Table 19.

Table 19. Maturity classes of private-sector (proprietary) maize cultivars available on the market in 1997, Latin America

	Extra-early	Early	Intermediate	Late	Extra-late
Central America					
Costa Rica	0	0	7	5	0
El Salvador	0	1	5	1	0
Guatemala	0	0	11	0	0
Honduras	0	1	11	5	2
Nicaragua	0	0	4	1	0
Panama	0	0	3	1	0
Caribbean					
Cuba	0	0	0	0	0
Dominican Republic	0	0	0	0	0
Haiti	0	1	0	0	0
Mexico	**11**	**21**	**50**	**38**	**29**
Andean Zone					
Bolivia	0	1	7	7	1
Colombia	0	1	14	4	10
Ecuador	2	0	2	3	0
Peru	0	0	2	2	0
Venezuela	3	4	49	10	1
Southern Cone					
Argentina	3	14	32	57	27
Brazil	3	25	39	48	5
Chile					
Paraguay	2	15	22	21	3
Uruguay					

Source: CIMMYT maize impacts survey.

Note: Some varieties and hybrids were being sold in more than one country, so the data do not necessarily refer to *different* cultivars (i.e., the same cultivar may have been counted in more than one country). For this reason, summing the country-level counts will tend to overstate the total number of *different* cultivars on the market.

Intermediate and late-maturing materials predominated in most countries, except in the Southern Cone countries, where the product lines of private seed companies were fairly evenly distributed across a range of maturity classes.

Overall patterns in private-sector (proprietary) materials. In an effort to get around the multiple-counting problem, a "single-entry database" was constructed containing all of the proprietary materials available on the market in Latin America in 1997. In the single-entry database, redundant entries for individual OPVs or hybrids were eliminated. (For example, even though Pioneer Hybrid 3001 was being sold in six countries, the single-entry database contains only one record for Pioneer Hybrid 3001.) The single-entry database cannot be used to examine patterns at the level of individual countries, since materials listed in the database are not associated with specific countries. However, the single-entry database can be used to analyze patterns in the overall set of private-sector (proprietary) materials available throughout Latin America in 1997, and it permits direct comparisons with the aggregate results presented earlier relating to public-sector releases.

Summary statistics relating to the overall set of private-sector (proprietary) materials available on the market in Latin America in 1997 appear in Figure 3.

As expected, the vast majority (97%) of all proprietary cultivars being sold in Latin America in 1997 were hybrids. The preference of the private sector for marketing hybrids is plainly based on commercial considerations, including the following: (1) many farmers who plant hybrids are large-scale commercial growers who require large quantities of seed; (2) farmers who plant hybrids tend to purchase fresh seed every year; and (3) hybrid seed commands higher prices than OPV seed and thus provides increased profit opportunities for seed companies.

Among all proprietary cultivars, yellow-grained materials slightly outnumbered white-grained materials, reflecting the importance assigned by private seed companies to addressing the needs of commercial feed grain producers. The predominance of yellow-grained materials among proprietary cultivars contrasts sharply with the pattern observed among public-sector releases, which were dominated by white-grained materials suited for the preparation of local food dishes.

Proprietary cultivars included a wide range of grain textures, with the distribution skewed slightly toward the harder (flint) end of the spectrum. This pattern, which is quite similar to that observed among public-sector releases, presumably indicates that private seed companies, like public breeding programs, make an effort to offer a wide range of grain textures to meet diverse local preferences.

Lowland tropical materials dominated the product lines of Latin American seed companies, accounting for more than 60% of all proprietary cultivars being sold in 1997. In terms of its domination by lowland tropical materials, the overall set of proprietary cultivars resembled the overall set of public-sector releases. Beyond that, however, the relative emphasis placed on different mega-environments differed markedly. Temperate materials ranked second in importance among private-sector materials, no doubt due to the emphasis being placed on meeting the needs of commercial producers in Argentina. Materials adapted to highland production environments made up a minuscule 1% of all proprietary cultivars available on the market.

Intermediate- and late-maturing materials dominated the product lines of private seed companies, just as they did in the case of public-sector releases. But at the same time, private seed companies clearly recognize that there is demand for early maturing materials, and their product line indicates that they are making an effort to meet this demand: nearly 20% of all proprietary materials were classified as early or extra-early.

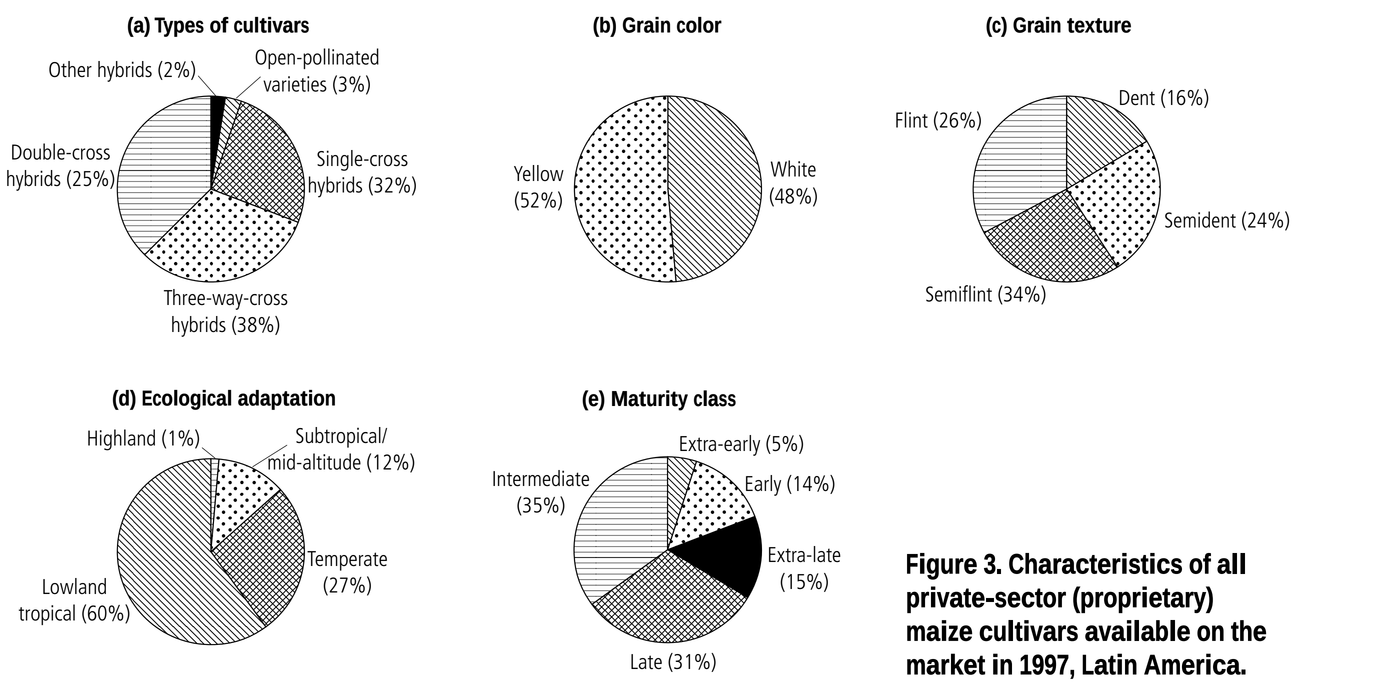


Figure 3. Characteristics of all private-sector (proprietary) maize cultivars available on the market in 1997, Latin America.

Use of CIMMYT Germplasm

To what extent do maize breeders in Latin America make use of CIMMYT germplasm? Since the main product of the CIMMYT Maize Program is improved germplasm, one obvious way to measure the impact of CIMMYT's maize breeding efforts is to determine the extent to which CIMMYT germplasm is present in cultivars developed by public and private breeding programs throughout the region.

Unfortunately, because of the way modern maize breeding is carried out, it is not always easy to document the use of CIMMYT germplasm. At least three factors make it difficult to identify and track the use of improved germplasm in maize:

1. Many improved OPVs and most modern hybrids have closed pedigrees, meaning that information about their genetic backgrounds is not publicly available. Breeding programs, especially commercial programs that respond to economic incentives, have a clear incentive to keep pedigrees closed, because once the genetic background of an improved OPV or hybrid becomes public knowledge, other breeders will quickly be able to produce the same OPV or hybrid.

2. Maize breeding strategies vary widely, and individual breeders use a range of techniques, most of which involve multiple cycles of selfing, crossing, and/or backcrossing. Selection strategies vary widely and frequently change. Because of the complex and frequently *ad hoc* nature of maize breeding, the precise genetic histories of many improved OPVs and hybrids cannot be known with complete certainty.

3. Even when the genetic history of a particular OPV or hybrid is known, it is not always clear how credit for the breeding effort should be attributed. Modern maize breeding is truly international, and most breeders routinely work with a wide range of source materials obtained from all over the world. Also, the breeding process requires a great deal of teamwork, because promising experimental materials must be evaluated in many different locations, which requires the participation of collaborators. Thus it can be difficult to assign credit to a particular breeder or breeding program.

Notwithstanding these complicating factors, an attempt was made to document the use of CIMMYT germplasm by public and private breeding programs.[4] Since many of the survey respondents were unwilling to provide complete pedigrees for their commercial cultivars,

4 In this context, "CIMMYT germplasm" is defined as germplasm that has undergone at least three cycles of selection at the hands of CIMMYT breeders and has been distributed as a CIMMYT population, pool, inbred line, experimental variety, or experimental hybrid.

information about the use of CIMMYT germplasm had to be requested in fairly general terms. For each improved OPV and hybrid listed in the two varietal databases, the following questions were posed (possible responses appear in italics):

- Does this OPV or hybrid contain CIMMYT germplasm? *(yes* or *no)*

- If the OPV or hybrid contains CIMMYT germplasm, what was the name of the CIMMYT population, pool, or inbred line that was used?

  Name of first CIMMYT population, pool, or inbred line: ________________________
  Name of second CIMMYT population, pool, or inbred line: ______________________
  Name of third CIMMYT population, pool, or inbred line: ______________________

- How was the CIMMYT germplasm used?

Population, pool, or experimental variety used as follows:
Class 2 = basic germplasm (substantial improvement done after received from CIMMYT)
Class 3 = selection from CIMMYT variety trials, with some improvement for local adaptation
Class 4 = direct use of CIMMYT material, no additional improvement performed

Inbred line or hybrid used as follows:
Class 2 = pedigree program (substantial improvement done after received from CIMMYT)
Class 3 = direct use of one or more CIMMYT inbred lines in the formation of the hybrid
Class 4 = direct use of a CIMMYT hybrid (all the inbred lines came from CIMMYT)

Most of the respondents representing public breeding programs were willing to provide this information about the genetic background of public-sector varietal releases. Thus, it was possible to classify almost all public-sector releases according to the amount of CIMMYT germplasm in their backgrounds.

With private-sector (proprietary) cultivars, however, the situation was different. Many private seed company representatives were willing to disclose whether or not CIMMYT germplasm had been used in developing a particular commercial cultivar, and, in cases in which CIMMYT germplasm had been used, they were also willing to indicate how it had been used. In these cases, it was possible to characterize each cultivar as belonging to Class 2, Class 3, or Class 4. Other seed company representatives, however, were reluctant to provide detailed information about the genetic background of specific materials and were prepared to indicate only in very general terms whether or not CIMMYT germplasm had been used in developing a particular cultivar or set of cultivars.

Because of the reluctance of some seed company representatives to provide detailed pedigree information, about one-half of the proprietary cultivars thought to contain CIMMYT germplasm could not be assigned with confidence into Class 2, Class 3, or Class 4. Therefore, proprietary materials were divided into three main categories:

1. definitely do not contain CIMMYT germplasm;

2. definitely contain CIMMYT germplasm (this category was further subdivided into Class 2, Class 3, or Class 4); and

3. probably contain CIMMYT germplasm (conservatively assumed to be Class 2).

Many of the seed company representatives interviewed during the survey stated that even general information about the genetic background of commercial hybrids might be of value to rival companies. Therefore, they agreed to answer questions about the use of CIMMYT germplasm only on the condition that the information not be publicized. For this reason, information on the genetic background of specific cultivars does not appear in this (or any other) CIMMYT publication.

