Impact of Public- and Private-Sector Maize Breeding Research in Asia, 1966-1997/98

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Chapter 1

The Maize Economy of Asia

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Maize has always been a second-priority crop in Asia after rice. Recently however population growth and rising consumption of livestock products (in turn fueled by rising per capita incomes) have led to increased demand for maize. To serve this increased demand, Asian maize farmers are gradually shifting to higher yielding maize varieties and using more modern production technologies. In response, maize research and development (R&D) agencies in the region are aligning their research strategies to better serve the changing production and market requirements.

Importance of Maize

Worldwide, maize ranks first in terms of production among cereals, just ahead of wheat and significantly ahead of paddy rice. In developing economies, maize ranks first in Latin America and Africa, but only third in Asia after rice and wheat (FAO 2001). Globally, 561 million tons (m t) of maize were harvested in 1995-97 from just under 140 million hectares (m ha). Seventy-six percent of this area was located in developing countries (CIMMYT 1999). During the same period, around 151 m t of maize grain (27% of world production) were harvested in Asian countries from 42 m ha (30% of global maize area) (Table 1). This level of production represented a significant increase from 1983-85, when 94 m t of maize were produced annually from 35 m ha. Asia's contribution to worldwide harvested maize area and maize production also increased markedly between the two periods (Table 1).

It is projected that by 2020 demand for maize in developing countries will surpass the demand for both wheat and rice. Globally, maize demand is projected to increase by 50% from its 1995 level of

Table 1. Average annual maize area, yield and production, Asia and the world, 1983-85 and 1995-97

	1983-85			1995-97		
	Area (m ha)	Yield (t/ha)	Production (m t)	Area (m ha)	Yield (t/ha)	Production (m t)
Asia	35.6	2.7	96.6	41.9	3.6	151.7
South	7.5	1.3	10.0	8.0	1.5	12.3
Southeast	8.2	1.6	13.4	8.5	2.2	19.1
East	18.9	3.7	70.8	24.3	4.8	117.0
West[a]	1.0	2.3	2.4	1.1	3.1	3.3
World	126.7	3.4	429.9	136.7	4.1	561.5
Asia as percentage of world	28.1	79.4	22.5	30.7	87.8	27.0

Source: CIMMYT (1987, 1999).

[a] Data for West Asia, 1983-85, computed from FAOSTAT database, Production Domain, May 2000.

558 m t to 837 m t by 2020 (IFPRI 2000). In developing countries, rising incomes and the consequent growth in meat and poultry consumption have resulted in a rapid increase in the demand for maize as livestock feed. This trend is particularly evident in East and Southeast Asia, where maize demand is projected to increase from 150 m t in 1995 to 280 m t in 2020 (IFPRI 2000). Unabated population growth and the persistence of poverty have also kept food maize demand high in poor countries, as in some parts of South Asia.

Environmental, technological and institutional factors have led to differentiation in maize production systems across Asia. In the intensive production systems of East Asia, maize is grown mainly in favorable environments by commercial farmers who plant high-yielding varieties (HYVs), apply high levels of purchased inputs and make extensive use of machinery. By contrast, in the more extensive production systems of South Asia, maize is grown mainly in marginal environments by subsistence-oriented farmers who rely heavily on manual labor or animal power.

The major maize producers in Asia are China and Korea (D.P.R.) in East Asia; Indonesia, Thailand and Philippines in Southeast Asia; India, Nepal and Pakistan in South Asia; and Turkey, Iran and Afghanistan in West Asia. The major maize consumers in the region are Jordan, Lebanon, Sri Lanka, Malaysia and the Republic of Korea (see Annex 1, p.10).

Principal Maize Production Environments

Maize (*Zea mays L.*) is a versatile crop that adapts easily to a wide range of production environments. Maize grows at latitudes ranging from the equator to slightly above 50° North and South, from sea level to over 3,000 meters above sea level (masl), under heavy rainfall and in semi-arid conditions, and in temperate and tropical climates. The growing cycle can range from three months to more than a year (Dowswell *et al.* 1996). Maximum grain yields have been recorded in locations where temperatures reach 30-32ºC during the day and drop to 11-18ºC at night, but the crop can tolerate wide deviations from this ideal range (Dayanand 1998).

The diverse environments in which maize is grown in Asia reflect the crop's adaptability to a wide range of production conditions, as well as its suitability for many different types of cropping systems. Maize can be grown as a monocrop, as an intercrop or as a relay crop; it can be harvested green (fodder) or when fully mature (grain and stover).

