E C O N O M I C S

Working Paper 97-06

Adoption, Management, and Impact of Hybrid Maize Seed in India

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Abstract: This paper presents results of a 1995 survey of 864 maize-growing households in six states that account for more than 70% of India's maize area: Andhra Pradesh, Bihar, Karnataka, Madhya Pradesh, Rajasthan, and Uttar Pradesh. The current adoption of improved open-pollinated maize varieties (OPVs) and hybrids is quantified, the relationship between adoption of improved germplasm and use of improved crop management practices is examined, the economic impacts of adoption are estimated, farmers' seed procurement and management practices are described, and implications for maize research and development policy are discussed. On the whole, the survey results confirm that India's national maize seed industry is expanding rapidly. Since seed policy reforms were introduced in the late 1980s, the area planted to improved OPVs and hybrids has grown rapidly, and adoption of improved germplasm has fueled important changes in farmers' crop management practices. However, special policy measures may be needed to ensure that the benefits of improved germplasm are widely shared, such as the introduction of targeted input subsidies designed to reduce the cost of adopting improved seed and complementary inputs, government investment in irrigation infrastructure to reduce production risk in drought-prone environments, and market development initiatives to provide small-scale producers with access to stable and reliable outlets where they can sell surplus grain.

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Finally, we owe a special debt of gratitude to the many rural households that agreed to participate in the survey. We sincerely hope that our findings will contribute to the development of improved production technologies that will help to improve their lives.

Executive Summary

This paper describes the results of a recent IARI/CIMMYT study that examined the use of improved maize seed in India. The study had multiple objectives: to quantify the current level of adoption of improved open-pollinated varieties (OPVs) and hybrids, to explore the relationship between adoption of improved germplasm and use of improved crop management practices, to estimate the economic impacts of adoption, to describe farmers' seed procurement and management practices, and to discuss implications for maize research and development policy. Data for the study were collected in 1995 through a survey of 864 maize-growing households located in Andhra Pradesh, Bihar, Karnataka, Madhya Pradesh, Rajasthan, and Uttar Pradesh. Together, these six states account for more than 70% of the area planted to maize in India.

Key findings of the study included the following:

- During the 1994/95 cropping season, approximately 45% of India's maize area was planted to improved OPVs and hybrids. Unlike earlier years, when farmers grew mainly public sector materials, most of the improved materials currently grown are proprietary hybrids developed by private seed companies. Use of improved OPVs and hybrids is highest in states where maize is an important commercial crop and lowest in states where maize is primarily grown for home consumption.
- Uptake of improved maize germplasm has been accompanied by changes in crop management practices. Farmers who grow improved OPVs and hybrids apply more fertilizer and use herbicides and insecticides with greater frequency than do farmers who grow local varieties. The change in behavior has an economic explanation: improved OPVs and hybrids have the ability to respond to improved management practices, so increased investment in purchased inputs is profitable. Diffusion of improved germplasm thus has served as an important catalyst for changes in crop management practices.
- Maize varietal preferences vary considerably from one production environment to the next. All things being equal, maize-growing households prefer OPVs and hybrids that yield well, but the characteristics associated with high yield vary according to each production environment. Consumption characteristics are also important, with consumer preferences once again varying from one region to another.
- In states where maize is an important commercial crop and adoption of hybrids is extensive, the majority of maize-growing households replace their seed annually; typically these households purchase seed from an external source, such as a private trader or a government seed agency. But in states in which maize is grown mainly for home consumption and adoption of hybrids is low, the vast majority of maize-growing households rarely or never replace their seed, preferring to replant seed saved from their own harvest. Slightly more than one-fifth of all households reported that they sometimes replant F_2 hybrid seed. Of these households, many indicated that they plant F_2 hybrid seed because they are reluctant to invest scarce resources in a crop as risky as maize and/or because the yield difference between F_1 and F_2 generations of hybrid seed is relatively small.

What has been the aggregate economic impact of hybrid maize adoption? Based on differences observed between average yields of OPVs and average yields of hybrids, and taking into account the area planted to OPVs and hybrids in each state, it is possible to estimate the gross annual increase in maize production attributable to the adoption of hybrids and associated crop management practices. In the absence of hybrids, maize production in the six states would have been more than one million tons lower during 1994/95 than it actually was.

What is the total demand for hybrid maize seed in India? The survey findings on hybrid adoption rates can be combined with the findings on farmers' seed management practices to generate an estimate of the potential demand for hybrid maize seed. Assuming an average planting rate of 20 kg/ha, and using official government estimates for hybrid adoption rates in the states that were not covered by the survey, potential demand for hybrid maize seed in 1995 for all of India was approximately 31,000 t. When the estimated figures for potential demand for hybrid seed are adjusted using a hybrid seed recycling factor (based on the reported incidence of F_2 seed use), the estimated effective demand for hybrid maize seed for all of India is around 27,500 t.

On the whole, the survey results confirm that India's national maize seed industry is in a phase of rapid expansion. Since seed policy reforms were introduced in the late 1980s, the area planted to improved OPVs and hybrids has grown rapidly, and adoption of improved germplasm has stimulated important changes in farmers' crop management practices. However, despite the considerable gains that have been made in meeting the needs of commercial farmers, many poor farmers who do not represent an attractive market for commercial seed have yet to experience the benefits of improved germplasm. Special policy measures therefore may be needed to ensure that the benefits of improved germplasm are widely shared. Such measures might include introduction of targeted input subsidies designed to reduce the cost of adopting improved seed and complementary inputs (especially fertilizer), government investment in irrigation infrastructure designed to reduce production risk in drought-prone environments, and market development initiatives designed to provide small-scale producers with access to stable and reliable outlets where they can sell surplus grain.

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Introduction

Maize was the first major cereal crop in India to be affected by hybridization, but the impact of hybrid technology in the Indian maize sector was not immediately apparent. Following the release in 1961 of the first commercial maize hybrid, uptake of hybrid seed remained modest until the early 1980s. During this period, the production and distribution of seed of most staple food crops remained firmly in the hands of public organizations, as government policies limited the private sector's role to producing and selling the seed of selected vegetable crops and ornamental plants.

Policy reforms introduced during the late 1980s in an attempt to encourage greater private sector participation in the Indian seed industry stimulated a noticeable increase in investment in plant breeding research and seed production. The maize seed industry was particularly affected by these policy reforms. During the early 1990s, the number of private maize seed companies operating in India rose sharply, and private sector investment in maize research increased significantly (Singh, Pal, and Morris 1995). Meanwhile, the increased availability of proprietary hybrids produced by private seed companies accelerated the diffusion of hybrid maize seed.

Although the recent changes clearly have benefited many of India's maize farmers, concern has been expressed in some circles that private seed companies, in their efforts to generate profits for shareholders, are concentrating on large-scale commercial growers while ignoring small-scale, subsistence-oriented farmers who do not represent an attractive market for commercial seed. In the absence of detailed information about the circumstances under which maize seed is actually used, it is difficult to know whether or not this concern is justified. The present study was undertaken in an attempt to document the adoption of hybrid maize seed in a range of production environments, to describe household-level seed procurement and seed management practices, and to explore options for future maize research and development policies.

This report summarizes the results of a recent study of maize seed management practices in six important maize-growing states that together account for more than 70% of the area planted to maize in India. Specific objectives of the study included:

- to quantify and document the adoption of improved maize germplasm and its relationship with the use of improved crop management practices;
- to estimate the economic impact of the adoption of improved maize germplasm;
- to describe farmers' seed procurement and seed management practices; and
- to discuss the implications for maize research and development policy.

To provide an idea of the context in which this survey was undertaken, the paper begins with a brief overview of India's maize economy and a summary of recent developments in the national maize seed industry. Next, the field data collection activities undertaken as part of this study are described, and the maize-growing households included in the sample are profiled. The paper then reviews farm-level germplasm adoption patterns. Estimates of the gross economic benefits associated with the adoption of improved OPVs and hybrids are developed. Farm-level seed procurement and seed management practices are described, and the relationship between adoption of improved germplasm and adoption of improved crop management practices is explored. The concluding section of the paper summarizes the main findings of the study and discusses policy implications.

The Maize Economy of India

Among the cereals grown in India, maize ranks as one of the most important. Traditionally, maize was grown as a staple food destined primarily for home consumption. Farm household requirements, governed by quality and taste preferences, influenced production decisions. However, in recent years significant changes have occurred as the result of the increasing commercial orientation of the agricultural economy and rising demand for diversified end uses, especially feed and industrial uses. At the same time, substantial investment in maize research has generated improved production technologies that have provided farmers with the means to respond to changes in demand.

Maize Production and Consumption Trends

Maize in India is grown in a wide range of production environments, ranging from the temperate hill zones in Himachal Pradesh in the North to the semiarid desert margins in Rajasthan in the West to the humid tropical zones in Karnataka in the South. Between 1955 and 1975, the total area planted to maize expanded at an average annual rate of more than 2.2%, causing national maize area to grow from 3.7 million hectares to almost 6 million hectares (Table 1). Beginning in the early 1970s, however, expansion in maize area abruptly ceased, as maize was forced to compete with other crops for increasingly scarce land.