Public breeding programs

Data on the use of CIMMYT germplasm by public maize breeding programs in Latin America appear in Table 20. Use of CIMMYT germplasm is expressed in terms of the percentage of all public-sector varietal releases that were identified as containing some CIMMYT material in their genetic background. Over one-half (55%) of all improved OPVs and hybrids released by public breeding programs during 1966-97 were identified as containing CIMMYT germplasm, reflecting the extensive reliance of national maize breeding programs on CIMMYT materials.

Although CIMMYT germplasm has been popular throughout Latin America, the frequency of its use has varied by sub-region (Table 21). Public breeding programs in Central America have been particularly heavy users of CIMMYT breeding materials. CIMMYT germplasm was present in over 87% of all public varieties and hybrids

Table 20. Use of CIMMYT germplasm by public maize breeding programs, Latin America, 1966-97 (% of cultivars released containing CIMMYT germplasm)

		By ecological adaptation:			
	All public releases	Lowland tropical	Subtropical/ mid-altitude	Highland	Temperate
Central America	**87.4**	**94**	**44**	**–**	**–**
Costa Rica	100.0	100	31	–	–
El Salvador	100.0	100	–	–	–
Guatemala	76.9	100	–	–	–
Honduras	100.0	100	–	–	–
Nicaragua	81.0	79	100	–	–
Panama	78.6	79	–	–	–
Caribbean	**66.7**	**70**	**0**	**–**	**–**
Cuba	66.7	67	–	–	–
Dominican Republic	83.3	83	–	–	–
Haiti	50.0	60	0	–	–
Mexico	**33.3**	**52**	**18**	**10**	**–**
Central America, Caribbean, and Mexico	**53.2**	**74**	**22**	**10**	**–**
Andean Zone	**57.0**	**66**	**46**	**39**	**–**
Bolivia	72.9	77	62	50	–
Colombia	26.1	41	13	0	–
Ecuador	52.0	80	31	50	–
Peru	56.7	60	0	60	–
Venezuela	75.7	76	–	–	–
Southern Cone	**56.2**	**70**	**–**	**–**	**30**
Argentina	40.9	100	–	–	30
Brazil	67.3	67	–	–	–
Chile	–	–	–	–	–
Paraguay	62.5	63	–	–	–
Uruguay	–	–	–	–	–
South America	**56.7**	**68**	**46**	**39**	**30**
Latin America	**54.8**	**71**	**27**	**29**	**30**

Source: CIMMYT maize impacts survey.

Table 21. Approximate CIMMYT germplasm content of publicly developed maize cultivars, Latin America, 1966–97 (% of cultivars released)

	Proportion of source germplasm originating from CIMMYT:			
	0%	1-33%	34-66%	67-100%
Central America	**12.6**	**0.0**	**9.4**	**78.0**
Costa Rica	0.0	0.0	27.8	72.2
El Salvador	0.0	0.0	20.0	80.0
Guatemala	23.1	0.0	10.3	66.7
Honduras	0.0	0.0	0.0	100.0
Nicaragua	19.0	0.0	0.0	81.0
Panama	21.4	0.0	0.0	78.6
Caribbean	**33.3**	**0.0**	**0.0**	**66.7**
Cuba	33.3	0.0	0.0	66.7
Dominican Republic	16.7	0.0	0.0	83.3
Haiti	50.0	0.0	0.0	50.0
Mexico	**67.6**	**5.0**	**13.5**	**14.0**
Central America, Caribbean, and Mexico	**46.8**	**3.0**	**11.4**	**38.9**
Andean Zone	**43.4**	**6.6**	**11.2**	**38.8**
Bolivia	27.1	6.8	10.2	55.9
Colombia	73.9	0.0	6.5	19.6
Ecuador	48.0	20.0	16.0	16.0
Peru	45.5	9.1	18.2	27.3
Venezuela	24.2	3.0	9.1	63.6
Southern Cone	**53.2**	**15.6**	**27.0**	**4.3**
Argentina	71.2	16.4	11.0	1.4
Brazil	32.7	0.0	57.7	9.6
Chile	–	–	–	–
Paraguay	37.5	62.5	0.0	0.0
Uruguay	–	–	–	–
South America	**47.5**	**10.4**	**17.8**	**24.3**
Latin America	**47.1**	**6.5**	**14.4**	**32.0**

Source: CIMMYT maize impacts survey.

released in Central America between 1966 and 1997, and in Costa Rica, El Salvador, and Honduras 100% of the public-sector releases contained CIMMYT germplasm. CIMMYT materials were used less extensively in South America, although the level of use was still very high; in both the Andean Zone and the Southern Cone sub-regions, over 56% of all public varieties and hybrids released between 1966 and 1997 contained CIMMYT germplasm. Ironically, the Latin American country in which CIMMYT materials have been used least is Mexico, where only 33% of public-sector releases have contained CIMMYT germplasm. The relatively low level of use of CIMMYT germplasm within Mexico appears to be attributable to two factors. First, the Mexican national program has direct access to many of the same source materials from which CIMMYT's main lowland tropical populations were developed; Mexican breeders thus have had little cause to rely on CIMMYT's lowland tropical germplasm. Second, many of the varieties and hybrids released by the Mexican national program have been targeted at highland environments; because the importance of these environments is limited outside Mexico, they did not receive explicit attention from CIMMYT until 1985.

As expected, CIMMYT germplasm has been used most extensively to develop cultivars adapted to lowland tropical environments. During 1966-97, CIMMYT germplasm was present in over 70% of all public-sector releases showing adaptation to lowland tropical environments. CIMMYT germplasm was present much less frequently among public-sector releases showing adaptation to subtropical/mid-altitude environments (27%), highland environments (29%), and temperate environments (30%).[5]

The extensive use of CIMMYT's lowland tropical materials by national breeding programs can be attributed in large part to the popularity of several highly successful lowland tropical materials. Noteworthy among these is CIMMYT Population 21 (Tuxpeño), a short-statured, intermediate-maturing, white dent material developed from a Mexican landrace. Population 21 was present in at least 90 different varieties and hybrids released by national breeding programs throughout Latin America, a record that is surely unequaled in the developing world (Table 22). Other widely used lowland tropical materials that are direct or indirect products of CIMMYT's maize breeding program include CIMMYT Population 32 (ETO Blanco),

Table 22. Use of popular CIMMYT materials in cultivars developed by public maize breeding programs, Latin America, 1966-97

	Number of public MVs containing:			
	Population 21 (Tuxpeño)	Population 32 (ETO)	Population 43 (La Posta)	Suwan-1
Central America	**35**	**17**	**15**	**21**
Costa Rica	3	4	5	3
El Salvador	6	0	1	5
Guatemala	15	5	3	5
Honduras	8	3	5	4
Nicaragua	3	0	1	4
Panama	0	5	0	0
Caribbean	**0**	**7**	**0**	**0**
Cuba	0	2	0	0
Dominican Republic	0	4	0	0
Haiti	0	1	0	0
Mexico	**16**	**0**	**0**	**14**
Central America, Caribbean, and Mexico	**51**	**24**	**15**	**35**
Andean Zone	**26**	**12**	**12**	**4**
Bolivia	1	6	3	1
Colombia	5	0	0	0
Ecuador	4	3	1	0
Peru	0	3	0	0
Venezuela	16	0	8	3
Southern Cone	**13**	**0**	**0**	**0**
Argentina	0	0	0	0
Brazil	13	0	0	0
Chile	–	–	–	–
Paraguay	0	0	0	0
Uruguay	–	–	–	–
South America	**39**	**12**	**12**	**4**
Latin America	**90**	**36**	**27**	**39**

Source: CIMMYT maize impacts survey.

5 Since the CIMMYT Maize Program does not work with temperate materials, it came as a surprise to learn that CIMMYT germplasm has been present in 30% of all public varieties and hybrids showing adaptation to temperate environments.

CIMMYT Population 43 (La Posta), and the Thai variety Suwan-1, which was developed through a collaborative breeding effort involving scientists from the Rockefeller Foundation, the Department of Agriculture of Thailand, Kasetsart University, and CIMMYT .

National maize breeding programs have used CIMMYT germplasm in different ways (Table 23). A significant proportion of the public-sector releases in Central America and the Caribbean containing CIMMYT germplasm can be characterized as Class 4 cultivars, which are experimental varieties and hybrids distributed by CIMMYT that have simply been given a local name and released with little or no additional improvement at the hands of local breeders. At the other extreme, in the Southern Cone sub-region over 90% of the public-sector releases containing CIMMYT germplasm can be characterized as Class 2 cultivars, which are locally developed varieties and hybrids that contain a relatively small amount of CIMMYT germplasm in their parentage. This pattern provides further evidence that it is efficient for small countries with relatively modest national breeding programs to release CIMMYT varieties and hybrids with little or no additional improvement, whereas it is efficient for large countries with relatively strong national breeding programs to subject promising CIMMYT materials to several additional cycles of selection and/or crossing before releasing locally adapted cultivars.

Table 23. Manner of use of CIMMYT germplasm by public breeding programs, Latin America, 1966-97 (% of cultivars released)

	Cultivars containing CIMMYT germplasm:			
	Class 2	**Class 3**	**Class 4**	**Total**
Central America	**60.4**	**25.2**	**14.4**	**100.0**
Costa Rica	94.4	5.6	0.0	100.0
El Salvador	73.3	13.4	13.3	100.0
Guatemala	63.3	13.3	23.3	100.0
Honduras	35.0	30.0	35.0	100.0
Nicaragua	47.1	52.9	0.0	100.0
Panama	45.5	54.5	0.0	100.0
Caribbean	**42.9**	**14.3**	**42.9**	**100.0**
Cuba	33.3	33.3	33.3	100.0
Dominican Republic	80.0	0.0	20.0	100.0
Haiti	0.0	0.0	100.0	100.0
Mexico	**82.0**	**15.3**	**2.8**	**100.0**
Central America, Caribbean, and Mexico	**67.0**	**20.8**	**12.2**	**100.0**
Andean Zone	**67.6**	**26.1**	**6.3**	**100.0**
Bolivia	51.2	46.5	2.3	100.0
Colombia	58.3	41.7	0.0	100.0
Ecuador	76.9	7.7	15.4	100.0
Peru	61.1	16.7	22.2	100.0
Venezuela	100.0	0.0	0.0	100.0
Southern Cone	**92.4**	**4.5**	**3.0**	**100.0**
Argentina	100.0	0.0	0.0	100.0
Brazil	91.5	8.6	0.0	100.0
Chile	–	–	–	–
Paraguay	80.0	0.0	20.0	100.0
Uruguay	–	–	–	–
South America	**76.8**	**18.1**	**5.1**	**100.0**
Latin America	**71.6**	**19.5**	**8.8**	**100.0**

Source: CIMMYT maize impacts survey.

How has the use of CIMMYT germplasm by national breeding programs changed through time? Figure 4 shows trends in the percentage of public-sector releases containing CIMMYT germplasm, as well as changes in the proportion of these releases falling into each of the three classes (since CIMMYT does not work with temperate germplasm, Figure 4 refers to non-

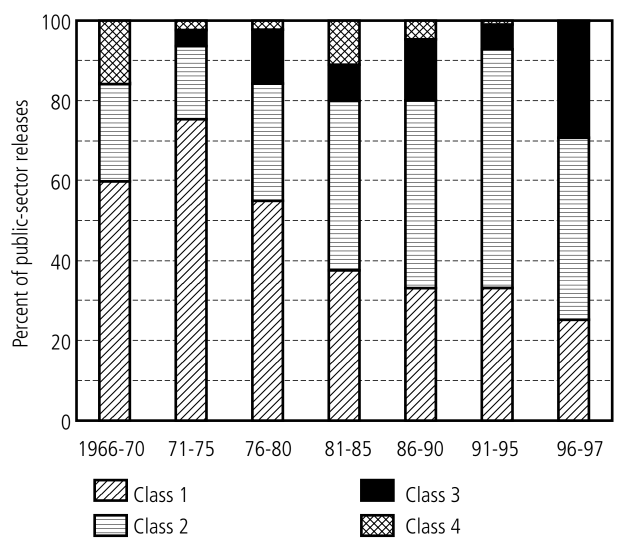


Figure 4. Use of CIMMYT germplasm as source materials by public maize breeding programs, Latin America, 1966-97.

temperate releases only). The use of CIMMYT germplasm by national breeding programs has increased through time, to the extent that today nearly three-quarters of all public varieties and hybrids released in Latin America contain CIMMYT germplasm. At the same time, there has been a marked decrease in the proportion of these releases characterized as Class 4 (direct selection of a CIMMYT experimental variety or hybrid). This indicates that national programs are now much less likely to make direct use of germplasm obtained from CIMMYT; rather, they tend to subjet it to additional cycles of selection before using it to form finished cultivars.

