CIMMYT

World Maize
Facts and Trends 1997/98

Maize Production in Drought-Stressed Environments: Technical Options and Research Resource Allocation

Paul W. Heisey and Gregory O. Edmeades

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Abstract: This publication, through its focus on maize production in drought stressed areas of developing countries, explores economic, research, and policy issues related to maize agriculture in marginal areas of the developing world generally. Key questions in the debate over agriculture in marginal vs. favorable production areas are reviewed with a focus on maize. Questions include whether maize production is expanding into marginal areas, if production from such areas is necessary to meet future demand, and what is the relationship between marginal production environments and poverty. Different research resource allocations (leading to technological change) are modeled to compare gains and losses to producers and consumers in marginal, favorable, and urban areas of a country. A thorough overview of technical constraints and responses for maize production in drought-stressed environments is also presented. The authors conclude that agricultural research for marginal and, particularly, for drought-stressed areas will continue to be justified on the basis of meeting future demand requirements. Evidence that the marginality of agricultural land is related to poverty is decidedly mixed because of a range of factors outside the realm of agroclimatic conditions. To better determine efficient research allocations, considerably more study in this neglected area will be required. Such research should incorporate data from case studies, and more accurate definition of marginal areas provided by data from geographic information systems, crop modeling, and refined economic measures. The publication concludes with a brief overview of the world maize situation in 1997/98, followed by selected statistics on production, consumption, and trade for all regions of the world.

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Contents

Acknowledgments

Foreword

Determining how to meet the demand for more food by the developing world's growing population is a critical and complex challenge. "Critical" because the well-being of hundreds of millions of people and the environments they inhabit hang in the balance. "Complex" because of the multifaceted nature of the challenge which spans diverse disciplines ranging from macroeconomics to molecular genetics.

This challenge has spawned an important debate over *where* we'll obtain additional food production. Will it come from further increasing yields on favorable lands? From increasing production on marginal lands by both increasing yield potential and actual area devoted to agriculture? Or from a combination of the two sources? Of particular importance to CIMMYT, national agricultural research programs, and other institutions concerned with the fight against world hunger and poverty is ascertaining how best to allocate research resources within this context.

This issue of the *Facts and Trends* series casts substantial light on the "favorable vs. marginal" debate through the prism of maize production in drought-stressed environments of the developing world. It reviews the technical options for increasing production in those areas and through statistics and case evidence from Asia, Latin America, and particularly sub-Saharan Africa, it provides a glimpse of the current status of maize production in drought-stressed areas, longer term production trends, and relationships between production and poverty. Looking to the future, the report models the effects of research resource allocation scenarios (presented as technical change) on production and the welfare of different populations.

Should we continue allocating agricultural research resources to marginal areas? Yes. However, the allocation of ever-tightening resources must be made on a case-by-case basis. Noting this, the authors suggest some concrete criteria to consider in the allocation process. They also point out the dearth of research in the area of research allocation for favorable vs. unfavorable environments and the need for further study to provide firmer grounds for critical resource allocation decisions.

CIMMYT's *1997/98 World Maize Facts and Trends* includes our customary overview of the current world maize situation (Part 2) and selected statistics on national and regional maize production, consumption, and trade in 1997/98 (Part 3). We trust that, again, readers will find these user-friendly sections informative and helpful and that our featured report on maize production in drought-stressed areas makes a positive contribution to the important debate on research resource allocation for marginal lands.

Timothy G. Reeves
Director General

Part 1

Maize Production in Drought-Stressed Environments: Technical Options and Research Resource Allocation

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Introduction

The "Favorable vs. Marginal" Debate

Most, if not all, of the "success stories" produced by agricultural research in developing countries over the past three or four decades have occurred in "favorable" areas where irrigation is available or rainfall is good. The most notable success stories were the rapid increases in wheat and rice production occurring during the Green Revolution. The reduction in food prices and increases in real rural wages observed in favorable agricultural areas suggest that yield gains have played an important role in reducing poverty (Singh 1990; David and Otsuka 1994; Datt and Ravallion 1998), although admittedly the links between yield increases and poverty reduction have not been analyzed exhaustively. These successes have also provided a respite for more fragile, "marginal" agricultural environments. Farmers in favorable areas could produce more food, which curtailed pressure to farm in more marginal areas.

In the wake of such progress one might expect to find a gratified sense of accomplishment. Instead, the contrast between success in favorable agricultural environments and more limited progress in marginal environments has led to considerable debate over how to allocate research

resources between the two kinds of environments, raising a number of ancillary questions.

♦ Is agricultural production expanding into marginal environments?
♦ What costs will agriculture incur on the resource base of fragile lands? Is crop production in those areas sustainable?
♦ How much agricultural production is needed from marginal environments to ensure food security at the local and national levels?
♦ What is the impact of crop production in marginal areas on poverty?
♦ What technological options are available for increasing production on marginal lands? Do research resources need to be reallocated toward agriculture for drought-stressed marginal environments?

Some have argued that nations systematically underinvest in agricultural research for marginal environments, to the detriment of the poor people living in those areas. Others contend that diverting research resources away from favorable areas would do more harm than good, because returns to investments in agricultural research in marginal areas are low. Decision makers require a better understanding of these issues, because they have considerable—and poorly understood—implications for future food security. For example,

Borlaug and Dowswell (1997) have stated that "the only way for agriculture to keep pace with population and alleviate world hunger is to increase the intensity of production in those ecosystems that lend themselves to sustainable intensification while decreasing the intensity of production in more fragile ecologies." In contrast, Leonard (1989) has posited that agricultural intensification in more favorable areas leads to labor displacement and often to land consolidation, giving displaced people little recourse but to move onto marginal lands. Although he agrees that production should be maximized in favorable areas, Leonard argues that the goal of agricultural development in marginal areas should be to provide livelihoods and minimize adverse environmental impacts.

Focusing the Debate: Maize, Drought Stress, and Resource Allocations

In this report we use the example of maize production in drought-stressed areas of the developing world to provide some perspective on the "favored vs. marginal" debate.[1] Maize is a lightning rod for this debate.

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[1] This report focuses on maize grown in tropical or subtropical environments in developing countries, because these are the areas where most of the maize in the developing world is grown. The report will not consider maize grown in countries where most, if not all, maize is produced in temperate environments (e.g., China, Argentina, Chile, and Turkey).

Compared to wheat and rice (the other major staples in developing countries), maize is more likely to be grown in areas that are regarded as marginal. Physical as well as economic factors can make an area "marginal" for maize production; physical factors include drought stress, low soil fertility, soil acidity, persistent weed problems (such as *Striga*), and steep slopes. Any single factor or combination of factors usually operates along a continuum, which means that defining an environment as "marginal" inevitably implies simplification.

Drought stress is one of the two physical factors most responsible for limiting maize production in developing countries; soil infertility is the other. The tendency for maize to be grown in areas subject to the vagaries of rainfall is thought by some to be a major reason why improved varieties and management practices have diffused more slowly for maize than for wheat or rice (see "Drought Stress and the Spread of Green Revolution Technology in Maize," p. 3). There are no technological means, other than the introduction of reliable irrigation, for restoring *all* maize lost to drought stress. Global estimates of losses from drought are usually based on expert opinion and must be regarded with caution (Loomis 1997; White and Elings 1997). Nonetheless, Edmeades, Bolaños, and Lafitte (1992) estimated that annual drought losses in the early 1990s across nontemperate maize areas totaled about 19 million tons, representing a 15% reduction in production. Losses can be far more extreme: a devastating drought in southern Africa in 1991-92 reduced maize production by about 60% (Rosen and Scott 1992).

This report will provide a broader understanding of maize production in marginal, drought-stressed areas and the implications for research resource allocation, by demonstrating that:

♦ Drought is a widespread phenomenon that even affects maize in better-watered areas.

♦ Areas most likely to be affected by drought stress are spread fairly evenly among the world's major regions, but the *relative* importance of water constraints appears highest in sub-Saharan Africa. (Better delineation and assessment of the extent and distribution of drought environments by combining data from geographic information systems [GIS], international databases on precipitation, crop modeling, and economic measures is highly desirable.)

♦ Accurate measurement of the economic impacts of drought is difficult. Maize yields are clearly lower and more variable in drought-stressed areas, but often yield growth rates are not observably lower.

♦ Recent years have not witnessed a pronounced expansion of maize into drought-stressed environments. Nevertheless, problems related to soil infertility and sustainability of agriculture in these sometimes fragile environments warrant further research.

♦ Over the past 25 years, both crop breeding and crop management research have made considerable progress in developing technologies that mitigate the effects of drought stress. The greatest future yield gains in drought-stressed environments may come from changes in crop management, though yield gains from improved varieties may also be significant. A great deal remains to be done, however, to diffuse new varieties and new management techniques to farmers.

♦ There are few clear, direct links between drought-stressed maize environments and poverty.

♦ Based on efficiency or equity considerations, there does not appear to be a strong case for reallocating maize research resources away from more favorable to more drought-stressed environments. Within drought-stressed regions, an unresolved economic research question is the relative importance to give to crop management research, crop improvement, and extension. At the same time, it is also clear that some research for these environments is still justified.

Organization of This Report

The next section provides more specific background information on drought-stressed, marginal environments by explaining how drought stress is measured in maize and detailing its effects, both within the maize plant and across geographic areas. We then examine the interrelated questions raised earlier about marginal environments, poverty, and food security. Next, we explore the technological options available for mitigating the effects of drought stress in maize and analyze the economic issues bearing on allocating research resources to marginal maize production environments. We conclude by describing research that could help resolve some of the problems posed by the "favored vs. marginal" debate.

Drought Stress and the Spread of Green Revolution Technology in Maize

The Green Revolution was marked by a rapid acceleration in the production of wheat and rice. But maize, particularly in the developing world, has yet to undergo an equivalent production transformation. There are a number of possible reasons for this dissimilarity, including drought stress.

