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The Maize Seed Industries of Brazil and Mexico: Past Performance, Current Issues, and Future Prospects

Miguel A. López-Pereira and João Carlos Garcia*

CIMMYT

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Abstract

This paper describes results of a study of the main factors affecting the development of the maize seed industries in Brazil and Mexico (and, by extension, other developing countries). The authors develop a framework that researchers and policy makers can use to evaluate seed industry performance in developing countries. This framework is used to analyze the seed industries of Brazil and Mexico, where very different sets of circumstances influence seed industry development, efficiency, and structure. The analysis gives special attention to the different maize breeding strategies pursued by the public and private sectors, measures of industry competitiveness and efficiency, and the trade-offs involved in developing and producing different kinds of maize seed, particularly improved open-pollinated maize varieties versus different types of hybrids. The authors identify key seed industry issues for researchers, administrators of national maize programs, and agricultural policy makers in developing countries, especially issues related to the appropriate roles for public and private organizations in maize seed industries in the developing world.

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Acronyms and Abbreviations

ABRASEM	Associação Brasileira dos Produtores de Sementes (Brazilian Seed Producers Association)
AMSAC	Asociación Mexicana de Semilleros, A.C. (Mexican Seed Producers Association)
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center)
CONASEM	Comisión Nacional de Semillas (National Seed Commission)
CNPMS	Centro Nacional de Pesquisa de Milho e Sorgho (National Maize and Sorghum Research Center)
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuaria (National Agricultural Research Enterprise)
EMGOPA	Empresa Goiana de Pesquisa Agrícola (Agricultural Research Enterprise of Goiana)
ESALQ	Escola Superior de Agricultura Luiz de Queiroz (Luiz de Queiroz School of Agriculture)
IAC	Instituto Agronómico de Campinas (Agronomy Institute of Campinas)
IAPAR	Instituto Agronómico do Paraná (Agronomy Institute of Paraná)
IARCs	International agricultural research centers
IIA	Instituto de Investigaciones Agrícolas (Institute of Agricultural Research)
IITA	International Institute for Tropical Agriculture
INIA	Instituto Nacional de Investigaciones Agrícolas (National Institute of Agricultural Research)
INIFAP	Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (National Institute of Research on Forestry, Agriculture and Livestock)
INM	Instituto Nacional del Maíz (National Maize Institute)
IPRs	Intellectual property rights
ITESM	Instituto Tecnológico de Estudios Superiores de Monterrey (Monterrey Technological Institute for Advanced Studies)
MVs	Modern varieties
NAFTA	North American Free Trade Agreement
NARSs	National agricultural research systems
NGOs	Nongovernmental organizations
OCEPAR	Agricultural research and extension service of Paraná
OEE	Oficina de Estudios Especiales (Office of Special Studies)
OPVs	Open pollinated varieties
PLANASEM	National Seed Plan
PROCAMPO	Agricultural Support Program
PRONASE	Productora Nacional de Semillas (National Seed Producing Enterprise)
R&D	Research and development
SAM	Sistema Alimentario Mexicano (Mexican Food System Program)
SARH	Secretaría de Agricultura y Recursos Hidráulicos (Ministry of Agriculture and Water Resources)
SAVE	State Agricultural Research Service
SNICS	Servicio Nacional de Inspección y Certificación de Semillas (Seed Certification and Inspection Service)
SPSB	Serviço de Producão de Semente Básica (Basic Seed Production Service)
UAAAN	Universidad Autónoma Agraria Antonio Narro (Antonio Narro Autonomous Agricultural University)
UANL	Universidad Autonóma de Nuevo León (Autonomous University of Nuevo León)
UFRS	Universidade Federal de Rio Grande do Sul (Federal University of Rio Grande do Sul)
UNAM	Universidad Nacional Autónoma de Mexico (National Autonomous University of Mexico)
UPOV	International Union for the Protection of New Varieties of Plants

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The Maize Seed Industries of Brazil and Mexico: Past Performance, Current Issues, and Future Prospects

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Introduction

Maize is the third most important cereal crop in the world after wheat and rice. The world produced 499 million metric tons per year over 1990-92 on about 130 million hectares, for an average yield of 3.8 t/ha (Table 1). Developing countries accounted for 64% of this maize area and for 42% of production. On average, maize yields in developing countries in 1990-92 were 2.5 t/ha, compared to 6.2 t/ha in industrialized countries.

The demand for maize in the developing countries over the next 10-20 years is expected to grow by more than 4% per year (Byerlee and Saad 1993). Most of the increase in demand will result from the growing use of maize for feed. Consumers in developing countries will switch from coarse grains such as maize to more convenient cereal grains such as rice and wheat as food sources, and they will consume more maize in the form of animal products.

Can developing countries meet the projected demand for maize? Even if maize area in developing countries remains stable over the next decade, at its recent level of approximately 84 million hectares (Table 1), developing countries will need to achieve substantial gains in maize productivity if they are to meet the increased demand for maize with their own production. Otherwise many countries will have to increase their maize imports dramatically over the next two decades. The productivity gains that will be needed are much greater than the 1.7% per year gains in yields in developing countries over 1980-91 (Byerlee and López-Pereira 1994).

Because cropped area is not expected to contribute substantially to increased maize production for most developing and industrialized countries, the principal way to meet the increasing demand for maize is through productivity gains in current maize-producing areas.[1] The development and diffusion of appropriate improved maize varieties and hybrids, combined with

Table 1. Maize, wheat, and rice area, yield, and production in developing and industrialized countries, 1990-92 annual averages

	Maize	Wheat	Rice
Developing countries			
Area (million ha)	83.6	101.7	142.5
Yields (t/ha)	2.5	2.4	3.5
Production (million t)	212.2	240.0	496.0
Industrialized countries			
Area (million ha)	46.2	123.0	4.4
Yields (t/ha)	6.2	2.7	5.8
Production (million t)	286.7	327.6	25.5
World			
Area (million ha)	129.8	224.7	146.9
Yields (t/ha)	3.8	2.5	3.6
Production (million t)	498.9	567.6	521.5
Developing countries share of			
Area (%)	64	45	97
Production (%)	42	42	95

Source: FAO Agrostat data tapes.

[1] This also depends on the price of maize relative to other crops such as sorghum in the future. If the price of maize is more attractive than that of sorghum, total crop area might be the same but maize will tend to substitute for sorghum, thereby increasing maize production. The long term trend in the real price of maize, however, is downward.

improved agronomic practices, will become increasingly important for increasing maize production in developing countries.

The use of improved seed can contribute greatly to higher yields (see Table 2) and is usually the first step in the process of agricultural technology adoption. Adoption of improved seed has been found to be crucial to the adoption of complementary practices that result in increased productivity (Byerlee and López-Pereira 1994). It is reasonable to expect substantial yield gains as a country's maize farmers move from growing local varieties to growing appropriate modern varieties (MVs)[2] and adopt improved agronomic practices (Byerlee and López-Pereira 1994).

The public research systems in most developing countries, along with the private research system in countries having more advanced seed industries, have released a large number of MVs of maize over the last 25 years (Table 3 lists public sector releases). Evidence from El Salvador, Zimbabwe, and Malawi suggests that small-scale farmers will use MVs of maize, including hybrids, under low levels of management (Cutié 1976; Rohrbach 1989; Byerlee and Heisey 1993). However, with a few notable exceptions MVs have not been adopted by farmers, especially small-scale subsistence farmers. On average, 48% of the 1990 maize area in developing countries was planted to MVs, compared to over 69% for wheat (López-Pereira and Morris 1994; Byerlee and Moya 1993). Important maize-producing countries that planted less than 50% of their maize area to MVs in 1990 include Tanzania, Mozambique, India, Philippines, and Mexico.

The reasons for this lack of adoption are complex and include poor research-extension links, the release of materials that are not well adapted to farmers' growing conditions, farmers'

Table 2. Maize yields and adoption of modern varieties (MVs) in developing and industrialized countries, 1990

	Number of countries	Adoption of MVs[a] (%)	Local varieties (%)	Average yields (t/ha)
Developing countries with low percentage of OPVs and hybrids	36	26	74	1.49
Developing countries with high percentage of OPVs and hybrids	15	71	29	2.13
Argentina, Brazil, Chile, China[b]	4	76	24	3.59
Industrialized countries	8	99	1	7.24

Source: FAO Agrostat data tapes and CIMMYT maize varietal releases database.
[a] Improved open-pollinated varieties (OPVs) and hybrids.
[b] Maize production in these developing countries is of a commercial nature and/or occurs in temperate regions, and farmers commonly use hybrid maize seed.

[2] The term "MV" denotes both improved open-pollinated varieties and hybrids of maize.

attitudes towards the risk involved in using new technologies, and the lack of effective seed delivery systems (Byerlee and López-Pereira 1994; Timothy, Harvey, and Dowswell 1988). The true challenge may be to find solutions to these constraints, especially effective seed delivery systems, rather than to develop more improved seed technologies *per se*.

The recent profound agricultural reforms in many developing countries regarding trade, regulation, and the privatization of many activities traditionally performed by public organizations, especially the development and diffusion of new agricultural technologies, could substantially affect the development of their maize sectors. In the case of maize seed industries, policy reforms have had particularly visible effects. Most Latin American countries now permit the private sector to participate actively in maize seed industries, especially in seed production and marketing but also in research and development (R&D) or breeding. This is a remarkable occurrence, given the large presence of public national systems in developing country seed industries until recently (López-Pereira and Filippello 1994). Increasingly open markets may induce some countries to rely more on regional or international trade to meet a greater proportion of their demand for maize than in the past, especially countries where maize technology is still underdeveloped, and this has important implications for the development of maize seed industries.

Why Study Seed Industries?

The circumstances we have just described — the increased productivity gains needed to meet the growing demand for maize, the slim possibility that maize area will increase, the crucial role that MVs must play in achieving productivity gains, and the dramatic agricultural reforms in developing countries — all point to the importance of understanding the structure and evolution of seed industries, from germplasm development to seed multiplication and marketing.

Table 3. Public maize varieties and hybrids released in nontemperate areas of developing countries, 1966-90

		Percentage of releases that are:		
Region	**Number of releases**	**Open-pollinated varieties**	**Conventional hybrids[a]**	**Non-conventional hybrids[b]**
Sub-Saharan Africa	290	62	23	15
West Asia and North Africa	28	14	68	18
Asia[c]	182	78	15	7
Latin America[d]	342	64	30	6
Total	**842**	**64**	**26**	**10**
Total number of releases by type		**543**	**216**	**83**

Source: López-Pereira and Morris (1994).
[a] For example, single-cross, three-way, and double-cross hybrids.
[b] For example, top-cross and varietal hybrids.
[c] Excludes temperate China.
[d] Excludes Argentina and Chile.

This study seeks to provide maize researchers, administrators in the national and international agricultural research systems, and agricultural policy makers with new information on factors affecting the development of the maize seed industries in two contrasting settings, Brazil and Mexico (and, by extension, other developing countries). The study has three specific objectives:

- To provide a framework that researchers and policy makers can use to evaluate maize seed industry performance and efficiency in developing countries.
- To use that framework to assess the factors affecting the development, efficiency, and structure of the maize seed industries of Brazil and Mexico, giving special attention to the maize breeding strategies of the public and private sectors, industry competitiveness and efficiency, and the development of improved open-pollinated maize varieties versus different kinds of hybrids.
- Based on the analysis of the Brazilian and Mexican seed industries, to identify key issues for researchers and administrators of national and international maize programs and for agricultural policy makers in developing countries, regarding the role of public and private organizations in maize seed industries.

Methods and Data Sources

We have chosen to analyze the maize seed industries of Brazil and Mexico, respectively the second and third largest maize producers in the developing world, because they differ significantly in their adoption of improved maize seed, the development of their maize seed industries, seed legislation and regulations, their strategies for developing improved maize seed, and the private sector's level of involvement in the seed industry. Most of the analysis is based on extensive interviews with officials from public and private seed organizations during 1992. Officials and researchers from all seed companies in the private sector and all public sector organizations were interviewed (Appendix A).[3] We have also made considerable use of secondary data on maize, including area and yields, production environments, area planted to improved and local varieties, seed legislation, directories of national and international maize seed companies, public maize research institutions, maize seed production and trade, maize varieties and hybrids developed by the seed industry (both public and private), and other relevant data. Technical information on maize varieties and hybrids was collected during the interviews with seed organizations, primarily information on the cost of developing open-pollinated varieties (OPVs) and different kinds of hybrids, the time needed to develop different kinds of maize germplasm, the costs of producing different seed types, seed industry structure, and potential yield and yield stability of each seed type in representative maize environments. The costs and benefits of using improved seed, factors affecting farmers' decisions to purchase improved seed, and the average number of years farmers keep seed of OPVs and hybrids before replacing it, were also explored.

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[3] Occasionally we include information on the United State maize seed industry to provide an example of a developed seed industry with little or no direct participation of public sector organizations.

The remainder of this paper is organized as follows. This section presents a general framework for maize seed industry analysis, which is used later to evaluate the Brazilian and Mexican seed industries. The next section describes the maize sectors of Brazil and Mexico and is followed by a brief account of the history of maize breeding in each country. After that we turn our attention to the main components of the Brazilian and Mexican maize seed industries, particularly the size of the industry, concentration, public-private sector participation, the relative efficiency of seed production, and seed regulations. Issues relevant to the analysis of maize seed industries are discussed, such as the relative yield advantages of different maize seed types, the potential and actual seed market, farmers' seed replacement decisions, the comparative costs of producing OPVs and hybrids, and the basic economic principles behind the structure of maize seed industries. In the last two sections of the paper, we review the main issues that will shape maize seed industries in the future and summarize our findings.

A Proposed Framework for Seed Industry Analysis

The main objective of maize seed industries is to deliver high quality seed to maize farmers in a way that provides an adequate return to seed producers and to seed users. Maize seed industries pursue three broad activities:

- Breeding, testing, and releasing improved varieties and hybrids (R&D).
- Producing and conditioning seed.
- Marketing and distributing seed.

These three activities are highly interdependent, since the satisfactory performance of each one depends on the effectiveness with which the others are performed. Different organizations can perform any of the activities; which organizations are involved and which activities they perform depend on the degree of development of the industry. These organizations include (see López-Pereira and Filippello 1995):

- international agricultural research centers (IARCs);
- public national agricultural research systems (NARSs);
- multinational seed companies;
- private national companies;
- nongovernmental organizations (NGOs);
- seed cooperatives; and
- individual seed producers.

One way to determine the degree of development of maize seed industries is by examining the relative roles of the public and private seed sectors and by applying some indicators of competitiveness and efficiency.

Because of the large investment necessary to start a new breeding program, the R&D phase of the industry presents the characteristic of economies of scale. In other words, initiating a breeding program requires large capital investments, but expanding from a certain minimum size is less expensive than initiating the program, and the per unit costs of production are reduced as the operation expands, up to a certain limit. However, economies of scale do not seem to prevail in the other phases of the industry, especially in seed production and conditioning. Once varieties and hybrids are developed and registered, the process of producing, conditioning, and marketing commercial seed does not involve as much fixed investment. Working capital for variable costs is the key element. Capital-constrained organizations have the opportunity to enter the industry during these latter phases, which is what many companies do.

For these reasons, R&D in maize seed industries tends to be dominated by a relatively small number of large breeding programs, which also dominate other seed industry activities. However, many small-scale companies participate in the industry by producing and marketing seed for other companies or by producing their own seed based on publicly developed materials. For example, from 1973 to 1993, the four largest seed companies in the United State (US) held a 50-60% market share, and the eight largest companies held a 62-73% market share. The rest of the market was controlled by a very large number of medium and small companies. In a highly developed seed industry, one would expect that fewer than ten companies would capture about 75% of the market and that a relatively large number of small seed companies would capture the rest.

We consider a seed industry to be highly efficient when there is a high level of competition, a certain minimum level of investment in R&D, new materials are released every year (and others are taken off of the market), public and private sector organizations have complementary functions, and benefits from the industry are distributed throughout the sector, including maize farmers. Several indicators can be used to determine industry development, performance, and efficiency. Some of the most important ones are listed below.

- **R&D investment.** The total investment in breeding programs is one of the most important indicators of industry development, especially the investment made by the private sector. Normally, in a developed seed industry, investment in R&D represents around 10% of the total value of seed sales.

- **Costs of production and conditioning as a percentage of the seed price.** Most of the variable costs in the industry are accounted for after varieties and hybrids are developed. Efficient seed companies estimate that no more than 50% of the price of seed should be production and conditioning costs.

- **Gross profit margins.** As the industry develops and becomes more competitive, gross margins decrease. Only those seed companies that become cost effective will remain profitable. In competitive industries seed companies must survive with gross margins of about 15% of the price of seed.

- **Market share of four largest companies.** In general, the seed industry can be considered competitive if the four largest companies control less than two-thirds of the market.
- **Market share of public companies.** In highly developed seed industries, a relatively small group of public companies participates in seed production and distribution. However, public breeding programs are a very important source of the maize varieties and hybrids used by private companies in developing countries, particularly when the industry is in the early stages of development. When the industry is more developed, private companies run their own breeding programs and the public sector reduces its direct participation in the seed industry. The lower the market share of public companies in seed sales, the more competitive and efficient the industry becomes. There are exceptions to this rule, especially in countries with large proportions of small-scale farmers and where maize is a staple food, and also in countries having diverse maize growing environments. In these cases, a very active private sector can coexist with a strong public sector.
- **Ratio of the number of hybrids and OPVs to total maize area.** The number of hybrids on the market is a good indicator of industry development and of the degree to which seed companies offer products for different maize growing environments. The extent to which a company can bring new products to market (which can also be described as the extent of product turnover or degree of innovation) indicates its efficiency. The chances for success increase as new and better products replace old products, allowing the company to remain competitive.
- **Area under improved seed and types of farmers using improved seed.** No matter how efficient maize seed companies may be, the ultimate test of success is the extent to which farmers use their products (varieties and hybrids). The proportion of area under improved seed is a good indicator of industry performance, especially when hybrids are commonly used. Information on the kinds of farmers using improved seed indicates the degree to which the benefits generated by the industry are distributed among maize sector participants and is a gauge of the industry's health. If virtually all farmers use improved seed, as in Zimbabwe, the benefits of improved seed are distributed among all — seed companies, commercial farmers, and small-scale farmers — and the industry is healthy.

Some of these indicators will be discussed later in the context of the Brazilian and Mexican seed industries. Before doing so, however, we will outline the main characteristics of the maize sector in each country (trends in maize production, consumption, and utilization; the different maize growing environments; and differences in the two maize economies) and describe their history of maize breeding research.

Main Characteristics of the Maize Sectors of Brazil and Mexico

Trends in Production and Trade

Brazil and Mexico are the third and fourth largest maize producers in the world and rank second and third among developing countries (China is first). Maize production grew by 3.6% annually in Brazil over the last three decades (Figure 1), although the more recent rate has been lower (2.6% per year) (Table 4). Maize area expanded through the 1980s at 1.1% per year, mostly because the Cerrados region in central Brazil was opened to agricultural production over the last 15 years, and maize and soybeans were the favored crops in this region. It is likely that maize area in Brazil will continue to show a slight upward trend as more of the Cerrados is brought into production. The total area planted to maize each year in Brazil depends on its profitability relative to that of other industrial crops, such as soybeans and sugarcane, and Paterniani (1985) has suggested that this may be one factor behind the low productivity of maize.

Average maize yields in Brazil are about 2 t/ha, which is relatively low for a country that uses substantial amounts of improved seed. However, the national average conceals regional differences in maize productivity. In the North and Northeast, small-scale, subsistence farmers produce maize in mixed cropping systems, mainly with beans and cotton. The use of improved seed and other inputs is very low and seed companies are not active, mainly because the semiarid climate causes unstable yields and high production risks. Farmers' yields average about 0.5 t/ha (Figure 2). In the West-Central and Southern region, where the climate is more favorable for maize production, the use of improved maize seed and fertilizers is common, and medium- and large-scale farmers produce maize for the feed industry. Farmers in West-Central Brazil obtain yields surpassing 2.5 t/ha (Figure 2).

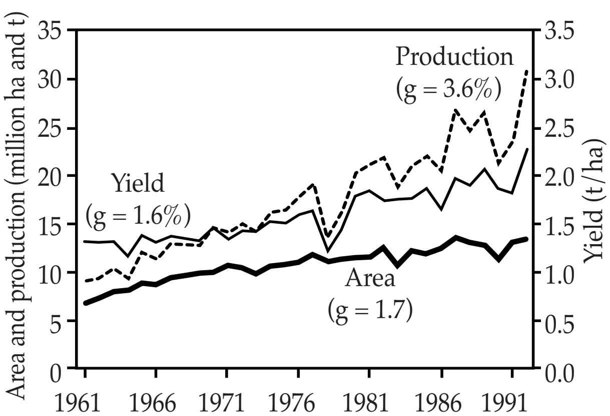


Figure 1. Maize area, yield, and production in Brazil, 1961-92.
Source: FAO Agrostat data tapes.