Private breeding programs

To what extent have private seed companies in Latin America made use of CIMMYT germplasm? Until quite recently, attempts to document the use of CIMMYT germplasm by private seed companies had met with little success. In 1992, for example, many private companies declined to participate in the CIMMYT survey. Among the few that agreed to participate, most refused to discuss their use of CIMMYT germplasm, arguing that even general information about the genetic background of specific commercial hybrids is too sensitive to be disclosed. Fortunately, this posture now seems to be changing. Two main factors seem to have contributed to the recent shift in attitude. First, many seed company representatives now understand that CIMMYT has made good on its promise to respect the confidentiality of pedigree information. Second, they have seen that the information about the genetic background of public- and private-sector cultivars is used in a way that is useful to all breeding programs and harmful to none. The change in attitude is very important, because for the first time it has been possible to shed light on an important area that in the past has remained in the dark.

Table 24 presents information on the use of CIMMYT germplasm by private seed companies in Latin America. As in the case of Tables 16-19, the data in Tables 24-27 refer to all proprietary cultivars available in the market in 1997. Because of the multiple-counting problem described earlier (arising because the same proprietary cultivars are often sold in several countries at the same time), sub-regional and regional totals are not included.

Table 24 and Figure 5 make clear that private seed companies in Latin America have made extensive use of CIMMYT germplasm. In every country except Argentina, where most maize is produced in temperate environments, more than 80% of all private-sector (proprietary) materials available in the market in 1997 contained CIMMYT germplasm in their parentage.[6] In many countries the percentage of private-sector cultivars

Table 24. Use of CIMMYT germplasm by private seed companies, Latin America, 1997 (% of proprietary cultivars available on the market)

	Number of cultivars available on the market	Without CIMMYT germplasm (%)	With CIMMYT germplasm: Definitely (%)	Probably (%)	Total CIMMYT (%)
Central America					
Costa Rica	13	0.0	30.8	69.2	100.0
El Salvador	7	14.3	85.7	0.0	85.7
Guatemala	11	9.1	90.9	0.0	90.9
Honduras	21	4.8	81.0	14.3	95.3
Nicaragua	5	0.0	100.0	0.0	100.0
Panama	4	0.0	0.0	100.0	100.0
Caribbean					
Cuba	0	na	na	na	na
Dominican Republic	0	na	na	na	na
Haiti	1	100.0	0.0	0.0	0.0
Mexico	155	18.7	43.2	38.1	81.3
Andean Zone					
Bolivia	15	0.0	40.0	60.0	100.0
Colombia	29	0.0	62.1	37.9	100.0
Ecuador	10	10.0	50.0	40.0	90.0
Peru	6	16.7	50.0	33.3	83.3
Venezuela	65	4.6	80.0	15.4	95.4
Southern Cone					
Argentina	133	71.4	2.3	26.3	28.6
Brazil	122	6.6	9.0	84.4	93.4
Chile	–	–	–	–	–
Paraguay	61	11.5	6.6	82.0	88.6
Uruguay	–	–	–	–	–

Source: CIMMYT maize impacts survey.

containing CIMMYT germplasm exceeded 90%, and in five countries, all proprietary cultivars available in the market in 1997 contained CIMMYT germplasm. These percentages are considerably higher than the figures reported in Table 20 for the public-sector releases, but it should be recalled that the figures referring to public-sector releases were calculated based on cultivars released since 1966. When the focus is restricted to more recent public-sector releases (e.g., cultivars released since 1990), the percentage containing CIMMYT germplasm is similar.

As expected, use of CIMMYT germplasm was concentrated among lowland tropical materials. CIMMYT germplasm was present in relatively few proprietary materials showing adaptation to subtropical/mid-altitude environments, highland environments, and temperate environments (Table 25).

Table 26 shows how CIMMYT germplasm has been used by private seed companies. (The results in Table 26 are based on cultivars definitively known to contain CIMMYT germplasm and specifically classified as belonging to Class 2, Class 3, or Class 4.) The table is dominated by Class 2

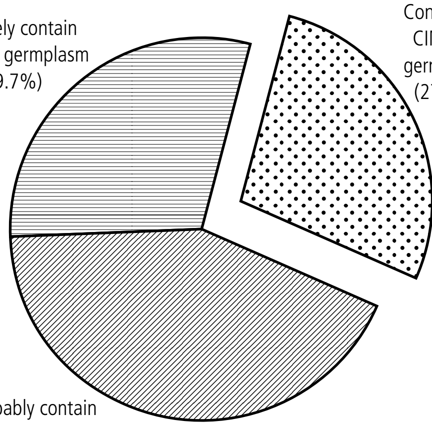


Figure 5. Use of CIMMYT germplasm by the private sector, Latin America (% of all proprietary materials available on the market in 1997).

materials, indicating that private companies rarely make direct use of CIMMYT varieties and hybrids; instead, they subject them to additional cycles of selection and improvement before releasing them as finished cultivars.

Not all private seed companies use CIMMYT materials in the same way. Figure 6 shows differences in the way CIMMYT germplasm is used by different types of seed companies. Domestic seed companies are more likely to sell cultivars that are more directly derived from CIMMYT source materials (Class 3), whereas multinationals virtually always make further improvements in CIMMYT source materials before incorporating them into commercial cultivars (Class 2).

The finding that private seed companies use CIMMYT germplasm extensively will come as no surprise to professional maize breeders, most of

Table 25. Ecological adaptation of proprietary cultivars containing CIMMYT germplasm, Latin America, 1997 (% of cultivars available on the market)

	Lowland tropical	Subtropical/ mid-altitude	Highland	Temperate
Central America				
Costa Rica	91.7	8.3	0.0	0.0
El Salvador	100.0	0.0	0.0	0.0
Guatemala	100.0	0.0	0.0	0.0
Honduras	94.7	0.0	5.3	0.0
Nicaragua	100.0	0.0	0.0	0.0
Panama	100.0	0.0	0.0	0.0
Caribbean				
Cuba	na	na	na	na
Dominican Republic	na	na	na	na
Haiti	na	na	na	na
Mexico	60.7	34.4	4.1	0.8
Andean Zone				
Bolivia	100.0	0.0	0.0	0.0
Colombia	100.0	0.0	0.0	0.0
Ecuador	100.0	0.0	0.0	0.0
Peru	100.0	0.0	0.0	0.0
Venezuela	100.0	0.0	0.0	0.0
Southern Cone				
Argentina	5.3	0.0	0.0	94.7
Brazil	96.5	0.0	0.0	3.5
Chile	–	–	–	–
Paraguay	98.1	0.0	0.0	1.9
Uruguay	–	–	–	–

Source: CIMMYT maize impacts survey.

6 The discussion of the use of CIMMYT germplasm by private seed companies omits any mention of the countries of the Caribbean region, since private companies have very little presence in these countries.

whom are well aware that there are considerable (though largely undocumented) flows of germplasm among and between public- and private-sector breeding programs. However, this is the first time that it has been possible to document the extent to which CIMMYT germplasm is present in proprietary cultivars. The fact that private seed companies are making considerable use of CIMMYT germplasm would appear to provide grounds for questioning recent calls to scale back public investment in international maize breeding research, ostensibly because private seed companies would readily assume the breeding functions performed by CIMMYT. The issue will be difficult to resolve, however, until additional information is available about the way in which CIMMYT materials are being used, and by whom. It is hoped that private seed companies will become increasingly cooperative in divulging detailed information about their breeding practices, so that five years from now when the CIMMYT impacts survey is next updated it will be possible to shed additional light on this important issue.

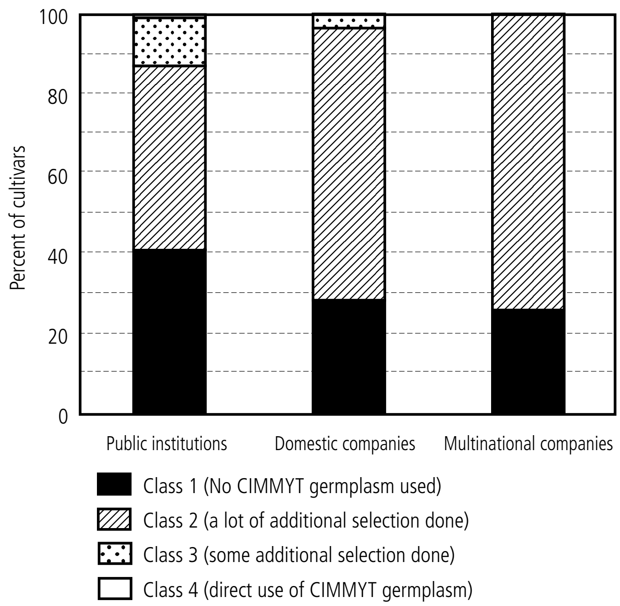


Figure 6. Manner of use of CIMMYT maize germplasm by different types of organizations, Latin America, 1990s.

Table 26. Manner of use of CIMMYT germplasm by private seed companies, Latin America (% of proprietary cultivars available on the market in 1997)

	Cultivars containing CIMMYT germplasm in which manner of use is known with certainty:			
	Class 2	Class 3	Class 4	Total
Central America				
Costa Rica	100.0	0.0	0.0	100.0
El Salvador	100.0	0.0	0.0	100.0
Guatemala	100.0	0.0	0.0	100.0
Honduras	100.0	0.0	0.0	100.0
Nicaragua	100.0	0.0	0.0	100.0
Panama	100.0	0.0	0.0	100.0
Caribbean				
Cuba	na	na	na	na
Dominican Republic	na	na	na	na
Haiti	na	na	na	na
Mexico	96.8	3.2	0.0	100.0
Andean Zone				
Bolivia	100.0	0.0	0.0	100.0
Colombia	100.0	0.0	0.0	100.0
Ecuador	100.0	0.0	0.0	100.0
Peru	100.0	0.0	0.0	100.0
Venezuela	79.0	21.0	0.0	100.0
Southern Cone				
Argentina	100.0	0.0	0.0	100.0
Brazil	100.0	0.0	0.0	100.0
Chile	–	–	–	–
Paraguay	100.0	0.0	0.0	100.0
Uruguay	–	–	–	–

Source: CIMMYT maize impacts survey.

Table 27. Approximate CIMMYT germplasm content of proprietary cultivars, Latin America (% of proprietary cultivars available on the market in 1997)

	Proportion of source germplasm originating from CIMMYT:			
	0%	1-33%	34-67%	68-100%
Central America				
Costa Rica	0.0	84.6	0.0	15.4
El Salvador	14.3	14.3	14.3	57.1
Guatemala	9.1	27.3	27.3	36.4
Honduras	4.8	23.8	52.4	19.0
Nicaragua	0.0	40.0	40.0	20.0
Panama	0.0	100.0	0.0	0.0
Caribbean				
Cuba	na	na	na	na
Dominican Republic	na	na	na	na
Haiti	100.0	0.0	0.0	0.0
Mexico	18.7	44.5	30.3	6.5
Andean Zone				
Bolivia	0.0	100.0	0.0	0.0
Colombia	0.0	62.1	6.9	31.0
Ecuador	10.0	70.0	20.0	0.0
Peru	16.7	50.0	16.7	16.7
Venezuela	4.6	35.4	21.5	38.5
Southern Cone				
Argentina	71.4	28.6	0.0	0.0
Brazil	6.6	86.1	7.4	0.0
Chile	–	–	–	–
Paraguay	11.9	88.1	0.0	0.0
Uruguay	–	–	–	–

Source: CIMMYT maize impacts survey.

Adoption of Maize MVs

Information presented in the preceding sections of this report describes how CIMMYT-related germplasm has found its way into maize varieties and hybrids developed by public breeding programs and private seed companies throughout Latin America, but it does not indicate the extent to which farmers use these varieties and hybrids. To assess the impacts of maize breeding research, it is important to determine the extent to which commercial materials have been taken up by farmers. This section of the report presents evidence on the adoption of improved varieties and hybrids in Latin America.