Improved seed and fertilizer, together with water control, are generally considered the basis of the Green Revolution in cereals production. Use of these inputs in maize has lagged behind wheat and rice, and a much lower proportion of maize area is irrigated (Table 1). Input use is linked, albeit tenuously, with the pattern of yield growth in the major cereals in developing countries. Over the past 35 years, maize yields in developing

countries have grown somewhat more slowly and variably[2] than either wheat or rice yields, if China is excluded.[3] Why have input use and yield growth in maize fallen behind wheat and rice?

The fact that most maize is grown under rainfed conditions, coupled with its particular sensitivity to drought stress at flowering, suggests that drought stress is certainly one factor that has discouraged the use of improved inputs in maize. If rainfed maize production is somewhat variable and precarious, complementary

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[2] Variability is measured by the coeffecient of variation of maize yields, adjusted for trend in yield.

[3] Including China, by far the developing world's largest producer of all three cereals, makes the patterns somewhat more ambiguous. In this instance, maize yields would grow faster than rice yields and somewhat less variably than wheat yields.

inputs (e.g., improved seed and fertilizer) might diffuse more slowly, because small-scale farmers may be less inclined to risk the resources required to purchase them.

It is unlikely, however, that lack of water control is the only factor responsible for restricting the spread of new maize technology. For example, in Zimbabwe, weather conditions are highly variable, but nearly all maize farmers use hybrids. Drought, it seems, may only be part of a more general problem: Improved maize varieties, and possibly crop management technologies, may not spill over from their target agroecological zones as extensively or as readily as in rice or wheat, because maize is grown in a greater range of environments.

Table 1. Input use in wheat, rice, and maize, developing countries (various years)							
	Wheat		**Rice**		**Maize**		
Improved varieties	**Area planted to semidwarf wheat varieties[a] (%)**	**Year of estimate**	**Area planted to modern rice varieties[a] (%)**	**Year of estimate**	**Area planted to hybrid maize (%)**	**Area planted to maize improved open-pollinated varieties (%)**	**Year of estimate**
All developing countries	74	1994	74	1991	45 / 20[b]	15 / 20[b]	1992 / 1992
Fertilizer	**N applied to wheat (kg/ha)**	**Year of estimate**	**N, P_2O_5, K_2O applied to rice (kg/ha)**	**Year of estimate**		**N, P_2O_5, K_2O applied to maize (kg/ha)**	**Year of estimate**
All developing countries	97	1994	104	early 90s		70 / 57[b]	early 90s / early 90s
Irrigation	**(% area)**	**Year of Estimate**	**(% area)**	**Year of estimate**		**(% area)**	**Year of estimate**
All developing countries[c]	40[+]-50[+]	early 90s	52	1991		8	early 90s

Source: Byerlee (1996); CIMMYT (1989a, 1991, 1994, 1996); IRRI (1995); FAO/IFA/IFDC (1992); Heisey and Mwangi (1996); and authors' calculations.
[a] For wheat and rice, excludes scientifically bred tall varieties.
[b] Excluding China, Brazil, Argentina, and South Africa.
[c] For maize, irrigated area refers only to non-temperate maize. Temperate maize in developing countries is largely unirrigated.

Like seed of other cereals, maize seed travels over long distances (López-Pereira and Morris 1994; Sriwatanapongse, Jinahyon, and Vasal 1993), but it differs from other cereals in the direction of its flows. In wheat, seed flows in both directions—between developing and industrialized countries—despite the differences in growing environments (Smale and McBride 1996). With maize, transfers are much less common between the lowland tropical environments, which characterize many developing countries, and the temperate environments, which are common to industrialized countries. At least one reason for this has been the photoperiod sensitivity of tropical maize, a trait that makes tropical hybrids generally ill-suited to temperate areas because of their late maturity and poor adaptation to these environments. The transfer of temperate cultivars to the tropics has also been limited by aggressive tropical diseases and insects, especially in the lowlands.

Hybrid maize prominently exemplifies this point. The development of hybrids substantially boosted temperate maize yields. Hybrid research for lowland tropical environments began much later than for the temperate zones and, at present, maize yield potential in lowland tropical areas is considerably lower than in temperate environments. "Daily integrals of radiation for tropical and temperate zones are generally similar but peak radiation levels during the day are often greater in the tropics. Peak levels cause problems in

photosynthesis . . . that strongly limit biomass production and yield" (Loomis 1997). Furthermore, in temperate areas, hours of sunlight are greater during the summer and temperatures are more conducive to higher yields. Although the issue has not been studied extensively (for wheat, see Maredia and Byerlee, forthcoming) there appears to be less potential for technology spillovers in maize than for other major cereals, mainly because of its lack of broad adaptation and the diversity of environments in which it is grown.

Another factor behind the slower diffusion of new technology for maize production is its greater reliance on a viable seed industry for the diffusion of new hybrids and varieties. Since the use of improved seed and other inputs are often linked, the slower adoption of improved maize seed has probably affected the use of these inputs.

In rice and wheat, farmer-to-farmer seed diffusion has been the basis of the rapid spread of new varieties. Maize, however, is a naturally cross-pollinating crop. Its yield deteriorates through inbreeding when plants self-fertilize and it demonstrates hybrid vigor when plants cross-fertilize. This means that farmers exercise very limited control over the genetic content of seed in comparison to a plant breeder or seed production operation.[4] Historically, this has meant

that breeding programs face a choice of whether to concentrate their efforts on hybrids, improved open pollinated varieties (OPVs), or both. Relative to wheat and rice, maize presents many more questions of institutional design in the development of seed industries. Patterns of farmer-to-farmer seed diffusion are also different in maize (Morris 1998).

In some instances, maize breeders may have paid insufficient attention to the consumption characteristics required by farmers (Byerlee et al. 1994). Consumption characteristics, however, have also been important in rice (Unnevehr 1986) and wheat (Khan 1987), so it seems unlikely that this particular constraint has exerted an exceptional influence in the case of maize.

The deferred arrival of the Green Revolution in the maize fields of the developing world highlights the point that technology diffusion in maize appears to be a more complicated process than in wheat or rice. Greater diversity of growing environments, narrower adaptation, greater importance of seed industry organization, and, in some cases, the importance of consumption characteristics all interact to foster or restrain the spread of maize technologies.

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[4]   Non-commercial maize farmers often attempt to influence or maintain the genetic content of their seed (Louette and Smale 1996). The point here is that it is much more difficult to maintain a high level of genetic purity in maize than it is in rice or wheat.

Measuring Drought Stress and Its Effects

Estimating the Impact of Drought Stress on Maize Production

This section reviews how drought stress reduces maize yields and discusses general approaches used to measure drought stress and its effects. Defining drought stress in the maize plant is a relatively straightforward matter. Arriving at a definitive geographic characterization of stressed areas, however, is far more difficult for three reasons. First, drought stress is a global phenomenon, differences being of degree rather than kind. Second, severely drought-stressed areas tend to be distributed in a patchwork fashion around the world, rather than concentrated in a few readily recognized geographic areas. Finally, drought stress varies from year to year, so long periods of observation are needed to characterize the distribution of stress over time. Nevertheless, such geographic characterizations, even with their limitations, are crucial for making decisions about resource allocations for research.

Effects of Drought Stress on the Maize Plant

Drought stress particularly affects the ability of the maize plant to produce grain at three critical stages of plant growth: early in the growing season (when plant stands are established), at flowering, and during mid- to late grain filling (see "Drought and Stages of Maize Growth," p. 6). Periods of vulnerability must be considered within the context of regional rainfall patterns. Most tropical maize is produced under rainfed conditions during a single rainy season. Some equatorial areas, however,

have two rainy seasons per year, and maize is often produced during both of them.

By damaging plant stands at the beginning of a season, drought can strongly curtail yield. This is relatively common because the probability of drought is high at this time. A farmer confronted with this situation has several management options; all require replanting later in the season. They include replanting the field(s) with the same cultivar, planting a shorter maturity cultivar, or planting a different species that matures more rapidly or is more tolerant than maize to drought stress.

Mid-season drought is less likely to occur than drought at the beginning or end of the season, but it can be devastating because maize is particularly susceptible to drought stress during this period when the plant flowers. Short of irrigation (which is not an option in most tropical maize production systems), the farmer has no management alternatives since it is too late in the season to replant. Grain yield reductions from mid- to late grain filling are not nearly as severe as those produced by a similar stress during flowering. Again though, farmers are left with no management options for responding to the stress.

General Approaches to Measurement

Measuring the degree of drought stress can help guide agricultural research. Measuring its economic impact at the individual farmer or regional level can demonstrate the magnitude of the problem and help guide agricultural policy and research allocations. At least three types of data are required for such measurement: joint probability distributions of an index of the water deficit in the maize crop at different stages of growth; measures of the effects of the water deficits on crop yield; and the geographic distribution of maize planted by farmers.

Some of the approaches used to measure the incidence and intensity of water deficits have been summarized by White and Elings (1997) (Table 2). Generally, the development of classifications of drought-stressed areas that are consistent across large regions of the world has proven difficult. The most accurate estimates of drought stresses and associated yield losses in maize could be made by combining crop simulation models with global databases on climate, soil properties, and the spatial distribution of the maize crop (Edmeades and Bänziger 1997). Such global databases are under construction but remain incomplete, particularly with respect to crop distribution.

Table 2. Example of approaches for defining agroecological zones, including indication of their reliability, cost, reproducibility, and degree of quantification. Note the number of asterisks indicates a range from low (one) to high (five).

Approach	Reliability	Cost	Reproducibility	Degree of quantification
Expert opinion	**	**	*	*
Cluster analysis of monthly weather data	**	**	***	**
Cluster analysis + expert opinion	***	***	**	***
Cluster analysis of crop simulation results	****	****	***	*****
Cluster analysis of simulation results + expert opinion	*****	*****	**	****

Source: White and Elings (1997).