Although total maize area has remained virtually unchanged for the past 25 years, significant shifts have occurred in where and when maize is grown. The most significant change has been the rapid area expansion in winter (*rabi*) maize, particularly in the states of Bihar, Andhra Pradesh, and Karnataka; in large part, this expansion resulted from the introduction of improved materials showing good cold tolerance. In the traditional maize-growing states of Madhya Pradesh and Rajasthan, maize area has expanded, whereas it has declined in Uttar Pradesh because of increased competition from higher value alternative crops

Under the impetus of the spread of improved germplasm and crop management practices, average maize yields have registered continuous growth for more than four decades (Table 1). However, the rate of growth has been somewhat uneven. After rising rapidly at more than 3% per year during the 1950s and early 1960s, yields grew more slowly during the 1970s and 1980s as maize was displaced from many favorable production zones by newly introduced, high yielding wheat and rice varieties. More rapid maize yield growth resumed in the 1990s.

Rising yields, coupled with steady expansion in area, led to strong growth in maize production of over 3% per year during the 1950s and 1960s (Table 1). Beginning in 1970, production growth slowed noticeably as maize area stabilized. Nonetheless, continuing yield growth fueled overall growth in production averaging more than 2% per year, and by the mid-1990s, annual total maize production was approaching almost 10 million tons. Not surprisingly, in view of the uneven performance of maize yields, production during the 1970s and 1980s was characterized by marked year-to-year variability. Despite this variability, the real cost of production decreased, and real prices received by farmers had also declined by a similar amount, indicating that productivity gains were largely passed on to consumers.

Virtually all of India's maize is utilized domestically. Domestic uses include food, feed, and industrial uses. About 70% of the crop is consumed directly as food, with the remaining 30% going in roughly equal proportions to feed and industrial uses (Singh and Pal 1992). According to recent National Sample Survey data, annual per capita food consumption of maize, historically confined mainly to rural areas, declined from around 12 kg during the early 1970s to around 6 kg in the 1980s. The decline can be attributed to two factors. First, maize is an inferior good, so that as incomes have risen, consumers have shifted from maize to other preferred cereals such as rice and wheat. Second, public distribution of wheat and rice at concessional prices has lowered the relative prices of these two cereals and led to substitution away from maize (Pal et al. 1993). In spite of these factors, annual per capita maize consumption in rural areas of traditional maize growing states such as Madhya Pradesh and Rajasthan remains high.

As direct human consumption of maize has declined, feed and industrial uses have risen. Feed demand for maize has been driven by rising incomes, which have led consumers to consume ever greater amounts of meat, particularly poultry. Increased industrial demand for maize has come primarily from the starch industry.

Table 1a. Maize area, yield, and production, India (1954-56 to 1994-96)

	1954-56	1964-66	1974-76	1984-86	1994-96
Area (000 ha)	3,737	4,830	5,963	5,840	6,067
Yield (kg/ha)	772	992	1,071	1,294	1,554
Production (000 t)	2,887	4,790	6,393	7,557	9,429

Source: DES, Government of India.

Table 1b. Growth in maize area, yield, and production, India (1954/55 to 94/95)

	1954/55 to 1964/65	1964/65 to 1974/75	1974/75 to 1984/85	1984/85 to 1994/95
Area (% annual growth)	2.43	1.78	(0.19)	0.55
Yield (% annual growth)	3.46	0.45	1.88	3.37
Production (% annual growth)	5.89	2.22	1.68	3.92

Source: Calculated by the authors from DES, Government of India data.

Recent Developments in the Maize Seed Industry

The passage in 1966 of the Central Seed Act laid the legal foundation for India's present-day seed industry. In addition to setting out regulations governing the production and distribution of seed, the Central Seed Act prescribed certification standards and assigned responsibility for their enforcement to the state governments. A distinguishing feature of the Central Seed Act was that effective control over seed of most staple food crops remained firmly in the hands of government organizations. Private companies gradually came into existence, but only in certain segments of the market (e.g., vegetables and flowers), but seed production and distribution for important cereals such as rice, wheat, sorghum, and maize were actively pursued through state agencies.

Policy reforms introduced during the late 1980s had important implications for the seed industry. In 1987, the seed industry licensing policy was modified to encourage greater participation by private companies, and in 1988 the doors to foreign competition were thrown open when the New Policy for Seed Development was passed. The New Policy for Seed Development, a landmark piece of legislation, permitted private companies to import seed of vegetables, flowers, and ornamental plants, subject to certain restrictions regarding access to and disposal of foreign exchange; under certain conditions, it also permitted imports of seed of coarse grains, pulses, and oilseeds. Meanwhile, import duties on seed and seed processing equipment were reduced significantly.

Although they applied to all crops, the seed industry reforms introduced during the late 1980s had an especially noticeable impact on maize. By lowering barriers to entry and loosening restrictions on certain previously prescribed procedures, they cleared the way for increased participation by private companies. Within a few months, dozens of new companies sprang up and began producing maize seed to sell in direct competition with the government seed agencies. These included not only Indian-owned companies but subsidiaries of large transnational companies active in the global seed trade. Initially the domestic companies concentrated on producing seed of public varieties and hybrids, but as competition intensified, many of them launched research programs in an effort to develop proprietary products that could be differentiated in the marketplace. By 1994, the level of private sector investment in maize research was approximately equal to the level of public sector investment, and seed sales by private companies had surpassed those of public seed organizations.

Data Sources and Analysis

Data for the present study were collected through a survey of 864 maize-growing households distributed among six states. The data pertain to the 1994/95 agricultural year.

Sample Design

A five-stage, clustered, purposive sampling procedure was used to select households for inclusion in the study. The five stages involved selection of: (1) states, (2) districts, (3) blocks, (4) villages, and (5) households. The sampling procedure, summarized in Table 2, is described below.

1. Given the resources available for the study, it was feasible to interview approximately 850 maize-growing households. Partly for statistical reasons, and partly out of logistical considerations, it was decided to interview 144 households in each of six states, giving a total of 864 households. The six states that had the largest area planted to maize in 1995 were selected: Uttar Pradesh, Rajasthan, Madhya Pradesh, Bihar, Karnataka, and Andhra Pradesh (Figure 1).
2. For each of the six states, a list of districts was prepared and arranged in order of their contribution to state maize area. Six districts were randomly selected from among the most important maize-growing districts, defined as those which collectively accounted for at least 80% of the state maize area. Districts containing negligible amounts of maize area were eliminated because it would have been difficult to locate maize-growing households in those districts.
3. For each of the 36 districts, two blocks were selected at random. In a small number of cases, when it was determined that the selected blocks were extremely inaccessible by road, a second selection was made.
4. For each of the 72 blocks, two villages were selected at random from a list of villages known to contain significant numbers of maize producers. These villages were identified based on conversations with knowledgeable block-level officials.
5. For each of the 144 villages, six households were selected at random from a list of maize-growing households compiled with the assistance of village leaders. In cases in which it was not possible to locate a member of one of the six initial households, another household was randomly selected from the list.

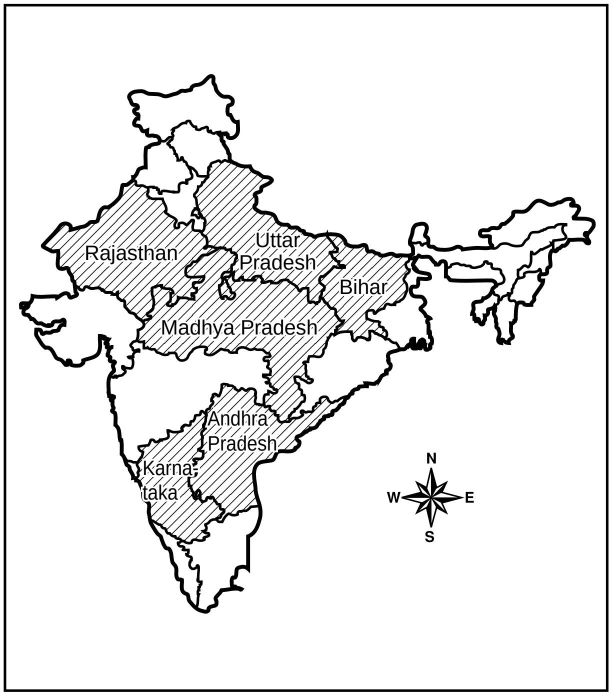

Figure 1. States include in the 1995 IARI/CIMMYT survey.

Table 2. Sampling procedure used in the 1995 IARI/CIMMYT survey

Sampling stage	Sampling unit	Selection criterion	Units at this level	Cumulative units
1	State	States with largest maize area	6	6
2	District	Random selection from among largest districts accounting for >80% of state maize area	6	36
3	Block	Random selection from among blocks located in maize-growing areas	2	72
4	Village	Random selection from among accessible villages	2	144
5	Household	Random selection from among maize-growing households	6	864

Sample Representativeness

The six states included in the survey contained approximately 70% of the area planted to maize in India in 1993-95 and accounted for a similar proportion of total national maize production (Table 3). Average maize yields recorded in the six states during 1993-95 ranged from 42% below the national average yields to 89% above. Thus the maize-growing households in these six states can be considered representative of a significant proportion of all maize-growing households found throughout India.

Despite the comprehensive nature of the sample, however, care should be taken in attempting to extrapolate the findings reported here to the national level. For at least four reasons, the sampling procedure might have introduced some degree of bias in the selection of households.

First, although the states that were not included in the sample account for a relatively small proportion of total national maize area and production, they include many marginal production environments in which the use of improved germplasm may be low.

Second, districts containing a negligible portion of state maize area were excluded from the sampling frame on the grounds that it would have been difficult to locate maize-growing households; these districts in which maize presumably is a minor crop may be characterized by nonrepresentative patterns of technology use.