Before presenting evidence on adoption, a caveat is necessary. In Latin America as elsewhere, formulating precise estimates of the area planted to improved germplasm is complicated by at least four factors. First, the physical environments and cropping systems in which maize is grown are extremely diverse, so that the uptake of improved cultivars often varies widely even within individual countries; this greatly increases the difficulty of formulating accurate country-level adoption estimates. Second, a lot of maize in Latin America is grown by subsistence-oriented farmers who do not regularly purchase commercial seed; information on how these farmers manage their maize varieties tends to be limited. Third, much of the commercial maize seed sold in Latin America now moves through the private sector; since many private companies consider seed sales information to be confidential, it is generally difficult to get seed sales data for use in gauging adoption trends. Fourth, many farmers in Latin America save seed from their own harvest to plant in the following season (a practice known as "seed recycling"); this makes it difficult to identify improved germplasm in the field, especially since maize is a cross-pollinating crop and the genetic makeup of cultivars can quickly change in the presence of seed recycling (see Morris, Risopoulos, and Beck 1999).

Because of the difficulties inherent in estimating the adoption of improved germplasm, we have chosen to present two quite different types of data that relate to the uptake and use of improved maize varieties and hybrids. First, we present information about commercial maize seed sales collected from the public seed production agencies and private seed companies that participated in the CIMMYT survey. Although commercial seed sales data do not provide a direct measure of the total area under improved cultivars (since a considerable portion of the total area is planted using recycled seed), commercial seed sales data nevertheless provide important insights into the strength of demand for improved cultivars. After reviewing the evidence on commercial seed sales, we turn to direct estimates of the area planted to improved maize varieties and hybrids.

COMMERCIAL MAIZE SEED SALES

Production and distribution of maize seed is big business in Latin America. In 1996, public agencies and private companies produced nearly 300,000 t of commercial maize seed for distribution within the region (Table 28).[7] Commercial seed production was concentrated in the Southern Cone of South America, with two countries, Brazil and Argentina, accounting for slightly over 78% of all the commercial maize seed produced in Latin America. Commercial seed production was relatively modest in Mexico, Central America, and the Andean Zone of South America, suggesting that use of improved seed in these regions is still quite limited.

As in many other parts of the developing world, in Latin America the maize seed industry is dominated by private companies; public agencies and non-governmental organizations (NGOs) together accounted for less than 3% of the total volume of maize seed produced in 1996. Within the private sector, multinational seed companies have assumed a leading role; in 1996, multinationals accounted for nearly three-quarters of all private sector seed sales throughout the region (Table 28).

Table 28. Sales of commercial maize seed, Latin America, 1996 (t)

	Public seed agencies	Private companies (domestic)	Private companies (multinational)	NGOs[a]	Total
Central America	**56**	**3,329**	**1,328**	**704**	**5,397**
Costa Rica	3	110	0	0	113
El Salvador	17	1,718	0	321	2,055
Guatemala	36	201	1,306	0	1,543
Honduras	0	806	22	134	963
Nicaragua	0	223	0	249	452
Panama	0	271	0	0	271
Caribbean	**2,051**	**150**	**0**	**198**	**2,399**
Cuba	1,606	0	0	0	1,606
Dominican Republic	445	50	0	37	532
Haiti	0	100	0	161	261
Mexico	**4,042**	**5,599**	**22,785**	**218**	**32,645**
Central America, Caribbean, and Mexico	**6,149**	**9,078**	**24,113**	**1,120**	**40,441**
Andean Zone	**820**	**16,730**	**3,468**	**102**	**21,120**
Bolivia	21	2,363	121	102	2,607
Colombia	50	2,355	830	0	3,235
Ecuador	548	2,263	0	0	2,811
Peru	201	1,395	0	0	1,596
Venezuela	0	8,354	2,517	0	10,871
Southern Cone	**126**	**49,220**	**182,029**	**1,129**	**232,504**
Argentina	0	15,272	61,597	1,129	77,998
Brazil	0	31,709	120,052	0	151,761
Chile	–	–	–	–	–
Paraguay	126	2,239	380	0	2,745
Uruguay	–	–	–	–	–
South America	**946**	**65,950**	**185,497**	**1,231**	**253,624**
Latin America	**7,095**	**75,028**	**209,610**	**2,351**	**294,084**

Source: CIMMYT maize impacts survey.

a Some seed produced by non-governmental organizations (NGOs) was distributed free of charge.

Not surprisingly, multinationals have concentrated on major commercial markets. In the four largest seed markets in Latin America (Brazil, Argentina, Mexico, and Venezuela), the top three industry leaders are all multinationals (Table 29). Interestingly, the multinational seed companies have yet to penetrate some of the smaller regional markets. For example, in Central America most commercial maize seed is still produced by small domestic seed companies or medium-sized regional companies with a restricted geographical focus. In the Caribbean countries, the public sector remains an important player, in large part because of the Cuban maize seed industry, which remains firmly in the hands of the state.

Reflecting the prominent role played by the private sector, most of the commercial seed sold in Latin America is

7 The data on commercial maize seed sales discussed in this section were provided by the 36 public seed agencies and 172 private seed companies interviewed as part of the CIMMYT survey. In 1996 these organizations accounted for approximately 97% of all commercial maize seed sold in Latin America, so the data provide an accurate picture of the entire market.

hybrid seed (Table 30). Although public seed agencies continue to sell nearly as much varietal seed as hybrid seed (Figure 7), which is consistent with their commitment to serve small-scale producers who do not regularly purchase commercial seed, public agencies account for such a small share of the overall market that the total volume sold of varietal seed is negligible.

Table 29. Leading maize seed producers, Latin America, 1996

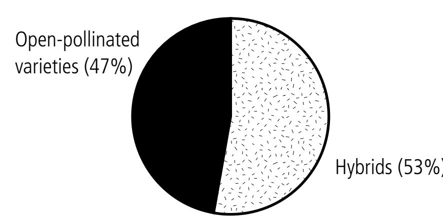
	#1 seed producer	#2 seed producer	#3 seed producer	Combined market share (%)
Central America				
Costa Rica	Piscis[b]	Desarrollos del Futuro Nima	Agrocosta[b]	90
El Salvador	Semillas	Prosela	Lombardia	85
Guatemala	Cristiani	Seminal	ICTA	78
Honduras	Cadelga	Hondugenet	Segovia	68
Nicaragua	SAGSA	Agrosemillas	Gurdian	70
Panama	Melo	Semillas Superiores	Margarita	95
Caribbean				
Cuba	Ministry of Agriculture[a]	–	–	100
Dominican Republic	Ministry of Agriculture[a]	Productores de Semillas Dominicana	National University[a]	97
Haiti	ORE	Agrotechnique	–	100
Mexico	Pioneer[b]	Asgrow[b]	Dekalb[b]	68
Andean Zone				
Bolivia	Agroceres[b]	Cargill[b]	Pioneer[b]	68
Colombia	Valle	Pioneer[b]	Cargill[b]	68
Ecuador	Agripac	Senaca	Emsemillas	84
Peru	Cargill[b]	Semillas Peruanas	La Molina Maize Program[a]	70
Venezuela	Seminaca	Sehiveca	Sefloarca	62
Southern Cone				
Argentina	Dekalb[b]	Cargill[b]	Pioneer[b]	62
Brazil	Agroceres[b]	Cargill[b]	Pioneer[b]	70
Chile	–	–	–	–
Paraguay	Cargill[b]	Agroceres[b]	Pioneer[b]	76
Uruguay	–	–	–	–

Source: CIMMYT maize impacts survey.
[a] Public organization.
[b] Multinational company.

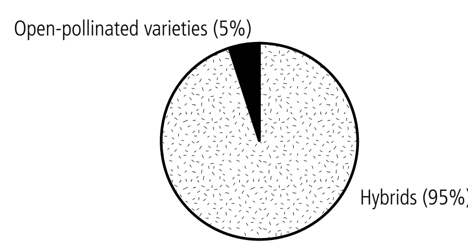
Table 30. Composition of maize seed sales, Latin America, 1996 (000 t)

	Public seed agencies			Private seed companies[a]		
	Varieties	Hybrids	Total	Varieties	Hybrids	Total
Central America	**33**	**23**	**56**	**962**	**4,382**	**5,344**
Costa Rica	3	0	3	0	110	110
El Salvador	15	2	17	10	2,010	2,020
Guatemala	15	21	36	145	1,363	1,508
Honduras	0	0	0	389	574	963
Nicaragua	0	0	0	377	95	472
Panama	0	0	0	41	230	271
Caribbean	**1,057**	**194**	**1,251**	**311**	**0**	**311**
Cuba	612	194	1,606	0	0	0
Dominican Republic	445	0	445	50	0	50
Haiti	0	0	0	261	0	261
Mexico	**1,728**	**2,314**	**4,042**	**427**	**28,125**	**28,552**
Central America, Caribbean, and Mexico	**2,818**	**2,531**	**5,349**	**1,700**	**32,507**	**34,207**
Andean Zone	**391**	**402**	**793**	**3,202**	**16,577**	**19,779**
Bolivia	21	0	21	1,081	1,088	2,169
Colombia	50	0	50	716	2,469	3,185
Ecuador	181	367	548	276	1,988	2,264
Peru	139	35	174	528	762	1,290
Venezuela	0	0	0	601	10,270	10,871
Southern Cone	**126**	**0**	**126**	**8,655**	**223,723**	**232,378**
Argentina	0	0	0	1,236	76,762	77,998
Brazil	0	0	0	7,391	144,370	151,761
Chile	–	–	–	–	–	–
Paraguay	126	0	126	28	2,591	2,619
Uruguay	–	–	–	–	–	–
South America	**517**	**402**	**919**	**11,857**	**240,300**	**252,157**
Latin America	**3,335**	**2,933**	**7,068**	**13,557**	**272,807**	**286,364**

Source: CIMMYT maize impacts survey.
[a] Including non-governmental organizations (NGOs).



(a) Composition of 1996 maize seed sales (public agencies)



(b) Composition of 1996 maize seed sales (private companies)

Figure 7. Composition of maize seed sales, Latin America, 1996.

Commercial maize seed sales in Latin America have increased rapidly. During 1990-97, sales reported by the public and private seed organizations that participated in the CIMMYT survey grew at an average annual rate of just under 9.0 % (Table 31). The pattern of growth has not been smooth, however, as sales within individual countries or regions have sometimes fluctuated considerably around the long-term trend in response to climatic variability and/or policy shocks that have temporarily affected the area planted to improved seed. For example, commercial maize seed sales in Mexico fell sharply in 1995 after the government introduced policy reforms that significantly reduced the profitability of maize production.

Since 1990, virtually all of the growth in commercial maize seed production has occurred in the private sector; seed production reported by public agencies has barely increased (Figure 8). Because most of the growth in seed production has been concentrated in the private sector, hybrids have assumed an increasingly important role in the overall seed market (Figure 9).

How competitive are Latin America's maize seed industries? By some measures, national maize seed industries in many countries are very concentrated. Based on data provided by the companies that participated in the CIMMYT survey, in 1996 the combined market share of the three leading seed companies varied from a low of around 62% in Argentina and Venezuela to a high of 95% or more in Panama, Haiti, and Cuba (Table 29). These levels of industrial concentration are high by global standards, exceeding even the level found in the United States, where the three largest maize seed

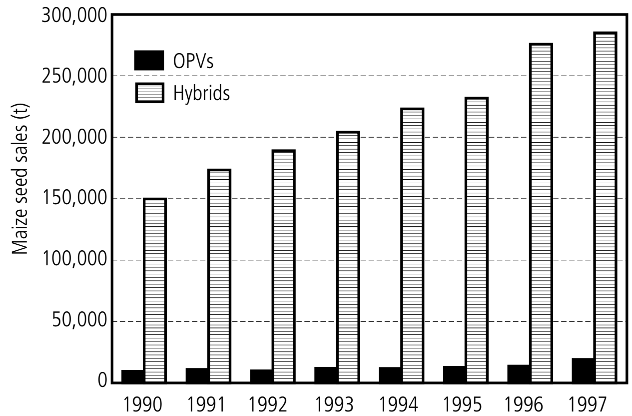


Figure 8. Evolution of commercial maize seed sales, OPVs versus hybrids, Latin America, 1990-97.
Source: CIMMYT maize impacts survey.