Drought and Stages of Maize Growth

Drought affects maize grain yield to some extent at almost all growth stages, but in all cereals the effects of drought stress are most pronounced when the stress falls during flowering (Salter and Goode 1967). For maize, Robins and Domingo (1953) first quantified the large yield reductions that occur when drought stress coincides with the flowering period. When Denmead and Shaw (1960) reduced plant water status to the wilting point during the pre-flowering, flowering, and post-flowering stages, yield reductions were 25%, 50%, and 21%, respectively. Claasen and Shaw (1970) observed that stressing plants to wilting prior to silking reduced grain yields by 15%; at silking, by 53%; and when stress was applied in the three weeks after silking, by 30%. Shaw (1976) summarized these and other data (Figure 1) and showed that stress in the period from about 7 days before to 15 days after anthesis reduces maize grain yield two to three times more than at other growth stages. More recent observations by Grant et al. (1989) suggest that extreme sensitivity was confined to the period 2–22 days after silking, with a peak at 7 days after silking, when kernel numbers were reduced to 45% of the control. In this study, kernel weight also displayed sensitivity when stressed (falling to 51% of control) in the period 12–16 days after silking. Yield reductions as high as 90% and an incidence of barrenness reaching 77% were recorded by NeSmith and Ritchie (1992) when plants were stressed in the interval

from just prior to tassel emergence to the beginning of grain filling.

Maize is thought to be more susceptible to drought at flowering than other crops because its florets develop virtually simultaneously and are usually borne on a single ear on a single stem. Unlike other cereals, in maize the male and female flowers are spatially separated (often about 1 m), and pollen and fragile stigmatic tissue must be exposed to a desiccative environment for pollination to occur. Furthermore, when drought (and other abiotic stresses) reduce photosynthesis at flowering, silk growth
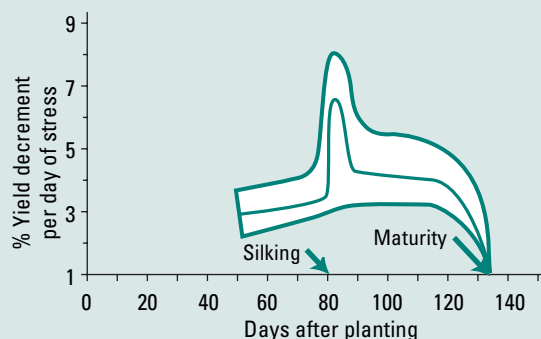
Figure 1. Schematic diagram of relationship between age of crop and percentage yield decrement due to one day of moisture stress. Source: Shaw (1976).

is delayed, leading to an easily measured increase in the anthesis-silking interval (ASI) (DuPlessis and Dijkhuis 1967). Grain yield of maize grown under severe drought stress at flowering is highly correlated with kernel *number* per plant (r = 0.90**) and with ASI (-0.60**) (Bolaños and Edmeades 1996). Silk growth and kernel number appear to depend directly on the flow of photosynthetic products produced during the three weeks of extreme sensitivity that bracket flowering (Schussler and Westgate 1995).

Although reasonable quantities of plant reserves are usually formed well before flowering and stored in the stem, during its first two weeks of life the developing maize ear has very little capacity to access them. Pollination, in many cases, has been shown to be successful in drought-stressed plants, only to be followed by abortion of the kernels a few days later (Westgate and Boyer 1986). Drought also lessens the capacity of developing kernels to use available assimilates because the functioning of a key enzyme, acid invertase, is impaired (Zinselmeier et al. 1995; Westgate 1997). Once kernels enter the linear phase of biomass accumulation about two to three weeks after pollination, they develop the capacity to access reserve assimilates stored in the stem and husk. If kernels successfully reach this stage, they will normally grow to at least 30% of the weight of kernels on unstressed plants, even though the drought may become more severe (Bolaños and Edmeades 1996).

The critical events that determine how many kernels the plant has, or if it even has a fertile ear, take place between one week before flowering to two weeks after flowering. It is not surprising, therefore, that CIMMYT researchers have concentrated on this period in a search for genetic variability for tolerance to drought that will stabilize kernel numbers per plant, and hence grain yield (see "Methods for Selecting Maize for Tolerance to Drought Stress," p. 20).

A general definition of a marginal environment proposed by CIMMYT (1989b) is an area "in which irremediable climatic or soil conditions limit yields to less than 40% of potential yields as defined by temperature and available solar radiation" (Edmeades, unpublished; Morris, Belaid, and Byerlee 1991). "Irremediable conditions" are those that entail prohibitive costs for amelioration, except over the very long term (Fischer 1988). Applying this definition has proven difficult because of problems in quantifying the costs of providing irrigation.

Three simpler, rainfall-based definitions of drought-stressed maize environments are presented here. All could be improved by integrating information on soil infiltration and water-holding capacity. In the tropics, a marginal rainfed maize environment in the lowlands may be defined as having seasonal precipitation below 500 mm and in the highlands as having seasonal precipitation below 300-350 mm. Lower temperatures associated with higher elevations account for the reduction in water requirements.

In view of the crucial nature of drought at flowering, Chapman and Baretto (1996) suggest an alternative rainfall-based definition—the amount of rain received during the four-week period around flowering, over the long term. Less than 100 mm during this period indicates the region is unsuitable for maize production; more than 200 mm suggests suitability for most maize cultivars. For the purposes of this report, rainfall between 100 and 200 mm around the flowering period could indicate that an area is marginal for maize production.[5]

Yet another drought measure based on rainfall is the ratio of precipitation (P) to potential evapotranspiration (PE). For example, favorable maize growing environments could be defined as those with growing seasons that include n or more consecutive months when $P/PE > 0.5$; marginal environments would be areas with $n-1$ or fewer months when $P/PE > 0.5$.[6]

As mentioned earlier, identifying drought-stressed production zones and attendant yield losses implies analyzing *differences in degree rather than in kind*. Maize, which is produced primarily under rainfed conditions, may experience drought stress in diverse production environments, even those classified as "favorable." For example, in the world's largest maize producer, the USA, one-fourth of the maize crop in the more favorable growing areas can be expected to experience at least moderate drought stress in any given season (Reeder 1997). Drought may significantly reduce US maize yields once every four to five years (Edmeades, Bolaños, and Lafitte 1992). These differences of degree help explain why estimates of yield based on expert opinion often vary between environments. They also imply that any classification of maize area into "more stressed" and "less stressed" areas involves considerable simplification.

Measuring Drought Stress in the Developing World at the Global Level

Our assessment of drought stress in the developing world begins with expert opinion—the simplest, though least quantifiable and reproducible methodology—because this approach provides the broadest global coverage. We restrict our scope to the non-temperate maize areas included in the CIMMYT (1988) mega-environment database.[7] Some 95 million hectares of maize are planted annually in developing countries. Of this, nearly 70 million hectares are non-temperate. Eighty percent of the developing world's temperate maize area is located in China. Table 3 summarizes areas reported to experience drought stress frequently (where a yield loss of 25% or more annually over a long period of time may be expected)[8] by major growing environment—tropical highland/tropical highland transitional, midaltitude/subtropical, and lowland tropical—primarily defined by mean growing season temperature.

According to these criteria, drought stress is evenly distributed across the world's major regions and is a particularly severe problem for slightly more than one-fifth of the tropical and subtropical maize planted in developing

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5   Note that this definition requires implicit assumptions about planting date, the maturity of the maize cultivar, and the mean evaporative demand as affected by altitude.
6   This physical definition deliberately ignores the technical option of planting an early maturing cultivar.
7   The CIMMYT mega-environment database is an updated and electronic iteration of the 1988 mega-environment study of maize. In the study, developed by maize field staff and national program collaborators, major crop production environments were defined country by country and region by region. Contributors were asked to determine the maize area, average yield, and production constraints for their respective areas. The accumulated totals for regions, and eventually the entire tropical maize producing world, were assembled into a series of maize mega-environments.
8   This category combines two categories from the original mega-environment database.

countries (Table 3). The likelihood of drought stress is greatest in the highland/transitional zone, largely because of the prevalence of drought in the extensive highlands of Latin America. The largest absolute area subject to the severe drought stress is the lowland tropics. In nearly all major region/environment combinations in the developing world, mean yields are reportedly lower in regions often affected by drought stress than elsewhere (Table 4). For sub-Saharan Africa, at least, Edmeades et al. (1997f) demonstrate a positive relationship between national average maize yields and rainfall totals during the growing season in major production areas

(Figure 2), indicating that total rainfall may indeed be a simple, useful predictor of areas or seasons that are subject to drought.

In the case of Latin America, new data sources are contributing to more exact measures and characterizations of drought-stressed areas; these include GIS data on large maize production
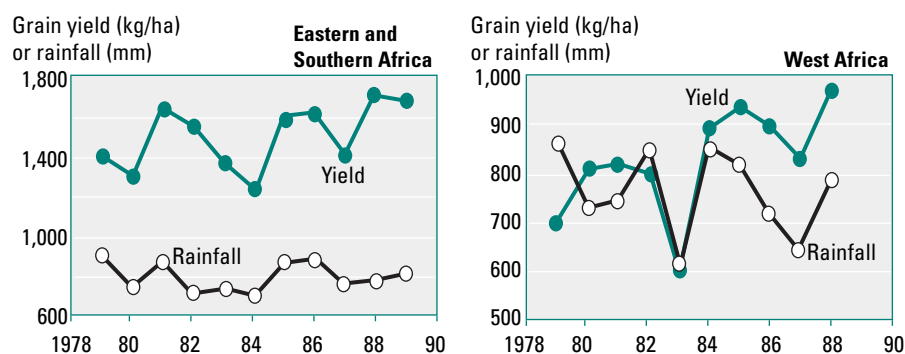
Figure 2. The relationship between national average maize yields and seasonal rainfall totals by year, for Eastern and Southern Africa, and West Africa. Source: J. Corbett, ICRAF.