Table 4. Basic characteristics of the maize sectors of Brazil and Mexico

	Brazil	Mexico
National maize area, 1990-92 (million ha)	12.6	7.2
National maize yields, 1990-92 (t/ha)	2.0	2.0
National maize production, 1990-92 (million t)	25.2	14.6
Maize growth rates, 1981-92 (%/yr)		
Area	1.1	-0.1
Yields	1.5	1.0
Production	2.6	0.9
Net maize imports (million t)		
1970-72	-1.0	0.1
1980-82	0.6	2.4
1990-92	0.7	2.3
Type of seed used (1990)		
Hybrids (%)	43	8
Improved OPVs (%)	7	12
Local varieties (%)	50	80

Source: FAO Agrostat data tapes; López-Pereira and Morris (1994).

Average farm sizes also vary by region, with very small maize farms in the Northeast and medium- and large-scale farms in the West-Central region (see Table 5 for a general classification of farm sizes in Brazil).

In Mexico, growth in maize production has been fueled exclusively by yield gains over the last 30 years (Figure 3). From 1 t/ha in the early 1960s, maize yields climbed to about 2 t/ha in 1990-92, a growth rate of 2.4% per year. Maize area remained virtually unchanged, averaging 7 million hectares per year in the last decade, and growth in maize yields slowed to 1% per year in the 1980s (Table 4). Declining maize area and slow yield growth rates caused production to stagnate.

Maize is produced mainly by small-scale farmers on an average area of less than 5 ha; very few holdings surpass 10 ha (Table 6). The North and the Bajío regions are more important in irrigated maize production, whereas maize in the Central and Southern regions is produceed under rainfed conditions. Yields of irrigated maize are roughly twice as high as those of rainfed maize (Table 7).

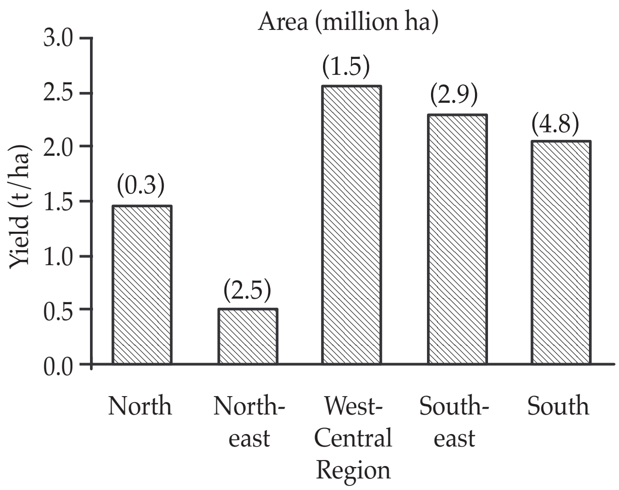


Figure 2. Maize area and yield in Brazil by region, 1990-91.
Source: IBGE (various years).

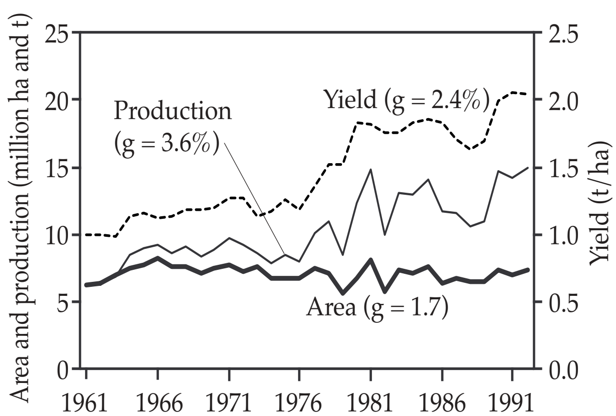


Figure 3. Maize area, yield, and production in Mexico, 1961-92.
Source: FAO Agrostat data tapes.

Table 5. Maize area, production, and yields in Brazil, by size of cultivated maize area, 1985

Class (ha)	Average maize area (ha)	Area million ha	Area %	Production million t	Production %	Yields (t/ha)
< 2	0.9	1.6	13	1.6	9	1.0
2-10	3.9	5.5	45	7.9	43	1.4
10-50	17.4	3.3	28	5.2	28	1.6
> 50	107.1	1.7	14	3.7	20	2.2
Total	**3.5**	**12.1**	**100**	**18.4**	**100**	**1.5**

Source: IBGE (various years).

Table 6. Maize area and production in Mexico, by type of producer and size of maize area, 1990

Class	Area		Maize yields (t/ha)	Production	
	million ha	%		million t	%
Ejidos[a]	4.46	64.4	1.81	8.09	60.9
Private property					
< 5 ha	0.46	6.6	1.61	0.74	5.6
> 5 ha	2.01	29.0	2.21	4.45	33.5
Total	6.92	100.0	1.92	13.28	100.0

Source: Estimates based on Centro de Investigaciones Agrarias (1980).
[a] *Ejidos* are communally owned land.

In the last few years maize yields jumped substantially (Figure 3) as farmers in some regions of Mexico used more improved seed and other inputs. High official guaranteed prices and the increased production of improved seed by the private sector encouraged maize production. The maize sector is expected to experience further changes resulting from the policy reforms introduced in recent years, especially the Agricultural Support Program (PROCAMPO) and the North American Free Trade Agreement (NAFTA). The Mexican economy has been restructured, and many state enterprises have been privatized, including many in the agricultural sector (particularly fertilizer and seed companies). These changes are likely to result in higher maize imports, mostly from the US, and greater use of improved seed in some regions of Mexico.

Table 7. Maize area in Mexico by region and moisture regime, annual averages for 1989-91

	North and Bajío	Mesa Central and South	Total Mexico
Area (million ha)			
Irrigated	0.68	0.33	1.01
Rainfed	2.29	3.63	5.91
Total	2.97	3.95	6.92
Production (million t)			
Irrigated	2.42	1.02	3.44
Rainfed	3.83	6.01	9.84
Total	6.25	7.03	13.28
Yield (t/ha)			
Irrigated	3.55	3.13	3.42
Rainfed	1.68	1.66	1.67
Total	2.11	1.78	1.92

Source: Dirección General de Estadística, SARH, Mexico.

In Brazil and especially Mexico, high population growth and relatively low rates of production growth, combined with increased demand for maize as an animal feed, have created a widening deficit of domestically produced maize (Table 4, Figure 4). Up to the mid-1970s, Brazil was a net exporter of maize, but the country has since become a net importer, although recent good harvests have reduced the need to import maize. Until the 1970s, Mexico exported a substantial amount of maize, but by the late 1980s it imported over 3 million tons per year. Although production grew at an average rate of over 2% in both countries over 1961-92 (Figures 1 and 3), this was not enough to meet increased demand brought on by strong population growth and especially by rising incomes.

Uses of Maize

One marked difference in the maize economies of Brazil and Mexico is the way the cereal is used. Whereas in Brazil a large proportion of the maize produced is used in commercial feed rations (especially for poultry and pig operations — see López-Pereira 1992) and only a relatively small proportion is used as food (Figure 5), in Mexico the situation is just the opposite (Figure 6). Maize is of historical importance in Mexican culture and remains by far the most important staple food, especially in rural areas where it is consumed in a variety of forms. In Brazil, a large proportion of the maize harvest, especially in the Southeast and South, is sold to produce commercial feed rations or used on the farm as animal feed. About 17 million tons of commercial feed were produced in 1992 (López-Pereira 1992), and about 12 million tons of maize were used for that purpose. These characteristics of the maize sectors in the two countries have important implications for their respective seed industries, as the more commercially oriented Brazilian maize farmers tend to use improved seed more readily than Mexico's small-scale, subsistence farmers.

Maize Growing Ecologies and Adoption of Improved Varieties

The technology used to produce maize in Brazil differs from that in Mexico, partly because of the differing agroecological conditions under which the crop is produced. The number, importance, and characteristics of different growing ecologies for maize production in the two countries can be seen in Table 8. Growing ecology characteristics make maize production in Mexico more complex than in Brazil. Whereas all the maize produced in Brazil can be characterized as tropical lowland or subtropical and has yellow grain, in Mexico maize is found in all four growing ecologies

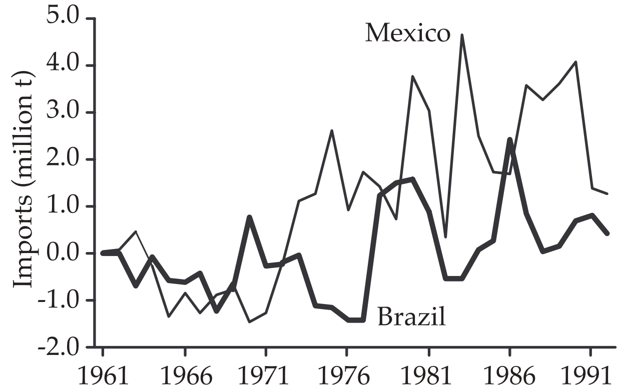


Figure 4. Net maize imports in Brazil and Mexico, 1961-92.
Source: FAO Agrostat data tapes.
Note: negative numbers indicate net exports.

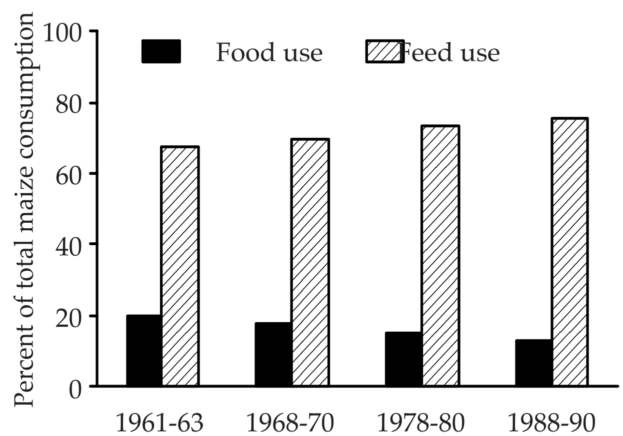


Figure 5. Trends in food and feed uses of maize in Brazil, 1961-90.
Source: FAO Agrostat data tapes.

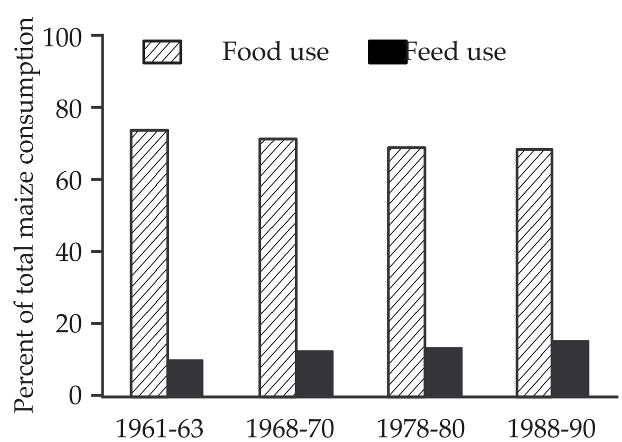


Figure 6. Trends in food and feed uses of maize in Mexico, 1961-90.
Source: FAO Agrostat data tapes.

of the tropics and subtropics. Even though white is the preferred grain color, many other colors of grain are found as well. A substantial proportion of the maize in Mexico is produced in highland environments, where biotic and abiotic stresses are more difficult and for which fewer improved materials have been developed (see, for example, López-Pereira 1993).

Because maize growing ecologies are more uniform in Brazil than in Mexico, especially with regard to altitude, breeding research can cover the needs of relatively large regions. The variety of growing environments in Mexico is widened by other variables such as maturity ranges and grain types and colors (Table 8). The relatively large proportion of maize in subtropical and low altitude tropical environments in Brazil was an important factor in the development of strong maize breeding programs based on germplasm

Table 8. Maize growing environments in Brazil and Mexico, 1990

	Brazil	Mexico
Total maize area (million ha)	11.4	7.3
Percentage of maize area by growing ecology[a]		
Tropical lowlands	68	36
Tropical midaltitudes	-	7
Tropical highlands	-	35
Subtropical	32	22
Percentage of maize area by grain color/type		
Yellow dent	50	1
Yellow flint	50	1
White flint	-	78
White dent	-	19
White floury	-	1
Percentage of maize area by germplasm maturity class		
Extra early maturing germplasm	-	3
Early maturing germplasm	21	13
Intermediate maturing germplasm	47	14
Late maturing germplasm	32	69
Extra late maturing germplasm	-	1
Percentage of maize area by moisture regime		
Rarely drought stressed	4	18
Sometimes drought stressed	48	49
Frequently drought stressed	32	17
Usually under some drought stress	17	16
Percentage of maize area by soil type		
Normal	52	100
Acidic	48	-

Source: CIMMYT maize varietal releases database; CIMMYT Maize Program (1988).

[a] Maize growing ecologies are defined as follows (CIMMYT Maize Program 1988): Tropical lowland ecologies are regions within the Tropics of Cancer and Capricorn with altitudes below 900 masl; tropical midaltitude ecologies are regions within the tropics with altitudes between 900 and 1,800 masl; tropical highland ecologies are regions within the tropics and altitudes above 1,800 masl; subtropical ecologies are regions falling between 22.5° and 35° latitudes North and South; and temperate ecologies are regions above 35° latitude North and below 35° latitude South. For Mexico, the classification corresponds approximately to national maize growing ecologies as follows: tropical lowlands = trópico húmedo; subtropical = trópico seco/norte; midaltitude = Bajío and transition zones; and highland tropics = Altiplano/Mesa Central.

introduced from other Latin American countries and the US, as well as local germplasm. The diversity of growing environments in Mexico, particularly the variation in altitude, means that exotic germplasm has more limited utility.

These differences in growing environments are reflected in the extent to which farmers use improved germplasm. Table 9 shows that much more hybrid seed is used in the subtropical environments of both countries. The use of hybrid seed in the Mexican tropics is very low (see Table 8 for area sown to improved seed in each growing ecology). Overall, about 55% of the maize area in Brazil and 20% in Mexico has been estimated to be planted to improved varieties and hybrids (see also López-Pereira and Morris 1994).

The disparity in maize yields in Brazil between the Northeast and the West-Central region reflects differences in maize production technology and growing ecologies (Map 1). A somewhat parallel situation occurs in Mexico (Map 2). Commercial, large-scale maize production — some of it under irrigation — is found in the North and the Bajío region, where yields surpass 3.5 t/ha. In the South, where small-scale farmers produce most of the maize, the use of improved seed is very low and yields are about 1.5 t/ha. Relatively low levels of improved seed are used, although levels of fertilizer and pesticide are relatively high (Hibon et al. 1992).

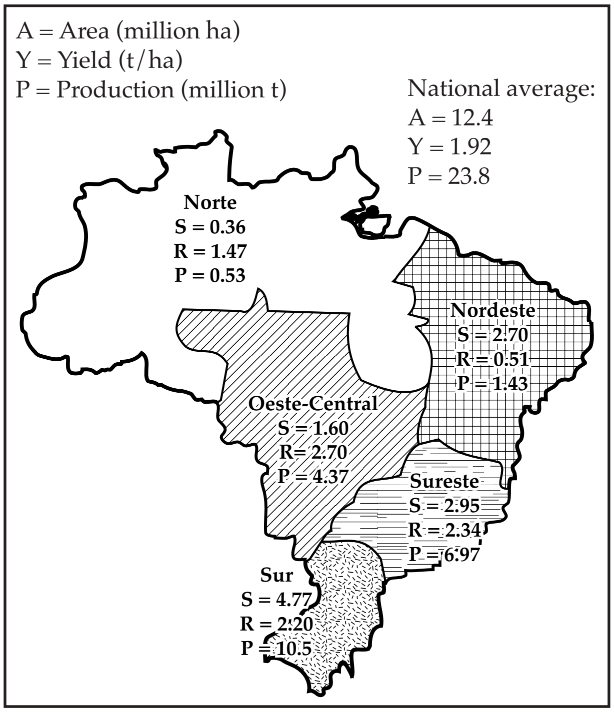
Table 9. Adoption of improved open-pollinated maize varieties (OPVs) and hybrids in Brazil and Mexico, by growing ecology, 1990

	Percentage of maize area	
Ecology[a]	Brazil	Mexico
Tropical lowlands		
Improved OPVs	10	31
Hybrids	33	2
Local varieties	57	67
Tropical midaltitudes		
Improved OPVs	..	1
Hybrids	..	49
Local varieties	..	50
Tropical highlands		
Improved OPVs	..	1
Hybrids	..	1
Local varieties	..	98
Subtropical		
Improved OPVs	0	2
Hybrids	88	31
Local varieties	12	67
All maize ecologies		
Improved OPVs	7	12
Hybrids	50	11
Local varieties	43	77

Source: CIMMYT maize varietal releases database.
[a] See Table 8 for definitions of maize growing ecologies.

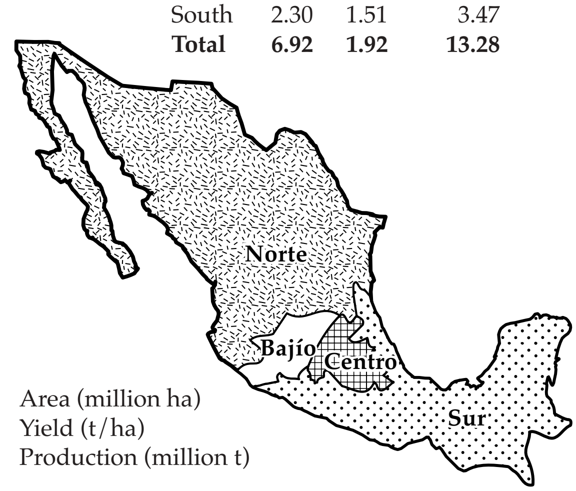
Mexico has much greater scope than Brazil for increasing maize productivity through more widespread use of improved seed, for a substantial area with potential for high productivity is still planted with local maize seed (see Table 9). If farmers in these areas adopt improved maize seed, the seed industry could grow considerably in the next decade. The rate of growth will depend to a great extent on how patterns of land use might change as a result of recent policy reforms (discussed later in this paper and in more detail in Appendix B).

Virtually all the commercial maize area in Brazil is already under hybrids and the potential for increasing farmers' use of improved seed in the North and Northeast is limited. Unless there are substantial increases in maize area in the central regions of Brazil, especially in the Cerrados, the maize seed industry will remain stable at best in terms of growth, and competition among private companies will probably intensify. However, the relatively low maize yields in Brazil indicate that the productivity of maize can increase as farmers who already use hybrids continue to demand higher yielding materials. Breeding objectives appear to have currently shifted to specialty materials with early maturity and short stature (Paterniani 1985).



Map 1. Maize production in Brazil by region, 1989-91 average.
Source: IBGE.

Region	Area	Yield	Production
North	2.10	2.27	4.78
Center	1.65	2.16	3.56
Bajío	0.86	1.70	1.47
South	2.30	1.51	3.47
Total	**6.92**	**1.92**	**13.28**



Map 2. Maize production in Mexico by region, 1989-91 average.
Source: D.G.E., SARH.

History of Maize Breeding in Brazil

Initiation of Maize Breeding Research

Maize breeding research in Brazil began with the creation of the Instituto Agronómico de Campinas (IAC), a public organization, in the State of São Paulo in 1887 (Pardey, Roseboom, and Anderson 1991). The IAC was created in response to the expansion in coffee area from Rio de Janeiro State to São Paulo State, and at first IAC research focused exclusively on coffee (Sorj and Wilkinson 1990). Later, IAC was split into two divisions, one emphasizing applied research and the other basic research. Within this latter division, a genetics section was formed. Although coffee research remained the main activity, the genetics section began maize breeding research in the early 1930s after Brazilian researchers who obtained doctorates in the US returned to Brazil.

These US-trained scientists stocked their breeding programs with maize germplasm from the US. This germplasm, in combination with materials from Brazil (especially Cateto and Paulista Dents — see Brieger et al. 1958) and other Latin American countries, led to the development of superior hybrids, mainly from the Cateto and Azteca populations, in the late 1930s and early 1940s (Sorj and Wilkinson 1990). In 1946, IAC released the first Brazilian double-cross hybrid, H-3531, formed from four Cateto inbred lines (Wellhausen 1978). The second double-cross hybrid, H-4624, was released by IAC in 1953 and contained two inbred lines from Cateto, one from

Tuxpeño (introduced from Mexico), and an inbred line derived at IAC from Paulista Dent (Wellhausen 1978). As can be seen in Figure 7, Brazilian breeders were very successful in taking advantage of heterotic responses to develop increasingly superior hybrids, which became the foundation of the seed industry.[4]

Maize breeding also began in the 1930s at the Universidade Federal de Viçosa, in the state of Minas Gerais. This program, influenced like IAC by US hybrid programs and US-trained Brazilian scientists, also emphasized hybrids. At first maize breeders at Viçosa used only US germplasm, but its susceptibility to diseases and poor adaptation to different latitudes forced the combination with Brazilian and Mexican germplasm. In 1945, with financial support from the Rockefeller Foundation, two breeders left Viçosa to form the seed company Agroceres (Ribeiral, pers. comm., 1990), which became the leading maize seed producer and one of the largest agribusiness conglomerates in Brazil.