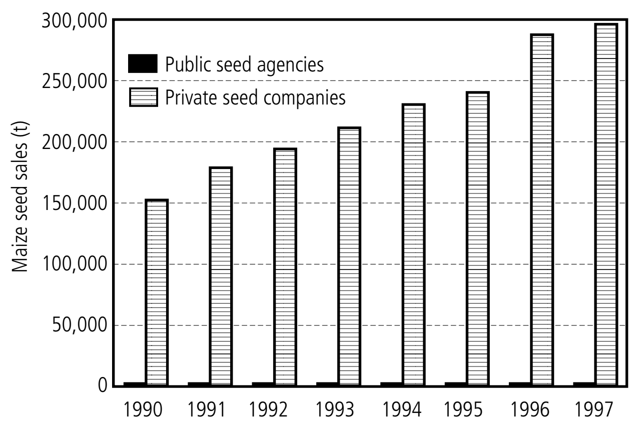


Figure 9. Evolution of commercial maize seed sales, by type of seed organization, Latin America, 1990-97.
Source: CIMMYT maize impacts survey.

Table 31. Evolution of commercial maize seed sales (t), Latin America, 1990-97

	1990	1991	1992	1993	1994	1995	1996	1997
Central America	3,085	3,001	3,019	3,661	3,744	4,222	5,365	5,822
Caribbean	40	40	40	316	368	292	261	305
Mexico	15,982	18,762	25,071	33,749	35,350	32,230	32,363	41,249
Central America, Caribbean, and Mexico	**19,107**	**21,803**	**28,130**	**37,726**	**39,462**	**36,744**	**37,989**	**47,376**
Andean Zone	16,389	18,741	21,838	22,693	16,189	16,274	20,814	26,828
Southern Cone	123,483	143,660	148,799	155,680	178,948	191,367	232,503	230,030
South America	**139,872**	**162,401**	**170,637**	**178,373**	**195,137**	**207,641**	**253,317**	**256,858**
Latin America	**158,980**	**184,204**	**198,767**	**216,099**	**234,599**	**244,385**	**291,305**	**304,225**

Source: CIMMYT maize impacts survey.

companies currently account for approximately 60% of the market (Duvick, personal communication).

High levels of industrial concentration provide grounds for concern only if they are associated with evidence of oligopolistic or monopolistic pricing practices. Despite the apparent high levels of concentration in many national maize seed industries, seed pricing practices appear to be competitive throughout Latin America. Seed prices for different types of materials reflect relative differences in production costs, suggesting that seed production costs are transmitted efficiently to the retail level (Figure 10, Table 32). In absolute terms, seed-to-grain price ratios in Mexico, Central America, and the Andean Zone are quite similar to those prevailing elsewhere in the developing world; in the Southern Cone region, they are somewhat higher, no doubt because the Southern Cone countries are net exporters of maize, so domestic maize grain prices tend to be unusually low.

Table 32. Seed-to-grain price ratios, by type of material, Latin America, 1997

	Open-pollinated varieties (OPVs)[a]	Double-cross hybrids[b]	Three-way-cross hybrids[b]	Single-cross hybrids[b]
Central America	**6.0**	**9.0**	**11.0**	**12.7**
Costa Rica	na	11.25	na	na
El Salvador	na	7.35	na	na
Guatemala	6.2	10.1	11.0	na
Honduras	6.6	9.8	10.7	na
Nicaragua	5.4	9.6	na	8.8
Panama	4.7	13.0	7.4	13.1
Caribbean	**2.3**	**na**	**na**	**na**
Cuba	na	na	na	na
Dominican Republic	na	na	na	na
Haiti	2.3	na	na	na
Mexico	**7.0**	**10.7**	**14.3**	**16.2**
Central America, Caribbean, and Mexico	**5.5**	**10.4**	**14.0**	**16.2**
Andean Zone	**5.8**	**9.0**	**13.6**	**9.3**
Bolivia	6.2	32.8	31.0	na
Colombia	4.8	8.8	9.7	9.3
Ecuador	7.2	10.0	16.34	na
Peru	7.0	21.9	18.9	na
Venezuela	4.6	7.4	9.2	na
Southern Cone	**6.6**	**18.7**	**26.5**	**35.9**
Argentina	4.8	19.1	21.3	30.8
Brazil	6.9	17.6	31.6	43.0
Chile	–	–	–	–
Paraguay	8.3	25.7	40.1	53.8
Uruguay	–	–	–	–
South America	**6.3**	**17.0**	**25.4**	**35.7**
Latin America	**6.3**	**15.7**	**23.9**	**33.0**

Source: CIMMYT maize impacts survey.
a Weighted by volume of 1997 OPV seed sales.
b Weighted by volume of 1997 hybrid seed sales.

Area planted to improved germplasm

How extensive is the area planted to improved maize varieties and hybrids in Latin America? No country in the region conducts surveys to determine varietal use patterns at the national level, so estimates of the area planted to improved varieties and hybrids must be pieced together based on indirect evidence. The adoption figures presented here (which relate to the 1996/97 cropping season) were compiled using two types of information. First, knowledgeable professionals (mainly national maize program scientists and seed company representatives) were asked to make direct estimates of the *area planted to improved germplasm*. Second, commercial maize seed sales data were used to calculate the *area potentially planted to improved germplasm*. The estimates derived using these two approaches turned out to be quite similar for all but one or two countries, leading us to conclude that the figures are reasonably accurate.

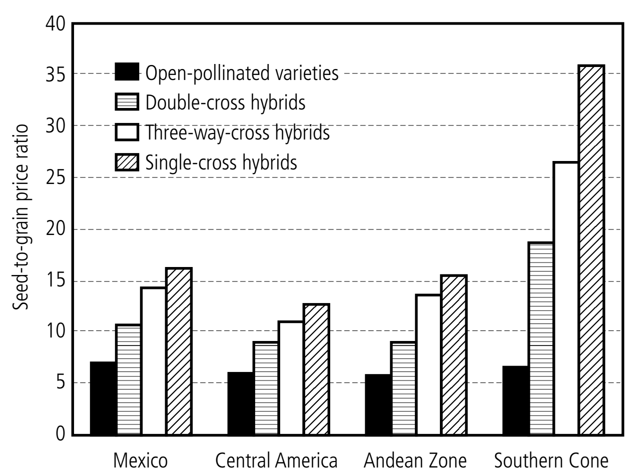


Figure 10. Seed-to-grain price ratios, Latin America, 1996.
Source: CIMMYT maize impacts survey.

Direct estimates. Respondents to the CIMMYT survey provided direct estimates of the area planted in 1996 to improved OPVs and hybrids. These estimates, which we will refer to as "national agricultural research system (NARS) expert opinion estimates," were based partly on survey data, partly on seed sales data, and partly on observations made in farmers' fields.

When the NARS expert opinion estimates of the total area planted to maize in 1996 in each country were compared to official FAO data, minor differences were noticed in some countries (Table 33). Because FAO data are widely used, and for consistency with earlier CIMMYT impacts studies, the NARS expert opinion estimates were therefore adjusted to make them consistent with official FAO data. This was done by multiplying the estimates provided by the survey respondents of the percentage area planted to each category of germplasm by the official FAO data on the total area planted to maize in each country (obtained from the FAO Agrostat database).

Table 34 presents the adjusted estimates of the area planted in 1996 to improved OPVs and hybrids. Table 35 presents the same data expressed in terms of the percentage area planted to each category of

Table 33. Maize area, Latin America, 1996 (comparison of NARS expert opinion estimates and FAO statistics)

	1996 maize area (NARS expert opinion) (000 ha)	1996 maize area (FAO statistics) (000 ha)	Ratio of NARS estimates to FAO statistics
Central America	**1,770.0**	**1,636.6**	**1.08**
Costa Rica	15.0	13.3	1.14
El Salvador	295.0	294.6	1.00
Guatemala	700.0	575.1	1.22
Honduras	400.0	399.6	1.00
Nicaragua	280.0	280.9	1.00
Panama	80.0	73.1	1.09
Caribbean	**388.0**	**373.6**	**1.04**
Cuba	85.0	74.0	1.15
Dominican Republic	28.0	42.6	0.66
Haiti	275.0	257.0	1.07
Mexico	**7,500.0**	**7,900.0**	**0.95**
Central America, Caribbean, and Mexico	**9,659.0**	**9,910.2**	**0.97**
Andean Zone	2,336.0	2,258.7	1.03
Bolivia	285.0	285.2	1.00
Colombia	650.0	652.6	1.00
Ecuador	545.0	570.0	0.96
Peru	370.0	320.9	1.15
Venezuela	486.0	430.0	1.13
Southern Cone	**17,844.0**	**16,957.4**	**1.05**
Argentina	3,960.0	2,610.0	1.52
Brazil	13,500.0	13,364.7	1.01
Chile	–	–	–
Paraguay	384.0	324.6	1.18
Uruguay	–	–	–
South America	**20,180.0**	**19,216.1**	**1.05**
Latin America	**29,837.9**	**29,126.3**	**1.02**

Source: CIMMYT maize impacts survey.

Table 34. Area planted to local varieties, improved OPVs, and hybrids (based on FAO area data), Latin America, 1996 (000 ha)

	Local varieties	Area planted to improved germplasm: OPVs	Hybrids	Total MVs	Total maize area (FAO adjusted)
Central America	**1,280.8**	**53.9**	**302.0**	**355.9**	**1,636.6**
Costa Rica	7.7	0.2	5.5	5.6	13.3
El Salvador	152.8	1.5	140.3	141.8	294.6
Guatemala	476.4	9.9	88.8	98.7	575.1
Honduras	336.8	28.6	34.3	62.8	399.6
Nicaragua	261.6	15.5	3.7	19.3	280.9
Panama	41.8	0.5	30.9	31.3	73.1
Caribbean	**256.6**	**69.1**	**47.9**	**117.0**	**373.6**
Cuba	4.1	26.6	43.3	69.9	74.0
Dominican Republic	10.2	32.4	0.0	32.4	42.6
Haiti	238.4	18.6	0.0	18.6	257.0
Mexico	**6,296.9**	**88.2**	**1,514.9**	**1,603.1**	**7,900.0**
Central America, Caribbean and Mexico	**7,829.0**	**219.4**	**1,861.9**	**2,081.2**	**9,910.2**
Andean Zone	**1,254.7**	**184.2**	**819.8**	**1,004.0**	**2,258.7**
Bolivia	136.5	77.3	71.5	148.7	285.2
Colombia	480.6	43.0	129.0	172.0	652.6
Ecuador	417.2	28.6	124.2	152.8	570.0
Peru	241.7	37.5	41.7	79.2	320.9
Venezuela	4.3	0.0	425.7	425.7	430.0
Southern Cone	**6,285.4**	**1,032.7**	**9,639.3**	**10,672.0**	**16,957.4**
Argentina	332.3	61.8	2,215.9	2,277.7	2,610.0
Brazil	5,803.4	976.6	6,584.6	7,561.3	13,364.7
Chile	–	–	–	–	–
Paraguay	209.3	5.4	109.9	115.3	324.6
Uruguay	–	–	–	–	–
South America	**7,533.8**	**1,216.2**	**10,466.1**	**11,682.3**	**19,216.1**
Latin America	**15,170.8**	**1,455.4**	**12,500.1**	**13,955.5**	**29,126.3**

Source: CIMMYT maize impacts survey.

a Figures may not sum to 100% due to rounding error.

germplasm. Of the 29.1 million ha planted to maize in 1996 in the countries covered by the CIMMYT survey, nearly 14 million ha (or 47.9%) were planted to improved OPVs and hybrids.[8]

These aggregate figures for all of Latin America mask considerable variation at the sub-regional level. Adoption of improved maize germplasm was highest in the Southern Cone, where 62.9% of the area planted to maize in 1996 was under improved cultivars. Adoption was next highest in the Andean Zone, where 44.5% of the area planted to maize in 1996 was under improved cultivars. Adoption of improved germplasm was lowest in the Caribbean (31.3%), in Central America (21.8%), and in Mexico (20.3%).