Table 3. Non-temperate maize areas often experiencing drought stress

	Environment											
	Highland/Transitional			Midaltitude/Subtropical			Lowland Tropical			Total		
	Total maize area	Area often stressed	%	Total maize area	Area often stressed	%	Total maize area	Area often stressed	%	Total maize area	Area often stressed	%
	('000 ha)			('000 ha)			('000 ha)			('000 ha)		
Sub-Saharan Africa	1,662	0	0	7,624	1,659	22	10,413	2,567	25	19,699	4,227	21
West Asia/ North Africa	0	0	—	843	0	0	0	0	—	843	0	0
Asia[a]	664	68	10	4,074	841	21	13,242	2,664	20	17,980	3,572	20
Latin America/ Caribbean	3,867	2,977	77	6,201	85	1	16,253	3,118	19	26,320	6,180	23
Total	6,193	3,045	49	18,741	2,585	14	39,908	8,349	21	64,842	13,979	22

Note: Data on areas "frequently" or "usually" stressed are from the CIMMYT maize mega-environment database (CIMMYT 1988). Remaining area is "rarely" or "sometimes" stressed. Areas and yields have been updated from the mega-environment database to make them consistent with 1995-97 areas and yields.
[a] Excluding West Asia.

Table 4. Estimated yields in less stressed and more stressed environments in developing countries

	Environment							
	Highland/Transitional		Midaltitude/Subtropical		Lowland tropical		Total	
	Less stressed	Often stressed	Less stressed	Often stressed	Less stressed	Often stressed	Less stressed	Often stressed
	(t/ha)		(t/ha)		(t/ha)		(t/ha)	
Sub-Saharan Africa	2.06	—	1.47	0.98	1.23	0.91	1.41	0.94
West Asia/North Africa	—	—	6.07	—	—	—	6.07	—
Asia[a]	3.89	1.92	1.76	1.39	2.15	2.13	2.14	1.95
Latin America/Caribbean	1.91	1.45	2.66	1.59	2.60	1.16	2.59	1.31
Total	2.37	1.46	2.22	1.13	2.11	1.39	2.16	1.36

Note: Data on areas "frequently" or "usually" stressed are from the CIMMYT maize mega-environment database (CIMMYT 1988). Remaining area is "rarely" or "sometimes" stressed. Areas and yields have been updated from the mega-environment database to make them consistent with 1995-97 areas and yields.
[a] Excluding West Asia.

environments, regional data on the relationship between precipitation (P) and potential evapotranspiration (PE) (Corbett and O'Brien 1997), and maize crop distribution data (Hyman, Jones, and Lema 1997). With these data we use an alternative definition of favorable maize growing environments (those in which five or more consecutive months are characterized by $P/PE > 0.5$) for our analysis. Remaining areas are classified as marginal. We assume, however, that if $P/PE > 0.5$ for two or fewer months, the maize area must be irrigated and should not be classified as marginal.

Figures 3 and 4 (Pg 10) show drought-stressed environments in Latin America. Maize crop distribution information for Latin America (Table 5) permits a summary of total maize area for each major growing environment and for marginal and favorable areas within those environments. These estimates may be compared with estimates derived from CIMMYT's mega-environment database, which is founded on expert opinion. There is a rough correspondence between mega-environment definitions derived by the two methods, but a large discrepancy in estimates of marginal maize areas. The mega-environment database is admittedly imprecise, but the GIS databases also require several refinements before they can be used as the foundation of precise classification.

The mega-environment definition must be fine-tuned, particularly at the boundary between subtropical and temperate environments. Next, the crop distribution data need to be reconciled with existing aggregate statistics, particularly in the midaltitude/ subtropical and highland environments, but also at the national level. Finally, a physical measure other than length of growing season is needed to identify drought-stressed environments, particularly in the highlands. The probability of drought at flowering appears to be more crucial than the length of the growing season in shaping experts' opinions of whether an area is often subject to drought stress.

A Comparison of Maize Production in Drought-Stressed and Favorable Environments

From a policy perspective it is particularly important to know the effects of drought stress on yields, not just drought's physical parameters. A complementary approach to defining drought-stressed environments that responds to this need is to measure differential yields, yield variability, and yield growth rates. These measures, more than most, are only indicative, because yield data may be linked only weakly to physical evidence of drought stress. Furthermore, it is very difficult to

aggregate production data across different agroclimatic zones, countries, or regions in a meaningful way. Nonetheless, linking reported drought stress to production and yield data is essential to informing efficient research resource allocation. Working hypotheses are that mean maize yields are lower, yields are more variable, and yield growth has been less rapid in areas more subject to drought stress.

These relationships are difficult to observe in cross-country correlations because countries have different levels of heterogeneity in maize growing environments, different yield levels, and very diverse maize areas. For example, across approximately 60 countries represented in the CIMMYT maize mega-environment database, there is no significant cross-country correlation between the reported percentage of area often subject to drought stress and aggregate maize yield, although the relationship is, as expected, negative.[9] This negative relationship results solely from the presence of sub-Saharan African countries in the sample.

When data are disaggregated, however, the expected relationship between yield and drought stress is often confirmed. In Kenya, for example, agroecological zones were determined using GIS (Hassan 1998). Two major zones, the midaltitude and transitional, were divided into "dry" and "wet" subzones based on mean rainfall. In the midaltitude zone, both actual and potential yields were about 30% lower in the dry subzone than in the wet subzone. In the transitional zone, dry subzone yields were more than 50% lower than those in the wet subzone (Table 6).

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[9] Correlations were estimated both in unweighted form and weighted by aggregate country maize areas.

Table 5. Comparison of estimates from mega-environment database and GIS maps, Latin America

Environment	ME database			GIS maps		
	Total maize area	Area often stressed	%	Total maize area	Area often stressed	%
	('000 ha)			('000 ha)		
Highland/Transitional	3,867	2,977	77	5,660	1,017	18
Midaltitude/Subtropical	6,201	85	1	9,131	290	3
Lowland tropical	16,253	3,118	19	15,313	1,769	12
Total	26,320	6,180	23	30,104	3,076	10

Figure 3. Mega-environments and maize distribution in Mexico and Central America. Source: Centro Internacional de Agricultura Tropical (CIAT), Texas A&M spatial characterization tool.

100 0 100 Kilometers

● 1 Dot = 10,000 ha of maize

Highland temperate

Lowland tropics

Mid-altitude

Subtropical

Temperate

Tropical highland

Highland tropical transitional

400 0 400 Kilometers

Figure 4. Mega-environments with maize distribution in South America. Source: Centro Internacional de Agricultura Tropical (CIAT), Texas A&M spatial characterization tool.

Data for rainfed maize in Mexico show that the expected relationships between drought stress and yield can also hold at an intermediate level of aggregation. We classified each Mexican state by the amount of growing season rainfall and the extent to which it falls in the highland/transitional environment. Excluding irrigated crops, maize yields in low-rainfall states are clearly lower than yields in high-rainfall states (Table 6). Within a broad rainfall category, states with more highland/transitional maize have lower yields than states with more midaltitude/subtropical or lowland tropical maize. This is particularly significant because, all other factors being equal, one would expect yields in the tropics to increase up to an altitude of about 1,800 m as growing seasons become longer and

cooler. These data suggest that drought stress may be partially responsible for lower yields in the highland/transitional zones of Mexico.

At the global level, there is a positive correlation between drought stress and yield variability. Once more, however, this is attributable solely to the data from sub-Saharan Africa. Again, more disaggregated data can show the expected relationship. In Mexico, for example, trend-corrected coefficients of variation[10] (CVs) of yield in rainfed maize are higher in the more drought affected zones (Table 7).

Aggregate yields (means for 1995-97) and trend-corrected CVs for most developing countries with primarily non-temperate maize are shown in

Figure 5. It is striking that most countries with large maize yield variability are in sub-Saharan Africa. Also, at any given level of mean maize yield, African countries tend to have higher yield variability. It appears that
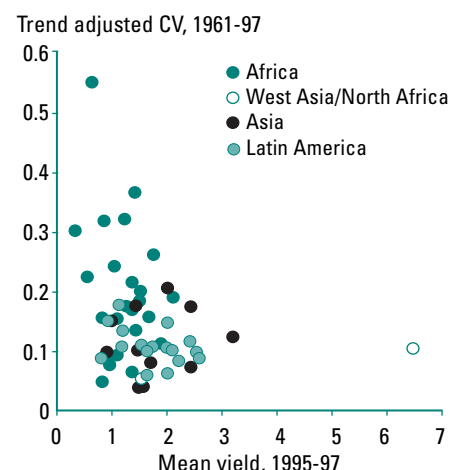
Figure 5. Mean yields and yield variability.

physical yield losses caused by drought and yield variability may have relatively more impact in sub-Saharan Africa than in Latin America or Asia because base yields are lower. As a result, yield losses may be of greater relative economic importance in Africa.

Evidence on differential yield growth over time is also weak. Countries can be divided into "more stressed" (over 20% of all maize area frequently or usually subject to drought stress) and "less stressed" categories. During 1961–97, maize yield growth rates for less stressed countries are higher than those

Table 6. Actual and potential maize yields by agroclimatic zone, Kenya, early 1990s

Agroclimatic zone	Major season maize yield (t/ha)	Percentage yield reduction, dry areas	Potential maize yield[a] (t/ha)	Percentage yield reduction, dry areas
Lowland tropics	1.36	na	3.11	na
Midaltitude zone				
Dry	1.03	28	2.67	33
Moist	1.44		4.01	
Transitional zone				
Dry	1.21	56	3.34	53
Moist	2.76		7.12	
Highland tropics	2.91	na	7.71	na

Source: Hassan (1998).
[a] Long-term yield data from the National Performance Yield Trial.