In India, maize is cultivated in locations where temperatures range from as low as 10ºC to as high as 45ºC and where rainfall ranges from as little as 200 millimeters per year (mm/yr) to as much as 2,500 mm/yr. Indian maize production has traditionally been concentrated in the southern "Corn Belt" states of Karnataka and Andra Pradesh, where the main maize crop is grown during the summer (*kharif*) season. In recent years, introduction of cold-tolerant varieties has led to the emergence of an irrigated winter (*rabi*) maize crop in the northern states of Bihar and Uttar Pradesh.

In Nepal, maize is grown in three of the country's four ecological zones. In the Terai (1,000 masl), an intensively cultivated flood plain, maize is the third most important crop after paddy and wheat. In the mid-hills (1,000-3,000 masl), a zone of steeply sloping land and many small river valleys, maize is the most important cereal crop, followed by millet and paddy. In the mountain zone (>3,000 masl), where only about 4% of the steeply sloping land surface is cultivated, maize covers about 30% of the total cropped area.

In Indonesia, maize production systems are distributed in a mosaic across the country. Maize is grown in *tegalan* (rainfed dryland) and in *sawah* (floodable wetland). There is also the specialized

tidal swamp maize production system, called *surjan*, found mainly in newly opened land outside Java, where rice is grown in standing water in sunken beds and maize is grown on raised beds (Subandi 1998).

In China, maize is grown in every province. Approximately two-thirds of the maize in China is grown in temperate production environments in the north; the rest is grown in the subtropical and tropical environments of the south (Dowswell *et al.* 1996, Pray *et al*. 1998).

No universally recognized system exists for classifying maize production environments. CIMMYT, which holds a global mandate for maize improvement in developing countries, has developed a classification system based on the concept of *mega-environments* (CIMMYT Maize Program 1988, Hartkamp *et al*. 2000).[1] CIMMYT maize breeders commonly distinguish four major maize mega-environments: the lowland tropics, tropical highlands, subtropics/mid-altitude zones and temperate zones (Table 2).

In Asia, maize is grown mainly in tropical lowland and temperate environments (Table 3). While tropical lowland production environments are found in all Asian countries, temperate production environments are found mostly in northern China (Vasal 1998). Within a given country, maize production may be concentrated within a single mega-environment (as in Thailand and Indonesia, where maize is grown mainly in lowland tropical zones), or it may be distributed across several different mega-environments (as in China, where maize is grown in lowland tropical, subtropical/mid-altitude, tropical highland and temperate zones).

Cropping patterns adopted by maize farmers reflect a confluence of factors. On the supply side, these include climatic conditions, land type, soil characteristics and water availability. On the

Table 2. Major maize mega-environments

Mega-environment	Latitude	Elevation (masl)
Lowland tropics	0–25^0 North and South	<1,000
Tropical highlands	0–25^0 North and South	>1,800
Subtropics/mid-altitude zones	26^0–36^0 North and South	1,000–1,500
Temperate zones	>36^0 North and South	All elevations

Source: S. Pandey (personal communication).

Table 3. Maize area by mega-environment, all developing countries of Asia, late 1990s

	Including China		Excluding China	
Mega-environment	Area (000 ha)	Proportion of total area	Area (000 ha)	Proportion of total area
Lowland tropics	13,456	35.4	13,456	53.6
Tropical highlands	958	2.5	958	3.8
Subtropics/mid-altitude zones	4,254	11.2	4,254	16.9
Temperate zones	19,300	50.8	6,433	25.6
Total	37,968	100.0	25,101	100.0

Source: Vasal (1998).

[1] A mega-environment is a broad, not necessarily contiguous production zone, delineated by certain ecological conditions (e.g., temperature, rainfall, soils), crop characteristics (e.g., maturity cycle, grain color, grain texture), biotic and abiotic constraints and socio-economic factors (e.g., production systems, cropping patterns, consumer preferences). A recent GIS-based approach by CIMMYT to defining mega-environments for maize research may be seen in Hartkamp *et al.* (2000).

demand side, utilization patterns play an important role. Maize-millet cropping systems are most common in South Asia, whereas rice-maize and maize-vegetable cropping systems predominate in Southeast Asia.

In Nepal, the maize-millet rotation is the most important rotation among farmers of the hill regions, covering about 45% of the cultivated area in the eastern hills. In some Terai districts served by good roads, high-value vegetable crops, such as cabbage, cauliflower and tomato, are grown after maize (Chaudhary *et al.* 1996).