Table 35. Area planted to local varieties, improved OPVs, and hybrids (NARS expert opinion estimates), Latin America, 1996 (% of total maize area)

	Area planted to local varieties	Area planted to improved germplasm		
		Improved OPVs	Hybrids	Total MVs
Central America	**78.3**	**3.3**	**18.5**	**21.8**
Costa Rica	58.0	1.1	40.9	42.0
El Salvador	51.8	0.5	47.6	48.1
Guatemala	82.8	1.7	15.4	17.1
Honduras	84.3	7.2	8.6	15.8
Nicaragua	93.1	5.6	1.3	6.9
Panama	57.1	0.6	42.3	42.9
Caribbean	**68.7**	**18.5**	**12.8**	**31.3**
Cuba	5.5	36.0	58.5	94.5
Dominican Republic	24.0	76.0	0.0	76.0
Haiti	92.7	7.3	0.0	7.3
Mexico	**79.7**	**1.1**	**19.2**	**20.3**
Central America, Caribbean, and Mexico	**79.0**	**2.2**	**18.8**	**21.0**
Andean Zone	**55.6**	**8.2**	**36.3**	**44.5**
Bolivia	47.9	27.1	25.1	52.2
Colombia	73.7	6.6	19.8	26.4
Ecuador	73.2	5.0	21.8	26.8
Peru	75.3	11.7	13.0	24.7
Venezuela	1.0	0.0	99.0	99.0
Southern Cone	**37.1**	**6.1**	**56.8**	**62.9**
Argentina	12.7	2.4	84.9	87.3
Brazil	43.4	7.3	49.3	56.6
Chile	–	–	–	–
Paraguay	64.5	1.7	33.9	35.6
Uruguay	–	–	–	–
South America	**39.2**	**6.3**	**54.5**	**60.8**
Latin America	**52.1**	**5.0**	**42.9**	**47.9**

Source: CIMMYT maize impacts survey.

a Figures may not sum to 100% due to rounding error.

Within sub-regions, adoption rates varied considerably between individual countries. For example in Central America, the percentage area under improved germplasm ranged from a low of 6.9% in Nicaragua to a high of 48.1% in El Salvador. The difference was even more extreme in the Caribbean, with the percentage area under improved germplasm ranging from a low of 7.3% in Haiti to a high of 94.5% in Cuba. Adoption rates were generally somewhat higher in the Andean Zone, although Venezuela stands out as a country in which virtually the entire national maize area was planted to improved cultivars. Adoption of improved germplasm was also found to be extensive in the Southern Cone, especially in Argentina, where 87.3% of the area planted to maize in 1996 was under improved cultivars.

One noteworthy feature of the adoption data presented in Tables 34 and 35 is the clear dominance of hybrids as compared to improved OPVs. Across all of Latin America, the area planted to hybrids in 1996 was nearly nine times larger than the area planted to improved OPVs, a finding that is consistent with commercial seed sales data. This serves to confirm that private seed companies are continuing to displace the public seed agencies and parastatal organizations that formerly produced most of the region's maize seed. The only sub-region in which improved OPVs have retained their popularity is the Caribbean, an area in which private companies have been reluctant to establish a presence because of the weak demand for commercial hybrids and the difficulty of doing business.

8 This area is considerably larger than the area reportedly planted to improved germplasm in Latin America in 1990, the year covered by the previous CIMMYT impacts study. However, the increase is partly attributable to the expanded geographical coverage of the 1996 survey. Argentina, Cuba, Dominican Republic, Haiti, and Panama were not included in the previous CIMMYT impacts study. Taking into account only those countries covered in the earlier study, the 1996 adoption figures come to 11.5 million ha, equivalent to 44% of the total maize area in those countries.

Seed-based estimates. To provide a check on the plausibility of NARS expert opinion, the area potentially planted to improved OPVs and hybrids in 1996 was estimated based on commercial maize seed sales data. This was done by dividing the quantities of commercial maize seed sold in 1996 by the average seeding rate, conservatively assumed to be 20 kg/ha.[9] This procedure generated country-by-country estimates of the area potentially planted in 1996 to newly purchased commercial seed (Table 36).

Since many Latin American maize farmers save seed from their harvest to replant in the following season, the numbers in Table 36 certainly underestimate the total area planted to improved OPVs and hybrids. To generate a more realistic set of estimates of the area planted to improved cultivars, the numbers in Table 36 were multiplied by a seed recycling factor to take into account farmers' seed management practices. Based on a recent review of the empirical evidence on farm-level seed recycling (Morris, Risopoulos and Beck 1999), the seed recycling factors were set conservatively at 3 for improved OPV seed and 1.1 for hybrid seed. The revised estimates of the area potentially planted in 1996 to improved OPVs and hybrids (adjusted to take into account farm-level seed recycling practices) appear in Table 37.

Table 36. Area potentially planted to maize MVs (calculated based on commercial seed sales), without seed recycling, Latin America, 1996

	Total 1996 maize area (000 ha)	Area potentially under OPVs (000 ha)	Area potentially under hybrids (000 ha)	Area potentially under MVs (%)
Central America	**1,636.6**	**49.8**	**220.3**	**16.5**
Costa Rica	13.3	0.2	5.5	42.5
El Salvador	294.6	1.3	100.6	34.6
Guatemala	575.1	8.0	69.2	13.4
Honduras	399.6	19.5	28.7	12.0
Nicaragua	280.9	18.9	4.8	8.4
Panama	73.1	2.1	11.5	18.5
Caribbean	**373.6**	**68.4**	**9.7**	**20.9**
Cuba	74.0	30.6	9.7	54.5
Dominican Republic	42.6	24.8	0.0	58.1
Haiti	257.0	13.1	0.0	5.1
Mexico	**7,900.0**	**107.8**	**1,522.0**	**20.6**
Central America, Caribbean, and Mexico	**9,910.2**	**225.9**	**1,751.9**	**20.0**
Andean Zone	**2,258.7**	**179.7**	**849.0**	**45.5**
Bolivia	285.2	55.1	54.4	38.4
Colombia	652.6	38.3	123.5	24.8
Ecuador	570.0	22.9	117.8	24.7
Peru	320.9	33.4	39.9	22.8
Venezuela	430.0	30.1	513.5	100.0[a]
Southern Cone	**16,452.6**	**439.1**	**11,186.2**	**68.6**
Argentina	2,610.0	61.8	3,838.1	100.0[a]
Brazil	13,364.7	369.6	7,218.5	56.8
Chile	98.6	–	–	–
Paraguay	324.6	7.7	129.6	42.3
Uruguay	54.7	–	–	–
South America	**18,711.3**	**618.7**	**12,035.1**	**65.8**
Latin America	**28,621.5**	**844.6**	**13,787.0**	**50.2**

Source: CIMMYT maize impacts survey.
a Maximum value = 100%.

Table 37. Area potentially planted to maize MVs (calculated based on commercial seed sales), with seed recycling, Latin America, 1996

	Total 1996 maize area (000 ha)	Area potentially under OPVs (000 ha)	Area potentially under hybrids (000 ha)	Area potentially under MVs (%)
Central America	**1,636.6**	**149.3**	**242.3**	**23.9**
Costa Rica	13.3	0.5	6.1	48.9
El Salvador	294.6	3.8	110.7	38.8
Guatemala	575.1	24.0	76.1	17.4
Honduras	399.6	58.4	31.6	22.5
Nicaragua	280.9	56.6	5.2	22.0
Panama	73.1	6.2	12.7	25.7
Caribbean	**373.6**	**205.2**	**10.7**	**57.8**
Cuba	74.0	91.8	10.7	100.0[a]
Dominican Republic	42.6	74.3	0.0	100.0[a]
Haiti	257.0	39.2	0.0	15.2
Mexico	**7,900.0**	**323.3**	**1,674.1**	**25.3**
Central America, Caribbean, and Mexico	**9,910.2**	**677.7**	**1,927.1**	**26.3**
Andean Zone	**2,258.7**	**539.0**	**933.8**	**65.2**
Bolivia	285.2	165.3	59.8	78.9
Colombia	652.6	114.9	135.8	38.4
Ecuador	570.0	68.6	129.5	34.8
Peru	320.9	100.1	43.8	44.8
Venezuela	430.0	90.2	564.9	100.0[a]
Southern Cone	**16,452.6**	**1,317.2**	**12,304.8**	**80.3**
Argentina	2,610.0	185.4	4,221.9	100.0[a]
Brazil	13,364.7	1,108.7	7,940.4	67.7
Chile	98.6	–	–	–
Paraguay	324.6	23.1	142.5	51.0
Uruguay	54.7	–	–	–
South America	**18,711.3**	**1,856.1**	**13,238.6**	**78.6**
Latin America	**28,621.5**	**2,533.8**	**15,165.7**	**60.8**

Source: CIMMYT maize impacts survey.
a Maximum value = 100 %.

9 Estimates of average seeding rates provided by survey respondents ranged from 16 kg/ha to 24 kg/ha, reflecting differences in seed size and variability in local planting practices.

These estimates of the area potentially planted in 1996 to improved germplasm should be interpreted with caution. Just because a certain quantity of commercial seed is sold does not necessarily mean that an equivalent area of maize is cultivated; a portion of the commercial seed that is sold each year is never planted, and some of the area planted to commercial seed is never harvested (for example, when farmers abandon fields part-way through the cropping season because of severe drought, disease infestation, or insect attack). Thus, these estimates of the area that was *potentially* planted to improved germplasm in effect provide an upper bound for the area that was *actually* planted. For this reason, they are best used as a check to verify the plausibility of the direct area estimates provided by knowledgeable professionals.

Table 38 presents a comparison of the direct estimates of the area planted to improved germplasm in 1996 (both the original NARS expert opinion estimates and the estimates adjusted to take into account official FAO maize area statistics) with the estimates based on 1996 seed sales data of the area potentially planted with improved germplasm. In the vast majority of countries, the area that theoretically could have been planted using the seed that was sold in 1996 (factoring in average levels of seed recycling) slightly exceeds the estimated area that was actually planted to MVs, suggesting that the direct area estimates are highly plausible. Only in two countries (El Salvador and Panama) do the direct estimates of the area planted to improved germplasm in 1996 exceed the area that theoretically could have been planted using the commercial seed that was actually sold in 1996. This discrepancy could have been caused by a number of things; for example, farmers in those two countries might have planted unusually large quantities of recycled seed; they might have planted unusually large quantities of seed purchased the previous year; and/or they might have imported unusually large quantities of seed from neighboring countries. Both El Salvador and Panama experienced seed shortages in 1996, which suggests that all three of these factors may have played a role.

Table 38. Area planted to improved germplasm: Comparison of direct area estimates made by NARS experts vs. indirect estimates based on commercial seed sales (000 ha)

	Area planted to improved germplasm (NARS expert opinion)	Area planted to improved germplasm (FAO adjusted)	Area potentially planted to improved germplasm (based on seed sales)[a]
Central America	**384.9**	**355.9**	**391.6**
Costa Rica	6.4	5.6	6.6
El Salvador	142.0	141.8	114.5[b]
Guatemala	120.1	98.7	100.1
Honduras	62.9	62.8	90.0
Nicaragua	19.2	19.3	61.8
Panama	34.3	31.3	18.9[b]
Caribbean	**121.5**	**117.0**	**215.9**
Cuba	80.3	69.9	102.5
Dominican Republic	21.3	32.4	74.3
Haiti	19.9	18.6	39.2
Mexico	**1,521.9**	**1,603.1**	**1,997.4**
Central America, Caribbean, and Mexico	**2,028.3**	**2,081.2**	**2,604.8**
Andean Zone	**1,038.4**	**1,004.0**	**1,472.8**
Bolivia	148.6	148.7	225.1
Colombia	171.3	172.0	250.7
Ecuador	146.1	152.8	198.1
Peru	91.3	79.2	143.9
Venezuela	481.1	425.7	655.1
Southern Cone	**11,229.8**	**10,672.0**	**13,622.0**
Argentina	3,455.8	2,277.7	4,407.3
Brazil	7,637.6	7,561.3	9,049.1
Chile	–	–	–
Paraguay	136.4	115.3	165.6
Uruguay	–	–	–
South America	**12,268.2**	**11,682.3**	**15,094.7**
Latin America	**14,296.5**	**13,955.5**	**17,699.5**

Source: CIMMYT maize impacts survey.
a With seed recycling.
b Reported seed sales theoretically inadequate to plant estimated area under MVs.