Around the same time, in Rio Grande do Sul State, the public sector started maize breeding at the Agricultural Research Station of Veranopolis, generating several hybrids known as SAVE. These hybrids were adapted to the temperate conditions of Southern Brazil, and they differed markedly from those developed for states in the Southeast, which were initially covered by IAC and Agroceres.

Population improvement under a recurrent selection scheme was started at IAC and the Escola Superior de Agricultura Luiz de Queiroz (ESALQ) in the late 1950s (Paterniani 1985). Tuxpeño germplasm was extensively used in population improvement. By the end of the

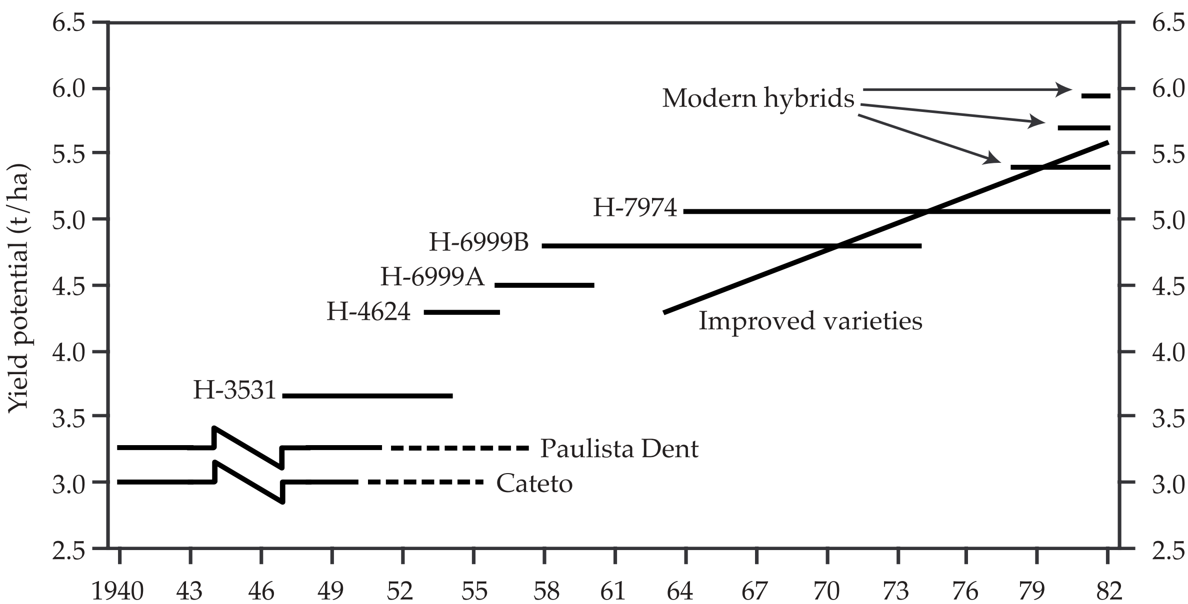


Figure 7. Gains in yield potential in maize hybrids and open-pollinated varieties (OPVs) through breeding in Brazil, 1940s to 1980s.
Source: Pateeniani (1985).

[4] More detailed accounts of the progress made by Brazilian maize breeding programs from 1940 through the 1980s can be found in Wellhausen (1978) and Paterniani (1985).

decade ESALQ had developed two varieties (Piramex and Centralmex) and the IAC had developed one (Maya). The IAC-ESALQ breeding strategy continued to produce high yielding varieties in the 1960s and 1970s. Figure 7 shows the progress in yield potential of improved OPVs and hybrids as a result of population improvement.

The introduction of US breeding methods and US and other foreign germplasm seem to have been the chief factors behind the early emphasis on hybrids. The development and release of successive generations of higher yielding hybrids by IAC was central to the development of a strong domestic private seed industry based on the production of public hybrids (Sorj and Wilkinson 1990). The private companies in São Paulo State never developed their own research capacity, which made them highly dependent on IAC, but Agroceres did develop its own maize breeding capacity, using germplasm from the public sector to generate its own hybrids. The company quickly became independent of the public breeding system as a direct source of hybrids.

By the 1960s, the Brazilian maize seed industry was firmly established, with Agroceres holding an important share of the market and many small private seed companies still highly dependent on the public system of the state of São Paulo for breeding. The IAC's extensive network of research stations and "seed houses" distributed a large proportion of seed in the state.

Introduction of Regulations to Control the Seed Industry

As the seed sector became more organized in the mid-1950s, formal seed legislation was introduced, first only in São Paulo State but soon thereafter in the country as a whole. Those first steps towards regulating the seed industry took the form of Rules for Seed Analysis in 1955 and the Hybrid Maize Service in 1956 (Santos et al. 1985), which provided guidelines for developing hybrid maize seed and for inspecting and regulating seed production fields. In 1957, a Certification of Hybrid Maize Seed decree was passed in the state of São Paulo. This decree is considered the starting point for the development of a private maize seed sector in Brazil. This initial process of regulating the seed industry prompted several foreign seed companies to become interested in the Brazilian market. In the mid-1960s, two of the most important multinational seed companies entered the Brazilian maize seed market. Cargill established operations in São Paulo, and Pioneer Hi-Bred based itself in the southern state of Rio Grande do Sul. Later, in the 1970s, other multinational companies entered the market (discussed later).

Brazil's first Federal Seed Law was approved in 1965, and its regulatory decree was approved the same year. The law mainly regulated seed trade, which was the chief concern of the team from the US Agency for International Development and Mississippi State University that was contracted to draft the legislation. Amendments to the seed law were then approved, defining an explicit division of labor between public and private seed sectors. The private sector was to be responsible for seed production and marketing, and the public sector was assigned the complementary role of producing genetic and parent seed within its research programs.

In the late 1960s, a National Seed Plan (PLANASEM) was developed, under which the development of improved germplasm and seed production and distribution were given high priority. The PLANASEM, and the government actions it generated, were decisive events in the development of breeding programs in many Brazilian universities and state institutes (see Santos et al. 1985; Sorj and Wilkinson 1990).

Changes in the Public Research System

As agricultural production expanded into the southern states and especially into the Cerrados, the national public agricultural research system was restructured. The National Agricultural Research Enterprise (Empresa Brasileira de Pesquisa Agropecuaria, EMBRAPA) was formed in the mid-1970s to "create a cooperative research system, national in scope, in which the federal and state governments, universities, and the private sector would work jointly." This mandate gave EMBRAPA national leadership in public agricultural research.

With the creation of EMBRAPA, agricultural research was organized by commodity rather than by discipline. Within this new framework, the National Center for Maize and Sorghum Research (Centro Nacional de Pesquisa de Milho e Sorgho, CNPMS) was founded in 1978 and established in the state of Minas Gerais, on the edge of the Cerrados. At the same time, expansion of maize area into other regions prompted state research systems to become involved in maize research, leading to the creation of many research institutes similar to IAC. However, there was a policy of encouraging private sector activity in seed industries, with the implied role for public research institutes being to complement the activities of the private sector. In fact, many of the materials developed by state research institutes are improved OPVs oriented to small-scale, resource-constrained farmers, while the private sector emphasizes medium- and large-scale farmers in the Southeast and South. The CNPMS, however, has been able to develop highly successful maize hybrids with wide adaptation, including adaptation to regions traditionally dominated by the private sector. Many hybrids and varieties were released in the early 1980s and were relatively successful among both small-scale seed production firms and farmers' cooperatives.

The major objective of the CNPMS was to develop maize germplasm adapted to the marginal production regions of the North, Northeast, and the Cerrados, regions then of little interest to the private sector. Growing conditions in the Northeast have proven very difficult, and progress in developing improved maize germplasm has been slow. The CNPMS has been more successful in the Cerrados, especially in developing germplasm tolerant to the acidic soils common in this region. By 1990, the CNPMS had developed 25 varieties and hybrids, mostly in collaboration with the International Maize and Wheat Improvement Center (CIMMYT), with which it established close relations almost from the beginning (López-Pereira and Morris 1994). Of these 25 improved varieties, 20 are OPVs and five are hybrids, reflecting the heavy emphasis on population improvement.

Many state research institutes have collaborative maize breeding programs with the CNPMS, which emphasize the development of OPVs adapted to local or regional conditions (see Sorj and Wilkinson 1990). Still other state institutes and universities have maize breeding programs that are independent of the CNPMS. The most important of these are IAPAR (Instituto Agronómico do Paraná), EMGOPA (Empresa Goiana de Pesquisa Agrícola), ESALQ in São Paulo, the Universidade Federal de Rio Grande do Sul (UFRS), and Viçosa University. Cooperatives are another important element in the Brazilian maize seed industry. Several cooperatives employ maize breeders who test the materials developed by the CNPMS and other public research institutions, and they release varieties for their members.

In summary, the public sector played a crucial role in helping to develop the maize seed industry during its early years. As the industry matured and became self-sustaining, the role of the public sector became increasingly complementary to that of the private sector. Today, the public sector produces and markets very little commercial seed, but it still plays an important role in maize breeding, conducting strong programs at the CNPMS and in some state research institutes and universities.[5]

Consolidation of the Private Seed Sector and Regulatory System

The emergence of the private sector was supported by legislation that enabled private companies to prosper by producing and marketing seed of public materials. The arrival of multinational companies in the maize seed market, with all their financial and genetic assets, increased competition among private companies, although Agroceres and, later, Cargill retained a sizable share of the market. By 1993, about seven private maize seed companies supported by foreign capital, Agroceres, and about 45 smaller national companies, in addition to many very small regional cooperatives and individual farmer-producers, sold maize seed.

The Brazilian system for regulating the seed industry is composed of the institutions and guided by the statutes listed in Table 10. The seed law passed in 1977 and the seed regulation law passed in 1978 are the main mechanisms for regulating seed production, although each state has its own seed certification system and other regulatory agencies preside over phytosanitary requirements and certification for inter-state seed flows and exports. Compared to the seed law of 1965, the 1977 law and 1978 regulation include more detailed and specific rules for the fiscal and phytosanitary supervision of plant breeding and seed production and marketing. The 1977-78 legislation created certification agencies and the National Seed Commission (CONASEM), which have brought more dynamism and efficiency to the industry. Brazilian seed producers are organized into the Associação Brasileira dos Produtores de Sementes (ABRASEM), which has a powerful influence on seed legislation and regulations. A new seed law is currently under discussion in the Brazilian Congress and, if passed, will include plant variety protection regulations.

Interestingly, the maize seed industry in Brazil has become highly competitive based on relatively low seed prices. For example, the ratio of the price of a double-cross hybrid to the price of commercial maize grain was about 11:1 in 1993, and the ratio of the price of an improved OPV to the maize grain price was about 7:1. These ratios compare to a seed:grain price ratio of about 35:1 for single-cross hybrids in the US and higher in Europe

[5] It should be noted that the maize seed industry is a special case and that for other crops, such as wheat, the public sector and cooperatives dominate seed production and distribution as well as breeding (Jacobs and Gutiérrez 1986).

(López-Pereira and Filippello 1994). Moreover, in the early years of industry growth, seed:grain price ratios were lower. Even private sector hybrid seed sold at a ratio of less than 4:1 (see Table 11), while in the US the seed:grain price ratio in the 1960s averaged 13-15:1 (Byerlee and López-Pereira 1994). These differences in seed price may be explained at least partially by the high seed yields obtained in the traditional seed-producing regions in the country, the relatively lower labor costs, the highly competitive seed sector, and maize farmers' price-sensitivity, which allows for very low profit margins. Competition in the private seed sector is believed to have increased in the maize seed market after the successful introduction of the public hybrid BR-201, which is marketed by a consortium of small private seed companies under contract with EMBRAPA and the Basic Seed Production Service (SPSB) (see below).

Table 11. Hybrid maize seed prices in Brazil in the 1960s

	Maize seed:grain price ratio	
Year	Public seed ompany	Private seed company
1960	2.5	2.7
1965	3.3	3.9
1967	3.1	3.5

Source: Based on Silveira (1984).

Table 10. Maize seed industry organizations and regulations in Brazil

Organization/regulation	Name
National association of seed producers (ABRASEM)	Associação Brasileira dos Produtores de Sementes
State Associations of seed producers	One in each state (e.g., Associação dos Produtores de Sementes de Minas Gerais)
National seed regulatory body	Comissão Nacional de Sementes e Mudas (CONASEM)
State seed regulatory bodies	Comissões Estaduais de Sementes e Mudas (CESMs) (One per state)
National seed trade regulatory body	Ministerio da Agricultura, Serviço de Defensa Sanitaria Vegetal
Federal public research institution	EMBRAPA-CNPMS
Federal public seed company	EMBRAPA-SPSB (sells only basic seed of public materials)
State-level research institutes	IAC, IAPAR, EPAMIG, EMGOPA, and others
Current seed law and regulatory decree 81771, July 7 1978)	Lei de Sementes e Mudas (Lei No. 6507, December 19, 1977). Regulamenta a Lei No. 6507 (Decreto No.
Plant variety protection	Not allowed
Types of maize seed	Genética (genetic), básica (basic), registrada (registered), certificada (certified)

Note: The full names of these organizations can be found in the list of acronyms at the beginning of this paper.

Maize seed imports are virtually banned in Brazil, since domestic production has exceeded demand in the last several years. Although there are no official statistics on maize seed exports, some seed is exported to neighboring countries, especially to Bolivia and Paraguay, where the maize seed industry is not well developed.

The maize seed market in Brazil has made a complete transition in the last 30 years with respect to the participation of public and private sector organizations in seed production and marketing (Table 12). In the 1960s, the public system in the state of São Paulo produced about 50% of the maize seed in the country, and by 1980 this share was less than 10%. In 1993, the public sector accounted for only 2% of the commercial seed distributed in the country. It should be noted, however, that an important proportion of the seed marketed by the private sector was of public origin.

In the last 12 years, the maize seed market seems to have reached a plateau in Brazil. Total seed production has remained at or above 115,000 t (Table 12), and the two largest private seed companies have controlled more than 50% of the market. A consortium of small private companies, called UNIMILHO, has been able to capture a sizable share of the market, estimated at 15% in 1993 (F.J. de Almeida, pers. comm.).

In summary, the Brazilian maize seed industry is one of the most sophisticated in the world, and it is certainly the largest and most sophisticated in the developing world outside of China. Brazil's strong, competitive private sector seems to meet the needs of all farmers who demand maize seed (with the great exception of the North and Northeast). Through the years, the public sector has modified its role in the industry. It has gone from being the sole player in the industry to adopting a complementary position, encouraging competition in the private sector and especially supporting the participation of the domestic private sector. The large national and multinational private seed companies rely on their own breeding programs for the development of hybrids, and the smaller seed companies produce and market hybrids and varieties developed by the public sector. For example, many of the smaller seed companies, who target mainly small-scale farmers, rely on the CNPMS, IAC, and other public organizations for production and marketing of improved OPVs and hybrids. State research organizations and cooperatives follow the same philosophy of conducting research for marginal maize producers.

Table 12. Trends in maize seed production by public and private organizations in Brazil, 1960-93

Year	Total seed production (000 t)	Private sector share of sales (%)
1960/61	9.8	50
1970/71	47.3	70
1980/81	114.8	92
1990/91	120.0	96
1992/93	121.7	98

Source: Based on Silveira (1984); Sorj and Wilkinson (1990); interviews with public and private sector officials in 1992; CIMMYT maize seed industry survey, 1993.

History of Maize Breeding in Mexico

Initiation of Maize Breeding Research, Seed Regulations, and the Rise of the Private Seed Sector

Although the first agricultural experiment station in Mexico is believed to have been established in 1906, the first attempts at systematic agricultural research started around 1933, when the General Bureau of Agriculture established the Department of Experimental Stations (Pardey, Roseboom, and Anderson 1991). It is not clear if any maize research was done then, but by the early 1940s formal maize breeding research had probably started. In 1943, the Government of Mexico and the Rockefeller Foundation created the Office of Special Studies (Oficina de Estudios Especiales, OEE) as a research branch of the Ministry of Agriculture (Wellhausen 1950). Initially the OEE emphasized training Mexican scientists and conducting maize and wheat research; later, other crops were added to the research mandate. One of the first tasks of the OEE was to collect maize races, identify them, and improve them for the development of varieties. By 1949, two improved varieties had been released, Rocamex V-21 and Rocamex VS-101 (Roberts et al. 1949).

In 1947, the Institute of Agricultural Research (Instituto de Investigaciones Agrícolas, or IIA), a public organization, was created to centralize the agricultural research being done by the Department of Experiment Stations, with the OEE supporting crop research and personnel training (Matus Gardea, Puente González, and López Peralta 1990). The IIA specialized almost exclusively in maize and bean research. Recognizing the need to improve maize production in Mexico, the government formed the Maize Commission (Comisión del Maíz) in 1947, with the main objective of developing and distributing improved maize seed to farmers in Central Mexico. This was the first formal attempt to produce and distribute improved maize seed in Mexico. Two years later, the Maize Commission was renamed the National Maize Commission (Comisión Nacional del Maíz), thereby providing a national institutional framework for improving Mexican maize production.

In the 1950s, the government gave strong support to agricultural production, investing heavily in irrigation infrastructure. In 1960, the IIA and OEE were combined into the National Institute of Agricultural Research (Instituto Nacional de Investigaciones Agrícolas, INIA). This institute was one of a new generation of national agricultural research institutes created in Latin American countries with financial and technical support from US agencies and foundations (Pardey, Roseboom, and Anderson 1991; Polanco-Jaime 1991). Up to this point, the maize seed sector was very small, and no legislation regulated seed production. Virtually all agricultural research in Mexico was done by public organizations. The private sector was not active in breeding maize or producing and marketing seed, but from 1943 to 1970 IIA, OEE, and later INIA developed approximately 65 improved varieties and hybrids (Table 13).

Table 13. Relative emphasis on the development of open-pollinated and hybrid maize varieties by INIFAP, Mexico, 1940-90

Period	Total number of materials released	Percent OPVs	Percent hybrids
1942-50	23	56	44
1951-60	35	46	54
1961-70	7	29	71
1971-80	48	56	44
1981-90	34	71	29
Total	**147**	**56**	**44**

Source: CIMMYT maize varietal releases database.

The shape of the maize seed industry was further defined in the 1960s as the first seed law was passed (Polanco-Jaime 1991; Diario Oficial de la Federación 1961); the National Maize Commission became the National Seed Producing Enterprise (Productora Nacional de Semillas, PRONASE); and research priorities at INIA were modified to emphasize the development of hybrid maize. Under the new seed law, enacted in 1961, several regulatory bodies were established to control crop research and seed certification, production, and marketing. Officially, all research was controlled by the Ministry of Agriculture and Water Resources (Secretaría de Agricultura y Recursos Hidráulicos, or SARH) through INIA, and any private sector initiative was monitored closely. The creation of PRONASE, with its mandate to produce and distribute commercial seed of all varieties developed by INIA, created a quasi-monopoly in the seed industry, which limited and delayed the private sector's participation in research and seed production. Although it was not very clearly stated in the seed law of 1961, in effect registration and seed certification were prerequisites for private companies to sell seed. Seed certification was the responsibility of the Certification and Inspection Service (Servicio Nacional de Inspección y Certificación de Semillas, SNICS) (Barkin and Suárez 1983). The agricultural credit system gave preference to public organizations by linking the approval for loans to specific technological packages defined by the public research system. The tight control of the private sector and the monopoly power enjoyed by the public sector in Mexico contrast strongly with the situation in Brazil, where private sector initiatives were encouraged when they first started to develop in the 1950s. Even so, the 1960s saw the first sign of activity by private seed companies and cooperatives in Mexico (the latter especially in the Northwest), and by the end of the decade, several national and multinational seed companies operated in addition to PRONASE. These multinational companies mostly imported foregin materials for testing in Mexico or they imported commercial seed for sale.

The public research scene changed as the OEE and INIA split once again, in 1966. The OEE became CIMMYT, which was to dedicate its efforts exclusively to maize and wheat on a global basis, and INIA retained its broad research mandate for Mexico, which included maize breeding research. The two institutions continued to collaborate closely, especially in wheat breeding. For maize breeding, the main result of dividing INIA and the OEE was that INIA emphasized the development of improved OPVs of maize rather than hybrids (Barkin and Suárez 1983). At the beginning of the 1970s, CIMMYT too changed its strategy to emphasize the development of OPVs. This decision was based on the perceived needs of the CIMMYT Maize Program's main clients — maize farmers in developing countries — and on the awareness that maize seed industries in most parts of the developing world could not yet reliably deliver hybrid seed to farmers. These changes in emphasis are evident in Table 13, which presents trends in the types of maize released by the Mexican maize breeding system (see Table 3 for the relative importance of OPVs and hybrids released in developing countries in 1966-90).