Table 7. Maize yields and yield variability for rainfed maize, Mexican states by moisture and environment, 1989-96

Environment	Low rainfall[a]	Low rainfall[b]	Higher rainfall[c]	Higher rainfall[d]
	Highland/ Transitional	Midaltitude/ Subtropical/ Lowland tropics	Highland/ Transitional	Midaltitude/ Subtropical/ Lowland tropics
Mean yield (t/ha)	0.68	0.77	1.70	2.06
CV*[e]	0.160	0.249	0.139	0.094

[a] States included are Aguascalientes, Durango, San Luis Potosí, and Zacatecas.
[b] States included are Baja California, Baja California Sur, Coahuila, Chihuahua, Nuevo León, Sonora, and Sinaloa.
[c] States included are Distrito Federal, Guanajuato, Hidalgo, México, Michoacán, Oaxaca, Puebla, Querétaro, and Tlaxcala.
[d] States included are Campeche, Colima, Chiapas, Guerrero, Jalisco, Morelos, Nayarit, Quintana Roo, Tabasco, Tamaulipas, Veracruz, and Yucatán.
[e] Trend-corrected coefficient of variation.

[10] In all the analyses of yield variability, trend-corrected coefficient of variation of yield $CV^* = CV\sqrt{(1 - R^2)}$, where CV is the non-corrected coefficient of variation of aggregate maize yields for a given period; R^2 is the corrected coefficient of determination for the semilogarithmic trend regression of yields over the same period.

for more stressed countries only if examination is restricted to sub-Saharan Africa. Multiple regressions of yield growth rates on a number of explanatory factors, including proportion of maize area often stressed, are very weak. Few coefficients are significant; the coefficient of the stress variable, again, is only significant in separate regressions confined to sub-Saharan Africa. Disaggregated data on yield growth rates for Mexico (Hibon et al. 1992; authors' calculations) or Kenya (Tiffen, Mortimore, and Gichuki 1994; Hassan and Karanja 1997) show no clear pattern delineated by the level of drought stress. In El Salvador in the late 1960s and 1970s, yield growth may have been higher in less stressed areas (Walker 1980).

In summary, provided appropriate comparisons are made within otherwise similar growing environments and disaggregation is sufficient, maize yields in more frequently drought-stressed environments are clearly lower and more variable than they are in less frequently drought-stressed areas. Less evidence can be found that yield growth rates in recent years have been influenced by drought-stress conditions at either aggregated or disaggregated levels.

Is Maize Spreading into Drought-Stressed Environments?

Research policymakers at both the national and international levels at times express the opinion that "maize is being grown where it should not be grown" or "policies favor the expansion of maize at the expense of other crops," particularly more drought-resistant crops like sorghum and millet. There are two issues here: Are people moving

onto more marginal lands and planting maize there, and is maize supplanting other crops like sorghum and millet? Most of the available evidence refers to crop substitution. This evidence shows that the patterns by which maize has spread around the world outside of its zone of origin are complex and that diffusion has occurred over a long time. The data that follow do not suggest a pronounced expansion of maize into low rainfall environments during the last 40 years.

Outside of Africa, maize area has expanded, but there is little substantiation that most of this expansion has taken place in drought-stressed areas. Maize may have replaced some sorghum or millet in parts of Pakistan, but most change occurred before 1980 (Government of Pakistan, various issues). In India, there is documentation that some maize production has shifted from irrigated to rainfed areas (Singh, Pal, and Morris 1995). Aggregate statistics (FAO, various issues; IRRI, various issues) suggest that in some areas of Southeast Asia, maize may have rapidly displaced upland rice in the 1970s and 1980s. Though this expansion might have occurred in areas classified as "marginal" based on criteria other than drought (for example, poorer quality soils on sloping land vulnerable to erosion), there is little evidence that the majority of this land is more drought-stressed than other maize growing areas in these countries. In Latin America, evidence is equally limited and inconclusive. In Mexico, for example, the pattern of the past 25 or 30 years has been one of fluctuating rainfed maize area, accompanied by expansion of irrigated area (Hibon et al. 1992; SAGAR and predecessors, various issues).

Although maize arrived on the coasts of Africa in the sixteenth century (Miracle 1966), not until the 1930s did it become a staple of the African population in eastern and southern Africa. The preponderance of the evidence favors the interpretation that most of the replacement of sorghum or millet by maize in those regions, including drier areas, occurred before or immediately after World War II. Maize area in eastern and southern Africa has continued to grow in more recent decades, although not at the rates found in western and central Africa (FAO, various issues; Part 3). Maize area does not appear to have expanded more rapidly in eastern and southern Africa than combined sorghum/millet area, although there are differences at the individual country level. More disaggregated evidence suggests that maize spread into drier parts of Zimbabwe between the two World Wars (Miracle 1966) and into some drier regions of Kenya between 1930 and the late 1950s (Tiffen, Mortimore, and Gichuki 1994).

In recent years, maize area has grown more rapidly in West Africa, where its role as a traditional staple is less prominent than elsewhere in Africa. At least some of this maize replaced sorghum or millet, though most of the replacement has been in the Sudano-Guinean zone,[11] which is often defined as semiarid. The total annual rainfall (800–1,100 mm) and its unimodal distribution in the region suggest that rainfall there differs little from that in parts of eastern and southern Africa where maize is widely cultivated. Temperatures are generally higher in this rainfall zone of West Africa than in

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[11] This zone runs west to east from southern Senegal to southern Chad. Its northern limits are roughly at 11° N latitude.

eastern and southern Africa, which may have limited the spread of maize. Previously, human settlement in the Sudano-Guinean zone was limited by human and livestock diseases (Sanders, Shapiro, and Ramaswamy 1996).

Maize expansion in the Sudano-Guinean zone has been fueled by improved infrastructure, commercialization of agriculture, new maize varieties, and associated technologies. In some countries, fertilizer subsidies have played a role, and, particularly in Francophone countries, the recommendation of maize as a rotation crop in cotton-based systems has been important. In recent years, maize area has probably contracted somewhat as subsidies have been lowered and institutional support withdrawn (Smith et al. 1997, 1994; Fusillier 1994; Sanders, Shapiro, and Ramaswamy 1996).

Data indicate that although maize is more sensitive to drought than either millet or sorghum, its superior productivity under better conditions makes it a viable option beyond previously conceived boundaries. Carter (1997) demonstrated with farm-level data that in a region of Burkina Faso with 600–800 mm rainfall spread over 4–5 months, the probability of falling below a given yield level was nearly always lower for maize than for sorghum or millet. Even in the southern Sahel, where rainfall averages 400–600 mm over 3–5 months, the probability of a food shortfall was lower with maize than it was with millet, the most widely cultivated staple. At very low yield levels, millet dominated maize, indicating that in years of extreme drought, food shortfalls would be less severe when farmers grew millet.

Two factors probably modify these conclusions. First, in the areas alluded to, maize is often cultivated on small, fertile plots that are close to the household (Sanders, Shapiro, and Ramaswamy 1996). A more balanced comparison would use cereals grown on more extensive, less fertile plots further from the household. Second, because many farmers in those areas have limited experience growing maize, farmers' perceptions of yield risk may not be equivalent to those resulting from trial data.

Mudhara and Low (1990) studied the performance of maize, pearl millet, and sunflower for normal planting in natural region IV of Zimbabwe, where mean seasonal rainfall ranges between 450 and 560 mm. They found that for most, but not all, economic criteria, maize performed better than either sunflower or pearl millet. This assessment was supported by farmers' actual planting decisions.

In summary, there has not been a large expansion of maize into extremely drought-stressed areas of the developing world in recent years. Some of the recent growth in maize area has probably taken place on "marginal" lands, but it is quite likely that some of these lands are classified as marginal based on soil quality rather than moisture availability. In the past, the far wider diffusion of maize in parts of eastern and southern Africa than in western Africa resulted more from historical factors than rainfall conditions. In areas where maize is cultivated widely, this crop choice can be shown to be an economically rational one, although in some cases this conclusion may be qualified by assumptions concerning the levels of

complementary inputs and infrastructure.[12]

Is there potential that global climate shifts in maize growing environments, rather than farmer migration or changes in cropping patterns, may exacerbate the problem of drought stress in the future? Estimates are subject to considerable uncertainty, but the time frame of predicted temperature increases is such that considerable, if not complete, adjustment by breeders, agronomists, and farmers can be expected ("Global Climate Change, Crop Water Use, and Maize Production in Developing Countries," p.14).

What is the Relationship between Marginal Production Environments and Poverty?

Many people believe that farmers in marginal agricultural environments are poorer than most of their counterparts in more favorable regions. Is this belief supported by empirical evidence? Without comprehensive data and accurate measures, it is difficult to arrive at a meaningful answer to this question. Unfortunately, as with the concept of "marginal" lands, poverty may be easier to define than to measure precisely. Relating these two elusive factors is harder yet (Pinstrup-Andersen and Pandya-Lorch 1994). Studies across crops and across regions of the world have yielded different conclusions about the relationship between poverty and the marginality of agricultural environments (Table 8).

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[12] Worldwide, there are few general relationships between yield risk for individual cereals and stability of farm family income (Anderson, Hazell, and Evans 1987).