AREA PLANTED TO CIMMYT-DERIVED GERMPLASM

What has been the impact in Latin America of CIMMYT-derived maize germplasm? The area planted to improved OPVs and hybrids containing CIMMYT-derived germplasm could not be estimated directly, because cultivar-specific adoption data were not available. Therefore the area under CIMMYT-derived OPVs and hybrids was estimated indirectly, based on the parentage of the commercial seed sold in 1996.

Table 39 shows the proportion of the commercial maize seed sold Latin America in 1996 that consisted of improved OPVs or hybrids containing CIMMYT germplasm in their parentage. Approximately three-quarters of all the seed sold in that year contained CIMMYT-derived germplasm. The proportion varied considerably by sub-region and by country. In Central America, cultivars based on CIMMYT-derived germplasm accounted for 100% of the OPV seed and 96.4% of the hybrid seed sold; the figures were nearly as high in the Andean Zone.

Table 39. Proportion of commercial maize seed sold in 1996 that contained CIMMYT germplasm, Latin America (%)

	Proportion of OPV seed sold in 1996 that contained CIMMYT germplasm	Proportion of hybrid seed sold in 1996 that contained CIMMYT germplasm
Central America	**100.0**	**96.4**
Costa Rica	100.0	100.0
El Salvador	100.0	93.3
Guatemala	100.0	98.3
Honduras	100.0	99.8
Nicaragua	100.0	100.0
Panama	100.0	100.0
Caribbean	**31.8**	**44.5**
Cuba	59.0	44.5
Dominican Republic	7.9	N/A
Haiti	16.9	N/A
Mexico	**73.0**	**90.0**
Central America, Caribbean, and Mexico	**66.2**	**89.5**
Andean Zone	**94.3**	**98.3**
Bolivia	94.0	100.0
Colombia	100.0	100.0
Ecuador	99.3	99.4
Peru	79.5	95.8
Venezuela	100.0	97.5
Southern Cone	**68.8**	**72.3**
Argentina	100.0	27.9
Brazil	63.0	95.5
Chile	–	–
Paraguay	92.9	95.0
Uruguay	–	–
South America	**76.3**	**74.1**
Latin America	**73.6**	**76.1**

Source: CIMMYT maize impacts survey.

Use of CIMMYT-derived cultivars was also extensive in Mexico (where 73% of the OPV seed and 90% of the hybrid seed contained CIMMT germplasm), as well as in the Southern Cone (where 76.3% of the OPV seed and 74.1% of the hybrid seed contained CIMMT germplasm). CIMMYT-derived cultivars had a more modest impact in the Caribbean region, where only 31.8% of the OPV seed and only 44.5% of the hybrid seed contained CIMMT germplasm.

One country that stands out in Table 39 is Argentina, where CIMMYT germplasm was present in 100% of the OPV seed but in only 27.9% of the hybrid seed. This unusual pattern can be attributed to the fact that OPVs in Argentina are grown mainly by small-scale semi-subsistence farmers in the warm (tropical and subtropical) northern part of the country, whereas hybrids are grown mainly by large-scale commercial producers in the cool (temperate) southern part of the country. In keeping with its mandate to serve all producers, Argentina's national maize program has released a number of improved OPVs adapted to the warmer conditions found in the north of the country; many of these improved OPVs contain CIMMYT germplasm. In contrast, private seed companies have concentrated on developing commercial hybrids adapted to the cooler environments found in the south of the country; most of these hybrids were developed using temperate germplasm introduced from North America. Since CIMMYT does not work with temperate germplasm, these hybrids contain relatively little CIMMYT germplasm.

The commercial seed sales data in Table 39 were used to estimate the area planted to CIMMYT-derived cultivars. The area planted to improved OPVs and hybrids containing CIMMYT germplasm was estimated by assuming that the proportion of the area planted to CIMMYT-derived cultivars was similar to the proportion of commercial seed that consisted of CIMMYT-derived cultivars.

Table 40 shows the extent of adoption of CIMMYT germplasm in Latin America. Throughout the region, of the nearly 14 million ha planted to maize MVs in 1996, 10.6 million ha (or 75.8%) were under improved OPVs and hybrids that contained CIMMYT germplasm in their parentage. Reflecting the overall trend within the seed industry, hybrids are now the predominant delivery mechanism for CIMMYT germplasm; more than 9.5 million ha were planted to CIMMYT-derived hybrids in 1996, as compared to only 1.1 million ha planted to CIMMYT-derived OPVs.

Table 40. Area planted to improved OPVs and hybrids that contained CIMMYT germplasm, Latin America, 1996

	Area under CIMMYT-derived materials:			Expressed as a proportion of	
	OPVs (000 ha)	Hybrids (000 ha)	Total (000 ha)	Total national maize area (%)	Improved maize area (%)
Central America	**53.9**	**291.1**	**345.0**	**21.1**	**96.9**
Costa Rica	0.2	5.5	5.6	42.4	100.0
El Salvador	1.5	130.9	132.4	44.9	93.4
Guatemala	9.9	87.3	97.2	16.9	98.5
Honduras	28.6	34.2	62.8	15.7	99.9
Nicaragua	15.5	3.7	19.3	6.9	100.0
Panama	0.5	30.9	31.3	42.9	100.0
Caribbean	**22.0**	**21.3**	**43.3**	**11.6**	**37.0**
Cuba	15.7	19.3	35.0	47.3	50.0
Dominican Republic	2.6	0.0	2.6	6.0	7.9
Haiti	3.1	0.0	3.1	1.2	16.9
Mexico	**64.4**	**1,363.4**	**1,427.8**	**18.1**	**89.1**
Central America, Caribbean, and Mexico	**145.2**	**1,666.4**	**1,811.6**	**18.3**	**87.0**
Andean Zone	**173.7**	**805.9**	**979.6**	**43.4**	**97.6**
Bolivia	72.6	71.5	144.1	50.5	96.9
Colombia	43.0	129.0	172.0	26.3	100.0
Ecuador	28.4	123.5	151.9	26.6	99.4
Peru	29.8	40.0	69.8	21.7	88.1
Venezuela	0.0	415.0	415.0	96.5	97.5
Southern Cone	**710.5**	**6,969.2**	**7,679.7**	**45.3**	**72.0**
Argentina	61.8	618.2	680.0	26.1	29.9
Brazil	615.3	6,288.3	6,903.6	51.7	91.3
Chile	–	–	–	–	–
Paraguay	5.0	104.4	109.4	33.7	94.9
Uruguay	–	–	–	–	–
South America	**928.0**	**7,755.4**	**8,683.4**	**45.2**	**74.3**
Latin America	**1,071.6**	**9,512.6**	**10,583.8**	**36.3**	**75.8**

Source: CIMMYT maize impacts survey.

As the commercial seed sales data would suggest, adoption of CIMMYT-derived cultivars was highly correlated with the adoption of MVs in general. Approximately three-quarters of all commercial maize seed sold in Latin America in 1996 contained CIMMYT germplasm, so where the overall rate of MV adoption was high (e.g., Andean Zone, Southern Cone), use of CIMMT germplasm was also relatively high. In contrast, where the overall rate of MV adoption was more modest (e.g., Central America, the Caribbean, Mexico), the use of CIMMYT germplasm was also relatively modest.

Factors affecting the adoption of improved germplasm

Why does the use of improved germplasm differ between countries? What explains the fact that MV adoption rates are high in some countries and low in others? Can the factors associated with differences in MV adoption rates be identified?

Determinants of MV adoption: Some hypotheses. Morris, Smale, and Rusike (1998) present an evolutionary interpretation of the growth of national maize seed industries that can be used to develop testable hypotheses about factors that may be associated with adoption of MVs. These authors begin with the empirical observation that in country after country, maize seed industry development often seems to follow the same general path. As national maize seed industries develop, typically they pass through a "life cycle" characterized by successive stages of growth. Four stages of growth can be distinguished, although in reality these stages represent arbitrarily selected points along a continuum: Pre-industrial (Stage 1), Emergence (Stage 2), Growth (Stage 3), and Maturity (Stage 4). Each of these stages of development is normally associated with a particular combination of technical, economic, and institutional characteristics (Table 41).

The life cycle theory of seed industry development suggests that in any given country, the MV adoption rate at a particular point in time is likely to be influenced by a combination of technical, economic, institutional, and political factors that jointly determine the effective demand for MVs and the available supply. These factors are discussed in detail by Heisey et al. (1998). Effective demand for MVs depends mainly on the profits that farmers expect to earn by adopting MVs; these expected profits are determined by the yield gain associated with adopting MVs, the prices farmers receive for their maize, and the cost of the technology (especially the price of improved seed). The available supply of MVs is determined by expected industry-level profitability of producing and selling improved seed, which depends on research costs, market structural factors that determine the strength of effective demand, the presence or absence of intellectual property rights, and the price of improved seed.

How well do these technical, economic, institutional, and political factors explain observed levels of MV adoption? Data collected via the CIMMYT survey were used to test some simple hypotheses about how farm-level profitability, market structural conditions, the cost of research innovation, and the political importance of maize affected the adoption of maize MVs in Latin America (for details, see Kosarek 1999). Despite a number of conceptual and practical problems, the exercise provided an opportunity to determine whether an empirical relationship exists between use of MVs (expressed as the percentage of each country's national maize area planted to hybrids in 1996) and factors that influence supply and demand of MV technology.[10]

Table 41. Characteristics associated with the stages of maize seed industry development

	Stage 1: Pre-industrial	Stage 2: Emergence	Stage 3: Expansion	Stage 4: Maturity
Orientation of agriculture	Subsistence	Semi-subsistence	Mostly commercial	Completely commercial
Predominant seed technology	OPVs	OPVs, some hybrids	Some OPVs, hybrids	Hybrids
Seed procurement practices	On-farm production, farmer-to-farmer exchange	On-farm production, farmer-to-farmer exchange, some purchasing	Frequent purchasing	Annual purchasing
Seed production	On-farm	On-farm, public organizations	On farm, public organizations, private companies (national)	Private companies (global)
Seed market coverage	Local	Local, regional	Local, regional, national	Local, regional, national, global
Sources of seed information	Direct experience, other farmers	Public agencies	Private seed companies	Private seed companies
Locus of seed research and development	On farm	Public organizations	Public and private organizations	Public and private organizations (specialized)
Supporting legal systems	Customary law	Civil	Commercial (domestic)	Commercial (global)
Intellectual property rights	None	None	Trade secrets	Plant varietal protection, patents

Source: Morris, Smale, and Rusike (1998).

10 One obvious problem was that observations were available for only a single year, 1996, which did not allow estimation of complete technology diffusion paths. This made it more difficult to discern relationships between the explanatory factors and the level of adoption, because in most countries the level of adoption observed in 1996 represented a point along a dynamic adjustment path, rather than something close to a static ceiling adoption level.

MV adoption model. The following model was estimated using 1996 data for the 18 Latin American countries covered by the CIMMYT survey:

HYAREA = *f* (RATIO, RATIO2, MARK, NPC, PVP, CIMMYT, PRIVATE)

where:

HYAREA = proportion of non-temperate maize area planted to hybrids;
RATIO = maize seed-to-grain price ratio;
RATIO2 = maize seed-to-grain price ratio squared;
MARK = proportion of national maize crop that is marketed;
NPC = nominal protection coefficient for maize;
PVP = dummy variable showing presence or absence of plant varietal protection (PVP) laws;
CIMMYT = proportion of commercial maize seed that contained CIMMYT germplasm; and
PRIVATE = share of national seed market controlled by private companies.

Variables and measures. The variables used to estimate the model are briefly described below, as are the expected relationships between the dependent variable and the explanatory variables.

Dependent variable:
The dependent variable in the equation is the proportion of non-temperate maize area within each country planted to hybrids (HYAREA). The area planted to hybrids is a more reliable measure of MV use than the area planted to all improved materials (hybrids plus improved OPVs), because the area planted to improved OPVs is difficult to estimate precisely given the high incidence of OPV seed recycling. Temperate production zones were excluded from the analysis, because these zones are not targeted by CIMMYT (only Argentina was affected by this restriction).