Consolidation of the Private Seed Sector

By the end of the 1980s, the maize seed industry was firmly established. Although PRONASE remained the main player, multinational companies participated actively in the industry. National private companies and cooperatives participated in the industry to a lesser extent, especially in seed production, marketing, and imports (from the southern US).

Several special events and circumstances contributed to the rapid growth of the maize sector and especially the seed industry in the 1980s. The Mexican Food System Program (Sistema Alimentario Mexicano, SAM) implemented substantial subsidies aimed at increasing the production of basic food grains, particularly maize and beans, which led to a considerable increase in the use of improved maize seed. Both PRONASE and the private sector (largely with imported seed) benefited from increased seed sales. The collapse of international oil prices marked the onset of a deep economic crisis in Mexico. The capacity of the public sector (including PRONASE) to adapt and deliver services effectively was weakened. Financial support for the National Institute of Research on Forestry, Agriculture, and Livestock (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, INIFAP), formed in 1985 by combining all research branches of SARH, deteriorated markedly in the 1980s (Polanco-Jaime 1991). The end of the decade saw a new initiative to form a free trade zone in North America among Canada, Mexico, and the US.

To prepare for greater private sector involvement in the economy and less restrictive regional trade, the Mexican government made a series of changes in the constitution which directly affected the agricultural sector, including a new seed law and regulation and much more open and unrestricted participation of the private sector in agricultural research (particularly in seed production and marketing). Participation by multinational seed companies was openly allowed and the role of PRONASE was curtailed with respect to maize seed sales. Moreover, INIFAP was allowed to distribute its improved varieties through the private sector, especially small national seed companies, and not just through PRONASE, on the basis of payment for basic seed. (PRONASE was not required to pay for basic seed before 1991.)

The new seed law, passed in 1991 (Diario Oficial de la Federación 1991), and its regulatory decree, passed in 1993 (Diario Oficial de la Federación 1993), are much more flexible towards research by the private sector, unless that research involves transgenic materials. The new law allows companies to market seed based on their own liability and guarantee of quality without going through the official certification process. Seed can be certified by private organizations or individuals.[6] Mexican seed producers have also organized themselves into the Mexican Seed Producers Association (AMSAC), which participates very actively in seed industry regulation. As part of its efforts to revamp the agricultural sector and the economy in general, Mexico is debating whether to join the UPOV (International Union for the Protection of New Varieties of Plants) and considering plant variety protection legislation (discussed later in this paper).

All these events, combined with high guaranteed producer prices for maize relative to other crops and the consequent increase in maize area in Mexico in the late 1980s and early 1990s, led to greater private sector participation in the maize seed industry and a corresponding reduction of PRONASE's share of the maize seed market. Although privatization substantially changed public and private sector participation in maize seed production and sales, the resulting maize seed bonanza may not last much longer. Gradual liberalization of

[6] See Appendix B for more details on Mexican policy reforms affecting the agricultural sector, especially the maize seed industry.

the maize market, following the implementation of NAFTA in 1994, will lead to a reduction of guaranteed producer prices and a corresponding reduction of maize area in favor of other crops. The industry seems to be entering an uncertain period that may take a few years to run its course.

It should be emphasized that the public sector is still a major player in maize breeding research in Mexico. The National Maize Institute (Instituto Nacional del Maíz), based at Antonio Narro University in the northern state of Coahuila, has a strong maize breeding program that has developed and released several maize varieties and hybrids, which are produced and marketed by several small-scale private companies. Maize breeding at CIMMYT is not especially oriented towards Mexican conditions, but the germplasm developed at CIMMYT is used by INIFAP and many other public and private seed organizations in their breeding activities. Several collaborative breeding projects exist between INIFAP and CIMMYT. Unlike Brazil, in Mexico no state institutes (with the exception of the universities) are involved in agricultural research, because all agricultural research is coordinated by INIFAP. Under the new seed legislation, some national private companies have initiated modest testing programs using mainly public germplasm from INIFAP and CIMMYT as a starting point for developing their own varieties. The multinational companies have increased their investment in breeding research in Mexico substantially. Several of them already market hybrids they developed in Mexico.

Table 14 lists the main organizations and regulatory bodies shaping the Mexican maize seed sector today. Table 15 provides historical data on seed produced by public and private organizations. Two main features of the industry can be seen in Table 15: the recent growth in seed production and the private sector's dominance in maize seed production and marketing.

Table 14. Maize seed industry organizations and regulations in Mexico

Organization/regulation	Name
National association of seed producers	AMSAC
State-level associations	Nonexistent
National seed regulatory bodies	SNICS; Comité Consultivo de Variedades de Plantas (CCVP); Registro Nacional de Variedades de Plantas (RNVP)
State seed regulatory bodies	Comités Técnicos de Semillas (COTESES) (not in all states)
National seed trade regulatory body	SARH, Departamento de Sanidad Vegetal
Federal public research institution	SARH-INIFAP
Current seed law and regulatory decree	Ley sobre Producción, Certificación y Comercio de Semillas decree (September 15, 1991). Reglamento de la Ley sobre Producción, Certificación y Comercio de Semillas (May 26, 1993)
Plant variety protection	Under discussion
Types of maize seed	Original (original), básica (basic), registrada (registered), certificada (certified), verificada (verified)

Note: The full names of these organizations can be found in the list of acronyms at the beginning of this paper.

In summary, the maize seed industry in Mexico, long controlled by public sector organizations, is in transition. Private sector initiative is increasing and public organizations have redefined their roles across the industry, from breeding to seed production and distribution to regulation. Although responding to different forces, the seed industry in Mexico seems to be following a route similar to that taken by the Brazilian industry about 30 years ago, with increasing liberalization of the research system and a redefined role for public research organizations.

Analysis of the Maize Seed Industries of Brazil and Mexico

Whereas the previous section of this paper described the evolution of the maize seed industries of Brazil and Mexico, in this section we take a closer look at the current structure of the maize seed industries in each country.

Table 15. Trends in maize seed production by public and private organizations in Mexico, 1970-93

Year	Total seed production (000 t)	Private sector share of sales (%)
1970/71	8.5	13
1980/81	30.1	22
1990/91	22.1	54
1992/93	40.0	91

Source: Based on Matus Gardea, Puente González, and López Peralta (1990); Polanco Jaime (1991); Barkin and Suárez (1983); interviews with public and private seed sector officials in 1992; CIMMYT maize seed industry survey, 1993.

Getting maize seed from experimental plots to farmers' fields is a lengthy process in which many different actors participate. The flows of breeding materials to and from public and private organizations and their clients are depicted in Figure 8. Local maize varieties and landraces are part of the genetic reservoir that public and private breeding organizations draw upon to develop new, improved OPVs and hybrids. These improved materials are tested and subjected to a varietal release process. After a variety is approved for release, seed can be produced, conditioned, and distributed to farmers.

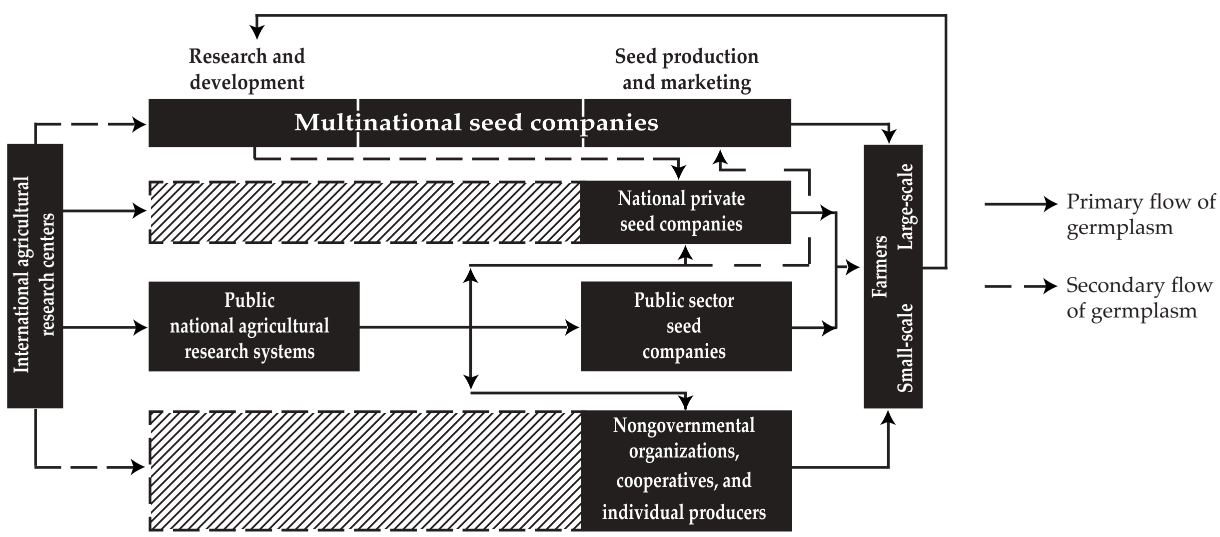


Figure 8. Framework for viewing public and private sector interactions in maize seed industries.
Source: Adapted from Byerlee, Morris, and López-Pereira (1993).

Each of these functions can be performed by different actors: multinational seed companies; national private seed companies; other entities, including NGOs, cooperatives, individual farmer/seed producers; national public research and seed production organizations; and the IARCs. Which actors are involved and the functions they perform depend on the degree of development of the industry. The IARCs, such as CIMMYT and the International Institute for Tropical Agriculture (IITA), develop basic noncommercial maize germplasm products, including improved populations, OPVs, and inbred lines, which are made available to public and private research organizations free of charge (see López-Pereira and Filippello, 1995, and López-Pereira and Morris, 1994, for more details on the CIMMYT Maize Program). The public NARSs often combine materials from IARCs with local materials, selecting varieties and hybrids for local release after extensive evaluation. The NARSs may offer germplasm to private organizations for a fee and/or produce and distribute commercial maize seed directly through public seed companies. Multinational seed companies usually develop their own (proprietary) hybrids. Commercial seed of these hybrids is usually produced by the multinational or by private national companies under contract, subject to royalty agreements. Private national companies may also produce their own materials or use materials developed by the public research system. Seed cooperatives, NGOs, and individual farmer/seed producers also produce improved seed developed by public sector organizations, for sale mostly to small-scale farmers.

In 1993, the Brazilian maize seed industry was composed of the organizations presented in Table 16. Although the participation of the private sector in R&D is very strong, private organizations are not as pervasive in R&D as in production and marketing, because the CNPMS and other public organizations have full breeding programs. With the exception of some seed of improved OPVs and hybrids that is sold by public organizations such as IAC, commercial seed — including the materials developed by the CNPMS — is largely produced and marketed by private companies. In recent years, the private sector accounted for 98% of the maize seed produced and sold in Brazil (Table 17).

Private sector organizations were responsible for about four-fifths of the total estimated investment in maize breeding of US$ 17.0 million in 1992 and employed 72 of the 110 maize breeders (Table 18). The private sector had 118 maize hybrids on the market in 1992, compared to only 9 from the public sector (Table 19). Almost half of the public materials were improved OPVs. These figures can be compared to an investment of US$ 115 million in maize breeding in the US in 1990; the US industry had 641 maize breeders in the private sector and 72 in the public sector (Byerlee and López-Pereira 1994).

The maize seed industry in Mexico in 1993 was structured somewhat differently than the Brazilian industry (Table 20). It was composed of the organizations presented in Table 20. One important difference between the seed industries of the two countries is that public organizations in Mexico retain a strong influence on R&D and also seed production and marketing (Table 17). Maize research at INIFAP, the national research institute, is organized by region, and 55 researchers work on maize breeding , compared to a total of 34 in the private sector (Table 21). Public organizations account for about 40% of the US$ 8 million invested in maize breeding. In addition, several universities have breeding programs (Table 20), although only one has commercial hybrids on the market.

Another important difference between the Brazilian and Mexican seed industries is the relatively limited participation of NGOs and cooperatives in maize seed production and marketing in Mexico. In Brazil, cooperatives and NGOs produce and market seed, especially of improved OPVs, and some cooperatives hire maize breeders to test public materials. Public organizations have retired almost completely from seed production and marketing in Brazil. Moreover, although public R&D remains important in Brazil, private R&D dominates the industry, with multinational and several national companies supporting strong breeding programs.

Table 16. The maize seed industry in Brazil by type of organization and activity, 1993

Type of organization	Seed research and development	Seed production and marketing
Public sector		
Research institutes		
EMBRAPA-CNPMS	X	..
EMBRAPA-SPSB	..	X[a]
IAC (São Paulo)	X	X
SAVE (Rio Grande do Sul)	X	..
EMGOPA (Goias)	X	X
OCEPAR (Paraná)	X	X
IAPAR (Paraná)	X	..
Universities		
Viçosa	X	..
ESALQ/USP	X	..
Other public[b]	X	..
Private sector		
Multinational companies:		
Cargill	X	X
Braskalb	X	X
Pioneer	X	X
Germinal	X	X
ICI	X	X
Domestic companies:		
Agroceres	X	X
Dinamilho	X	X
Colorado	X	X
Agromen	X	X
Grao de Ouro	X	X
UNIMILHO[c]	..	X
Others	..	X
Social sector		
Cooperatives (e.g., Cotrijui, Cotia)	X	X
Producers associations	X	X

Note: Research and development (breeding) and commercial seed production and marketing (commercial maize seed imports are not allowed in Brazil). Full names of acronyms are listed at the beginning of this paper.

[a] EMBRAPA markets its maize hybrids and OPVs through the private sector, principally the UNIMILHO group. The SPBS coordinates this activity.

[b] Includes other state research and extension institutes and universities conducting maize research.

[c] UNIMILHO is an association of private seed companies producing and marketing EMBRAPA maize hybrids under a franchise system. Some UNIMILHO companies have modest breeding programs.

Privatization of maize seed production and marketing is well advanced in Mexico. The system in which the public sector sells basic seed to the private sector for the production and marketing of commercial seed is still evolving, but it is likely to become an important vehicle for diffusing improved seed developed through public R&D, which has happened in more developed seed industries. Private sector R&D in Mexico, however, remains largely in the hands of multinational companies. Only a handful of national private seed companies have R&D programs (Table 21); these are very modest and rely on public research organizations (mainly INIFAP and Antonio Narro University) for parent seed.

Table 17. Private sector share (%) of maize seed sales in Brazil and Mexico, 1985-86 and 1992-93

	Private sector share of total maize seed sales		
	Open-pollinated varieties	Hybrids	Total
Brazil			
1985-86	91	97	96
1992-93	92	98	98
Mexico			
1985-86	43	63	54
1992-93	83	92	91

Source: CIMMYT (1987); estimates by authors, based on interviews with seed organization representatives in Mexico and Brazil.

As in Brazil, in Mexico hybrids developed by the private sector dominate the maize seed market. In 1992, 78% of all the materials marketed in Mexico were proprietary (Table 22). Interestingly, the private sector in Mexico appears to be further along in moving from double-cross hybrids to three-way and single-cross hybrids than in Brazil. Over 60% of all proprietary hybrids marketed in Mexico were three-way, single-cross, or modified single-cross hybrids, compared to only 21% in Brazil. Also, national private companies accounted for 50% of the improved OPVs on the market, which indicates a substantial investment in population improvement by the private sector.

Table 18. Investment in maize breeding by public and private organizations in Brazil, 1992

Type of organization	Total investment in maize breeding (US$ millions)	Number of maize breeders		
		B.Sc./M.Sc.	Ph.D.	Total
Public organizations				
EMBRAPA/CNPMS	1.3	7	4	11
Other public[a]	1.5	14	13	27
Total	2.8	21	17	38
Private organizations				
National private companies	6.1	25	6	31
Multinational companies	8.1	38	3	41
Total	14.2	63	9	72
Total Brazil	**17.0**	**84**	**26**	**110**
Private sector participation (%)	**84**	**75**	**35**	**65**

Source: Interviews with officials in public and private sector; CIMMYT Global Maize Research Impacts Survey, 1990.
[a] Includes other state-supported research institutes.

Finally, the degree of industry concentration for the maize seed sectors of Brazil, Mexico, and the US is presented in Table 23. The share of the maize seed market held by the four largest companies in the US fell from 57% to 51% between 1981 and 1991, indicating increased competition and a larger share of the market for the rest of the (many small) seed companies. The same downward trend was seen in the market share held by the eight largest seed companies. The figures for the US indicate that competition for market share is keen even in mature industries, and smaller seed companies have some scope to increase their presence in the industry. The large geographical area where maize is produced in the US encourages small companies to specialize in hybrids adapted to small regions. The hybrids produced by large companies, which are intended to have a wider adaptation, often do not compete effectively in these regions.

Summary indicators for maize seed industries in Brazil, Mexico, and the US allow us to compare the degree of development of their maize seed industries (Table 24). In some instances, the Brazilian maize seed industry closely resembles the US industry, especially in average costs per maize breeder and number of maize breeders per million tons of maize seed sales. The Mexican industry is at variance with the US in most categories, although it resembles the US in one important indicator of industry performance, namely the R&D investment as a percentage of total value of seed sales. The share of maize breeders in the Mexican private seed sector was much lower than in Brazil and the US in 1992.

The large maize area in South and Southeast Brazil would lead one to expect that, as in the US, many small regional companies would compete effectively with the industry leaders for market share. Brazil has more than 100 maize seed companies (López-Pereira and Filippello 1994), but the four largest controlled 66% of seed sales in 1992, down from 70% in 1981, mainly because of the large market share of the two largest seed companies. Together, these companies have held over 60% of the market for many years. This situation may change, however, if the UNIMILHO group continues to capture larger shares of the market by selling EMBRAPA hybrids.

Table 19. Commercial maize seed — open-pollinated varieties (OPVs) and hybrids — marketed in Brazil, by type of seed organization, 1992

		Number of hybrids			
	Number of OPVs	**Double cross**	**Other conventional[a]**	**Non-conventional[b]**	**Total**
Public materials	8	5	1	3	17
Proprietary (private) materials					
Multinational seed companies	0	48	21	0	69
Private domestic companies	1	41	4	3	49
Total proprietary	1	89	25	3	118
Total Brazil	**9**	**94**	**26**	**6**	**135**
Percentage proprietary (private)	**11**	**95**	**96**	**50**	**87**

Source: CIMMYT maize varietal database.

[a] For example, single-cross, three-way, modified single-cross, and modified three-way hybrids.

[b] For example, top-cross hybrids, varietal hybrids.

In Mexico, the market share held by the four largest companies fell from 90% to 83% between 1981 and 1992. Moreover, PRONASE, the largest seed company in 1981, was not among the four largest companies in 1992, which reflects the recent changes in agricultural policy in Mexico. However, over the same period the total share held by the eight largest companies did not change substantially (from 93% to 90%), which suggests that the largest seed companies captured the market left by PRONASE. Within the private seed sector, the multinational companies have a majority control in seed sales, with only a handful of

Table 20. The maize seed industry in Mexico by type of organization and activity, 1993

Type of organization	Seed research and development	Seed production and marketing	Seed trade
Public sector			
Research institutes			
INIFAP	X	..	..
PRONASE	..	X	..
Universities			
UAAAN	X	X	..
Universidad Autónoma Chapingo	X	..	..
UNAM	X	..	..
Colegio de Postgraduados	X	..	..
UANL	X	..	..
ITESM	X	..	..
Universidad de Guadalajara	X	..	..
Private sector			
International companies			
Semillas Híbridas	X	X	X
Híbridos Pioneer de México	X	X	X
Asgrow Mexicana	X	X	X
Cargill de México	X	X	X
Northrup King y Cia.	X	X	X
CERES Internacional	X	X	X
Domestic companies			
Semillas TACSA	X	X	X
ASPROS Comercial	X	X	..
Semillas Conlee Mexicana[a]	..	X	X
AAALPES/Berentsen	..	X	..
Semillas Correa	X	X	..
Semillas Máster de México[a]	..	X	X
Semillas WAC de México[a]	..	X	X
Semillas Agrícolas Mexicanas[a]	..	X	X
Cia. Beneficiadora del Bajío	X	X	..
Semillas Calber[a]	..	X	X
Others[b]	..	X	..
Social sector			
Patronatos	..	X	..
Producers' unions	..	X	..

Note: Full names of acronyms are listed at the beginning of this paper.

[a] These companies started modest breeding programs in 1992/93.