Third, blocks that were not easily accessible by public transport were excluded from the sampling frame, because the enumerators would have had difficulty reaching them; these relatively inaccessible blocks may be characterized by nonrepresentative patterns of technology use.

Fourth, villages identified by block officials as containing few or no maize producers were excluded from the sampling frame on the grounds that it would have been difficult to locate maize-growing households; these villages in which maize presumably is a minor crop may be characterized by nonrepresentative patterns of technology use.

Table 3. Characteristics of maize-producing states included in the 1995 IARI/CIMMYT survey, 1993-95 average

	Maize area		Maize production		Maize yield	
State	(million ha)	(% of national total)	(million t)	(% of national total)	(t/ha)	% of national average
Andhra Pradesh	0.31	5.2	0.81	8.5	2.59	162.9
Bihar	0.72	12.0	1.35	14.1	1.86	117.0
Karnataka	0.33	5.5	0.99	10.3	3.01	189.3
Madhya Pradesh	0.89	14.8	1.20	12.5	1.34	84.3
Rajasthan	0.93	15.5	0.87	9.1	0.93	58.0
Uttar Pradesh	1.07	17.8	1.46	15.3	1.38	86.8
Subtotal – six states	4.25	70.6	6.68	69.8	1.57	98.7
Total – all India	6.02	100.0	9.57	100.0	1.59	100.0

Source: Government of India.

For these reasons, it is possible that the final sample of maize-growing households included in the study might not be perfectly representative of the entire population of maize-growing households in India. The possibility of selection bias should be taken into account in interpreting the survey results.

Data Collection

The survey was conducted between April and August, 1995. Enumerators were recruited in each of the six target states to ensure fluency in local languages. All of the enumerators were current or former graduate students in agricultural sciences at one of the state agricultural universities, so they were knowledgeable about local agricultural production practices. Working singly or in pairs, the enumerators were able to complete all 144 interviews for each state within about a month. Data collection was staggered slightly from state to state to provide sufficient time for the survey supervisors to spend several days training each group of enumerators and participating in the first few days of interviews.

Characteristics of Sample Households

Demographic characteristics of the sample households appear in Table 4. Both the average age of the household head and the level of education of the household head varied from state to state. The generally higher level of education that characterizes heads of maize-growing households in Andhra Pradesh and Karnataka would appear to be consistent with the greater incidence of commercial maize production in these two states; in contrast, heads of maize-growing households exhibit relatively less schooling in Madhya Pradesh and Rajasthan, states in which maize is grown primarily by subsistence-oriented farmers. Average family size and occupational orientation (percentage of family members working on the farm) also vary between states, reflecting differences in family structure and in the importance of agriculture.

Cropping patterns reported by sample households for 1994/95 are depicted in Figure 2. Cereals dominated the cropping pattern in all six states, with clear regional differences evident in the relative importance of individual crops. Among cereals, rice dominated the

Table 4. Demographic characteristics of sample households

			Education of household head[a]				
State	n	Average age of household head (years)	No formal schooling	Primary schooling only	Secondary schooling or higher	Average family size	Family members working on farm
Andhra Pradesh	144	41	19%	34%	48%	5.4	20%
Bihar	144	49	11%	32%	56%	9.2	22%
Karnataka	144	39	19%	31%	49%	7.5	47%
Madhya Pradesh	144	44	13%	54%	33%	8.7	55%
Rajasthan	144	43	53%	26%	21%	8.2	51%
Uttar Pradesh	144	49	12%	30%	59%	11.2	33%
Total (six states)	864	44	20%	35%	46%	8.4	38%

Source: IARI/CIMMYT survey.
[a] Figures may not sum to 100% because of rounding error.

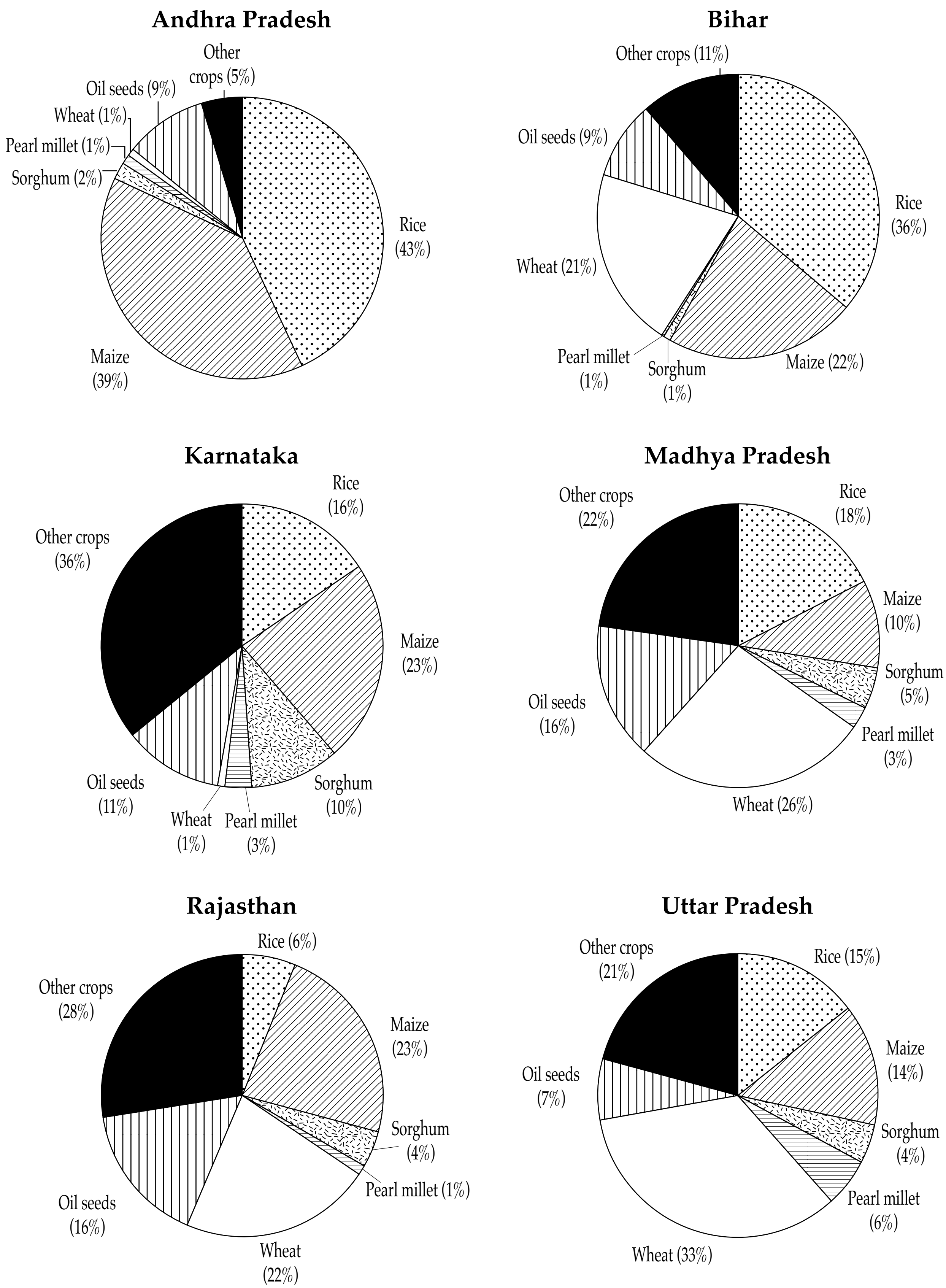

Figure 2. Cropping patterns reported by sample households, 1994/95.

cropping pattern in Andhra Pradesh and Bihar and occupied a significant percentage of cropped area in Karnataka and Madhya Pradesh. Wheat was the leading cereal in Uttar Pradesh, Madhya Pradesh, and Rajasthan (in the latter state, the area planted to wheat was almost equal to the area planted to maize). Minor cereals, including sorghum and pearl millet, accounted for a negligible portion of the area cropped by sample households, but oilseeds occupied between 7% and 16% of total cropped area in all six states. The importance of other crops (which included sugarcane, cotton, and pulses) was highly variable.

Information on maize cropping patterns reported by the sample households for the 1994/95 season appears in Table 5. Not surprisingly, the importance of maize varied by state and season. During summer (*kharif)* season, maize occupied more than one-third of the cropped area in Rajasthan (38%) and Andhra Pradesh (37%), between one-third and one-quarter of the cropped area in Uttar Pradesh (30%) and Karnataka (26%), and slightly less than one-fifth of the cropped area in Bihar (19%) and Madhya Pradesh (18%). Differences in the importance of maize were even more pronounced during *rabi* season. Among the households surveyed in Andhra Pradesh, fully 44% of total area cropped during *rabi* season was planted to maize. Maize was also found to be an important *rabi* crop among the households surveyed in Bihar (32%) and Karnataka (20%). In contrast, no maize was reported to be grown during *rabi* season in Madhya Pradesh, Rajasthan, and Uttar Pradesh.

Table 5. Maize area as percentage of total cropped area, by season, sample households

State	*Kharif*	*Rabi*	Weighted total[a]
Andhra Pradesh	37	44	39
Bihar	19	32	22
Karnataka	26	20	23
Madhya Pradesh	18	0	10
Rajasthan	38	0	23
Uttar Pradesh	30	0	14
Total (six states)	29	14	22

Source: IARI/CIMMYT survey.
[a] Weighted total may differ from average of figures for each season because absolute size of cropped area often differs between seasons.