Global Climate Change, Crop Water Use, and Maize Production in Developing Countries

Many scientists have predicted that we are entering an era of global warming caused by the entrapment of solar energy by atmospheric gases. Carbon dioxide (CO_2), methane, nitrous oxide, and other gases have the capacity to absorb rather than transmit long-wave radiation reflected from the earth's surface. Atmospheric CO_2 has increased from 315 ppm in 1958 to more than 350 ppm today, and it may exceed 600 ppm by 2040 (Allen 1990). It has been forecast that if current trends continue, the atmosphere's concentration of CO_2 will double in 50–80 years. Accompanying this will be a rise in the earth's mean surface temperature by 2.0–5.4°C; the increase at higher latitudes is projected to be about twice that of the tropics (Allen 1990). The timing of this increase will be influenced by policy changes that affect CO_2 emissions and, perhaps, by an as-yet-unknown level of CO_2 absorption by the oceans. Consequences of these changes are hard to predict, but the following developments seem likely.

♦ **Increased crop water use, because relative humidity falls with increasing temperature.** Stomatal conductance is reduced as the concentration of CO_2 increases. It may appear that this would save water, but without evaporative cooling, leaves heat up, thereby accelerating leaf senescence and reducing photosynthesis. Allen (1990) concludes that if CO_2 rises to 800 ppm, canopy temperatures would rise 4°C *without any direct effects from global warming,* leading to a decline in water use efficiency for C_4 species like maize.

Winter rainfall may increase in mid-to-high latitudes, and mid-latitude areas (e.g., the US Corn Belt) may experience drier summers. Changes in rainfall patterns, however, are predicted with very low precision. It is likely that cloudiness, windiness, and absolute humidity will also increase (Rosenberg, McKenney, and Martin 1989), but models are very imprecise in these areas (Smil 1990).

♦ **Accelerated rates of crop development, causing crops to mature more rapidly and produce lower yields** (Muchow, Sinclair, and Bennett 1990). For maize this will be only partially offset by increased rates of photosynthesis that result directly from higher concentrations of CO_2.

♦ **Reduced respiration rates caused by high CO_2 concentrations (Ziska and Teramura 1992), but increased photosynthetic rates.** Crop-specific simulation models predict that doubling the CO_2 concentration from 300 ppm to 600 ppm will produce yield increases of 25–40% for C_3 species (e.g., rice, wheat), to as little as 7% for C_4 species such as maize (Idso 1989; Allen 1990; Rosenzweig et al. 1992). These increases are caused by increased leaf area and increased numbers of grains rather than increased grain weight or changed partitioning.

♦ **More heat stress for maize crops in the tropics, in some cases resulting in pollen sterility** (Schoper et al. 1987).

♦ **Less stable weather** (Mearns 1995), a shift that we may have already begun to experience with the severe regional droughts of the last decade (e.g., Rosen and Scott 1992) and the record-breaking El Niño event of 1997–98.

♦ **Major shifts in weather patterns**, exemplified by a summer rainfall pattern being replaced gradually by winter rainfall.

♦ **Higher sea levels**, rising by perhaps 0.2–1.5 m, as polar ice melts, increasing salinity and waterlogging in coastal lands (Schneider 1989).

Has global climate change begun? Seven of the 10 warmest years on record have occurred since 1990 and the other three occurred after 1983 (Kerr 1991; *New York Times,* 18 December 1998). The consensus is that global warming is indeed underway.

What are the consequences for maize production? Can we keep up with the pace of climate change? Taken as a whole, global warming is likely to increase the incidence of drought in many established crop producing areas. Crosson and Anderson (1992) conclude that although productivity and production will be affected by a doubling of CO_2, it is impossible to predict which countries will win and which will lose.

An extensive study based on modeling yields of staple crops under climate change scenarios (a doubling of CO_2) in 18 countries has been reported by Rosenzweig et al. (1995). If the CO_2 concentration doubles, the findings suggest that crop production in the tropics will decline by 9–10%, while crop yields in higher latitudes may well increase. Declines will result largely from temperature-induced acceleration of crop growth cycles and reduced soil moisture

(Iglesias and Minguez 1995). Production declines are predicted to be more severe in Africa, dropping about 17% (e.g., Muchena and Iglesias 1995).

Evidence suggests that shortages of land and especially water will be the most difficult problems facing farmers in the tropics during the next four decades (Crosson and Anderson 1992), but these scarcities are expected to have less impact on maize than on other cereals. In sub-Saharan Africa, the ongoing decline in soil fertility (Waddington and Heisey 1997) continues to reduce water use efficiency, particularly in maize. Taking into account projected changes in population and the supply and demand for food under a scenario of doubled CO_2 concentrations, Fischer et al. (1995) have concluded that food production at the global level will not be affected very much, but that shifts will favor developed countries, while producing negative impacts on the food supplies of tropical developing countries.

In most studies of global climate change, insufficient allowance has been made for the genetic improvement of crops, for example, better environmental adaptation or earlier or later maturity (Stockle et al. 1992). Nor have these studies fully considered managerial innovations (e.g., change in planting dates) or the effects of changes in prices and markets on technical innovations (Rosenzweig et al. 1992). The time scale of temperature increases is such that considerable, if not complete, adjustment by breeders, agronomists, and farmers can be expected. Reported genetic improvements in tolerance to mid-season drought, accompanied by annual gains of around 100 kg/ha in grain yield (see "Methods for Selecting Maize for Tolerance to Drought Stress," p. 20), and observed increases in crop duration of around 1% per year (CIMMYT, unpublished data) suggest that plant breeders should be able to keep pace with changing environments without undue difficulty. Care must be taken, however, to ensure that genetic variation for maturity and tolerance to high temperatures and drought is available through conventional breeding and the newer techniques offered by genetic engineering. It is important that these traits are introduced systematically into maize germplasm in breeding programs like CIMMYT's, which cover a very wide mandate area. Technologies that augment the water naturally available to a crop by increasing capture and decreasing losses merit greater emphasis. Mulch management, reduced tillage, water harvesting, and an understanding of the circumstances that make these practices economically attractive on a whole-farm basis are becoming critical areas of research.

Table 8. Is there a higher incidence of absolute poverty in "low potential" rural areas? Previous studies.

	Yes	Mixed Evidence	No
Global	Leonard (1989) Hazell and Garrett (1996)		
Crop Specific		David and Otsuka (1994) (rice)	Byerlee and Morris (1993) (wheat)
Region or Country	Hazell and Fan (1998) (India)	Fan and Hazell (1997)	Kelley and Parthasarathy Rao (1995) (India) Renkow (1991) (Pakistan) Reardon, Delgado, and Matlon (1992) (West African semiarid tropics) Sanders, Shapiro, and Ramaswamy (1996) (West African semiarid tropics)

Despite these difficulties, in this section we will make some cautious observations on the production environment/poverty relationship based on the available data, using three indicators of marginal maize production[13] and three indicators of poverty.[14] With only one important exception, maize production indicators show no correlation with poverty measures. Neither the proportion of maize area often subject to drought stress or the variability of maize yields is related to any national-level poverty indicators.

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[13] Percentage area often subject to drought stress, aggregate maize yield, and trend-corrected coefficient of variation of yield.

[14] Gross national product per capita (World Bank 1997); the country poverty weights developed by the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (TAC Secretariat 1996); and the percentage of the rural population in absolute poverty (estimates also made by TAC Secretariat[1996] based on information in UNDP[(1995], World Resources Institute [1994], and World Bank [1995]).

The exception to these findings can be summed up as follows: Relatively richer countries have higher maize yields. This is true because African countries, which generally are poorer than other developing countries (except for those in South Asia), tend to have lower maize yields. Adding to this effect is the fact that *within* Asia and Latin America, relatively richer countries have higher maize yields. Within sub-Saharan Africa, however, there are no correlations between poverty indicators and maize production measures.

We also correlated the percentage of cereals area that is planted to sorghum and millet in 42 African countries with the poverty indicators cited earlier, but again found that no significant correlation exists, regardless of whether country observations are weighted by total cereals area. Particularly in sub-Saharan Africa, sorghum and millet are more likely to be grown in lower rainfall areas and on poorer soils than maize.

Several more disaggregated examples illustrate that linkages between poverty and marginal maize production areas are complex, sometimes counterintuitive, and often hard to pin down. In Kenya, for instance, Siaya and South Nyanza Districts of western Kenya have higher annual rainfall than Machakos District in the eastern part of the country. Both western Kenya and Machakos have experienced increased population pressures and growth in maize area and production. Land degradation has worsened in the western Kenya districts, which moved from being net food exporters in the 1950s and 1960s to net food importers today (Scherr 1993). In contrast, there is strong evidence that land degradation in Machakos has been arrested and even reversed. Though Machakos remains a

net food importer, the area produced a much higher percentage of its consumption requirements in the 1980s than it had 40–50 years earlier (Tiffen, Mortimore, and Gichuki 1994). Rainfall conditions alone are clearly insufficient for predicting the direction of trends in the quality of the resource base or per capita food production.

In Zimbabwe, on the other hand, it is well known that farmers in the communal areas, which are concentrated in less favorable agricultural production environments, are much poorer than commercial farmers located on lands with higher rainfall and better soils (Rukuni and Eicher 1994). In Mexico, unirrigated maize production is concentrated in the central and southeastern regions, in states where agricultural incomes are lowest (Hibon et al. 1992). Some of the poorest states, however, have the most reliable rainfall.

Clearly, the evidence that the marginality of agricultural land in general, or maize land in particular, is related to poverty is decidedly mixed. Pathways of agricultural development and marginalization may be more complicated than casually assumed. It is difficult to measure the linkages between marginal environments and poverty because it is hard to disentangle the effects of agroclimatic factors from those of many others, ranging from technological considerations to the influences of history, culture, and social institutions (Table 9).