[b] Includes many small regional private companies and individual farmers producing and selling public (INIFAP) OPVs and hybrids.

national private companies selling more than 100 t of seed. The full effects of the reduction in PRONASE's market share will be seen in the next three to five years, when R&D investment by the private sector results in increased competition. An important factor in the Mexican seed sector is seed imports, which averaged 4,000 t per year in the 1980s (see Matus Gardea, Puente González, and López Peralta 1990). Most of this seed was brought in by multinational companies.

A summary of the main characteristics of the maize seed industries in the two countries is presented in Table 25. The industries are at different stages of development. The Brazilian seed industry seems to be entering a stage in which the private sector dominates both R&D and seed production and marketing and in which three-way and single-cross hybrids start to appear on the market. This was the situation of the US seed industry in the early 1960s.

Table 21. Investment in maize breeding by public and private organizations in Mexico, 1992

Type of organization	Total investment in maize breeding (US$ millions)	Number of maize breeders		
		B.Sc./M.Sc.	Ph.D.	Total
Public organizations				
INIFAP	2.8	42	3	45
Others	0.5	8	2	10
Total	3.3	50	5	55
Private organizations				
National private companies	0.7	10	0	10
Multinational companies	3.8	19	5	24
Total	4.5	29	5	34
Total Mexico	**7.8**	**79**	**10**	89
Private sector participation (%)	**58**	**37**	**50**	**38**

Source: Interviews with officials in public and private sector; CIMMYT Global Maize Research Impacts Survey, 1990.
Note: Full names of acronyms are listed at the beginning of this paper.

Table 22. Commercial maize seed — open-pollinated varieties (OPVs) and hybrids — marketed in Mexico, by type of seed organization, 1992

		Number of hybrids			
	Double Number of OPVs	Other cross	Non-conventional[a]	conventional[b]	Total
Public materials	5	9	8	5	27
Proprietary materials					
Multinational seed companies	0	21	47	3	71
Private national seed companies	5	6	13	2	26
Total proprietary	5	27	60	5	97
Total Mexico	**10**	**36**	**68**	**10**	**124**
Private sector share (%)	**50**	**75**	**88**	**50**	**78**

Source: CIMMYT maize varietal database.
[a] For example, single-cross, three-way, modified single-cross, and modified three-way hybrids.
[b] For example, top-cross hybrids, varietal hybrids.

The Brazilian industry has become stable: market growth has reached a plateau, public sector organizations participate in the industry with activities that are complementary to private sector activities, and private companies, both national and multinational, are engaged in keen competition for market share. The Mexican industry, on the other hand, has entered a stage of rapid growth precipitated by policy changes favorable to the private sector.

Table 23. Maize seed industry concentration in the US, Brazil, and Mexico, 1981 and 1992

	Total maize seed production (000 t)	Market share of 4 largest companies (%)	Market share of 8 largest companies (%)
US			
1981	591	56.9	67.1
1991	584	51.4	62.5
Brazil			
1981	115	70.2	89.6
1992	120	66.0	84.0
Mexico			
1981	31	90.0	93.0
1992	40	83.0	90.0

Source: Estimated from Silveira (1984); Matus Gardea, Puente González, and López Peralta (1990); McMullen (1987); interviews with public and private seed sector officials in Brazil, Mexico, and the USA in 1992.

It is interesting to note one feature common to both countries. Relatively large regions of maize production have not been served by the seed industry — the North and Northeast in Brazil and the highland and southern regions of Mexico (Maps 1 and 2). The industry has generally concentrated on the regions with better growing conditions, relatively large-scale maize farmers, and higher yield potential (see Table 26 for Brazil). In Mexico, private sector organizations are looking at these previously unattended regions as possible sources of industry growth.

Factors Influencing Seed Industry Performance

Many factors affect seed industry performance and structure. In this section we discuss some of the most important factors, with special reference to the seed industries of Brazil and Mexico.

Table 24. Research investment intensity by public and private sector organizations in Brazil, Mexico, and the US, 1992

	Brazil	Mexico	US
Total maize breeders (no.)			
Public sector	38	55	72
Private sector	72	34	641
Country	110	89	713
Maize breeders in the private sector (%)	65	38	90
Average cost per breeder (US$ 000s)			
Public sector	74	60	n.a.
Private sector	197	132	n.a.
Country	154	88	157
R&D investment as share of total value of seed sales (%)	12	9	8
Maize breeders per million ha maize (no.)	8.7	12.4	25
Maize breeders per million t maize production (no.)	4.4	6.1	4.0
Maize breeders per thousand t maize seed sales (no.)	0.9	2.2	1.1

Source: Interviews with seed company officials and CIMMYT survey.
Note: n.a. = data not available.

R&D and the Time Required to Develop Maize Germplasm

One indication of the efficiency of a seed industry is the cost of producing maize seed and the resulting seed price. A general rule that is applied to seed production costs and prices in efficient, developed seed industries is that no more than 50% of the total seed price should reflect seed production and conditioning costs; the rest should reflect R&D costs, overhead, marketing, and gross margin (Figure 9).

Table 25. A comparison of the maize seed industries of Brazil and Mexico

Description	Brazil	Mexico
Total commercial seed production, 1992 (000 t)	115	40
Parastatal seed production company? (yes/no)	No	Yes
State research institutes? (yes/no)	Yes	No
Universities doing research? (yes/no)	Yes	Yes
International private seed company? (yes/no)	Yes	Yes
Number of private maize seed companies		
National	73	15
Multinational	5	6
Cooperatives/producers' associations	25	5
Value of commercial seed (US$ millions)	140	86
R&D share of sales (%)	12	9
Public sector participation in commercial seed production (%)	3	9
Participation of multinational companies in hybrid seed sales (%)	40	80
Price of commercial maize seed (1992) (US$/kg) (seed: grain price ratio)		
Open-pollinated varieties	0.70 (6.7)	1.75 (7.2)
Double-cross hybrids	1.10 (10.5)	2.58 (10.7)
Three-way hybrids	1.75 (16.7)	3.23 (13.3)
Price of maize seed controlled? (yes/no)	No	No
Price of commercial maize grain (US$/t)	105	242
Price of maize grain controlled? (yes/no)	No	Yes

Source: Based on CIMMYT maize varietal database and surveys of public and private sector organizations in Brazil and Mexico.

Table 26. Improved maize seed adoption in Brazil by region, 1992-93

	North-Northeast	South-Central	All Brazil
Maize area (million ha)	2.6	9.7	12.3
Total seed demand (000 t)[a]	52.0	195.0	247.0
Commercial seed sales (000 t)			
Open-pollinated varieties	6.3	7.3	13.6
Hybrids	0.5	107.8	108.3
Total seed sales	6.8	115.1	121.9
Area under improved, commercial seed (million ha)[a]	0.3	5.7	6.0
Improved seed adoption (%)	13.1	58.8	49.1

Source: CIMMYT world maize seed industry survey, 1993.

[a] Assuming an average seed rate of 20 kg/ha for both OPVs and hybrids.

Research and development is a costly and time-consuming phase of seed development and production. Years of painstaking work are required to develop an improved variety or hybrid. The research time varies considerably, depending on how much and what kind of basic germplasm is available, and on the degree to which it has already been improved and adapted, especially if the germplasm has been developed through a selfing program.[7]

Maize breeders at public and private organizations have estimated that depending on the type of basic germplasm available it may take as long as 12-14 years to develop a good commercial hybrid and 5-6 years to develop a good OPV (Table 27). These estimates are based on the assumption that a small germplasm base is the starting point and that minimum facilities and qualified personnel are available. Estimates by Brazilian and Mexican breeders of the financial costs of setting up and running a modest breeding program were in the range of US$ 0.5-1.5 million.

Maize scientists were also asked to estimate the time it would take to develop a good commercial inbred line if they had access to all the germplasm available at public national and international research institutions. Responses varied, but in general they ranged from six years if S_4 lines were available to only four years if highly homozygous lines (S_8) were available. The time needed for developing improved seed also will vary according to the environment for which selection is being done and the type of material being developed. Single-cross hybrids take less time to develop, since only two inbred lines are necessary, compared to double-cross hybrids, which require four lines with good combining ability. Another important factor is the number of crosses made per growing cycle, as the chances of developing good inbred lines are proportional to the intensity of the breeding effort.

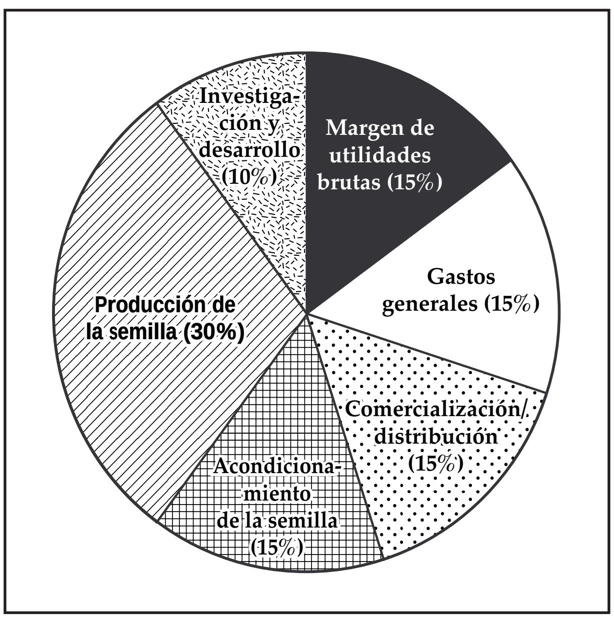


Figure 9. Typical breakdown of the price of hybrid maize seed.
Source: Pioneer Hi-Bread Internatinal (1992); Sehgal (1992).

The breeding effort is simplified as the number and complexity of the target environments are reduced. The number of testing sites can also be reduced if materials are developed for climatically homogeneous areas. In Mexico, many research stations are usually necessary for a breeding program to cover a significant maize-producing region. Even if a breeding program concentrates only on the irrigated and high-potential areas, several stations are needed because of the different altitudes of these areas (elevation influences the types of materials needed). The maize-producing regions in Brazil are more homogeneous; most of the highly productive areas are concentrated in the Southeast and South (Table 8). Although maize area in Brazil is about twice as large

[7] A plant that has been "selfed" has undergone self-pollination.

as in Mexico, relatively few stations are needed to cover large maize-producing regions. Materials developed there show wide adaptability and their development costs can be recovered faster.

The development of materials with wide adaptation is preferred since the number of materials to be developed is reduced and seed production becomes more cost-effective when these material are available. Materials with wide adaptation are also beneficial to farmers as the production risks are reduced. A good example of a successful material with wide adaptation is a double-cross hybrid developed by the CNPMS in Brazil, BR-201. In addition to showing high yield potential under varying management regimes, this hybrid has good tolerance to acidic soils and to drought, making it adaptable to much of the principal maize regions in Brazil, including the acidic soils of the Cerrados. As a result, BR-201 is the single most successful hybrid on the Brazilian market, planted on about 0.8

Table 27. Time required (years) to develop seed of open-pollinated varieties (OPVs) and different types of hybrids, with and without availability of public germplasm

		Inbred lines for:		
	OPVs	**Single-cross hybrids[a]**	**Three-way hybrids[a]**	**Double-cross hybrids[a]**
If public collections not available[b]				
Collection/classification	1	1	1	1
Improvement/adaptation	2	3	3	3
Selfing	..	2	3	4
Testing				
General and specific combining ability		2	2	2
Seed production ability		1	1	1
Adaptation in target regions	2	2	2	2
Total	**5**	**11**	**12**	**13**
If public collections available[c]				
Obtain public material/classify	1	1	1	1
Improvement/adaptation	1	1	1	1
Selfing		1	2	3
Testing				
General and specific combining ability		1	1	1
Seed production ability		1	1	1
Adaptation in target regions	2	2	2	2
Total	**4**	**7**	**8**	**9**

Source: Interviews with breeders from CIMMYT and private companies in Brazil and Mexico.
Note: Assumes that materials used to start the breeding program are adaptable to the region for which OPVs and hybrids are being developed and that two selection cycles per year are possible. Does not include highland areas, where only one cycle of selection per year can be done.

[a] The development of inbred lines for all types of hybrids is done simultaneously. Lines are developed without a specific objective and then the decision is made to use them in single-cross, three-way, or double-cross hybrids, depending on their characteristics.

[b] Assumes the breeding program starts with collections of landraces and improved materials other than those at public germplasm banks.

[c] Assumes public germplasm bank materials and other materials are readily available and that these can be brought into the country easily and legally.

million hectares in the 1992-93 crop year. As we will discuss later in this paper, the investment made in developing this hybrid has provided a high rate of return, given the widespread area over which it is planted.

Maize scientists estimate that, on average, a mature breeding program should develop at least two commercially successful inbred lines every three years. This would be the minimum required, given the costs of running research programs, advances in competitive breeding programs, and the need to renew the line of products on the market every five to seven years. It has also been estimated that in advanced maize seed industries it costs about US$ 0.5 million to develop a commercial inbred line when all costs are included (T. Little, pers. comm., 1992). Usually seed companies estimate a certain percentage (in the range of 5-10%) in the price of commercial seed as R&D costs (Figure 9), which includes the development and the estimated market life of the hybrids.

Although most private and public organizations in many countries have one or more outstanding cultivars which have been on the market for 15 years or more, the estimated average life of a material on the market is about nine years from the time of release to the last year in which it is sold. The process includes release and introduction/promotion (two to three years), full-scale production (three to four years), and decline/phase-out (three years). The main reasons for taking a material off of the market are related to changes in farmers' preferences, emerging susceptibility to biotic stresses, or the development of higher yielding materials by the company or its competitors.

Two additional factors affect the time and financial cost involved in developing improved seed. The first is the fact that a large number of materials enter a breeding program but only a few make it as successful commercial inbred lines or varieties (one scientist interviewed for this study characterized breeding as a "wasteful science"). Plant breeders estimate that of every 10,000 crosses originally made, probably 100 promising lines are developed after many cycles of testing and selection, and of these only about three will eventually become part of a commercial hybrid. The effort needed to identify a few outstanding lines places a heavy cost burden on breeding programs, especially small programs with limited resources, since the key to success is to increase the scale of breeding activities, i.e., to increase investment.

The second factor affecting the time and cost of developing improved seed is related to the first. Once a good inbred line or population is developed, it can be used in many ways to combine with other good lines to form hybrids or to develop new OPVs (in the case of populations). It is not uncommon for a whole product line of an organization to be based on relatively few outstanding lines. In the US, an important portion of the single-cross hybrids on the market has a narrow genetic base (that is, they are derived from a few outstanding inbred lines).

Organization size and access to financial resources thus strongly influence the time and financial cost of developing improved maize germplasm, especially the breeding research necessary to develop parental material. The time and capital resources for developing a breeding program may be prohibitive to many small companies lacking capital reserves.

Large national and multinational companies that can provide this capital to subsidiaries in developing countries may have an advantage over small local companies. However, if the public research system allows small (and large) companies to access its germplasm and technology, small companies may be able to get established and compete in the market by initially producing and selling public materials and targeting specific regional markets.

In countries with strong seed industries, public research institutes have played a key role in providing seed companies with the germplasm and technology they need to establish themselves in the market. The arrangement appears to be the same in many countries; the only difference is that now many public research organizations charge for the use of public germplasm. This system is well implemented in Brazil, and Mexico's INIFAP started selling basic seed of maize materials to private companies and even to PRONASE (Table 28 shows details of public basic seed prices and royalties in Brazil and Mexico). The availability of public germplasm from both national and international organizations can substantially reduce the time, effort, and costs entailed in starting a maize breeding program. If a company has just been formed and wants to start developing improved maize seed "from scratch," the minimum starting point would be the germplasm available from public institutions (that is, if the company has access to this germplasm). Although in some cases germplasm from national programs is not freely available to the private sector, basic seed of improved OPVs and hybrids developed by these institutions is made available to the private sector to produce and market commercial maize seed, thus providing a source of research capital for small companies just starting in the industry.

Highland maize breeding — A specific example of how public R&D can save time and financial resources for private sector organizations is the highland maize program at CIMMYT, which started in 1985. Highly homozygous inbred lines have been developed by this program since 1992. Realizing that the time they would need to release good materials has been shortened by the availability of this advanced public germplasm, private companies have become interested in starting highland maize breeding programs. Before this breeding program was initiated, private companies, both national and multinational, were not interested in highland environments because of the time required to develop materials adapted to the many microclimates in these areas. Now they see a possibility of

Table 28. Prices of basic seed and royalties paid by private companies for production and marketing of public maize varieties and hybrids in Brazil and Mexico, 1993

	Brazil	Mexico
Seed of improved open-pollinated varieties		
Price of basic seed (multiple of commercial seed price)[a]	10	5
Royalties on seed sales (%)	..	5
Hybrid seed		
Price of basic seed (multiple of commercial seed price)	20	7
Royalties on seed sales (%)	5	5

Source: Interviews with public and private seed sector officials in Mexico and Brazil.

[a] For example, if the commercial seed price of a double-cross hybrid is US$ 1/kg, the private company pays US$ 20/kg of the single-cross parents to produce the commercial seed in Brazil and US$ 7/kg in Mexico.

entering an untapped market — 2.9 million hectares of maize, or a potential 58,000 t of seed — with a much reduced investment of time and financial resources. Likewise, INIFAP has long had a breeding program for the Mexican highlands, from which several OPVs and hybrids have been developed. Several regional seed companies produce these materials for sale to farmers in highland areas. A crucial role for public institutions that has been identified in other seed industry studies (e.g., Jaffee and Srivastava 1992; Cromwell, Friis-Hansen, and Turner 1992) is to conduct initial research in difficult environments for private companies. Recognizing the great value of public germplasm in reducing the time needed to develop commercial products, private organizations in Brazil and Mexico traditionally have incorporated public germplasm into their own breeding programs. Although it is difficult to estimate, the amount of public germplasm used by private companies is substantial (López-Pereira and Morris 1994).

Public-private sector alliances in Brazil's maize seed industry — A second example of how public research benefits the private seed sector is the EMBRAPA-UNIMILHO hybrid seed program in Brazil. In 1987, EMBRAPA (CNPMS) developed BR-201 (described earlier), the first of a series of double-cross hybrids with outstanding characteristics, including wide adaptation, high yield performance, and tolerance to acidic soils. At this time the primary source of growth in maize production in Brazil was the expansion of maize area in the Cerrados, where the private sector's activities in the seed industry were modest. Then EMBRAPA developed a project in which private companies would produce and distribute seed of EMBRAPA's maize hybrids, beginning with BR-201. A supervisory committee was formed to select companies to participate in the program. These companies would purchase basic seed (the single crosses) to produce commercial seed of BR-201 under the technical supervision of EMBRAPA. The committee was composed of officials from EMBRAPA/CNPMS and the SPSB of EMBRAPA.

Seventeen small, regional seed companies were selected for the program, and the first commercial seed of BR-201 was produced in 1987. A modest 900 t of seed were sold in 1988. Problems with quality control surfaced, so EMBRAPA and the private companies decided to implement tighter standards for commercial seed production. Companies that did not meet quality standards were expelled from the group and other companies accepted in their place. By 1990 the companies in the program had organized themselves into a consortium called UNIMILHO, with the objective of enforcing higher quality standards as well as coordinating basic seed purchases from EMBRAPA and promoting BR-201. This strategy turned the program around, and sales of BR-201 increased dramatically in the following three years. By 1993, some 18,000 t of commercial seed of BR-201 were sold, and UNIMILHO had captured about 17% of the maize seed market. The UNIMILHO group has become the third largest maize seed producer in Brazil and BR-201 the single most widely used hybrid (Table 29).

Competition in the private sector has increased with the entry of 25 companies into the maize seed market, which has resulted in more options for maize farmers and lower prices for hybrid seed. The highly successful arrangement has also benefited EMBRAPA, which has received increased revenues from sales of the single crosses as well as royalties from gross seed sales. This appears to be an optimal situation, in which public sector research not only generates its own funds but also increases competition through the production and marketing of its hybrids by private companies. Farmers also benefit from low seed prices and good service. In turn, the private companies have benefited by not having to invest in R&D and yet managing to compete in the seed market with a successful hybrid.

However, this situation has provoked controversy, mainly among large seed companies. Although EMBRAPA does not prevent any company from entering the UNIMILHO group if it has the technical capacity to produce seed, large companies contend that the inbred lines, which are the product of investment in public research, should be freely available to anyone, including the large companies. Both EMBRAPA and UNIMILHO respond that large companies are welcome to join the system, as long as they abide by the rules (purchasing parent seed from EMBRAPA and paying royalties), something that the large companies, with large investments in breeding programs, are not interested in doing. Their interest lies in obtaining public inbred lines for their own breeding programs and developing proprietary materials to compete with BR-201. Despite this continuing controversy, the EMBRAPA-UNIMILHO alliance has nevertheless become stronger. They have established a special breeding project within the CNPMS to develop hybrids to replace BR-201. Two of these hybrids are already on the market, and small amounts of seed were sold in 1993 (Table 29). Two additional single-cross hybrids have been included in recent yield trials and should be released within the next three years.