Utilization patterns for maize reported by the sample households demonstrate the marked differences in the economic role of maize in the different states (Table 6). In Andhra Pradesh and Karnataka, maize is indisputably a commercial crop; most households sell virtually their entire production and retain only negligible amounts for home consumption or for use as in-kind wages to pay farm labor. In Madhya Pradesh, Rajasthan, and Uttar Pradesh, on the other hand, maize is partly a commercial crop and partly a subsistence crop; most households sell less than half of their

Table 6. Utilization of maize (% of total production by sample households)

State	On-farm food use	On-farm feed use	On-farm seed use	Used to pay laborers	Sold
Andhra Pradesh	2	5	<1	2	91
Bihar	10	6	2	28	54
Karnataka	5	6	<1	3	86
Madhya Pradesh	30	3	2	22	44
Rajasthan	32	2	2	22	42
Uttar Pradesh	27	6	2	20	44
Total (six states)	18	5	1	16	60

Source: IARI/CIMMYT survey.

production, preferring instead to retain important quantities for home consumption or for use as in-kind wages. Bihar represents an intermediate case; just over half of the maize produced in Bihar is sold, but a relatively large percentage of total production is retained for home consumption and especially for use as in-kind wages.

Adoption of improved maize production technologies may be influenced by household wealth, so it is relevant to ask whether there are differences in wealth across the sample. Table 7 presents information on the average size of the area cultivated by the sample households, which may be considered a proxy for wealth. Cultivated area per household ranges from less than 4 ha in the densely populated states of Bihar and Uttar Pradesh to over 5 ha in the more sparsely populated states of Rajasthan and Karnataka. When differences in the average household size are taken into account, the disparity in access to land becomes even more evident, with households in Bihar and Uttar Pradesh cultivating only about one-third of a hectare per person, less than half of the area cultivated in some other states.

Adoption of improved maize production technologies may also be influenced by the expected returns to investment in these technologies. Table 7 presents information on the sample households' access to irrigation, which presumably affects the degree of weather-induced production risk each household faces. Access to irrigation of any form is lowest in Rajasthan and Madhya Pradesh, where less than half of the land cultivated by sample households was reported to be irrigated. Access to irrigation is highest in Karnataka, followed by Andhra Pradesh, Uttar Pradesh, and Bihar. Across the entire sample, tubewells were by far the most common source of irrigation water.

Adoption of Improved Germplasm and Complementary Inputs

In India as elsewhere, it is difficult to make an accurate measurement of maize varietal adoption patterns at the farm level for at least three reasons.

Table 7. Area cultivated and access to irrigation, sample households

State	Cultivated area per household (ha)	Cultivated area per person (ha)	Percent irrigated, by source of irrigation			
			Canal	Tubewell	Tank	Total
Andhra Pradesh	4.22	0.78	3	46	23	71
Bihar	5.59	0.36	22	44	<1	67
Karnataka	3.91	0.76	26	69	< 1	95
Madhya Pradesh	3.35	0.54	12	38	< 1	43
Rajasthan	4.70	0.62	3	32	6	41
Uttar Pradesh	5.03	0.32	24	39	8	69
Total (six states)	4.47	0.52	15	45	6	64

Source: IARI/CIMMYT survey.
[a] Figures may not sum to 100% due to rounding error.

First, many farmers have difficulty precisely identifying the correct names of improved materials. Improved OPVs and hybrids frequently are known by the name of the government organization or private company from which seed was originally purchased, i.e., "SSC" (for State Seed Corporation) or "Proagro" (for Proagro seed company). In addition, some farmers apparently do not understand the difference between OPVs and hybrids; information provided by these farmers concerning the type of materials they use may therefore be inaccurate.

Second, even when farmers can identify the correct name of the variety or hybrid, plants actually growing in the field may not bear a close resemblance to the variety or hybrid whose seed was originally purchased. Because maize plants readily mate with other nearby maize plants when both flower at the same time, the common practice of recycling seed (i.e., saving harvested seed to replant in the following season) frequently leads to a loss in genetic purity through natural outcrossing. Consequently, when seed has been recycled for a number of years, it is difficult to know whether the variety or hybrid should be classified as "improved" or "local."

Third, many of the hybrids grown by Indian farmers are proprietary hybrids whose pedigrees are closed, making it difficult to identify the germplasm with certainty. Since the same varieties and hybrids are sometimes marketed by several seed companies under different names, variety- and hybrid-specific adoption data may be inaccurate.

Adoption of Improved Germplasm

Information reported by the sample households on their use of different types of maize germplasm appears in Table 8. As expected, use of improved OPVs and hybrids varies considerably between states. Use of improved materials is highest in states where maize is an important commercial crop (e.g., Karnataka, Andhra Pradesh) and lowest in states where maize is primarily grown for home consumption (e.g., Madhya Pradesh, Rajasthan, Uttar Pradesh). Bihar represents an interesting intermediate case; in Bihar, use of improved

Table 8. Percentage of maize area planted to different types of maize germplasm, by season, sample households

	Kharif[a]			*Rabi*[a]			Weighted total[a]		
State	Local varieties	Improved OPVs	Hybrids	Local varieties	Improved OPVs	Hybrids	Local varieties	Improved OPVs	Hybrids
Andhra Pradesh	10	13	77	1	17	83	6	15	79
Bihar	50	14	36	3	32	66	19	26	55
Karnataka	4	16	81	< 1	6	94	2	12	86
Madhya Pradesh	62	23	15	na	na	na	62	23	15
Rajasthan	74	18	8	na	na	na	73	18	8
Uttar Pradesh	61	31	8	na	na	na	61	31	8

Source: IARI/CIMMYT survey.
[a] Figures may not sum to 100% due to rounding error.

materials is high during *rabi* season (when the state's main commercial maize crop is grown) and low during *kharif* season (when many small-scale farmers plant maize as a supplementary food crop).

These findings based on household-level interviews are generally consistent with official statistics published by the Ministry of Agriculture on adoption of high yielding varieties (HYVs) of maize (Table 9). Only in two of the six survey states — Bihar and Rajasthan — do the survey results differ significantly from the official statistics. The survey results indicate that in 1995 fully 81% of the maize area in Bihar was planted to improved OPVs or hybrids, significantly more than the 57% reported by the Ministry of Agriculture. The discrepancy between the two figures apparently derives from the fact that the official statistics refer only to the *kharif* maize crop and do not take into account the *rabi* maize crop. Since use of improved maize seed in Bihar is concentrated during the *rabi* season, it is not surprising that our estimate is higher. The case of Rajasthan is more perplexing. The survey results indicate that during 1995 approximately 36% of the maize area in Rajasthan was planted to improved OPVs and hybrids, significantly higher than the 3% reported by the Ministry of Agriculture. Since there is no reason to assume that the survey results for Rajasthan are any less accurate than the results for the other states, we must conclude that adoption of improved maize seed in Rajasthan has accelerated rapidly in recent years and that official statistics have yet to reflect this fact.

The survey results showing marked differences between states in the level of adoption of improved maize germplasm are consistent with what is known about the activities of the national maize seed industry. Previous studies have shown that private seed companies have tended to concentrate on areas of high production potential (Singh, Pal, and Morris 1995). Many seed companies have established breeding stations and seed production facilities in Karnataka, Andhra Pradesh, and to some extent in Bihar, where they have concentrated on developing hybrids adapted to the needs of local commercial maize growers who represent an attractive market. Meanwhile, they have generally neglected relatively unfavorable production environments, such as those found in Uttar Pradesh, Rajasthan, and Madhya Pradesh.

Table 9. Comparison of IARI/CIMMYT survey results with official statistics

	IARI/CIMMYT survey results				
State	Area under OPVs (%)	Area under hybrids (%)	Area under OPVs and hybrids (%)	Official statistics[a] for area under HYVs (%)	Difference
Andhra Pradesh	15	79	94	92	2
Bihar	26	55	81	57	24
Karnataka	12	86	98	94	4
Madhya Pradesh	23	15	38	44	(6)
Rajasthan	18	8	26	3	33
Uttar Pradesh	31	8	39	36	3

[a] From Ministry of Agriculture, New Delhi.

Production Practices and Input Use

Although improved seed can make a contribution to productivity independently of other inputs, it also has the ability to increase the productivity of other inputs. If farmers can obtain hybrid seed that performs well under local conditions, the efficiency with which other inputs are converted into economically valuable outputs increases, which increases the incentives to invest in the other inputs. Therefore it is not surprising that technical change in agriculture frequently is driven by changes in crop varieties, which in turn depend on farmers having reliable access to improved seed.

To what extent, if any, has adoption of hybrid maize seed among sample households been accompanied by changes in crop management practices?

Fertilizer. Table 10 presents information on the total amount of nitrogen (N), phosphorus (P), and potassium (K) fertilizer applied to maize by the sample households. Three aspects of the data are noteworthy.

First, in states in which two maize crops per year are grown, considerably more fertilizer is applied during *rabi* season. The higher rate of fertilizer application during *rabi* season presumably stems from the fact that *rabi* maize is generally irrigated, so farmers face little danger of losing their investment in fertilizer as a result of drought-induced crop failure.

Second, hybrids receive considerably more fertilizer than OPVs.[1] The higher rate of fertilizer application to hybrids no doubt is attributable to the greater ability of hybrids to respond to improved fertility, which makes investment in fertilizer more attractive.