In Indonesia, maize cropping systems can be classified into high-productivity and low-productivity systems. High-productivity systems are characterized by abundant water supply and receive adequate fertilizer. Where these systems are common, farmers grow two to three maize crops in succession or rotate maize with cash crops, such as cassava. Low-productivity systems are located in less developed or remote areas and cover 69% of Indonesia's total maize area (Subandi 1998). In these systems, farmers apply less fertilizer and plant early maturing white or yellow local varieties that are mostly consumed directly by the household.

In the Philippines, traditional distinctions among maize production systems are based not on agro-ecological characteristics, but on grain color. The distinction is quite stark, because white-colored varieties are grown in low-productivity areas where maize is a staple, while yellow-colored varieties are grown in high-productivity areas where it is used as livestock feed.

More generally, throughout Asia white maize is grown mainly in marginal environments and used for home consumption. In these environments, which occupy several million hectares in the various ecological zones, use of improved varieties is uncommon, and application of fertilizer, pesticides and herbicides is inadequate. Subsistence farmers, who make up the majority of farmers in marginal areas, use few purchased inputs either because they lack capital needed to pay for them or because the inputs are simply not available. Improving the productivity of marginal environments through dissemination of improved production technologies remains a fundamental challenge for maize R&D, especially given that suitable early maturing genotypes are still lacking (Vasal 1998).

In Asia as in other regions of the developing world, there is a positive relationship between the share of white maize in total maize production and the importance of maize as a component of human diets (FAO and CIMMYT 1997).

Long-Term Production Trends

In 1996-98, China led Asia[2] in maize production. Chinese farmers produced 122 m t of maize on about 25 m ha, achieving average yields of 5 tons per hectare (t/ha) (Table 4). India was second after China in maize area harvested and production, followed by Indonesia and Thailand. Of the seven countries included in the CIMMYT study, Nepal was the smallest maize producer. Nepalese farmers produced 1.3 m t of maize on about 800,000 ha, achieving average yields of 1.6 t/ha.

The area planted to maize in Asia increased from 27 m ha during the 1960s to 38 m ha during the 1990s (1% average annual growth). During the same period, average maize yields rose from 1.4 t/ha to 3.7 t/ha (3.6% average annual growth). Due to the combined effects of area expansion and yield gains, maize production almost tripled from 35 m t to around 120 m t (4.6% average annual growth) (Tables 4 and 5). Figure 1 shows the relative contributions of area and yield to growth in maize production in Asia between 1961 and 1998.

2 Throughout this report, unless otherwise stated, "Asia" refers to the seven countries included in this study: China (the southern provinces), India, Indonesia, Nepal, the Philippines, Thailand and Vietnam.

Table 4. Maize production and net imports, selected Asian countries, 1996-98

	Area harvested (t / ha)	Yield (m t)	Production (000 t)	Net imports (m ha)
China (all)	24.6	5.0	121.9	-1,956.2
India	6.2	1.7	10.8	41.6
Indonesia	3.6	2.6	9.4	-469.3
Nepal	0.8	1.7	1.3	-0.2
Philippines	2.6	1.6	4.2	-421.9
Thailand	1.2	3.6	4.3	-177.2
Vietnam	0.6	2.5	1.6	56.4
Asia	39.7	3.9	153.6	-2,926.8

Source: Basic data from FAOSTAT database, Production Domain, April 2001.
Note: Some columns do not sum due to rounding.

Table 5. Growth (%) in maize area, yield and production, selected Asian countries and region, 1961-98

Country / period	Area	Yield	Production	Country / period	Area	Yield	Production
China (all)				Philippines			
1961-70	1.4	6.0	7.4	1961-70	2.8	3.0	5.8
1971-80	2.7	4.4	7.1	1971-80	3.4	2.3	5.7
1981-90	1.3	3.1	4.4	1981-90	2.0	2.9	5.0
1991-98	2.7	1.2	3.9	1991-98	-5.5	3.1	-2.4
1961-98	1.3	3.9	5.1	1961-98	1.3	2.5	3.8
India				Thailand			
1961-70	3.5	1.7	5.1	1961-70	9.8	2.5	2.3
1971-80	0.0	1.4	1.4	1971-80	4.2	0.3	4.5
1981-90	0.0	2.5	2.6	1981-90	1.3	0.7	2.0
1991-98	0.8	2.6	3.4	1991-98	-1.2	4.3	3.1
1961-98	0.6	1.6	2.2	1961-98	3.4	1.4	4.8
Indonesia				Vietnam			
1961-70	0.1	-0.1	0.0	1961-70	-1.6	-0.2	-1.8
1971-80	0.4	4.1	4.6	1971-80	7.2	-0.7	6.5
1981-90	2.1	3.8	5.9	1981-90	2.9	4.1	6.9
1991-98	2.9	3.2	6.1	1991-98	5.9	8.2	14.0
1961-98	0.6	3.1	3.9	1961-98	2.7	2.1	4.5
Nepal				Asia			
1961-70	0.0	-0.9	-0.9	1961-70	1.9	3.4	5.3
1971-80	0.0	-2.1	-2.1	1971-80	2.1	3.7	5.9
1981-90	5.6	0.5	6.1	1981-90	1.3	3.0	4.3
1991-98	0.8	0.7	1.5	1991-98	1.7	2.2	3.8
1961-98	2.1	-0.6	1.5	1961-98	1.2	3.4	4.6