The aggregate results strongly suggest that many more careful case studies of individual countries, or studies within individual countries, are necessary to extract general relationships between agricultural environment and poverty incidence. Although aggregate figures do not directly correlate marginal maize growing areas and poverty, this in no way suggests that farmers in such areas

Table 9. Factors other than agroclimatic conditions that influence linkages between environment and poverty	
Technological factors	Smallholder farmers are not inevitably displaced by intensification. Some aspects of intensification, notably new inputs such as seed and in some cases fertilizer, are scale-neutral.
	Degradation can occur on lands where intensification is occurring as well as in more marginal areas.
Farmer response to marginal production conditions	Farmers smooth consumption in the face of production variability, both through managing own-farm assets or reciprocity arrangements (Paxson 1992; Udry 1994; Carter 1997).
	Empirically, the majority of labor migration is rural-urban or across country boundaries, not simply rural-rural, as would be the case with widespread displacement of poorer farmers to more marginal lands.
	Non-cropping and non-farm incomes, generated by local activities and long-distance migration, are often more important than crop income in marginal areas (Reardon, Delgado, and Matlon 1992).
Policies, market relationships, and infrastructure	Rather than being an inevitable cause of labor displacement, mechanization can be a response to rising wages caused by labor withdrawal from the agricultural sector; much depends on the policy environment (Pingali, Hossain, and Gerpacio 1997).
	Market opportunities mediate the distribution of benefits from technological change. Infrastructure is a key determinant of these market relationships, although it is not often well understood.
History, culture, and institutions	Numerous social factors.

are not poor—they are just not necessarily poorer than their counterparts in other maize areas.

How Much Maize Does the Developing World Need from Drought-Stressed Environments?

Nearly all maize production, whether in developing or developed countries, will have to come from land that is susceptible to drought to varying degrees. It is instructive to explore the contribution that areas on the margin of maize production make to total maize output. Is it really possible, as some suggest, to meet future maize demand from better lands alone?

Our benchmark will be maize areas and yields in locations that are "often" subject to drought (listed in Table 3). Projected production, and in some cases projected area, are taken from the International Food Policy Research Institute (IFPRI) Impact model for 2020 (Rosegrant, Agcaoili-Sombilla, and Perez 1995; updated model projections from M. Rosegrant, personal communication, April, 1998).[15] All scenarios allow for maize imports into developing regions at the levels projected by IFPRI; in other words, they do not assume a goal of self-sufficiency. A more thorough analysis would consider soil fertility and vulnerability to erosion, for example, together with drought stress, and would rely on more accurate measurement. Some of the general principles that emerge from the following analysis, however, would hold regardless of changes in scope or measurement.

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[15] Impact model projections are modified to consider only non-temperate developing country maize production.

Initially we ask how rapidly yields must rise in favorable environments for supply to keep up with demand, assuming that future maize supplies are to come only from yield increases in favorable environments. We then modify our assumptions to allow some yield increases in drought-stressed environments.

In the first scenario, all land currently planted to maize that is often drought stressed is taken out of production by 2020. Only the current area that is "rarely" or "sometimes" drought stressed is planted to maize in that year. To meet the IFPRI model baseline projection of maize production in non-temperate areas, yields in these more favorable environments would have to rise by 90% to 4.1 t/ha, an annual rate of 2.7%. This projection implicitly assumes that some trade can occur between surplus and deficit non-temperate developing regions, regardless of location. At a more disaggregated level, to attain the forecast level of production for sub-Saharan Africa, maize yields in better environments would have to rise by 129% to 3.1 t/ha, an annual rate of 3.5%. At a still more disaggregated level, Kenya's maize yields from higher rainfall environments would have to increase by 147% to 5.4 t/ha, an annual rate of 3.8%; Zimbabwe's yields in more favorable areas would have to increase by 565% to 19.6 t/ha, an annual rate of 8.2%!

In the second scenario, maize area in 2020 is assumed to equal present area. For all non-temperate developing areas, yields on more favorable land would have to increase by 73% to 3.7 t/ha, an annual rate of 2.3%, to meet projected production by 2020. For sub-Saharan Africa, respective figures would be 111%, 2.9 t/ha, and 3.2% annually.

Maize yields in favorable areas of Kenya would still have to rise by 3.5% annually; for Zimbabwe, they would have to rise by 6.8% annually.

Figure 6 depicts the effects of relaxing the assumption that no yield increases will occur on more frequently drought-stressed areas. An overall yield increase of 25% on marginal lands, considered feasible by many crop scientists, is equivalent to an annual percentage increase of about 1%. At this level of yield increase on marginal lands, the required rate of increase on favorable lands is only slightly lower than with no increase on marginal lands.
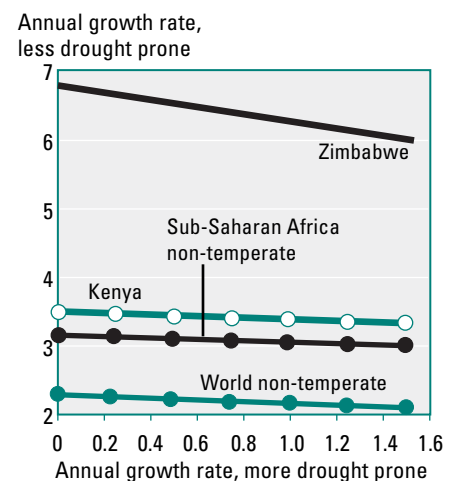
Figure 6. Yield growth rates to meet IFPRI production projections: No area expansion.

In the final scenario, non-temperate maize areas increase to the levels forecast by the IFPRI model (about 75 million hectares by 2020). All area expansion is assumed to take place in environments that are often drought stressed, with their correspondingly lower yield levels. In reality, this is an overly restrictive assumption, because there are modest possibilities for area expansion into better-watered lands. If yields do not increase in more drought-stressed areas, yields in more favorable

areas would rise by 61% to 3.5 t/ha, for an annual growth rate of 2%. Maize area in sub-Saharan Africa would increase by about 6 million hectares. Yields in less stressed areas of Africa would increase by 87% to 2.6 t/ha, implying annual growth of 2.6%. Some of the effects of allowing yield growth on both drought-stressed and better-watered lands are shown in Figure 7. A 25% increase in yields on marginal lands would reduce needed growth rates in favorable areas from about 2% annually to about 1.8% annually for the entire developing world, and from more than 2.6% annually to less than 2.4% annually in sub-Saharan Africa. To put these figures in perspective, we note that very few tropical countries have experienced yield growth of 2% or more over a sustained period.

Annual growth rate, less drought prone
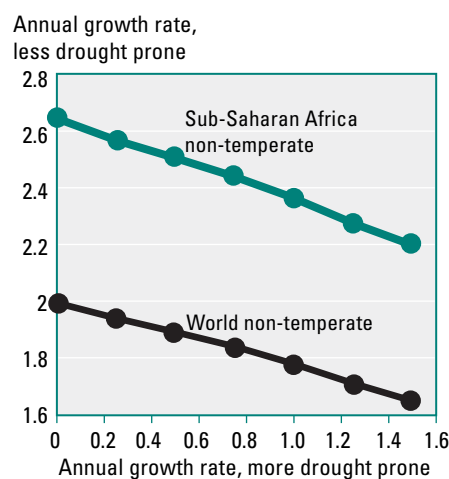
Figure 7. Yield growth rates to meet IFPRI production projections: Area expansion.

These projections point to an important conclusion: At the global level, increased maize yields on marginal lands will not contribute substantially to greater maize production. At the same time, future demand for maize will not be met without maintaining yields in drought-stressed areas that are currently planted to maize and extending maize area into

both wetter and drier regions. If these production demands are not met, the burden placed on more favorable environments appears to be too great. The more disaggregated the analysis, the stronger the case that a significant amount of maize will have to come from marginal environments.

Technologies for Maize Production in Drought-Stressed Environments

As we have seen, drought stress is the most widespread abiotic constraint to maize production in developing countries. What technological options are available to counter the effects of drought stress? Two basic approaches are possible. The first is to change the maize plant; the second is to change the maize plant's environment. We begin by reviewing efforts to breed maize that escapes drought by maturing early and to breed maize that tolerates drought stress. Next, we consider management alternatives: selecting planting dates to reduce the probability that the crop will be subject to drought stress during the course of the season and modifying planting and tillage methods to increase the water available to the plant for transpiration. Other crop management factors such as soil fertility maintenance and the control of weeds and diseases also have important roles in increasing the efficiency with which water is converted to maize grain. These will be considered at the end of this section.

Maize Cultivars: Drought Escape and Drought Tolerance

Where the length of the growing season is limited by any factor—rainfall, frost, crop rotations—one of the first principles of crop improvement is to fit the variety to the growing season (Ludlow and Muchow 1990). An early

maturing cultivar will escape terminal drought stress more often than its later flowering counterpart. This was the basis for some earlier success stories in maize breeding for dry environments, such as the R200 series of hybrids in Zimbabwe (Mashingaidze 1994) and the Katumani Composite-derived varieties in Kenya (Mugo and Njoroge 1997). Other breeding programs have followed suit in West Africa (Badu-Apraku et al. 1997) and India.

Earliness, however, is only one trait of importance for adaptation to drought-stressed environments. As a general rule, early maturing cultivars lack yield potential for good years when, contrary to expectations, rains are plentiful. Furthermore, just because a variety matures early does not mean that it will be able to tolerate drought stresses that occur during the season. Also, water availability can vary greatly in individual fields under tropical conditions (Bouma et al. 1997); for example, drought stress can be experienced on hillocks, where infiltration is low and soils are shallow, in an otherwise adequately watered field. As a result, a variety capable of performing well across the range of water availability within a single field, and across fields and years, can contribute to higher and more stable maize production (Edmeades and Bänziger 1997).

Plant breeders have amassed considerable knowledge about improving drought tolerance (Boyer 1996). Most of the maize breeding strategies that are now available for improving drought tolerance were developed and refined over a considerable period. At CIMMYT, for example, selection for drought tolerance

began in 1975 in one form of the lowland tropical maize population Tuxpeño Crema I, which was renamed Tuxpeño Sequía (Tuxpeño Drought) (Fischer, Johnson, and Edmeades 1983). Since initial results were encouraging, selection for drought tolerance was expanded in the mid-1980s to five additional lowland tropical maize populations (Edmeades et al. 1997a). Screening and selection were initiated within highland tropical populations in the early 1990s (Srinivasan et al. 1997) and in tropical midaltitude germplasm in southern and eastern Africa in 1997.