Third, relatively more fertilizer is applied to OPVs grown during the *kharif* season in Madhya Pradesh, Rajasthan, and Uttar Pradesh than elsewhere. At first glance, this finding seems curious. One would expect fertilizer use to be lower in these three states, where maize is often produced under highly uncertain rainfed conditions. However, at least two factors could be contributing to the relatively high rate of fertilizer application to OPVs in these three states: (1) relatively few hybrids are available showing good adaptation to local

Table 10. Fertilizer use (NPK, kg/ha) on maize OPVs and hybrids, by season, sample respondents

	Kharif			*Rabi*		
State	**OPVs**	**Hybrids**	**Difference**	**OPVs**	**Hybrids**	**Difference**
Andhra Pradesh	43	80	+ 86%	52	89	+ 71%
Bihar	45	67	+ 49%	72	118	+ 64%
Karnataka	43	77	+ 79%	62	100	+ 61%
Madhya Pradesh	54	61	+ 14%	na	na	na
Rajasthan	51	58	+ 14%	na	na	na
Uttar Pradesh	52	79	+ 52%	na	na	na

Source: IARI/CIMMYT survey.

[1] Throughout this section, the term "OPV" denotes both local varieties and improved OPVs.

conditions (so farmers prefer OPVs), and (2) only one maize crop per year is grown in these three states (so farmers apply more fertilizer because there is no carry-over effect from fertilizer applied during the *rabi* season).

Irrigation. Table 11 presents information on the average number of irrigations applied to maize. Two features of the irrigation use data are noteworthy. First, the *rabi* maize crop receives many more irrigations than the *kharif* crop, which is hardly surprising, considering that the *kharif* crop is planted to coincide with the onset of the monsoon. Second, regardless of the season, there is relatively little difference in the number of irrigations applied to OPVs compared to hybrids. This second finding suggests that adoption of hybrid maize seed in and of itself does not seem to be associated with greater use of irrigation.

Herbicide. Table 12 presents information on the percentage of sample households that reported using herbicide on their maize. Four aspects of the herbicide use data are noteworthy. First, use of herbicide on maize is uncommon. Second, use of herbicide is relatively more common on hybrids than on OPVs. Third, use of herbicide is relatively greater during *rabi* season than during *kharif* season. Fourth, herbicide use in Andhra Pradesh is significantly higher than in the other states included in the survey. Since there is no reason to assume that weed problems are greater in Andhra Pradesh than elsewhere, this

Table 11. Average number of irrigations applied to different types of maize germplasm, by season, sample respondents

	Kharif			*Rabi*		
State	**OPVs**	**Hybrids**	**Difference**	**OPVs**	**Hybrids**	**Difference**
Andhra Pradesh	1.50	1.70	+ 13 %	6.07	6.28	+ 3 %
Bihar	1.47	2.80	+ 42 %	5.45	5.54	+ <1%
Karnataka	1.85	2.19	+ 18 %	5.55	5.86	+ 6 %
Madhya Pradesh	0.60	0.86	+ 43%	na	na	na
Rajasthan	0.78	0.84	+ 8%	na	na	na
Uttar Pradesh	0.86	0.93	+ 8%	na	na	na

Source: IARI/CIMMYT survey.

Table 12. Percentage of farmers applying herbicide to maize, by season, sample households

	Kharif			*Rabi*		
State	**OPVs**	**Hybrids**	**Difference**	**OPVs**	**Hybrids**	**Difference**
Andhra Pradesh	16.0	25.6	+ 56 %	19.25	29.62	+ 54%
Bihar	1.0	1.6	+ 60 %	2.5	4.6	+ 84%
Karnataka	2.0	4.0	+ 200 %	8.6	16.72	+ 94%
Madhya Pradesh	1.0	2.5	+ 148 %	na	na	na
Rajasthan	1.3	4.7	+ 262 %	na	na	na
Uttar Pradesh	1.1	1.2	+ 10 %	na	na	na

Source: IARI/CIMMYT survey.

result presumably means that maize growers in Andhra Pradesh have had greater exposure to herbicide and better appreciate its value.

Pesticide. Table 13 presents information on the percentage of sample households that reported using pesticides on their maize. The pesticide use data closely resemble those for herbicide use in all four respects. First, use of pesticide on maize is uncommon. Second, use of pesticide is relatively more common on hybrids than on OPVs. Third, use of pesticide is relatively greater during *rabi* season than during *kharif* season. Fourth, pesticide use in Andhra Pradesh is significantly higher than in the other states.

Impact of Improved Maize Seed Adoption

Generally speaking, the survey results support the view that adoption of improved maize seed and complementary crop management practices has accelerated sharply in recent years. Uptake of improved technologies has been particularly pronounced in states where maize is an important commercial crop, most notably Karnataka and Andhra Pradesh (during both *kharif* and *rabi* seasons), as well as Bihar (during *rabi* season only). In these states, use of improved germplasm is extensive; in some cases, practically 100% of the area planted to maize is now being sown with hybrid seed. Adoption of improved germplasm has been accompanied by an increase in the use of complementary inputs, most notably fertilizer, and to a lesser extent herbicide and pesticide. Maize growers do not appear to be using purchased inputs indiscriminately, however; rather, they appear to be increasing application rates when and where it is profitable to do so.

What has been the impact of adoption of improved maize technologies? Since detailed plot-level input-output data were not collected as part of the household survey, production functions could not be estimated to isolate the yield increase attributable to each input (improved seed, fertilizer, herbicide, pesticide, etc.). However, by comparing the average yields reported for OPVs and hybrids, it was possible to determine the combined effect of adopting hybrid seed, applying greater quantities of purchased inputs, and/or introducing improved crop management practices. A number of patterns are evident in the yield data presented in Table 14. First, average yields of maize during *rabi* season are significantly higher than average yields in *kharif* season, no doubt reflecting the more favorable growing conditions under which most of the *rabi* crop is produced (e.g., more reliable water supply,

Table 13. Percentage of farmers applying pesticide to maize, by season, sample households

	Kharif			*Rabi*		
State	**OPVs**	**Hybrids**	**Difference**	**OPVs**	**Hybrids**	**Difference**
Andhra Pradesh	29.3	33.4	+ 14 %	36.3	45.2	+ 25%
Bihar	3.0	6.4	+ 113 %	25.5	35.4	+ 39%
Karnataka	5.6	6.3	+ 13 %	10.3	43.4	+ 321%
Madhya Pradesh	1.3	2.8	+ 115 %	na	na	na
Rajasthan	6.3	10.3	+ 64 %	na	na	na
Uttar Pradesh	1.0	1.2	+ 20 %	na	na	na

Source: IARI/CIMMYT survey.

higher level of solar radiation, lower insect and disease pressure). Second, average yields are significantly higher in the three states in which maize is grown as a commercial crop (Andhra Pradesh, Karnataka, Bihar) than in the three states in which it is grown as a subsistence crop (Madhya Pradesh, Rajasthan, Uttar Pradesh). Third, in all six states, average yields reported for hybrids are significantly higher than average yields reported for OPVs; the yield difference ranges from a minimum of 25% in Rajasthan to a maximum of 61% in Bihar. Given the increased use of purchased inputs associated with adoption of hybrid seed, the entire amount of the yield difference cannot be attributed to the adoption of hybrids. However, it would be fair to say that adoption of hybrid seed serves as the catalyst for changes in crop management practices, and that the combined effect on yields is substantial.

Based on the differences observed in each of the six states between average yields of OPVs and average yields of hybrids, and taking into account the area planted to OPVs and hybrids in each state, it is possible to estimate the gross annual increase in maize production attributable to the adoption of hybrids and associated crop management practices (Table 15). In the absence of hybrids, maize production in the six states would have been more than one million tons lower during 1994/95 than it actually was.

Table 14. Average maize yields (kg/ha), 1994/95 *kharif* and *rabi* seasons, sample households

	Kharif			*Rabi*		
State	**OPVs**	**Hybrids**	**Difference**	**OPVs**	**Hybrids**	**Difference**
Andhra Pradesh	2,358	3,451	+ 46 %	3,151	4,097	+ 30%
Bihar	1,723	2,769	+ 61 %	3,257	4,351	+ 34%
Karnataka	2,267	3,368	+ 49 %	3,298	4,341	+ 32%
Madhya Pradesh	1,897	2,419	+ 28 %	na	na	na
Rajasthan	1,945	2,427	+ 25 %	na	na	na
Uttar Pradesh	1,956	2,881	+ 47 %	na	na	na

Source: IARI/CIMMYT survey.

Table 15. Increase in maize production attributable to adoption of hybrids, 1994/95 *kharif* and *rabi* seasons, selected states

	Kharif			*Rabi*		
State	**Yield difference (kg/ha)**	**Hybrid area (000 ha)[a]**	**Production increase (000 t)**	**Yield difference (kg/ha)**	**Hybrid area (000 ha)[a]**	**Production increase (000 t)**
Andhra Pradesh	1,093	200	219	946	45	43
Bihar	1,046	162	170	1,094	196	215
Karnataka	1,101	243	268	1,043	50	52
Madhya Pradesh	522	68	36	na	na	na
Rajasthan	482	74	36	na	na	na
Uttar Pradesh	925	84	78	na	na	na
Total (six states)			807			310

Source: IARI/CIMMYT survey.
[a] Calculated based on the total maize area in each state and the level of adoption of hybrid maize.