Source: Basic data from FAOSTAT database, Utilization Domain, April 2001.

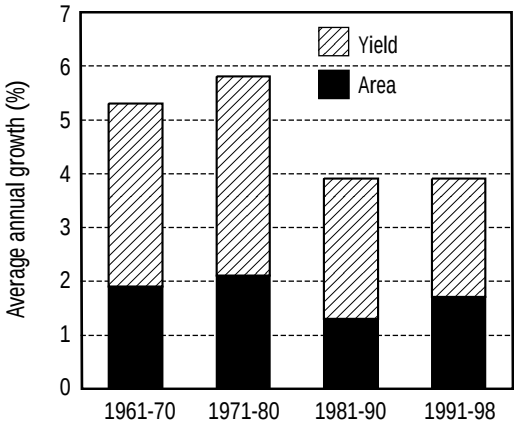

Figure 1. Area and yield contribution to maize production growth in Asia, 1961-98.
Source: FAOSTAT database, Production Domain, April 2001.

The aggregate regional figures conceal considerable variation in country-level trends, however. During the last four decades, Indonesia and Vietnam have experienced accelerating growth in maize area and yields, resulting in rapid growth in production. The most notable improvement came from Vietnam, where maize production declined by 1.8% per year during the 1960s because of the war, recovered after the liberalization of agricultural production in the late 1980s, and grew at a rate of 14% per year during the 1990s. In China and the Philippines, maize production has continued to increase, although annual rates of growth have slowed in recent years. Maize production in the Philippines increased by nearly 6% per year during the 1960s, but during the 1990s it declined at a rate of 2.4% per year.

Long-Term Utilization Trends

Maize has four principal uses: human food, livestock feed, industrial input, seed.[3] At the global level, growth in demand for maize has been driven mainly by rapidly increasing demand for livestock feed. Use of maize as an industrial input to produce food and non-food products has also increased, although less dramatically. Direct human consumption of maize has actually declined as per capita incomes have risen, enabling consumers to replace maize with more preferred foods (Table 6).

Maize utilization trends in Asia have paralleled those taking place at the global level. Food use of maize in Asia rose from 22 m t per year during the 1960s to 38 m t per year during the 1980s before declining to 32 m t per year during the 1990s. Meanwhile, feed use of maize grew explosively from about 10 m t per year

Table 6. Per capita income, maize net imports and per capita utilization, Asia and the world, 1982-84 and 1994-96

	1982-84			1994-96		
	Per capita income (US$)	Maize net imports (000 t)	Per capita utilization (kg / yr)	Per capita income (US$)	Maize net imports (000 t)	Per capita utilization (kg / yr)
Asia						
South	256	-24	10	382	-20	10
Southeast	853	-1,075	30	1,335	3,311	49
East	382	7,338	71	1,219	12,871	99
West[a]	-	286	29	2,152	3,345	29
World	2,650	-317	91	5,260	na	98

Source: CIMMYT (1984, 1999).
Note: na = not available.
[a] Averages for 1982-84 computed from the FAOSTAT database, June 2001.

3 In this report, "utilization" refers to all major uses of maize, whereas "consumption" refers specifically to the use of maize for human food.

during the 1960s to 89 m t per year during the 1990s (Figure 2). Across the entire period, food use grew at barely 1% per year, well below the 8% average annual growth in feed use. Seed use meanwhile remained constant at around 2% of total annual maize supply.