Explanatory variables:
Use of MVs is expected to be negatively associated with the price of improved seed, since high seed prices reduce the profitability of MVs and discourage adoption. In order to avoid exchange-rate problems and to facilitate comparisons between countries, seed prices were expressed as the ratio of the price of the most common type of hybrid seed to the farm-gate price of maize grain (RATIO).

The relationship between use of MVs and seed prices is not clear-cut, however, because the life cycle theory of seed industry development suggests that seed prices will tend to rise over time as the seed industry matures and farmers come to appreciate the value of MVs. A quadratic term (RATIO2) was therefore included to reflect the fact that the inverse relationship between seed prices and MV use is likely to weaken at high levels of MV adoption and eventually reverse.

Use of MVs is expected to be greater in commercially oriented production systems, since the technology choices of commercial farmers are driven by profitability considerations. The commercial orientation of the maize sector within a given country is reflected in the proportion of national maize crop that is marketed (MARK).

Use of MVs is expected to be positively related to the expected profitability of maize production, which depends in part on the prices received by farmers for their maize. The nominal protection coefficient (NPC) provides a direct measure of the degree to which producer prices are influenced by government policies. Higher NPCs indicate greater protection for the maize sector and hence greater profitability, which would be expected to encourage increased adoption of MVs.

Use of MVs is expected to be positively associated with the supply of MVs, which depends at least in part on the cost of research innovation. For private seed companies, the cost of research innovation is reduced when freely available public germplasm can be used to develop commercial cultivars. The proportion of seed sold that contains CIMMYT germplasm (CIMMYT) serves as a measure of the extent to which seed companies have been able to lower their research costs by capturing spillover benefits from publicly funded breeding efforts.

According to the life cycle theory of seed industry development, as national seed industries grow and mature, public research organizations and seed production agencies will gradually be displaced by private seed companies. Thus, MV use is expected to be positively associated with a more active participation by the private sector. The level of participation of the private sector is indicated by the share of national seed market controlled by private companies (PRIVATE).

Estimation results. Since the proportion of maize area planted to hybrids cannot fall below 0% or rise above 100%, the model was estimated using a two-limit tobit procedure. Results of the regression are shown in Table 42. All of the estimated coefficients show the expected signs, and all are statistically significant (one-tailed tests). Comparing across the 18 countries for which data were available, greater use of maize hybrids is associated with more commercially oriented maize sectors (MARK), higher levels of protection for the maize sector (NPC), stronger protection of intellectual property (PVP), lower research costs (CIMMYT), and a stronger presence on the part of the private seed industry (PRIVATE). Reduced use of hybrids is associated with higher seed prices (RATIO), although as expected this relationship weakens at high levels of hybrid use and eventually reverses (RATIO2).

Generally speaking, these regression results support the life cycle theory of seed industry development by confirming that use of improved germplasm tends to be greater in countries in which prevailing economic conditions, institutional structures, and government policies make it profitable for farmers to adopt MVs and for seed companies to produce and sell MVs. While this finding may seem self-evident, it is nonetheless noteworthy because it serves as a reminder that the adoption of improved germplasm ultimately depends on many factors over which researchers themselves have little direct control. The larger point should not be lost on policy makers: to promote widespread adoption of improved germplasm, it is necessary to have strong breeding programs that are capable of producing a steady supply of improved varieties and hybrids, but the existence of strong breeding programs in and of itself will not ensure adoption.

Table 42. Factors associated with adoption of hybrid maize, Latin America

Variable	Estimated coefficient	Standard error	b/s.e.	P [Z<z] or P [Z>z]
Constant	-3.400	0.450	-7.563	0.0000
RATIO	-0.075	0.013	-5.992	0.0000
RATIO2	0.002	0.000	5.710	0.0000
MARK	2.293	0.279	8.205	0.0000
NPC	0.895	0.158	5.648	0.0000
PVP	0.331	0.093	3.548	0.0002
CIMMYT	1.291	0.340	3.795	0.0001
PRIVATE	0.289	0.190	1.522	0.0645

Note: Estimated using two-limit tobit procedure truncated at 0,1. Wald test (chi squared): 112.51. Proportion of sample between the limits: 88.9.

Summary and Conclusions

What conclusions emerge from this updated look at the impacts of international maize breeding research in Latin America?

- *The primary locus of maize breeding research has shifted to the private sector.*

  During the past decade, the primary locus of maize breeding research in Latin America has shifted from government research organizations to private seed companies. Private-sector research and development (R&D) expenditures have increased steadily, while support to public maize breeding organizations has declined. Although research investment data remain incomplete, there can be little doubt that the level of private-sector investment now significantly exceeds the level of public-sector investment. Not only does the number of researchers employed by private seed companies exceed the number working for public research organizations, but on average private-sector researchers are better paid than their public-sector counterparts and enjoy larger operating budgets.

- *Commercial maize seed production is now dominated by private companies.*

  The decline in public-sector support for maize research has been accompanied by a gradual disengagement of the state from commercial seed production activities. The crushing economic crises that struck most Latin American countries during the 1980s triggered a series of structural reforms designed to reduce the fiscal burden imposed by inefficient state industries. Many money-losing government seed agencies were privatized or shut down because they were imposing an unacceptable burden on public treasuries; those that remain today account for an insignificant proportion of the total market. State disengagement from commercial maize seed production has been accompanied by rapid growth of the private seed industry. Private seed companies now dominate the market in virtually every country in Latin America, except for the countries of the Caribbean region.

- *The maize seed industry has become increasingly concentrated.*

  Mirroring a trend that is seen throughout the industrialized world, the emergence of a flourishing private maize seed industry in Latin America has been characterized by steady consolidation among firms. As the large multinational seed companies have penetrated the Latin American market, they have swallowed up many smaller local seed companies through acquisitions and mergers. The maize seed industry in Latin America is today highly concentrated; in most countries, the three largest seed companies control 75%

or more of the total market share. This level of concentration has raised concerns among some analysts about the possible exercise of oligopoly power.

- *The total area planted to improved germplasm continues to expand.*

  The area planted to improved maize germplasm in Latin America continues to expand. In 1996, nearly 14 million ha were planted to MVs, equivalent to approximately 48% of the total area planted to maize. This represents a significant increase from 1990, when just under 10 million ha were planted to MVs, equivalent to approximately 43% of the total maize area.

- *The pattern of adoption of improved germplasm has been uneven.*

  Use of improved germplasm has increased throughout Latin America as a whole, but the pattern of MV adoption has been uneven. Use of improved germplasm is concentrated in areas where maize is produced as a commercial crop. The most extreme example is the Southern Cone region, where approximately 63% of the total area planted to maize in 1996 was planted to MVs. In contrast, use of improved maize germplasm remains modest in regions characterized by subsistence-oriented agriculture. The area planted to MVs remains particularly limited in some of the poorest countries and/or regions of Latin America, including Mexico (20.3%), Central America (21.8%), and the Caribbean region (31.3%).

- *Use of hybrids has increased dramatically relative to use of improved OPVs.*

  The increasing importance of the private seed industry has been reflected in a marked shift in the types of improved materials being planted in farmers' fields. The area planted to hybrids has increased dramatically, while the area planted to improved OPVs has declined. By 1996, the area planted to hybrids already far exceeded the area planted to improved OPVs; in that year, over 12.5 million ha were planted to hybrids, compared to less than 1.5 million ha planted to improved OPVs. Despite warnings that hybrid technologies would be adopted only by large-scale commercial producers, in many countries hybrids have been adopted successfully by small-scale producers.

- *CIMMYT materials have been used extensively by public breeding programs.*

  Public maize breeding organizations have made extensive use of CIMMYT materials. From 1966 to 1997, approximately 55% of all varieties and hybrids released by public breeding programs in Latin America contained CIMMYT germplasm. Contrary to expectations, this percentage has increased over time. However, the way in which CIMMYT germplasm is used has changed. Public-sector breeders have increasingly tended to subject CIMMYT materials to additional cycles of selection before using them to form finished cultivars.

- *CIMMYT materials have been used extensively by private-sector breeders.*

  Private-sector breeders have used CIMMYT materials as extensively, if not more extensively, than public-sector breeders. Although many private companies are reluctant to provide detailed information about the genetic background of their commercial hybrids, we estimate that approximately 75% of all seed of proprietary hybrids sold in Latin America in 1996 contained CIMMYT-derived germplasm. The way CIMMYT materials are used tends to differ by type of seed company, however. Small seed companies that lack strong breeding capacity frequently make direct use of CIMMYT lines in forming hybrids. Large seed companies with strong in-house breeding programs (including most multinationals) rarely make direct use of CIMMYT lines; rather, these companies look to CIMMYT's broad-based populations and pools as sources from which inbred lines can be extracted.

- *The total area planted to CIMMYT-derived OPVs and hybrids continues to increase.*

  The total area planted to improved OPVs and hybrids that contain CIMMYT germplasm in their ancestry continues to increase. In 1996, CIMMYT-derived cultivars were planted on approximately 10.7 million ha, representing over 36% of the total maize area in Latin America and over 75% of the area planted to MVs. Use of CIMMYT-derived cultivars is concentrated in lowland tropical production environments. Use of CIMMYT-derived cultivars is relatively modest in temperate production environments, which is hardly surprising because CIMMYT does not target these environments.

- *Adoption of MVs depends on many factors beyond the control of breeders.*

  Adoption of improved germplasm is influenced by many factors, only some of which pertain to the characteristics of the germplasm itself. Generally speaking, the level of adoption of MVs is higher in countries where it is profitable for farmers to adopt MVs and for seed companies to supply MVs. For this reason, policy makers must be realistic about the ability of research organizations and seed companies to bring about desired changes in farm-level productivity. Improved germplasm—the principal output of research organizations and seed companies—is certainly necessary if farm-level productivity is to be raised, but improved germplasm in and of itself is not sufficient. Other things are needed as well, including attractive economic incentives, appropriate institutional structures, and favorable government policies.

References

CIMMYT Maize Program. 1998. *Maize Production Regions in Developing Countries.* Mexico, D.F.: CIMMYT.

FAO. 1998. FAOSTAT database. Rome, Italy: Food and Agriculture Organization of the United Nations.

Heisey, P., M.L. Morris, D. Byerlee, and M.A. López-Pereira. 1998. Economics of hybrid maize adoption. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner Publishers and CIMMYT. Pp. 143-158.

Kosarek, J. 1999. Factors that explain the diffusion of hybrid maize in Latin America and the Caribbean. M.Sc. thesis. The University of Illinois at Champaign-Urbana.

López-Pereira, M.A., C. Clancy, and M.L. Morris, 1992. Maize research investment and impacts in developing countries. Part 1 of *1991-92 CIMMYT World Maize Facts and Trends: Maize Research Investment and Impacts in Developing Countries.* Mexico, D.F.: CIMMYT.

López-Pereira, M.A., and M.P. Filipello, 1994. Maize seed industries revisited: Emerging roles of the public and private sectors. Part 1 of *1993-94 CIMMYT World Maize Facts and Trends: Maize Seed Industries Revisited: Emerging Roles of the Public and Private Sectors.* Mexico, D.F.: CIMMYT.

López-Pereira, M.A., and M.L. Morris. 1994. *Impacts of International Maize Breeding Research in the Developing World, 1966-1990*. Mexico, D.F.: CIMMYT.

Morris, M.L. (ed). 1998. *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner Publishers and CIMMYT.

Morris, M.L., J. Risopoulos, and D. Beck 1999. *Genetic Change in Farmer-Recycled Maize Seed: A Review of the Evidence*. Economics Program Working Paper 99/07. Mexico, D.F.: CIMMYT.

Morris, M.L., and M. Smale. 1997. *Organization and Performance of National Maize Seed Industries: A New Institutionalist Perspective.* CIMMYT Economics Program Working Paper 97/05. Mexico, D.F.: CIMMYT

Morris, M.L., M. Smale, and J. Rusike. 1998. Maize seed industries: A conceptual framework. In M.L. Morris (ed.), *Maize Seed Industries in Developing Countries.* Boulder, Colorado: Lynne Rienner Publishers and CIMMYT. Pp. 35-54.

Wood, D., and J. Lenné. 1997. The conservation of agrobiodiversity on-farm: Questioning the emerging paradigm. *Biodiversity and Conservation* 6: 109-129.

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