Procurement and Management of Improved Maize Seed

The aggregate data on varietal adoption and diffusion patterns indicate where improved maize germplasm has made an impact, but they reveal little about what is actually happening at the farm level. To shed light on microlevel aspects of hybrid seed use, households were questioned about their seed acquisition and management practices.

Maize Varietal Preferences

What characteristics do Indian farmers look for in a maize variety or hybrid? Survey participants were asked to cite the three characteristics that they consider most important in selecting a maize OPV or hybrid. In all six states, high yield was consistently ranked as the most important characteristic (Table 16). The second and third most important characteristics varied between states, ranging from agronomic performance (e.g., early maturity, drought tolerance) to resistance to biotic stresses (insects or diseases), grain color, fodder aspects, storage characteristics, and eating quality.

Although it is difficult to discern clear patterns in the responses, several trends stand out. Early maturity and/or drought tolerance were consistently mentioned in all six states, indicating that lack of a reliable water supply remains a major problem in most production environments. (This tendency was most evident in the exceptionally dry state of Rajasthan, where early maturity and drought tolerance were cited as important by almost all households – virtually to the exclusion of all other characteristics.) Insect and disease resistance were frequently mentioned in the southernmost states of Andhra Pradesh and Karnataka, presumably reflecting the greater incidence of disease and insect pressure in these states' warmer, moister production environments. Grain color was mentioned in several states; interestingly, many households in Andhra Pradesh, Madhya Pradesh, and Uttar Pradesh expressed a preference for yellow grain, while many households in Bihar favored white grain. In no state was grain texture (flint versus dent) mentioned as an important characteristic. Eating quality was considered important in several states, particularly those in which maize is a major food crop. Only in Madhya Pradesh were fodder aspects cited as important.

Generally speaking, the data presented in Table 16 reinforce the notion that maize varietal preferences vary considerably from one production environment to the other. All things being equal, maize-growing households prefer OPVs and hybrids that yield well, but the characteristics associated with high yield vary according to each production environment. Consumption characteristics are also important, with consumer preferences once again varying from one region to another.

Seed Replacement Patterns

How often do Indian maize farmers replace their seed? Table 17 presents information reported by sample households on the frequency of maize seed replacement. In Andhra Pradesh, Karnataka, and Bihar, states in which maize is an important commercial crop and adoption of hybrids is extensive, the vast majority of maize-growing households replace their seed annually. But in Madhya Pradesh, Rajasthan, and Uttar Pradesh, states in which maize is grown mainly for home consumption and adoption of hybrids is low, the vast

Table 16. Farmers' ranking of maize varietal characteristics (% of sample households)

State	Rank	High yield	Early maturity	Late maturity	Yellow color	White color	Insect resistance	Disease resistance	Drought tolerance	Waterlogging tolerance	Flinty grain	Dent grain	Good storability	Eating quality	Fodder aspects
	1st	92.4	6.3	0.7	—	—	—	—	0.7	—	—	—	—	—	—
Andhra Pradesh	2nd	—	3.5	—	21.5	—	63.2	—	11.8	—	—	—	—	—	—
	3rd	1.4	2.1	0.7	9.7	—	4.9	66.0	13.9	—	—	—	0.7	0.7	—
	1st	81.3	4.2	—	0.7	—	—	—	0.7	—	—	—	—	11.1	—
Bihar	2nd	2.8	16.7	—	4.2	38.9	12.5	1.4	9.7	1.4	—	—	2.1	7.6	—
	3rd	0.7	4.2	0.7	5.6	9.7	13.2	29.2	4.9	—	—	—	8.3	14.6	6.9
	1st	69.4	9.7	—	—	—	6.9	1.4	—	—	—	—	4.9	5.6	—
Karnataka	2nd	19.4	52.1	0.7	0.7	—	9.0	8.3	2.1	—	—	—	2.8	2.1	1.4
	3r\d	4.2	11.1	0.7	0.7	—	15.3	16.0	18.8	0.7	—	—	5.6	28.1	5.6
	1st	64.6	9.7	0.7	—	—	—	—	0.7	22.2	—	—	—	2.1	—
Madhya Pradesh	2nd	2.8	6.9	2.8	25.0	4.2	—	—	1.4	17.4	—	—	9.7	25.0	4.9
	3rd	0.7	—	—	—	0.9	0.7	—	0.7	1.4	—	—	19.4	31.3	45.1
	1st	95.1	1.4	—	—	—	—	—	1.4	—	—	—	—	—	—
Rajasthan	2nd	0.7	57.6	—	—	1.4	0.7	—	26.4	2.8	—	—	—	8.3	—
	3rd	0.7	96.5	—	—	—	—	—	—	—	—	—	—	—	—
	1st	73.6	20.1	0.7	1.4	—	—	—	0.7	—	—	—	—	2.1	—
Uttar Pradesh	2nd	2.8	49.3	1.4	25.0	2.8	—	—	13.9	0.7	—	—	—	2.8	—
	3rd	4.9	7.6	2.8	11.8	1.4	—	—	29.9	7.6	—	—	2.1	28.5	1.4
	1st	79.4	8.6	0.4	0.4	—	1.2	0.4	0.6	3.7	—	—	0.8	3.5	—
Total (six states)	2nd	4.8	31.0	0.8	12.7	7.9	14.2	1.6	10.9	3.7	—	—	2.4	7.6	1.0
	3rd	2.1	20.3	0.8	4.6	2.0	5.7	16.5	11.3	1.6	—	—	6.0	15.7	9.8

Source: IARI/CIMMYT survey.

majority of maize-growing households rarely or never replace their seed, preferring to replant seed saved from their own harvest.

In an effort to explain these marked differences in seed replacement practices, sample households were asked to explain why they replace or do not replace seed. Households that reported replacing seed on a frequent basis (annually or every two to three years) indicated that frequent replacement is necessary for three main reasons: (1) to maintain genetic purity, (2) to ensure a high germination rate, and (3) to avoid the difficulty and expense of on-farm storage. The relative frequency with which these three reasons were given did not vary much between states (Table 18).

Households that reported rarely or never replacing seed gave several reason to explain their behavior. The high cost of seed was often cited as a major constraint to frequent seed replacement, particularly in the commercial maize-growing states of Andhra Pradesh, Karnataka, and Bihar. In Madhya Pradesh, Rajasthan, and Uttar Pradesh, many households additionally indicated that they do not replace seed more frequently because seed is often unavailable. A significant number of households in these latter three states indicated that frequent seed replacement is unnecessary (Table 19).

Table 17. Frequency of maize seed replacement (% of sample households)

State	Frequency of maize seed replacement: Replace annually	Replace every 2-3 years	Replace every 4 years or more	Never replace
Andhra Pradesh	79	10	3	8
Bihar	74	13	3	10
Karnataka	85	7	3	6
Madhya Pradesh	4	14	14	68
Rajasthan	4	13	13	71
Uttar Pradesh	6	17	17	60
Total (six states)	42	12	8	38

Source: IARI/CIMMYT survey.

Table 18. Reasons for replacing seed (% of sample households that replace)

State	Loss of genetic purity	Poor germination rate	Difficulty and/or cost of storage	Other
Andhra Pradesh	54	24	13	0
Bihar	49	29	14	10
Karnataka	55	24	12	10
Madhya Pradesh	36	35	18	9
Rajasthan	35	35	17	11
Uttar Pradesh	44	30	15	13
Total (six states)	45	29	15	10

Source: IARI/CIMMYT survey.

Despite the efforts of government extension agents and seed company representatives to discourage replanting of F_2 hybrid seed, there is much anecdotal evidence suggesting that this practice is widespread. In an attempt to shed light on this issue, sample households were asked whether or not they replant F_2 hybrid seed. Slightly more than one-fifth of all households reported that they sometimes replant F_2 hybrid seed (Table 20). Among the many reasons given to explain this practice, two predominated:

First, many households indicated that they plant F_2 hybrid seed because they are reluctant to invest scarce resources in a crop as risky as maize. This attitude is very evident in states in which two cycles of maize are grown, particularly Bihar. Many households in Bihar reported that they purchase F_1 hybrid seed to plant during *rabi* season, when the maize crop is grown under irrigation, but that they prefer to replant F_2 seed during *kharif* season, when the maize crop is dependent on highly uncertain rainfall.

Second, many of the households that reported planting F_2 hybrid seed indicated that the yield difference between F_1 and F_2 generations of hybrid seed is relatively small. Considering that many of the commercial hybrids currently being sold in India are double-

Table 19. Reasons for not replacing seed (% of sample households that do not replace)

State	High cost of seed	Non-availability of seed	Seed replacement unnecessary	Other
Andhra Pradesh	92	4	3	2
Bihar	84	8	6	2
Karnataka	92	4	3	1
Madhya Pradesh	49	37	11	4
Rajasthan	43	29	24	4
Uttar Pradesh	44	40	10	6
Total (six states)	67	20	9	3

Source: IARI/CIMMYT survey.

Table 20. Frequency of planting of F_2 hybrid seed

State	Percent of households planting F_2 seed	Reason given for planting F_2 seed (% of households that replant)		
		Yield difference small	*Kharif* crop risky	F_1 seed not available
Andhra Pradesh	14	43	50	7
Bihar	47	19	72	9
Karnataka	13	24	38	38
Madhya Pradesh	20	70	15	15
Rajasthan	11	55	9	36
Uttar Pradesh	20	60	20	20
Total (six states)	21	38	43	19

Source: IARI/CIMMYT survey.

cross hybrids, this is undoubtedly correct; the expected yield decline in the F_2 generation of many double-cross hybrids is as low as 10-15%. Depending on the circumstances, and taking into account the possibility of weather-induced crop failure, farmers thus may be acting entirely rationally in planting F_2 hybrids.