Until quite recently, maize in Asia was a subsistence crop grown mainly for home consumption or for use in small-scale backyard pig and poultry operations. Today, it has become a leading cash crop produced as an input into large-scale commercial feed enterprises. For Asia as a whole, currently about 67% of total maize supply is used to feed livestock, about 20% is used as human food and the rest goes to other uses (industrial input, seed). Not surprisingly given its enormous size, China uses more maize than any other Asian country. Maize in China is used mainly to feed livestock, although a significant proportion of total supply is consumed directly by humans (Table 7). Among the countries included in the study, feed use of maize is highest in Thailand, where livestock producers use 96% of maize supply. Food use is highest in Nepal, where 70% of maize supply is consumed directly by humans. Consistent with these differences in country-level utilization figures, per capita consumption of maize is highest in Nepal (42 kg) and lowest in Thailand (0.5 kg) (Table 7).

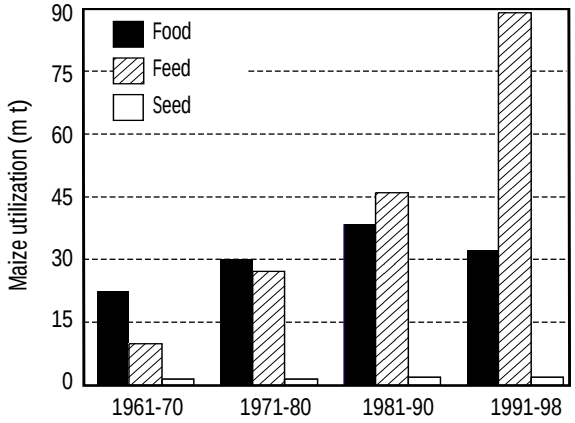

Figure 2. Average maize utilization as human food, livestock feed and seed, Asia, 1961-98.
Source: FAOSTAT database, Utilization Domain, April 2001.

As in the case of production, aggregate regional utilization trends conceal considerable variability at the country level. During the 1990s, average annual growth in maize utilization ranged from an astonishing 15% in Vietnam to an anemic 0.1% in the Philippines (Table 8). Within individual countries, utilization trends reflected the combined effects of two tendencies: changes in feed use (usually positive and large) and changes in food use (usually negative and small).

Trends in Trade

During 1961-98, Asia's maize exports grew at 3.9% per annum; imports grew much faster at 12% per annum. Trade peaked at a net export of 4.2 m t

Table 7. Maize utilization, selected Asian countries and region, 1996-98

	Utilization (m t)	Per capita consumption (kg)	Proportion for		
			Food	Feed	Other
China (all)	125.6	10.6	11	76	13
India	10.7	8.8	79	2	19
Indonesia	9.9	38.0	78	6	16
Nepal	1.3	42.1	70	18	12
Philippines	4.6	7.3	11	76	13
Thailand	4.4	0.5	<1	96	3.4
Vietnam	1.5	4.1	20	74	6
Asia	158.0	11.8	20	67	13

Source: Basic data from FAOSTAT database, Utilization Domain, April 2001.
Note: Some columns do not sum due to rounding.

during the 1970s but dramatically declined to a net import of 823,000 t during the 1990s. The shift from being a net exporter to a net importer was pushed largely by the increasing domestic demand from China, Indonesia and the Philippines. Although a major maize producer, China's growing population and rising per capita income contributed to increased demand for meat products and, consequently, to increased maize utilization.

India and Vietnam meanwhile moved from being net importers up to the 1980s to being net exporters in the 1990s. Supported by improved production technologies, the growth in maize production in these two countries exceeded that of utilization and allowed the change in trade status.

Thailand has always been a net exporter of maize grain. Its volume of net export however has been declining in recent years. Thailand's average annual maize export peaked at 2.3 m t during the 1980s but was barely 70,000 t during the 1990s. The exploding domestic demand for maize as livestock feed led to this trend.

The expanding opportunities for maize production in Asia present many challenges for the region's maize seed industries. To understand how maize R&D serves (or can better serve) the needs of commercial as well as subsistence maize farmers in Asia, important questions to consider include:

- How is the maize R&D system in Asia organized?
- What roles do the public and private sectors play in maize R&D system?
- How do public and private sectors serve the varying needs of maize farmers around Asia?
- What technological and policy issues related to maize R&D concern players in the seed industry?