To capitalize on the success of the BR-201 program, EMBRAPA has established a franchise system to produce and market some of the outstanding improved OPVs that the CNPMS has developed. One of these OPVs is BR-106, the most widely used improved OPV in Brazil. Under this system, cooperatives become franchisees for producing and marketing seed of BR-106, using parent seed provided by EMBRAPA-SPSB. Breeders at EMBRAPA-CNPMS will continue to improve BR-106 and each year the product of another breeding cycle will be available as basic seed. In 1993 Cycle 9 was available, and EMBRAPA claims that 25 franchisees produced about 10,000 t of BR-106 seed for the 1994-95 crop year. With this system EMBRAPA hopes to reach small-scale farmers who use local seed or recycle seed of improved OPVs and even hybrids for several seasons, making high quality, certified seed of OPVs available at low prices.

Table 29. Number of private seed enterprises participating in UNIMILHO, and sales of BR-201 seed in Brazil, 1987-93

Year	Number of companies	Sales of BR-201 (t)	UNIMILHO market share (%)
1987[a]	17	..	..
1988	24	923	0.9
1989	26	5,745	5.2
1990	28	12,646	11.0
1991	25	13,561	11.3
1992	25	15,000	15.0
1993	27	18,000 [b]	16.5 [b]

Source: EMBRAPA-CNPMS and EMBRAPA-SPSB.
[a] Commercial seed production started in 1987, sales in 1988.
[b] Expected for the crop year 1993/94.

Production and Conditioning Costs of Maize Seed

Production costs of different seed types depend primarily on the seed output per unit area and the costs of detasseling (López-Pereira and Espinosa 1993; López-Pereira and Filippello 1994b). Production costs are highest for single-cross hybrids, followed by three-way crosses and double crosses. On the other hand, the commercial grain yield potential increases as the number of inbred lines used decreases, since the greatest degree of heterosis is achieved in the formation of single-cross hybrids (only two inbred lines). The general ranking of yield potential for the different maize genotypes is lowest for local varieties and increases from improved OPVs to nonconventional hybrids, double crosses, three-way crosses, and finally single crosses. The size of the yield differential varies with the environment, management practices, and the genetic makeup of the material (CIMMYT 1987). Although the yield difference between single-cross hybrids and improved OPVs may be 30% or more under the optimal growing conditions usually found in temperate regions, these differences may be smaller in many regions of the developing world, where tropical and subtropical environments dominate. Lower production costs, easier protection of proprietary lines, and greater adaptability to low management conditions are the main reasons that double-cross hybrids are preferred in developing countries.

After maize varieties and hybrids have been developed, the most important factor determining their market price is seed production costs. These costs are in turn determined by the yield obtained from the seed crop, the additional production activities that each seed type requires, and the market price of commercial maize grain. Since inbred lines are usually highly homozygous and often yield little because of inbreeding effects, hybrids whose seed-producing (female) parent is an inbred line (as in single-cross hybrids) will have low seed yields and high production costs. In three-way hybrids, the inbred line normally serves as the pollen parent and a single cross as the seed parent; in double-cross hybrids, both parents are single crosses. Although the level of heterosis is not as high in double-cross hybrids as in single crosses, production costs are substantially lower because seed yields are substantially higher. Seed production costs of OPVs are the lowest of all, as seed yields are similar to the yields of commercial OPV crops. For a hybrid to be attractive for seed production, seed yield has to be at least high enough to cover development, production, processing, and promotion costs and to provide some return to the investment.

The second element in seed production costs is the difference in special requirements for the seed crop, especially the difference in producing seed of OPVs versus hybrids. The most important difference is the additional cost of detasseling required in hybrid seed production. Detasseling can comprise as much as 15% of total production costs in double-cross hybrids (CIMMYT 1987). The cost of parent seed can vary as well (both the R&D costs involved in developing parent seed and the costs of producing it). Parent seed of OPVs is relatively inexpensive, as it can be obtained fairly easily compared to parent seed of hybrids, especially single-cross hybrids. In developing countries parent seed and detasseling costs are estimated to represent 7% of the production cost of OPV seed and 22% of the cost of producing double-cross hybrids, whereas in the US these two items represent 39% of the cost of producing single-cross hybrids (CIMMYT 1987). In Mexico, for example, parent seed and detasseling costs are 11% of the production cost of OPVs and 20% of double-cross hybrids. Interestingly, costs of basic seed in Brazil are much lower than in Mexico, comprising only about 8-9% of total seed production costs for OPVs and double-cross hybrids.

Production costs of hybrids are also higher than for OPVs because part of the seed production area is occupied by plants that will not produce seed (the pollen parent). The proportion of male rows (pollen parents) can be as high as 33% (for a 4:2 F:M ratio), which is common in producing seed of single-cross hybrids, or 25% (12:4 F:M ratio), common for double-cross hybrids. In OPV seed production all plants serve as both pollen and seed producers. In the case of double-cross hybrids, the pollen-producing parent can be harvested for grain and sold commercially at market prices or given to the contract grower as part of the payment, which helps to reduce seed production costs. For single-cross and three-way hybrids, this is more difficult to do, because the pollen parent is an inbred line and the company will try to protect it from competitors. Thus the male inbred lines are usually eliminated just after they have fulfilled their role as pollinators.

The final important factor in seed production costs is the price of commercial maize grain in a country or region. In countries where maize grain prices are very high, seed production costs are high relative to costs in countries where maize grain prices are low. In Mexico the official price of maize is about US$ 242/t,[8] whereas in Brazil the price of commercial maize grain in 1992 was about US$ 105/t, indicating that seed production costs were much lower in Brazil than in Mexico. This difference was reflected in commercial seed prices.

Other incentives offered by seed companies to contract growers include the provision of technical assistance, parent seed, and the costs of detasseling. In Brazil and Mexico, as in many other countries, the seed crop is often produced under contract with maize farmers ("contract growers"), especially in the case of large seed enterprises. Growers receive a predetermined price for the seed crop, based on the price of commercial maize grain. The seed production contract usually stipulates that the farmer will receive the parent seed and manage the crop according to company specifications and requirements. At harvest time, the company will pay the farmer the value of the crop at the market or guaranteed commercial grain price plus a premium. This premium varies across countries and even across regions in a given country. It also depends on the gross yield of the crop. In Brazil, for example, the premium for double-cross hybrids ranges from 40% to 60%; in Mexico the premium for double-cross hybrids is about 80%. In the case of single-cross and three-way hybrids, companies usually offer a minimum yield level over which the premium is paid, since seed yields for these hybrids are normally low. The premium offered for OPVs is substantially lower, in the range of 20-40%, depending on seed yield.

Examples of the differences in total production costs for seed of OPVs and double-cross hybrids in Mexico and Brazil are presented in Tables 30 and 31. Production costs for seed of double-cross hybrids are about 30% higher than for seed of OPVs, and the total cost of producing the hybrid is reduced substantially when the pollen-producing parent also produces high grain yield. Attractive margins can be gained in seed production and marketing. Production costs of hybrids, when the seed parent is high yielding, allow for even higher gross margins. Taking into account average prices for maize seed in Mexico and Brazil (Table 32) and production and processing costs per kilogram (Tables 30 and 31), it would appear that gross margins of 100% are not uncommon in the industry. These margins are substantially higher for hybrids, reaching 200% for double crosses and even higher for three-way and single-cross hybrids. For private companies selling proprietary materials,

[8] The official price of maize in December 1992 in Mexico was MxP 750,000/t, which at an exchange rate of MxP 3,100/US$ 1 is equivalent to US$ 242/t.

Table 30. Seed production costs for open-pollinated varieties (OPVs) and hybrids, Brazil

		Costs of OPV seed	Costs of double-cross hybrid seed
Basic seed (US$/ha)[a]		150	440
Production costs (US$/ha)		523	873
Total production costs (US$/ha)		673	1,313
Gross yield (grain, kg/ha)			
Male		..	1,485
Female		5,700	3,015
Seed yield (kg/ha)[b]		4,000	2,412
Discarded grain (kg/ha)[c]		1,700	2,088
Total processing costs (US$/ha)		678	422
Total production and processing costs (US$/ha)		1,351	1,735
(Minus) value of discarded grain (US$/ha)[c]		179	219
Net production and processing costs	(US$/ha)	1,172	1,516
	(US$/kg)	0.29	0.63

[a] Basic seed price based on prices charged by EMBRAPA: OPVs at 10 times the price of commercial seed and hybrids at 20 times the price of commercial hybrid seed. Average prices used for commercial seed in these estimates is US$ 0.7/kg for OPVs and US$ 1.1/kg for hybrids.

[b] Seed yield after processing is assumed at 70% of gross yield for OPVs and 80% of gross yield of the female parent for hybrids.

[c] Discarded grain of the OPV and the female parent of hybrid plus yield of the male parent, valued at the price of commercial maize grain of US$ 105/t.

Table 31. Seed production costs for open-pollinated varieties (OPVs) and hybrids produced by small private companies, Mexico

		Costs of OPV seed	Costs of double-cross hybrid seed
Basic seed (US$/ha)[a]		194	452
Production and other costs (US$/ha)		1,534	1,785
Total production costs (US$/ha)		1,728	2,237
Gross yield (grain, kg/ha)			
Male		..	1,900
Female		4,500	3,900
Net seed yield (kg/ha)[b]		3,000	2,600
Discarded grain (kg/ha)[c]		1,500	3,200
Net processing costs (US$/ha)		929	828
Total production and processing costs (US$/ha)		2,657	2,965
(Minus) value of discarded grain (US$/ha)[c]		605	774
Net production and processing costs	(US$/ha)	2,052	2,291
	(US$/kg)	0.68	0.88

[a] INIFAP sells basic seed of OPVs at 5 times the price of commercial OPV seed and basic seed of hybrids at 7 times the price of commercial hybrid seed. Average prices for commercial seed used in these estimates are MX$ 6,000/kg for OPVs and MX$ 10,000/kg for hybrids. Exchange used was MX$ 3,100 = US$ 1.

[b] Seed yield after processing is assumed at 66% of gross grain yield for OPVs and 66% of gross yield of the female parent for hybrids.

[c] Discarded grain of the OPV and the female parent of hybrid plus yield of the male parent, valued at the official guaranteed price of MX$ 750,000/kg (Oct. 1992).

these margins should be enough to cover R&D costs as well as marketing, promotion, and overhead. When the company purchases parent seed from a public institution, these costs are reduced as there is no investment in R&D (as in the example in Table 30), and thus there is an implicit subsidy by the public sector of these private companies.[9]

Contrary to conventional wisdom, the data in Tables 30, 31, and 32 suggest it can be profitable to produce and market improved OPV seed, even if the frequency of sales is only every two to three crop seasons, as opposed to every crop season for hybrids. In Mexico, the average price of commercial OPV maize seed was about US$ 1.61/kg in 1992. The production, processing, and financial costs of this seed were only US$ 0.68/kg, for a gross margin of 136%. In hybrid seed production, commercial seed prices averaged about US$ 2.60/kg, and production costs were only US$ 0.90/kg, for a gross margin of 190%. It should be noted, however, that the seed was processed by plants belonging to Mexico's parastatal seed production company (PRONASE), so there were no fixed costs for recovering the investment that would have been necessary if this processing service had not been available. In Brazil, the price of OPVs was US$ 0.70/kg and total production costs were about US$ 0.27/kg, for a net profit of 159%. Production costs of double-cross hybrids are

Table 32. Maize grain and seed prices charged by public and private seed companies in Brazil and Mexico, 1993

Company and seed type	Seed price (US$/kg)	Seed:grain price ratio[a]
Brazil		
Public seed companies		
Open-pollinated varieties	0.48	3.8
Public hybrids	0.57	4.6
Private national companies		
Open-pollinated varieties	0.75	6.0
Public hybrids	1.15	9.2
Proprietary hybrids	1.23	9.8
Multinational seed companies		
Proprietary hybrids	1.33	10.6
Mexico		
Public seed companies		
Open-pollinated varieties	1.37	5.7
Public hybrids	2.74	11.3
Private national companies		
Open-pollinated varieties	1.77	7.3
Public hybrids	3.55	14.7
Proprietary hybrids	3.74	15.4
Multinational seed companies		
Proprietary hybrids	4.13	17.1

Source: Survey of private and public seed companies in Brazil and Mexico, 1993.
[a] Based on maize grain prices of US$ 0.125/kg for Brazil and US$ 0.242/kg for Mexico.

[9] As discussed below, however, this subsidy can be reduced when public sector organizations charge private companies a price that includes part of the R&D costs involved in developing the materials.

about US$ 0.36/kg and commercial seed prices US$ 1.10/kg, for a 200% profit margin. Although price and cost structures in these two countries are different, opportunities for high returns on the seed investment are very similar and at relatively low seed:grain price ratios (e.g. 10:1 for double-cross hybrids), suggesting that this may also be the case for seed industries in general, regardless of price policies, wages, land values, and other factors.

The relative differences in costs by the type of hybrid being produced can be seen in Table 33. Differences in detasseling costs and net seed yield comprise the bulk of the increase in production costs of three-way and single-cross hybrids relative to double-cross hybrids. Note that the differences in production costs by type of hybrid may vary across regions, depending (for example) on the ratios of male to female rows used. In Brazil, production costs are generally 17% greater for three-way hybrids than for double crosses, and about 83% greater for single crosses. The Brazilian example points to the importance of developing inbred lines capable of providing high net seed yields, since this will allow the production of three-way and single-cross hybrids at a lower cost (López-Pereira and Espinosa 1993). In Table 34, the cost structures for maize seed production are compared for Brazil, Mexico, and India, a country which has a fairly sophisticated seed industry. The structure of maize seed production costs in the three countries is remarkably similar, despite differences in the size and sophistication of the industries. Note the similarity between these cost structures and that of Figure 9.

In conclusion, these examples highlight the important role that the private sector can play in producing and marketing OPV seed and show the scope for this activity to be profitable. This role is most likely to be played by small-scale regional companies or individual farmers covering small areas to reduce marketing and transportation costs. Public institutions appear to have a potentially critical function of opening markets and industries to domestic private enterprise in many developing countries. Mexico's new seed legislation

Table 33. Relative costs of producing different types of hybrids in Brazil

Cost item	Double-cross hybrid	Three-way hybrid	Single-cross hybrid
Ratio of F:M rows	12:3	9:3	6:3
Detasseling costs (%)	100	125	166
Seed yield (kg/ha)[a]	2,240	2,100	1,400
Production costs per kg	0.045	0.060	0.119
Double-cross hybrid = 100	100	133	266
Other costs (equal for all hybrids)	100	100	100
Total	200	233	366
Total production costs of hybrids	100	117	183

[a] In producing seed of double-cross hybrids, the male parent is allowed to produce commercial grain, which is then sold in the market, thus reducing total seed production costs. In the case of three-way and single-cross hybrids, the male parent (an inbred line) is usually harvested after pollination to protect the line and no commercial grain is obtained.

has allowed many small private companies to produce public varieties and hybrids for regions long ignored by large national and multinational seed companies, which consider these regions unattractive segments of the market. In Brazil, the public maize research and seed system has provided basic seed for years to small private companies for the production of OPVs and hybrids. Judging by the apparent success of these arrangements, they could become more important models for public-private sector interaction in developing countries, helping to generate funds for public research institutes, increase competition in the industry, and serve farmers previously overlooked by seed companies.

Marketing and Distribution Costs and Pricing Strategies

Marketing and distribution costs include promotion, discounts, storage, and shipment of seed to distributors. Seed companies usually assign a percentage of the total seed price for marketing and distribution costs, just as they do with R&D costs. However, marketing and distribution costs vary substantially among companies. In general, when competition is more intense, companies have to invest more resources to emphasize their products' advantages over competitors' products — for example, by holding field days. Another strategy is to provide better customer service, such as technical assistance and free seed. Hence marketing and distribution costs normally constitute a high proportion of the total price of seed in highly competitive seed industries compared to industries dominated by one large enterprise. Other factors affecting marketing and distribution costs are related to the geographical distribution of the farmers served by the enterprise and the average size of their maize fields. Seed delivery costs increase if farmers are more dispersed (more outlets must be established) and if farmers require smaller quantities and thus smaller packages of seed.

In the case of maize seed, the quality of the product is not apparent until it is planted and the crop harvested. Seed is marketed on the basis of a company's or seller's prestige and the perceived value that the farmer places on purchasing new seed rather than retaining seed from previous harvests. Companies with a long-standing tradition of selling high quality hybrids can charge more for their products, as farmers expect (and usually obtain) extra benefits from them.

Table 34. Production and processing costs of double-cross hybrid maize seed for small private seed companies in Brazil, Mexico, and India, 1992

	Brazil		Mexico		India	
	Cost (US$/kg)	Percent of sale price	Cost (US$/kg)	Percent of sale price	Cost (US$/kg)	Percent of sale price
Basic seed[a]	0.18	16	0.20	12	0.08	14
Seed production	0.36	33	0.63	38	0.19	32
Seed conditioning	0.08	7	0.11	7	0.08	14
Total production and processing	0.62	56	0.94	57	0.35	60
Sale price of hybrid seed	1.10	100	1.66	100	0.58	100

Source: Surveys of seed companies in Brazil and Mexico; CIMMYT-Indian Agricultural Research Institute survey for India.

[a] Parent seed sold by public sector organizations to private seed companies. This cost can be considered part of the research and development cost for these companies.

Companies usually follow two basic strategies when pricing maize seed. The first is to set a single price for all types of hybrids regardless of their yield potential or relative production costs. This strategy is followed mainly to avoid the bookkeeping and extra paperwork required to track different prices. The price is usually set to cover all production costs, fixed costs, investment, recovery of R&D costs, and a profit margin. Several Mexican companies follow this strategy. The second strategy is to price hybrids according to their yield advantage over a standard, usually the average yield of the top competitor materials on the market.

A hypothetical example of this second strategy is presented in Table 35. In the example, a seed company finds that it can obtain a 25% share of the additional benefits that its hybrid offers to farmers relative to the average hybrids on the market. The company then charges US$ 0.28/kg more for its hybrid, or about 14%. The company can do this because the farmer will still be better off with the hybrid by obtaining an extra benefit of US$ 16.50/ha (75% of US$ 22.00) for an extra investment of only US$ 5.60/ha (US$ 0.28 * 20, assuming a seed rate of 20 kg/ha). This strategy of sharing the value added by improved seed 3:1 between the farmer and the seed company is followed by the leading companies in advanced seed industries in industrialized countries (Byerlee and López-Pereira 1994; Sehgal 1992.).

The data in Table 32 reveal the remarkable differences in prices charged for maize seed in Brazil and Mexico. (A historical view of prices charged by PRONASE and private companies for seed in recent years in Mexico can be seen in Figure 10; see Table 11 for past prices of maize hybrids in Brazil.) In Mexico the results of privatization and a higher guaranteed price of maize grain are reflected in substantial recent increases in the seed:grain price ratio by both public and private seed organizations. As noted earlier, however, at least some of the increased seed price can be attributed to improved service and seed quality as well as higher publicity and other costs, especially when the private sector participates more actively in the market relative to the public sector.

Table 35. Average-plus-share-of-value added pricing strategy for improved maize seed: the case of a double-cross hybrid

Item	Quantity	Price per kg (US$)	Total per ha (US$)
Seed cost (average for double-cross hybrids)	20	2.00	40.00
Average yield for double-cross hybrids (t/ha)	4.0		
Average yield of new hybrid (t/ha)	4.2		
Yield advantage and value added offered by new hybrid	200	0.11	22.00
Value of extra yield per kg of new hybrid seed		1.10	
Distribution of value added:			
Farmer (75%)		0.82	16.50
Seed company (25%)		0.28	5.50
Price of new hybrid: average double-cross seed price + share of value added		2.28	45.50

Making Demand and Supply Meet

One of the most important factors affecting industry performance, especially the performance of large seed companies, is the effectiveness with which they can predict the demand for maize seed. As we will see later, the demand for maize seed is determined by many factors, and maize farmers have several options regarding the type of seed they can use, including seed produced on the farm. In developed countries most maize farmers use commercial hybrid seed (López-Pereira and Filippello 1994). Maize area in these countries shows a long-term declining trend, but even so seed companies can count on a fairly predictable demand for seed.