Seed Procurement Practices

Where do Indian farmers procure maize seed? Table 21 presents information reported by the sample households concerning their seed procurement practices. Once again, marked differences are evident between states. In Andhra Pradesh, Karnataka, and Bihar, more than three-quarters of maize-growing households purchase their maize seed from external sources — usually private traders, or far less frequently one of the government seed agencies. But in Madhya Pradesh, Rajasthan, and Uttar Pradesh, two-thirds of maize-growing households produce their own seed by saving a portion of their own production for replanting the following cycle.

The extensive reliance on purchased maize seed provides compelling household-level evidence of the gains achieved in recent years by the formal maize seed industry. Judging from the data presented in Table 21, the private sector has been particularly effective at convincing farmers of the value of hybrid seed and inducing them to make regular seed purchases. This finding is supported by data reported previously on recent growth in hybrid seed sales (Singh, Pal, and Morris 1995).

While Indian farmers are evidently buying more hybrid maize seed, it is not clear to what extent they demand — or even recognize — specific products available in the marketplace. Efforts to determine whether or not the sample households are able to distinguish between individual hybrids proved inconclusive; in most cases, respondents were able to identify individual seed companies, but they were often unable to name specific hybrids sold by these companies. Thus, most households apparently select hybrid seed based on the general reputation of the seed company, rather than on knowledge of a specific hybrid.

How familiar are Indian maize farmers with private seed companies? Knowledge of individual seed companies was found to vary considerably across the sample (Table 22).

Table 21. Sources of maize seed (% of seed used by sample households)

	Maize seed procured from:				
State	Own harvest	Other farmers	Private trader	Government agency	Other
Andhra Pradesh	8	1	84	7	<1
Bihar	15	2	77	6	<1
Karnataka	5	1	73	20	<1
Madhya Pradesh	64	3	14	19	<1
Rajasthan	69	6	13	12	<1
Uttar Pradesh	67	10	9	14	<1
Total (six states)	38	4	45	13	<1

Source: IARI/CIMMYT survey.

The most widely recognized private maize seed companies were Pioneer and Mahyco, both of which were known to more than 50% of the sample households. These two industry leaders were followed at some distance by Proagro, Cargill, Kanchan Ganga, Nath, Messina Beej, Hindustan Lever, and Bisco, each of which was known to between 10% and 32% of the sample households. All other maize seed companies were known to less than 10% of the sample households.

Not surprisingly, knowledge of individual seed companies varied considerably between states, reflecting differences in market penetration. Most of the larger seed companies have been able to create brand awareness in all important maize-producing states, while many of the smaller companies clearly have focused on particular regional markets (e.g., Messina-Beej on Bihar, Hindustan Lever and Bisco on Karnataka).

Seed Management Practices

How do Indian farmers select their maize seed? Information provided by sample households on their seed selection practices appear in Table 23. Among households that produce their own seed, the vast majority make selections after the harvest, either while the ears are still in the field or after they have been transported back to the village. Very few households make selections prior to the harvest, when the crop is still growing and agronomic performance can be taken into account (e.g., plant architecture, maturity, resistance to biotic and/or abiotic stresses).

After ears have been selected for use as seed, they are usually separated from the rest of the harvest and subjected to special treatment. Grain destined for use as seed is carefully dried, cleaned, and packed so as to preserve its genetic purity and viability. It may also be treated to reduce damage during storage from fungal diseases or insect pests. In rare instances,

Table 22. Farmers' knowledge of leading private seed companies

	Percent of households recognizing each seed company						
Seed company	Total	Andhra Pradesh	Bihar	Karnataka	Madhya Pradesh	Rajasthan	Uttar Pradesh
Pioneer	60	92	96	40	39	94	—
Mahyco	52	87	50	49	31	90	6
Proagro	32	78	41	65	7	—	3
Cargill	28	59	2	88	—	19	—
Kanchan Ganga	26	56	5	82	14	4	—
Nath	22	54	9	42	17	10	—
Messina Beej	16	—	91	2	—	—	—
Hindustan Lever	11	—	2	63	—	—	—
Bisco	10	—	—	58	—	—	—
ITC-Zeneca	6	18	—	14	—	14	—
IEL	6	—	—	33	—	—	—
EID Parry	6	—	38	—	—	—	—
Vikki's	6	—	33	—	—	—	—

Source: IARI/CIMMYT survey.

seed is treated with commercial fungicide and/or insecticide; more frequently, protection against insect attack is ensured by dusting loose seed with wood ash prior to placement in storage containers or by suspending ears over a smoky fireplace (Table 24).

Demand for Hybrid Maize Seed

The survey findings on adoption of improved germplasm can be combined with the findings on seed management practices to generate a rough estimate of the potential demand for hybrid maize seed. The demand for hybrid maize seed was calculated as:

$$D_i = [(A_i * h_i) / r]$$

where:

D = demand for hybrid seed in state *i*,
A = area planted to maize in state *i*,
h = proportion of maize area planted to hybrid seed in state *i*,
r = maize seeding rate, and
i = state.

Table 23. Farm-level maize seed selection practices (% of sample households)

	Maize seed selection practice			
State	**Prior to harvest**	**After harvest, in field**	**After harvest, in house**	**Other**
Andhra Pradesh	4	12	14	70
Bihar	4	12	23	61
Karnataka	5	6	12	77
Madhya Pradesh	7	34	56	3
Rajasthan	6	40	51	3
Uttar Pradesh	3	31	63	3
Total (six states)	5	23	36	36

Source: IARI/CIMMYT survey.

Table 24. Seed treatment practices for on-farm storage (% of sample households)

	Percent of households treating seed with:				
State	**Insecticide**	**Fungicide**	**Ash**	**Smoke**	**No treatment**
Andhra Pradesh	2	2	—	2	94
Bihar	6	4	1	2	97
Karnataka	1	1	—	2	96
Madhya Pradesh	2	2	36	12	48
Rajasthan	2	1	47	6	44
Uttar Pradesh	3	4	14	31	47
Total (six states)	3	2	16	9	69

Source: IARI/CIMMYT survey.

Assuming an average planting rate of 20 kg/ha, the total potential demand for hybrid maize seed in 1995 in the six survey states was approximately 24,000 t.[2] If we accept the official government estimates for hybrid adoption rates in the states that were not covered by the survey, potential demand for hybrid maize seed in 1995 for all of India was approximately 31,000 t (Table 25).

These estimated figures for potential demand overstate the actual (or effective) demand for hybrid seed, because, as the survey results make clear, not all farmers replace their hybrid maize seed every cropping cycle. To estimate the effective demand for hybrid maize seed, the potential demand was adjusted downward using a hybrid seed recycling factor calculated from the information generated during the survey on seed recycling practices. For each state, the hybrid seed recycling factor was calculated as follows:

$$c = [(p_1 * 1) + (p_2 * 0.5)]$$

where:

c = hybrid seed recycling factor,
p_1 = percentage of households planting F_1 seed only, and
p_2 = percentage of households planting F_2 seed.

Adjustment of the estimated figure for potential demand for hybrid seed using the hybrid seed recycling factor yields an estimated effective demand for hybrid maize seed of slightly over 21,000 t in the six survey states and around 27,500 t for all of India. (The all-India figure assumes that the rate of hybrid seed recycling in the states not covered by the survey is equal to the average rate in the six states that were surveyed.)

Table 25. Potential demand for hybrid maize seed, India, 1995/96

	Total maize area (000 ha)	Percent planted to hybrids[a]	Hybrid maize area (000 ha)	Average planting rate[b] (kg/ha)	Potential seed demand (t)	F_2 seed recycling factor[c]	Effective seed demand (t)
Andhra Pradesh	307	79	242	20	4,844	0.93	4,505
Bihar	730	55	401	20	8,025	0.77	6,139
Karnataka	315	86	271	20	5,418	0.94	5,066
Madhya Pradesh	897	15	135	20	2,692	0.93	2,503
Rajasthan	916	8	73	20	1,466	0.90	1,319
Uttar Pradesh	1,084	8	87	20	1,734	0.95	1,639
Total/average (six states)	4,249	28	1,209	20	24,179	0.88	21,172
Other states	1,741	20	348	20	6,963	0.90	6,272
Total/average (all India)	5,989	26	1,557	20	31,142	0.88	27,444

[a] Weighted average of *kharif* and *rabi* figures; six states from IARI/CIMMYT survey results, other states from Ministry of Agriculture data.
[b] Recommended planting rate.
[c] Calculated from IARI/CIMMYT survey results.

[2] Recommended planting rates are considerably lower, ranging from 12 to 16 kg/ha depending on seed size. However, survey data indicate that most Indian farmers currently plant at significantly higher rates.

In the absence of reliable data on commercial hybrid maize seed sales, it is difficult to assess the reliability of these estimates. Based on a 1993 survey of the main government seed agencies and 21 leading private seed companies, Singh, Pal, and Morris (1995) estimated that hybrid maize seed production in 1992 totaled at least 13,000 t. Since many small private seed companies were not included in the survey, the actual amount of hybrid seed being produced in 1992 was thought to be significantly higher. Given the rapid rate at which hybrid seed sales have grown since the mid-1980s (Figure 3), it thus seems entirely plausible that hybrid seed sales could have reached 27,500 t by 1995.