Table 8. Annual growth (%) in maize utilization, selected Asian countries and region, 1961-98

Country / period	Total utilization	Food	Feed	Country / period	Total utilization	Food	Feed
China (all)				Philippines			
1961-70	7.7	2.3	21.7	1961-70	5.9	6.6	5.8
1971-80	7.4	5.2	9.8	1971-80	5.7	5.9	5.7
1981-90	3.4	1.1	3.9	1981-90	3.3	2.3	3.6
1991-98	4.9	-8.3	7.5	1991-98	0.1	-15.2	4.6
India				Thailand			
1961-70	4.9	5.0	4.0	1961-70	4.8	9.3	-3.1
1971-80	1.4	1.7	-0.8	1971-80	6.1	8.8	10.0
1981-90	2.6	2.6	2.5	1981-90	20.1	14.8	22.7
1991-98	3.3	3.5	2.6	1991-98	4.6	2.2	4.6
Indonesia				Vietnam			
1961-70	1.1	1.4	-0.7	1961-70	-0.1	-1.5	10.5
1971-80	4.6	4.0	11.6	1971-80	3.7	5.0	-4.2
1981-90	5.7	5.4	5.7	1981-90	6.3	4.2	16.7
1991-98	6.4	6.5	6.0	1991-98	15.3	-5.1	30.5
Nepal				Asia			
1961-70	-0.9	-0.7	-1.3	1961-70	5.6	1.6	18.4
1971-80	-2.1	-2.0	2.6	1971-80	6.2	3.9	9.4
1981-90	6.0	5.0	23.7	1981-90	3.8	2.0	4.4
1991-98	1.3	-2.2	45.1	1991-98	4.8	-2.6	7.5

Source: Basic data from FAOSTAT database, Utilization Domain, April 2001.

These questions are explored in Chapter 2 for the region as a whole and in greater detail for individual countries in Chapters 3-8.

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Annex 1

Maize Producers and Consumers in Asia

Table A1.1. Major maize producers in Asia

	West Asia			East Asia		South Asia			Southeast Asia		
Indicator	**Turkey**	**Iran**	**Afghanistan**	**China**	**Korea (D.P.R.)**	**India**	**Nepal**	**Pakistan**	**Indonesia**	**Thailand**	**Philippines**
Average maize area harvested, 1997-99 (000 ha)	573	148	200	24,996	576	6,223	800	879	3,547	1,263	2,594
Average maize yield, 1997-99 (t/ha)	3.9	6.3	1.2	4.9	2.3	1.7	1.7	1.4	2.6	3.6	1.6
Average maize production, 1997-99 (000 t)	2,260	932	243	121,363	1,338	10,964	1,343	1,251	9,358	4,483	4,266
Growth rate of maize area, 1988-99 (%/year)	1.3	28.1	-3.2	2.3	-1.8	0.6	0.9	0.3	1.5	-3.0	-4.3
Growth rate of maize yield, 1988-99 (%/year)	-0.6	8.0	-4.2	2.0	-12.0	1.5	0.8	0.3	2.7	4.0	3.4
Growth rate of maize production, 1988-99 (%/year)	0.7	36.1	-7.5	4.3	-13.8	2.2	1.6	0.6	4.2	0.9	-0.9
Maize area as % of total cereal area (average), 1997-99 (%)	4	2	7	27	42	6	25	7	24	11	41
Average net imports of maize, 1996-98 (000 t)	832	1,068	na	1,938	354	-26	3	5	453	179	393
Average % maize used for animal feed, 1995-97 (%)	39	92	20	76	<1	2	3	20	5	96	74
Average % maize used for direct human consumption, 1995-97 (%)	47	3	74	11	54	77	85	59	79	<1	14

Source: CIMMYT (2001).
Note: na = not available.

Table A1.2. Major maize consumers in Asia

Indicator	Jordan	Lebanon	Sri Lanka	Malaysia	Korea, Republic of
Average maize area harvested, 1995-97 (000 ha)	<1	2	33	24	18
Average maize yield, 1995-97 (t/ha)	11.4	2.0	1.0	1.8	4.1
Average maize production, 1995-97 (000 t)	4	4	34	44	74
Growth rate of maize area, 1991-97 (%/year)	++	++	2.0	3.8	-3.7
Growth rate of maize yield, 1991-97 (%/year)	++	++	-1.1	0.9	1.6
Growth rate of maize production, 1991-97 (%/year)	++	++	0.9	4.7	-2.1
Maize area as % of total cereal area (average), 1995-97 (%)	<1	5	4	4	2
Average net imports of maize, 1994-96 (000 t)	363	250	4	2,184	7,821
Average % maize used for animal feed, 1994-96 (%)	95	94	42	91	63
Average % maize used for direct human consumption, 1994-96 (%)	1	2	56	3	9

Source: CIMMYT (1999).

Note: ++ indicates that data are not available or incomplete.