In developing countries, maize production ecologies are quite different and a large proportion of the maize produced comes from small farms that use little commercial seed. A significant proportion of seed used in developing countries consists of improved OPVs, which represent an irregular market because farmers use OPV seed for several seasons. The demand for hybrid seed, the main product of the maize seed industry, is highly variable in developing countries and therefore difficult to predict. Although seed companies build some of the costs of carrying excess stocks into the price of seed, sometimes these stocks are greater than expected, and these provisions do not compensate for the losses. In Brazil, the demand for maize seed depends (among other things) on the availability of credit for the maize crop, which is determined by the federal government, and by the price of maize grain relative to the price of other commercial crops such as soybeans. For some time the Brazilian maize seed industry has had to carry over large stocks of seed from one year to the next. This translates into smaller returns or even losses for some companies, which have to sell excess seed stocks at less than cost or ship them to the Northeast, where they are also sold at very low prices. On the other hand, in Mexico over the past several years most private companies have sold all the seed that they have produced because the industry is expanding. Commercial farmers are demanding the best seed they can find to be able to compete in the North American maize sector (Appendix B). The industry is enjoying relatively large profits and expanding its R&D capacity, especially in the private seed sector (as discussed previously).

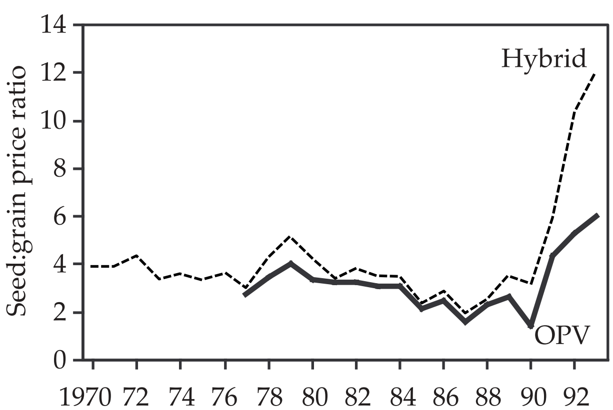


Figure 10. Price of maize seed in Mexico, 1970-93.
Source: SARH (PRONASE and Dirección General de Política Agrícola).

The Economics of Using Improved Seed

Regardless of how efficient and developed the seed industry may be from the supply side, farmers will not use improved seed if it is not profitable. The attractiveness of using improved seed from the farmer's viewpoint is an important element in industry performance, as it determines the demand for seed and the potential for growth in the industry. Many factors affect a farmer's decision to purchase seed. Information on the availability and characteristics of improved seed affects a farmer's knowledge of the new seed and access to it, as well as his or her perception of the risk involved in using it. Other factors influencing the decision to purchase improved seed include the difference in cost between the improved seed and the seed currently used, the yield advantage of improved seed over the current seed, access to capital and/or credit, and the cost of capital needed to finance the purchase of new seed.[10] Depending on their specific circumstances, farmers will weigh all of these factors and decide whether to continue purchasing improved seed of a given variety or hybrid, purchase commercial seed of a different variety or hybrid, or select grain from the previous harvest to use as seed.

The economics of replacing local seed with a new OPV or hybrid are very different from those of replacing one kind of improved seed with another. Farmers already using improved seed may have to choose between using the same improved (commercial) seed or replacing it with seed of a different variety or hybrid, or with a different type of hybrid (e.g., replacing a double-cross hybrid with a three-way hybrid). However, the most complex decision for a farmer regarding seed use is probably to switch from local seed produced on the farm to commercial seed produced and distributed by a seed company. This decision involves the highest degree of uncertainty and largest increase in seed costs, but it also promises the largest potential increase in benefits. Another important decision is to move from improved OPV seed to hybrid seed. Both of these decisions have implications related to the requirements of the crop planted with improved seed and the frequency with which the seed has to be purchased. Unlike local or improved OPV seed, hybrid seed cannot be reproduced on the farm from the previous crop, and it has to be purchased every time the maize crop is planted.

The decision over which kind of seed to use is also complicated because the benefits vary depending on what replaces what. In general, the greatest increase in benefits (and also in costs) comes with the switch from a local variety to an improved OPV or to a hybrid, where yield gains of 50% or more are common. When a farmer switches from an improved OPV to a hybrid, the yield gain and the benefits are smaller, probably no more than 25%. The smallest benefits are probably derived when farmers switch from an old hybrid or improved OPV to a new hybrid or OPV. These general observations should be qualified for situations in which local varieties perform exceptionally well and yield gains from improved seed are not so high, or situations in which an outstanding hybrid outperforms existing varieties and hybrids by a large margin.

One way to analyze the adoption of improved seed and take all these factors into account is to derive break-even yield curves for seed adoption. Break-even yield curves show the minimum yield advantage required from improved seed (relative to a given base yield) to compensate the farmer for the extra investment and the risks taken in using the seed (Figure 11). These curves illustrate two important characteristics of the economics of adopting improved seed. First, for a given seed price level, the yield advantage required from improved seed decreases as the current yield level increases. At very high current yield levels, the required yield advantage is less than 20% in most cases. Second, at

[10] More detailed analyses of the factors affecting the decision to purchase improved maize seed can be found in López-Pereira and Filippello (1994, 1995), López-Pereira and Espinosa (1993), and Byerlee, Morris, and López-Pereira (1993).

relatively low current yield levels, the required yield advantage of improved seed increases substantially as the price of seed increases. In the hypothetical example in Figure 11, a current yield level of 2 t/ha would require a yield advantage of slightly less than 20% if the seed:grain price ratio is below 10:1. In comparison, if the price ratio increases to 20:1, the yield advantage required to make changing varieties profitable to farmers increases to around 40%.

This analysis is supported by evidence from Brazil, Mexico, and other developing countries, where farmers who produce maize at low yield levels are more likely to adopt improved seed if seed:grain price ratios are less than 10:1. It also helps to explain how, as farmers' yields and incomes rise, smaller relative yield advantages are needed to make the use of improved seed attractive, even if seed prices increase. Moreover, this is a major economic reason why farmers in areas with favorable growing conditions are more likely to use improved seed and other inputs than farmers who produce maize under marginal growing conditions. Brazil and Mexico offer good examples of this characteristic, for most of the high-potential areas in these countries are already under improved seed, and in the more marginal maize production regions the use of improved seed is still very low (Table 9). To foster the use of improved seed in such areas, programs to develop and distribute improved seed at low prices are needed. The public seed sector has a crucial role to play in this regard by supporting small private seed companies and cooperatives.

The Roles of the Public and Private Sectors in the Seed Industries of Developing Countries

Although improved seed can be developed, produced, and distributed to farmers by public and/or private organizations, the optimal division of activities between the two types of organizations is not always clear. Given the great range of maize production circumstances in developing countries, with their multifarious agroclimatic and geographical conditions, farmer characteristics, maize uses, and agricultural policies, it is not surprising to find extreme variation in private/public participation in the maize seed industry.

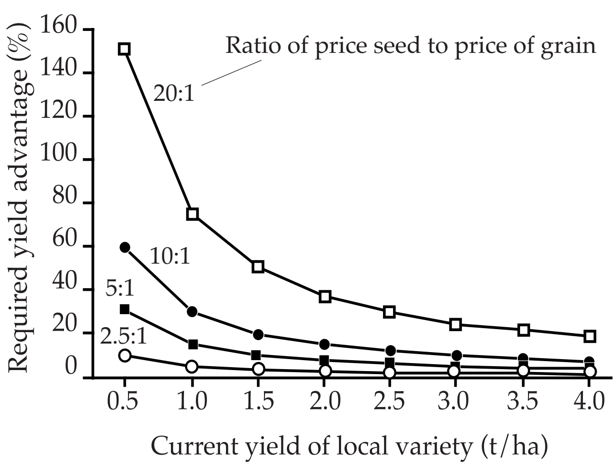


Figure 11. Required yield advantage over local seed to compensate for the additional cost of improved seed and provide a 100% return to investment, for different prices of improved seed and current yield levels.

In most cases the activities performed by the two sectors are complementary rather than competitive, but maize seed industries have evolved in a direction that places more responsibility in the hands of the private sector, especially in seed production and marketing (López-Pereira and Filippello 1994, 1995). Public organizations were central in the development of seed industries in industrialized countries because they assumed a substantial portion of the initial R&D investment, which was necessary to produce the breeding methodologies and improved germplasm that are now widely used by the private sector (Huffman and Evenson 1993). The great diversity of growing environments, maize farmers, and maize farming systems in many developing countries makes it less likely that the private sector can serve the needs of all farmers and remain profitable. Thus active public sector participation in maize R&D is still needed to complement private R&D and seed production and distribution. The public sector has two specific roles to play. Both are quite important in the maize seed industries of many developing countries.

- The public sector develops improved germplasm, inbred lines, or OPVs, thereby enhancing the competitiveness of private national seed companies and other small-scale seed organizations that produce and sell maize seed, and making it more profitable for private companies to produce seed for small-scale farmers in marginal environments.
- The public sector provides technical assistance and other support to small-scale seed producers to strengthen their ability to meet the needs of resource-poor farmers, or, alternatively, directly subsidizes private seed producers' efforts to develop and distribute OPVs and hybrids tailored to the needs of small-scale farmers.

As we have discussed earlier, when the industry reaches a stage at which private companies start to participate, at first these companies assume responsibility for seed production and marketing while the public sector supports them with breeding. The stronger and better managed private companies eventually develop their own breeding programs and become independent, producing their own improved varieties and hybrids. Another sign of development is the enactment of seed laws and regulations that allow private seed organizations to participate actively in the industry and permit multinational seed companies to enter the market, usually when the market is in an advanced stage of development and hybrid seed production is common.

Historically, it has been argued that in countries where maize is a staple food for an important part of the population (a case most applicable to countries in Latin America and Africa), the seed industry in all its stages should be under the control of government agencies and parastatal enterprises. This argument was usually based on food security reasons, since seed is an essential input for maize production (Pray and Ramaswami 1991). Government intervention has also been justified by the need to protect farmers from the excessive prices that private seed companies may be tempted to charge as a result of market failures, especially the high start-up costs that could result in highly concentrated industries.

Government intervention in the maize seed industries in developing countries ranges from complete control and official seed production monopolies (e.g., China) to minimal official controls and highly competitive seed industries (e.g., Brazil). Only a few studies have analyzed the effect of government intervention in maize seed industries (see Cromwell, Friis-Hansen, and Turner, 1992, for a recent study). Although Brazil, El Salvador, and

Thailand are examples of positive and effective government intervention in the maize seed industry, the experience in both developing and industrialized countries shows that heavy government intervention in the maize seed industry has generally hampered industry development[11] and that public involvement should diminish as the industry develops. It would appear that government intervention seems to be justified more by the need to promote industry competition than the need for the government to act as a competitor itself.

Table 36 indicates the level of involvement of public and private organizations in the maize seed industries of selected developing and industrialized countries. The public sector has a strong presence in R&D for hybrids and especially OPVs (where OPV seed is produced), but the presence of the private sector in seed production and marketing over the past 10 years in the developing world has increased. The private sector dominates seed production and marketing, even for OPV seed. (Note however that cooperatives and producers' unions are also important in seed production and marketing in some countries, such as Brazil and Zimbabwe.) In the specific case of Mexico, recent seed sales figures reflect the changes in seed legislation, with the private sector's share in both OPV and hybrid seed sales rising from about 50% in 1986 to 84% in 1992. In Brazil, the private sector has long dominated sales of seed, including OPVs; only a small percentage of sales comes from state research institutes in important maize-producing regions.

Table 36. Private sector share of maize seed sales in selected regions and countries, 1985-86 and 1992-93

Region/country	Number of countries	Private sector share of total sales (%)		
		Open-pollinated varieties	Hybrids	Total
Sub-Saharan Africa				
1985-86	11	57	95	83
1990-91	16	53	93	83
Asia[a]				
1985-86	11	69	38	39
1990-91	12	59	58	58
Latin America				
1985-86	13	70	96	92
1990-91	18	72	96	92
Latin America[b]				
1985-86	11	66	80	73
1990-91	16	75	90	82
Industrialized countries				
1985-86	7	100	100	100
1990-91	9	100	100	100

Source: CIMMYT (1987, 1990).
[a] Excludes China.
[b] Excludes Argentina and Brazil.

[11] This was the case in Mexico until a few years ago (Polanco-Jaime 1991; Echeverría 1990; Pray 1990), before the recently enacted seed regulation reduced the role of official agencies in the industry.

In countries with relatively small maize areas or with many diverse agroclimatic conditions that require substantial research for the development of maize varieties and hybrids, the role of the public sector may be very important, especially in the early stages of research. Market failures of the nature discussed above may prevent private enterprises from devoting adequate resources to the development of materials for regions with these characteristics. Therefore public investment in research may be necessary to develop seed technology for maize farmers there.

For seed industries at an intermediate stage of development, the government's central role may be to provide an environment conducive to the further development of the industry, encouraging competition among private companies based primarily on quality of products and service. This implies that the government should take the lead in research to improve germplasm for seed production and multiplication by the private sector; in providing training in seed production technology and the use of equipment; in providing basic infrastructure, credit, financial support, and an appropriate agricultural policy environment; and in conducting basic research and seed production for regions where market failures would limit the interest of private companies.

For well-developed seed industries, public sector involvement could consist of basic research by universities and agencies of the ministry of agriculture, coordination of quality control regulations, and the provision of services such as yield trials to private firms. This key role for the public sector has also been identified in other studies (Cromwell, Friis-Hansen, and Turner 1992). Results of research by public institutions would be in the public domain, accessible to all interested organizations, including large and small private companies. In some industrialized countries, seed technology has been developed and spread effectively when public materials are produced and marketed by private companies that pay a fee to the institution that developed them. This system has not only increased competition in the private sector but has served as an important source of funds for public agricultural research in times of scarce resources. Seed technology has also spread more effectively among small-scale farmers.

This discussion suggests that the most advantageous roles for the private and public sectors in maize seed industries are complementary rather than competitive. A scenario in which one or the other type of institution is completely excluded does not appear socially optimal. Experience also suggests that the roles of private and public organizations should evolve as the industry develops, until competition becomes the driving force in the industry and farmers are well served by an efficient industry dominated by private sector organizations.

In general, there is an important role for the government in maize seed industries because of the nature of the industry and the market failures that can occur. The type of role the government plays, and the extent of its intervention, depend on the degree of development of the industry and the kinds of maize farmers that form the potential clientele. The presence of a highly competitive private sector is similarly healthy for the industry. Public institutions, by definition, place less emphasis on efficiency of production and more on providing opportunities for farmers with more limited resources. Private companies must be more efficiency-oriented, so they tend to serve commercial farmers who have good access to resources. Efficiency and competition among private companies should result in the lowest possible seed price for farmers, and seed production and marketing should be placed in the hands of the private sector.

The Future of Maize Seed Industries

As seed industries develop into the next century, some issues are likely to become increasingly important, especially with the emergence of new biotechnologies and plant variety protection in developing countries. These issues are discussed below in general terms, with some reference to specific situations in Brazil and Mexico.

Biotechnology

It is generally agreed that in the foreseeable future molecular biology techniques will not replace conventional breeding methodologies but rather will make them more efficient and less costly. Byerlee (1994) describes two specific possibilities. First, the time required to develop superior materials can be reduced by using molecular markers and improved diagnostic tools that permit more precise selection of plants carrying genes for desirable traits (or rejection of plants possessing unwanted genes). These techniques would substantially reduce R&D costs. A second possibility is genetic transformation, the transfer of genes from unrelated species to provide traits that would not be available through conventional breeding techniques. The complexity of this process makes it likely that the first products will emphasize traits transferred through a single gene. Research on genetic transformation of cereal crops currently emphasizes pest resistance, herbicide tolerance, quality traits, and genetically induced male sterility to facilitate hybrid seed production (Byerlee 1994).

Much controversy surrounds the genetic transformation of maize for herbicide tolerance. Some argue that herbicide-tolerant materials will foster dependence on specific herbicides (e.g., Just and Hueth 1993); discourage reductions in herbicide use, especially in commercial maize production; and ultimately harm humans and the environment (e.g., Harrison, Jr. 1992; Duvick 1992; Wyse 1992). Others caution that herbicide-tolerant maize will favor commercial farmers over small-scale farmers (and laborers) who control weeds by hand (e.g., Hobbelink 1991). However, in some cases herbicide-tolerant maize may benefit both small-scale farmers and the environment. For example, some small-scale farmers in Mexico and Central America now use herbicides for land preparation and weed control in lieu of traditional slash and burn methods. This practice makes it possible to maintain a mulch of crop residues and weeds on the soil surface, which reduces erosion and improves moisture retention. However, these farmers typically use paraquat, a dangerously toxic herbicide. Maize varieties genetically engineered for tolerance to less toxic herbicides could encourage those farmers to use less toxic chemicals (Byerlee 1994).

The use of agricultural chemicals could be reduced substantially by the development of materials possessing genetic tolerance to insects and other pests, mainly through the incorporation of special *Bt* (*Bacillus thuringiensis*) genes and proteins. This approach is being emphasized by some private enterprises, national public organizations, and IARCs and is expected to benefit developing country farmers substantially.

The potential utility of biotechnology in the seed industry is apparent, but it does not dispel the uncertainty over how seed prices might be affected. It is not yet clear whether the potential cost savings (e.g., through reduced insecticide use) or revenue increases (e.g., through higher yields) will offset possible increases in seed prices. While the relatively low seed prices in developing countries provide some scope for absorbing part of the price increase expected if this seed reaches the market, it is possible that the seed could be priced out of the reach of many small-scale farmers in developing countries. This reinforces the importance of public national and international research organizations in underwriting the cost of R&D for maize hybrids intended for small-scale farmers.

Investment in biotechnology research is still largely confined to industrialized countries and to multinational seed and agricultural chemical companies (Byerlee and López-Pereira 1994). It is not likely that US farmers will see the products of biotechnology in commercial maize seed before the turn of the century. As investment in biotechnology research in developing countries started only recently, and assuming that the methodological advances achieved in industrialized countries can be transferred to developing country laboratories, another 15-20 years may elapse before farmers in developing countries see biotechnology products on a regular basis. Large multinationals have not been very interested in investing in biotechnology in developing countries because of the lack of patent or plant variety protection, the size of the potential market for biotechnology products, and other national regulations. Support for biotechnology research in IARCs, however, has increased substantially in recent years. The IARCs may be an important means of enabling developing country scientists to perform practical applications of biotechnology research and accelerating the introduction of biotechnology products to farmers there.

Public organizations are currently taking the initiative in biotechnology research in Brazil and Mexico, although some private companies are already interested in the applications of biotechnology research. To some degree, the status of biotechnology research in public and private organizations in developing countries is similar to that of maize breeding research a few decades ago. Most of the investment is made by the public sector in this early stage, but the potential remains for substantial participation by private sector organizations once basic research starts producing results and methods.

Are Intellectual Property Rights Regulations Needed?

Before the 1980s, developing countries showed little interest in intellectual property rights (IPRs) in relation to seed industries. Since then, increasingly global commercial relationships have forced many countries to update their seed laws and regulations and to consider introducing IPR legislation. In Brazil, Mexico, and many other developing countries, IPRs are controversial. In Mexico, the Congress is currently debating the nation's incorporation into the UPOV as well as other IPR regulations. Brazil has seen a more heated debate about the need to introduce IPRs and for several years has considered introducing new seed legislation (the current seed law and regulations were passed in 1977).

The IPR debate revolves around several issues: the need to introduce protection for the R&D investment that private companies might want to make; the rights of plant breeders to use any germplasm and other materials available for their research; and the need to protect maize farmers' right to produce their own seed on the farm, if they choose to do so. Maize seed organizations often argue that IPRs are unnecessary. Many maize seed industries developed without IPRs: maize seed companies protected the identity of their inbred lines (the industry's main basic product)[12] and thus prevented potential competitors from using them.

Despite these arguments against IPR legislation, there are many reasons for introducing it in developing countries, especially those with more advanced seed industries. Countries with IPR legislation may gain access to technology developed in other countries sooner than if they had no such legislation, especially the products of biotechnology and other advanced breeding techniques. Organizations in both Mexico and Brazil are making significant advances in these techniques and are likely to demand the introduction of IPRs in the near future. Because IPRs are included in all types of multilateral and regional trade agreements, most countries may have no choice but to introduce some kind of IPRs if they wish to participate in the world market. In this regard, the Mexican seed industry seems to have moved further along than Brazil in the IPR debate.

The Private Sector and the Small-scale Farmer

As agricultural policy reforms allow private organizations to play an increasingly dominant role in maize seed industries in developing countries, these private organizations are expected to concentrate their efforts where profit opportunities are greatest — the commercial, large-scale farming sector. This decision is based on the efficiency of research, as investment in R&D and seed production and marketing can be more effective where large numbers of similar farmers can adopt the technologies. However, this decision has important implications for small-scale farmers, whose socioeconomic characteristics and farming conditions make them unattractive clients for private companies (Cromwell, Friis-Hansen, and Turner 1992).

As discussed previously, public sector organizations will have to decide if, based on equity considerations, they will take responsibility for generating and providing technology for small-scale farmers. Here again experience in industrialized countries indicates that there is an important role for the public sector to play, and that private sector organizations can be involved as well. Because small-scale farmers constitute a large proportion of the maize producers in many developing countries, and because these farmers have very different characteristics even within regions, public organizations can foster the development of regional seed companies with specially adapted germplasm. These small-scale companies would then evolve to produce and market public varieties and hybrids within a particular region. Thus private sector development is encouraged by investment in public sector R&D for generating improved varieties. However, the same policy reforms that led to the privatization of maize seed industries could potentially change the priorities of public sector research towards a position of competition with private companies for the large-scale farmer sector (see below).