Summary and Policy Implications

Summary of Main Findings

Since India's seed policies were reformed beginning in the late 1980s, improved maize germplasm has diffused rapidly throughout many regions of the country. By 1995, approximately 45% of the total national area planted to maize was being planted to improved OPVs and hybrids.[3] Unlike earlier years, when farmers grew mainly public sector hybrids, the majority of the hybrids now being grown are proprietary hybrids developed by private seed companies.

In India as in many other countries, uptake of improved maize germplasm has been accompanied by changes in crop management practices. Farmers who grow improved OPVs and hybrids apply more fertilizer and use herbicides and insecticides with greater frequency than do farmers who grow local varieties. The change in behavior has an economic explanation: improved OPVs and hybrids have the ability to respond to improved management practices, so increased investment in purchased inputs is very profitable. Diffusion of improved germplasm thus has served as an important catalyst for changes in crop management practices.

The gross annual increase in maize production attributable to the adoption of improved seed and associated crop management practices is estimated to be over one million tons. However, the benefits associated with adoption of improved germplasm have not been distributed equally, as adoption patterns show considerable spatial and temporal

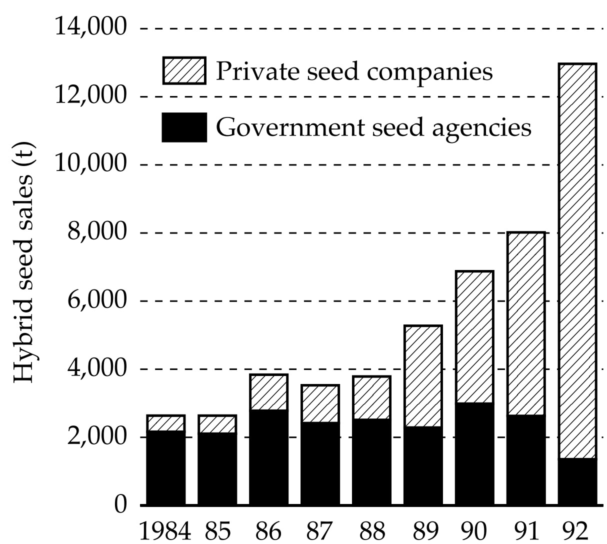

Figure 3. Sales of hybrid maize seed, India, 1984-92.
Source: 1993 IARI/CIMMYT seed industry study.

[3] In 1995, 51% of the maize area in the six states covered by the survey was planted to improved OPVs and hybrids. The estimated national adoption rate of 45% was obtained by combining this figure with official statistics on HYV adoption rates in states not covered by the survey.

variability. In states and/or cropping seasons in which maize is grown primarily by commercial farmers (e.g., Andhra Pradesh, Karnataka, Bihar during *rabi* season), virtually 100% of the maize area is planted to improved germplasm, including around 90% planted to hybrids. But in states and/or cropping seasons in which maize is grown primarily by subsistence-oriented farmers (e.g., Rajasthan, Madhya Pradesh, Uttar Pradesh, Bihar during *kharif* season), use of improved germplasm is much less extensive, and hybrid adoption levels have yet to attain 10%.

Indian farmers exhibit clear preferences when it comes to selecting maize OPVs and hybrids. The varietal characteristics they take into account fall into two basic groups: (1) characteristics that contribute to high yield (e.g., early maturity, drought tolerance, insect resistance, disease resistance), and (2) characteristics that determine whether or not the crop meets local consumption requirements (e.g., grain color, grain texture, taste, storability). Depending on their own particular circumstances, farmers place different degrees of emphasis on the relative importance of different characteristics. In unfavorable environments characterized by high levels of production risk (including many rainfed regions), farmers often value early maturity and drought tolerance above all other characteristics. But in more favorable environments subject to low levels of production risk (including many high rainfall and irrigated zones), grain quality characteristics usually assume greater importance.

Farmers who grow OPVs generally replace their seed at infrequent intervals, preferring instead to save seed from their own harvest for replanting the following cropping season. Most farmer-produced seed is selected following the harvest, once the crop has been transported back to the village. Ears selected for use as seed are usually stored separately from regular grain and may be treated with purchased chemicals (e.g., fungicide, insecticide), ashes, or smoke to prevent disease and/or insect damage during storage.

Most of the farmers who have adopted hybrids understand the importance of regularly replacing seed. In states and/or cropping seasons in which use of hybrids is extensive, the majority of maize farmers replace their seed at the beginning of each cropping cycle. However, a significant number of farmers recycle hybrid seed; over one-fifth of the households surveyed reported planting F_2 seed. Replanting recycled F_2 seed may well be rational when there is a high risk of crop failure, when the expected yield decline is low (as is frequently the case with double-cross hybrids), and/or when hybrid seed is expensive.

Although the market for hybrid maize seed in India is growing rapidly, knowledge of specific maize hybrids remains very limited. Most farmers select hybrid seed based on the reputation of the seed company, rather than on detailed knowledge about how a specific material performs. Knowledge of individual seed companies varies considerably. A few companies, notably Pioneer and Mahyco, have established national reputations and are well known throughout India. Other companies, including Proagro, Cargill, Kanchan Ganga, Nath, Messina Beej, Hindustan Lever, and Bisco, are well known in some states but not in others.

Implications for Seed Policy

From a policy perspective, the results presented in this paper provide grounds for both optimism and pessimism. On a positive note, our findings confirm that India's national maize seed industry is undergoing a phase of rapid expansion. Since seed policy reforms were introduced beginning in the late 1980s, the area planted to improved OPVs and hybrids has grown rapidly, and adoption of improved germplasm has fueled important changes in farmers' crop management practices. Significantly, from a budgetary point of view, these achievements have been realized during a period when the government has actually scaled back its involvement in maize seed production, as evidenced by declining volumes of subsidized maize seed sold by the National Seeds Corporation and the various State Seeds Corporations.

Efforts to liberalize the private maize seed industry are clearly paying off. Private seed companies have demonstrated the ability to develop superior hybrids, produce high quality seed, and distribute that seed to farmers at affordable prices. Fears that the Indian maize seed industry would be overrun by powerful multinational seed companies have proven largely unfounded; although many multinationals have established a presence in India, the Indian maize seed industry continues to be populated by a large number of Indian-owned companies that have demonstrated their ability to compete effectively in the marketplace. These positive developments send a strong signal that seed policy reforms are succeeding in bringing about their intended effects.

But despite the considerable progress that has been achieved thus far, policy makers would be well advised to keep a close watch on future developments in the national maize seed industry. If the Indian experience is at all similar to that of other countries, the diffusion of improved germplasm can be expected to slow once adoption levels in the commercial farming sector approach 100%. When that happens, the industry may suddenly stop growing as seed companies realize that further expansion into marginal production environments populated primarily by subsistence-oriented farmers is inherently unprofitable. At that point, instead of seeking to increase their sales by reaching out to farmers who have never tried hybrids, seed companies may decide to focus their efforts on capturing and retaining a bigger share of the limited – yet very lucrative — market comprised of commercial growers.

Although it is difficult to say just when growth in effective demand for improved maize seed will cease, it can safely be predicted that at least for the foreseeable future, many of India's poorest maize farmers are unlikely to provide attractive commercial opportunities for profit-oriented private firms. Since subsistence-oriented farmers are unlikely to be served effectively by the private seed industry, special policy measures will probably be needed to ensure that the benefits of improved germplasm are widely distributed. Such policy measures might include introduction of targeted input subsidies designed to reduce the cost of adopting improved seed and complementary inputs (especially fertilizer), government investment in irrigation infrastructure designed to reduce production risk in drought-prone environments, and/or market development initiatives designed to provide small-scale maize producers with access to stable and reliable outlets where they can sell surplus grain.

Implications for Research

The adoption data presented in this study indicate that India's maize research system has been quite successful in developing improved OPVs and hybrids that meet the needs of the nation's commercial maize growers. Public and private breeding programs can both claim a share of the credit for this success, because their activities are in many ways complementary. With the emergence of a flourishing private maize seed industry, many public breeding programs have begun to shift the main focus of their activities, moving "upstream" in the research pipeline in a conscious effort to strengthen their involvement in activities that are unlikely to be performed by the private sector, such as prebreeding, basic population improvement, development of special-trait germplasm, and inbreeding. Meanwhile, private seed companies have become adept at identifying specific markets and developing commercial hybrids adapted to these markets. The growing collaboration between the public and private research systems has been reflected in recent years in increasing interchanges of germplasm, information, and personnel.

Although the emergence of a flourishing private maize seed industry has relieved some of the pressure on public breeding programs, government research administrators must be careful to ensure that the allocation of research resources remains consistent with national policy objectives. In the past, maize breeding efforts in both the public and private sectors have focused disproportionately on favorable production environments. This focus has been understandable given the high expected payoffs in these environments, and up until now the strategy clearly has paid off. However, at some point a shift in focus will almost certainly become necessary. With hybrid adoption levels in some states already exceeding 90%, the expected returns from further research investment targeted at these states are undoubtedly declining, and eventually it may become appropriate to shift attention elsewhere.

Addressing the special needs of maize growers located in marginal production environments will not be easy. Experience suggests that it is usually very difficult to breed for the traits required by these environments, especially early maturity, drought tolerance, and waterlogging tolerance. Even if it is possible to develop materials with these traits, effective demand for commercial seed will often be weak. For these reasons, private companies are unlikely to show much interest in marginal environments, which means that responsibility for these environments is likely to fall squarely on the shoulders of the public sector.

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