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[12] Improved OPVs are relatively unimportant for seed companies, because farmers can reproduce the seed for several seasons without much loss of yield potential. However, farmers cannot reproduce seed of improved OPVs indefinitely, because after a few seasons the seed gets contaminated through crossing with other varieties.

Eventually, as competition becomes more intense in the private seed sector, profit opportunities will be exhausted among medium- and large-scale farmers. Some groups of small-scale farmers will then become attractive potential customers for the private seed industry.

The Need for a Strategy for Sustained OPV Seed Production and Distribution

With the exception of the system for disseminating seed of the variety BR-106, which is produced by farmer communities and cooperatives in Brazil, schemes for the development and promotion of OPVs among small-scale farmers in Brazil and Mexico have had the same general fate as in other countries. Usually OPVs have been distributed through *ad hoc*, short-lived programs sponsored by public seed companies. Public companies often do not sell the newest varieties developed by the breeding programs, so farmers find it difficult to replace their current cultivars with better, more recently released materials. Private breeding programs, instrumental in the development and diffusion of hybrid seed, remain largely uninterested in producing and distributing OPV seed, since this does not represent a reliable (and profitable) annual market like hybrid seed does. As in other countries, in Mexico and Brazil the main impediment to diffusing improved OPVs appears to be the lack of suitable mechanisms for producing and distributing seed on a continuing basis (Byerlee and López-Pereira 1994).

A promising means for providing OPV seed to farmers on a continuing basis may be to strengthen local seed organizations, which often concentrate on producing and distributing seed of improved OPVs and focus on the regions and farmers that could benefit most from OPVs. Public research organizations could support these seed producers as a way of achieving their own goal of reaching small-scale farmers (López-Pereira and Filippello 1994). Such an alternative would probably be useful in Brazil, where NGOs and other small-scale seed organizations already have a substantial share of the maize seed market. In Mexico, the changes in seed legislation should similarly allow the public sector to strengthen the capacity of local seed organizations to produce OPV seed for small-scale maize farmers and distribute it to them.

Finally, it should be noted that some recent evidence shows that small-scale farmers can use hybrids successfully and that these hybrids have yielded better than OPVs even under very difficult, low input conditions (see López-Pereira and Filippello, 1994). Because the controversy continues over the suitability of hybrids under such conditions (Byerlee and Heisey 1993; Friis Hansen 1992), additional evidence is needed to demonstrate the advantages of hybrids over OPVs and the feasibility of providing hybrid seed for the low input conditions found in many developing countries. When deciding whether to emphasize the development of hybrids or OPVs, research managers of public breeding programs, not only in Brazil and Mexico but in all developing countries, need to weigh the advantages of using hybrids versus OPVs or local varieties, as well as assess the opportunities or limitations presented by the institutional and policy environments.

A Shrinking, Profit-oriented Public Seed Sector

The recent trend towards selling public sector germplasm to private companies for maize seed production and marketing was discussed earlier. Although it may seem justified that under financial stress public organizations try to generate research funds from the products they develop, this practice may become controversial. The main source of contention is that, as resources are generated from the sale of germplasm products, public sector organizations will tend to shift their breeding priorities to areas where there is more scope for profit (such as developing hybrids for commercial farmers) and become competitors in the seed industry.

Public sector organizations will need to be extremely careful to avoid direct competition with private companies and at the same time encourage competition among private companies. Public germplasm should be made available to all private organizations that may be interested in it. Special attention should also be given to fostering the development of regional seed companies that can distribute improved seed to small-scale farmers. Public organizations will have to find a balance between their need to become more efficient in the use of public funds and their natural objective of serving the less favored small-scale farmers in developing countries.

On the other hand, if public breeding systems are required to generate their own funds, then perhaps their objectives should be more clearly defined to reduce the emphasis on meeting the needs of poor, small-scale farmers. If this is done, public breeding programs will be in a better position to justify operating in a profit-making mode. If, however, the main objective of public sector organizations is to meet the needs of small-scale farmers (as many such organizations claim), then they will have to be supported with public funds and with a strong public commitment so that they can meet this objective. The current situation is confusing, not only for public sector officials, but also for private seed companies, as there is an apparent inconsistency between the need to provide poor, small-scale farmers with seed and at the same time generate financial resources for the survival of public organizations.

Concluding Remarks

This study has described the development of the maize seed industries of Brazil and Mexico and analyzed their current situation, focusing on industry structure, efficiency in breeding and seed production and marketing, and the evolving roles of public and private sector organizations in the industry. Although we have emphasized the maize seed industries of Brazil and Mexico, much of the analysis and many of its implications apply generally to the industries of other developing countries.

The maize seed industries of Brazil and Mexico are at different stages of development. The Brazilian industry is further along in the process of defining the roles of public and private organizations, and the Mexican industry is further along in the process of updating its seed laws and regulations. The Brazilian seed industry has reached a stable market size, in which seed sales have remained at roughly the same level over the last decade, and possesses an industry structure that appears normal for this type of market. Industry concentration is somewhat high. Research and development, as well as seed production and marketing, are mainly in the hands of the private sector, at levels that seem adequate for the industry. Public sector organizations play a complementary role in the industry, in which federal and state-supported organizations contribute small but significant proportions of the R&D investment.

The Mexican maize seed industry is at a stage in which private sector participation is increasing rapidly in a growing market. Although much of the future of the industry depends on how the policy changes and NAFTA play out in the next 5-10 years, it seems reasonable to expect further growth in the industry, especially in areas of high potential productivity where improved seed is not currently used. The most important recent development in the industry, the enactment of a modern seed law and regulation, loosened many of the strict regulations placed on private sector organizations and gave public sector organizations more flexibility to distribute maize germplasm through different conduits. The public seed enterprise (PRONASE) has already become relatively small, and signs that it is more efficient than in the past have become apparent, although much is still to be done. The private sector appears poised for further strengthening, which should result in an increased investment in R&D. A salient feature of the industry is the high proportion of three-way and single-cross hybrids on the market, especially from the private sector, which suggests that the industry will soon be based on these types of hybrids.

In both Brazil and Mexico the public sector has redefined its role in the maize seed industry. The new tendency is for public organization to support the development of the private seed sector, especially local seed companies and other national seed organizations. The public sector has withdrawn from seed production and distribution completely in Brazil and to a great extent in Mexico, concentrating mostly on breeding, and this has increased competition in the industry. Both industries show the expected tendency towards a majority control of the market by a small number of enterprises, and a relatively large number of very active medium and small companies. This industry structure is more apparent in Brazil, whereas the Mexican industry, still in the expansion stage, shows signs that it will settle into a similar structure after it stabilizes.

Finally, it should be noted that, while this study may be perceived as an endorsement of the transition from maize seed industries dominated by public sector organizations to industries in which market forces and the private sector dominate, the shift to a seed sector dominated by private organizations can be carried too far. As noted recently by Haq (1992):

> The development pendulum is beginning to swing once again, from an over-commitment to the public sector to an overenthusiasm for the private sector.... Certainly the long overdue return to the market has started in many developing countries and I welcome it. But my fear is that the pendulum may swing once again too far and we may all live to regret it.

These remarks should serve to reinforce the main conclusions of this study, which are that there is an optimal mix of participation by both public and private organizations in maize seed industries and that this mix depends on the stage of development of the specific industry. For industries to develop and provide access to seed technology to all types of farmers, the real solution lies in the challenge of finding that optimal mix.

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Appendix A

Companies in Brazil, Mexico, and the US Contacted During the Study

Brazil
Public sector

- EMBRAPA-CNPMS (Centro Nacional de Pesquisa de Milho e Sorgho)
- EMBRAPA-SPSB (Serviço de Produção de Sementes Básicas)
- State of São Paulo: Instituto Agronómico de Campinas (IAC); Coordenadora de Assistencia Técnica Integral (CATI); Departamento de Sementes, Mudas, e Matrices (CATI/DSSM)

Private seed sector

- Sementes Germinal
- ICI Sementes do Brasil Ldta.
- Sementes Selecionadas (DeKalb)
- Sementes Cargill Ltda.
- Sementes Agroceres
- Dinamilho Carol
- Sementes Ribeiral
- Mogiana Sementes de Milho
- Sementes Fartura
- Agromen Sementes
- Sementes Colorado
- Sementes Semel Ltda.
- Primaíz Sementes
- Correntes Agropecuaria
- Rhodia Agro Ltda.
- Cooperativa Agricola Cotia

Mexico
Public sector

- Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias (INIFAP)
- Productora Nacional de Semillas (PRONASE)
- Patronato de Investigación y Experimentación Agrícola del Estado de Sonora (PIEAE/Sonora)
- Universidad Autónoma Agraria Antonio Narro (Instituto Mexicano del Maíz) (UAAAN)
- Instituto Tecnológico de Estudios Superiores de Monterrey (ITESM)
- Colegio de Postgraduados (CP)

Private sector

- Híbridos Pioneer de México, S.A. de C.V.
- Semillas Híbridas S.A. de C.V.
- Asgrow Mexicana, S.A. de C.V.
- Northrup King y Cía., S.A. de C.V.
- Semillas Agrícolas de México (SAMSA)
- ASPROS Comercial S.A. de C.V.
- Semillas CONLEE Mexicana, S.A. de C.V.
- Semillas CALBER
- Semillas del Golfo (SEDELGO)
- Semillas WAC de México
- Semillas Toro
- Semillas Horizon/Productora Agroindustrial de Matamoros (PAMSA)
- Semillas Master de México
- Semillas TACSA
- NOVASEM Semillas Mejoradas
- Asociación Mexicana de Semilleros, A.C. (AMSAC)

United States

- Pioneer Hi-Bred International, Inc.
- DeKalb Plant Genetics
- Cargill International Seeds
- Illinois Foundation Seeds, Inc. (IFSI)
- Crow's Hybrid Corn Company
- Purdue University

Appendix B

Recent Agricultural Policy Reforms in Mexico

Recent economic and legislative reforms in Mexico could dramatically influence agricultural production in the country in the next 10-20 years, especially basic food crop production. These reforms, and their potential effects on the maize seed industry, are discussed below.

North American Free Trade Agreement (NAFTA)
One of the events that has potential for radically changing the Mexican economy is the approval of NAFTA. Under the general agreement, all nontariff trade restrictions for agricultural products will be either eliminated or translated into tariff or quota systems. These tariffs or quotas will then be eliminated over 10-15 years, depending on the product. In the case of maize, under NAFTA the US can export to Mexico a maximum of 2.5 million tons of maize per year free of tariffs. This quota will grow by 3% per year for 15 years, at which time all maize trade will be free of any quotas or tariffs. In the intervening 15 years, any amount in excess of that quota will be subject to a 215% tariff. This over-quota tariff will be reduced gradually until it is completely eliminated at the end of the 15-year period. The high over-quota tariff represents approximately the ratio of the official guaranteed price for Mexican maize producers of US$ 242/t in October 1993 and the international maize price of about US$ 115/t (FOB Gulf ports price, adjusted for transport costs).

The distribution of agricultural area among staple crops is expected to shift in the next 10 years as the effects of NAFTA are felt, guaranteed prices decline, and maize imports at internationally competitive prices increase (see the discussion of the PROCAMPO program, below). Estimates of the final maize area after the effects of NAFTA are taken into account vary from 3 to 5 million hectares. It is expected that about 2.0-2.5 million hectares will be irrigated land with high productivity potential, with technology levels similar to those in the US and Canada. Thus Mexico can produce maize competitively with the other North American producers on only 2.0-2.5 million hectares.

These developments have profound implications for the Mexican maize seed industry. On the one hand, a smaller total maize area implies that the potential market for maize seed will also be smaller than the current 150,000 t (7.5 million hectares of maize at an average seed rate of 20 kg/ha). On the other hand, most of the area that is expected to be taken out of maize production is in regions where farmers do not use improved seed. Moreover, in some areas with high productivity potential, which are currently planted to unimproved or improved OPVs and/or advanced generations of OPVs and hybrids, farmers are expected to adopt improved maize seed, especially hybrids. Because all of the area in Mexico where maize is produced as a cash crop will have to be planted to hybrids to be competitive, maize area sown to hybrids may actually grow from its current low level, even though total maize area in Mexico is expected to decline in the next 10-15 years.

Assuming that 4 million hectares remain under maize in Mexico, about half of that will be under hybrids and the rest under unimproved and improved OPVs. The total potential market for hybrids will be around 40,000 t, up from the estimated current level of 25,000-30,000 t. The potential market for improved OPV seed is also 40,000 t, of which only about 10,000 t are supplied. There is, therefore, scope for growth of the maize seed industry in Mexico, despite the expected reduction in maize area in the medium term. Private companies have seen this and are expanding research and production capabilities. Other local small private firms have started their own research programs while producing and marketing some INIFAP varieties and hybrids.

The New Seed Law and Regulation

Regulation of the Mexican seed industry is done through the Secretaría de Agricultura y Recursos Hidráulicos (SARH, Ministry of Agriculture), based on the new Ley Sobre Producción, Certificación y Comercio de Semillas. This new law, in effect since September 1991, replaces the old law that was in effect since 1961. Unlike the previous seed law, the new one has a regulatory decree as well, passed in May 1993. The SARH is in charge of ensuring that the new law is applied by the four regulatory bodies for seed certification and registration:

- **The Comité Consultivo de Variedades de Plantas** (CCVP, Consultative Committee of Plant Varieties) evaluates plant varieties to confirm that the information in the certification card indeed belongs to the variety described.
- **The Registro Nacional de Variedades de Plantas** (RNVP, or National Plant Variety Registry) is where all plant varieties must be registered for identification. Agronomic, morphological, physiological, and biochemical characteristics of each variety intended for certification or verification must be included in the registration information, as well as the region(s) for which it is recommended.
- **The Servicio Nacional de Inspección y Certificación de Semillas** (SNICS, National Service for Seed Inspection and Certification), although not explicitly mentioned in the new law, has several functions, including certification of the origin and quality of seed offered for sale as "certified" seed and authorization of any private person or organization to perform such certification duties.
- **The Productora Nacional de Semillas** (PRONASE, National Seed Production Company) retains its role as the producer of all seed of varieties developed by SARH through its research institute, INIFAP. However, under the current arrangement, PRONASE receives no funding from the federal government. This means that it has to generate its own funds to cover operating expenses, including the payment of fees to INIFAP for the basic seed received and royalties on the value of seed sales. Moreover, PRONASE has to compete with private companies and individuals for basic and certified seed from INIFAP, since INIFAP may now transfer its seed to anyone. All these new arrangements were applied in 1991 and 1992 to make PRONASE a more efficient seed producer. The organization has retained all the assets it held before the new legislation went into effect, including federally owned buildings, processing plants, and other equipment, without having to pay rent or fees for their use.

Another legislative body involved in seed production is the Dirección Nacional de Protección Vegetal (National Directorate of Phytosanitary Protection), which handles matters related to maize seed imports and exports, including the inspection of hazardous seed materials.

Three specific characteristics of the new law may affect the level of involvement of public and private organizations. First, the law explicitly allows private companies to "verify" seed without having to go through the certification process. This system is similar to that in the US, where seed certification is not required because companies basically guarantee the quality of their products (this is sometimes called the "truth in labeling" principle). A second characteristic is that SARH, through INIFAP, is now explicitly allowed to transfer to anyone, for a fee if it considers it appropriate, all seed of varieties it develops. Moreover, even if INIFAP transfers seed to PRONASE, INIFAP is entitled to charge for basic or registered seed and to charge royalties for the sale of certified seed produced from this basic/registered seed. Third, private companies are allowed to conduct breeding research more freely than before, and the movement of germplasm in and out of Mexico has been substantially simplified. Even the trade of commercial seed has been greatly facilitated by the new law.

The New Agricultural Subsidy Program (PROCAMPO)

The Programa de Apoyo al Campo (PROCAMPO), announced in October 1993, is the new policy for subsidies to agricultural production, intended to replace the system of guaranteed official prices that was maintained in Mexico for many years. The PROCAMPO program seeks to reduce inefficiencies in the allocation of agricultural subsidies, which under the old guaranteed prices were captured mainly by commercial farmers and had little effect on subsistence maize farmers. The program also seeks to compensate Mexican farmers for the subsidies provided to US and Canadian farmers, who under NAFTA will be able to export cereal grains to Mexico under increasingly liberalized markets. A third objective of PROCAMPO is to allow land and capital resources in the agricultural sector to be allocated more efficiently to activities in which Mexican farmers may be able to compete effectively with their counterparts elsewhere in North America. One of the main problems of the old system of guaranteed prices was that it biased the allocation of resources in favor of crops receiving the heaviest price supports, especially maize.

In general, the main effect of PROCAMPO will be to replace the official price of basic crops with a direct, per-hectare subsidy. The crops included in the PROCAMPO program are maize, beans, wheat, soybeans, sorghum, rice, cotton, and safflower. During a transition period, a combination of guaranteed prices and direct per-hectare subsidies was in place. This period included the 1993-94 autumn-winter cropping season and the spring 1994 season, which constituted the 1994 crop year (Appendix Table B1 lists the subsidies that were in place for the main staple crops). Starting with the 1995 crop year (the 1994-95 autumn-winter season), crop prices were determined based on the price in international markets, and only a direct subsidy was provided to Mexican farmers. The PROCAMPO program is expected to be implemented over 15 years. During the first 10 years, US$ 3,900 million per year (in 1993 dollars) will be invested, and then a gradual reduction of the direct subsidy will be implemented over the following five years. By the end of the fifteenth year, all subsidies will end. This time horizon coincides with the planned removal of all subsidies for cereal grain trade between the three NAFTA partners. The Mexican government expects to reach 3.3 million farmers with the program.

Under PROCAMPO, a number of Mexican organizations and institutions involved in the previous guaranteed price system are modifying their roles. The program of direct subsidies is based on a register of Mexican producers of cereal grains and oilseeds undertaken in early 1993 and updated periodically. SARH is the official executing institution of PROCAMPO, through its different State Delegations, Rural Development Districts, and the ASERCA system. The main agency through which the guaranteed price system was implemented, CONASUPO, will continue to operate, but its commodity prices will be set by international prices, adjusted for transport costs and other operational costs (see SARH 1993a, 1993b, for more details).

The full effects of PROCAMPO and other changes in agricultural policy on land use patterns are not expected to be seen in the near future. Maize area is widely expected to fall from its recent level of 7.5 million hectares when PROCAMPO is fully operational. Wheat and sorghum should be affected to a lesser extent by NAFTA and PROCAMPO, since prices for these crops are already close to international prices.

Appendix Table B1. Subsidies to agricultural production in Mexico, before and after the introduction of PROCAMPO in October 1993

	Before PROCAMPO	After PROCAMPO	
Season and crop	Guaranteed price[a]	Guaranteed price[a]	Direct per-ha subsidy
Spring-summer 1993			
White maize[b]	242	..	..
Beans (preferred quality)[c]	677	..	..
Wheat	206	..	..
Autumn-winter 1993/94			
White maize[b]		210	106
Beans (preferred quality)[b]		581	106
Wheat		194	106
Spring-summer 1994			
White maize[b]		194	113
Beans (preferred quality)[c]		516	113
Wheat		194	113
Autumn-winter 1994/95 (PROCAMPO in full effect)			
White maize		..	113
Beans		..	113
Wheat		..	113

Source: SARH (1993a, 1993b).

[a] All prices in US$/t, based on an exchange rate of MX$ 3,100 per US$ 1 in December 1993.

[b] Price of nonwhite maize were (in US$/t): spring-summer 1993, 201.61; autumn-winter 1993/94, 174.19; spring-summer 1994, 161.29.

[c] Prices for beans of other qualities were (in U$/t): spring-summer 1993, 600; autumn-winter 1993/94, 514.52; spring-summer 1994, 456.45.

Other Changes in Agricultural Policy

Other changes in agricultural policy are potentially important for maize seed industries. First, privatization of agricultural input supply, especially fertilizer production, could have significant effects on maize production and seed industries. Second, agricultural credit will be more difficult for farmers to obtain, especially small-scale farmers. Subsidies on interest rates for agricultural credit, especially for basic crop production, have been largely removed and credit has become more expensive. Third, the land tenure system is expected to change as a result of the amendment to Article 27 of the Mexican Constitution (SARH 1992). The amendment permits privatization of communally held land (*ejidos*) and allows those with rights to *ejido* land (*ejidatarios*) to have more control over it than in the past. *Ejidatarios* can also associate with others to form enterprises for the exploitation *ejido* land. Finally, users' fees for irrigation water have changed to reflect more closely the actual costs of these services to the government.

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