Beck et al. (1997a) and Vasal et al. (1997) have reviewed a variety of options for developing drought tolerant maize. These options include:

♦ *The conventional breeding approach.* This is usually defined as an indirect strategy of multilocation testing of elite progenies in environments that represent a random selection of the potential variation in drought stress that a cultivar may encounter in its target environment (Rosielle and Hamblin 1981).

♦ *The development of stress tolerant maize under carefully managed drought-stress conditions.* Selection is done under different levels of managed drought stress to ensure that performance under unfavorable conditions does not compromise performance when water is available (Edmeades et al. 1997b; Boyer 1996).

♦ *The selection for secondary traits that are thought to increase plant adaptation to drought.* This is occasionally done for secondary traits alone, but more often an index of plant characteristics is used that includes a heavy weighting for grain yield (Fischer, Edmeades, and Johnson 1989; Edmeades, Bolaños, and Chapman 1997).

♦ *The use of high density planting together with the process of inbreeding.* High density planting and inbreeding, in which male and female flowering must coincide on the same plant, constitute a strategy for maize improvement aimed at "general" stress tolerance (Vasal et al. 1997). This practical method of exposing maize to an abiotic stress has been particularly exploited in temperate maize (Troyer 1983; Duvick 1992, 1997), as the mechanisms of tolerance to drought and to high plant density appear to be related (Dow et al. 1984).

♦ *The search for sources of drought tolerance among landraces and elite, but exotic, varieties already known to possess a high level of drought tolerance.* These sources are crossed with adapted, but relatively susceptible, varieties to boost their level of tolerance (Edmeades et al. 1997c).

♦ *The use of molecular techniques that offer new options for the efficient transfer of specific traits.* In this instance, traits associated with drought tolerance could be transferred from poorly adapted sources into elite, but susceptible, lines and varieties via marker-assisted backcrossing (Ribaut et al. 1997a; Ribaut and Betrán 1998). Ideally, markers will be used to select simultaneously for yield and important secondary traits, including the degree of barrenness measured as ears per plant (EPP) and the anthesis-silking interval (ASI) (Ribaut et al. 1996).

Successful breeding programs for improved tolerance to drought stress frequently combine two or more of these strategies. For example, the development of enhanced stress tolerance in CIMMYT's lowland tropical germplasm has been based on a combination of selection under managed stress and selection for secondary traits, a strategy well-suited to environments where severe drought stress can be expected. Many breeding programs routinely subject their progenies, hybrids, and varieties to stress through high plant densities and inbreeding, and then subject progenies to multilocation testing, a strategy suitable for relatively mild drought stress. Over the years, CIMMYT's research program has established the value of managed stress and the importance of two secondary traits, ASI and EPP (see "Methods for Selecting Maize for Tolerance to Drought Stress," p. 20). The program also uses a third trait, "staygreen,"[16] on a routine basis. Multilocation testing has also been employed, though with much less success than managed stress, in situations where losses from drought are severe (Byrne et al. 1995; Chapman, Edwards, and Crossa 1996). Recently, the use of molecular markers to accelerate breeding for drought tolerance has been explored. The first major attempts at marker-assisted selection to improve an elite, but susceptible, inbred line and a susceptible population have reached the final stages of field testing (Ribaut et al. 1997a, 1997b).

More and more, breeders looking for drought tolerance are likely to incorporate aspects of all six of these strategies, with the balance among them differing by the stage of the breeding process, the frequency and severity of drought stress in the target environment, and the availability of field screening facilities equipped with irrigation and laboratory equipment

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[16] "Staygreen" refers to delayed foliar senescence.

Methods for Selecting Maize for Tolerance to Drought Stress

CIMMYT maize physiologists and breeders working to increase drought tolerance have relied mainly on screening segregating progenies in a rain-free, irrigated environment. The timing of stress is carefully managed by withdrawing irrigation, so that genetic variation for tolerance is expressed to the greatest degree possible. Exhaustive attention has been focused on the flowering and grain–filling stages of crop development because of the susceptibility of the crop to drought at flowering (see "Drought and Stages of Maize Growth," p. 6). Screening under managed stress has been supplemented by international testing of progenies and varieties, often through a drought testing network, under a random sample of drought conditions in target environments. Details of this research have been reported elsewhere[17] and are summarized here.

Methods: Five diverse tropical lowland maize populations were targeted for the development of improved tolerance to water deficits that occur at flowering and during grain filling. The populations were structured as either full-sib or S_1 families and were screened for performance under several water regimes. Superior families (8-30% of those tested) were intercrossed; from those crosses the next group of families was formed for testing. This process

was repeated for a number of cycles and is thus known as recurrent selection. The result should be an increased frequency of alleles that favor good performance under drought stress.

Trials to screen progenies were sown in November, in the normally dry Mexican winter, on a heavy clay soil at CIMMYT's Tlaltizapán station (18°N; 940 masl). A total of 170-600 progenies from each population were grown in small plots (1.9 m^2) and exposed to three water regimes in replicated yield trials. An intermediate level of drought stress (IS) was imposed by withdrawing irrigation 10-21 days before flowering through the time the crop matured. A severe stress (SS) was imposed by withdrawing water 21-35 days prior to flowering and applying no additional water until the crop matured. All progenies were also evaluated under normally irrigated, well-watered (WW) conditions to observe their yield potential, in order to avoid selecting progenies that would not yield competitively in a wet year. Grain yields of IS and SS regimes generally averaged 40–60% and 10–25% of the yield under WW conditions, respectively. Selection of superior progenies was based on an ideotype—a concept of the ideal plant— with high grain yield under IS and SS treatments, delayed foliar senescence (or "staygreen") under IS and SS, a reduced anthesis-silking interval (ASI) under IS and SS, increased numbers of ears per plant (EPP)(i.e., decreased barrenness) under IS and SS, upright leaves, and small tassels. To avoid selecting escapes, every attempt was made to ensure that the male flowering date in the selected

fraction remained the same as the mean male flowering date of the bulk of the population. When earliness, a highly heritable trait, is desired, it is simpler to select for it directly under normal growth conditions. All traits from all three environments were combined to form a single selection index that was used to identify progenies that most closely conformed to the ideal plant type. Remnant seed from those families was sown, plants intercrossed, and a new set of progenies formed.

Evaluations of changes that occurred with selection were conducted after two, three, or eight cycles of selection, depending on the population. Plants were evaluated in large replicated plots grown under the same water regimes as those used during selection or under natural rainfed conditions. Initial and final selection cycles of the populations were also grown under low and high nitrogen (N) over two seasons. Yields under low N averaged a little less than half those under high N.

Results: The relationships between grain yield and the other traits measured during selection can be expressed as phenotypic and genetic correlations among progenies (Table 10). Grain yield shows a strong dependence on ASI and EPP (Figure 8). Gains in yield from selection averaged 102, 67, and 100 kg/ha/yr under SS, WW, and low N, respectively (Table 11). This equates to a 5% gain per year of selection under a typical severe midseason drought stress that reduces grain yields to around 2 t/ha. Improvements in yield were accompanied by major reductions in ASI and

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[17] See Fischer, Edmeades, and Johnson (1989); Bolaños and Edmeades (1993a, 1993b); Bolaños, Edmeades, and Martínez (1993); Bolaños and Edmeades (1996); Edmeades et al. (1997a, 1997b, 1997e); Bänziger, Edmeades, and Lafitte (1998).

barrenness under very dry conditions and by an increase in harvest index (i.e., the ratio of grain to total shoot weight) under all levels of drought stress.

Selection did not significantly alter indicators of the water status of the plants such as osmotic adjustment, leaf water potential, or staygreen, but led to a

reduction in tassel size, plant height, and in the weight of roots in the top 50 cm of the soil profile in one of the examined populations (Bolaños, Edmeades, and Martinez 1993a). Furthermore, when cycles of selection were tested under low N, gains were almost identical to those observed under water deficits. Recent research has confirmed that the frequency of hybrids tolerant to drought increases when lines are derived from drought tolerant populations, as opposed to lines extracted from related populations that have been improved for general performance through multilocation testing.

Grain yield (t/ha)

$$GY = e^{\{3.04-1.29 SQRT(ASI+2)\}}$$
$$(R^2 = 0.71; 48df)$$

Grain yield (t/ha)

$$GY = 0.737 - 3.67\ (EPP) + 5.67\ (EPP)^2$$
$$(R^2 = 0.91; 47df)$$
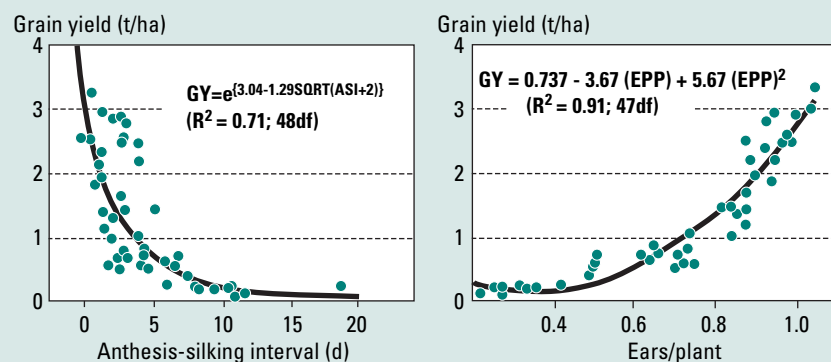
Figure 8. Relationship of grain yield to anthesis silking internal (ASI) and ears per plant (S_{1-3}) grown under a range of available water. Data are means of 50 trials containing subsets of a total of 3,509 progenies. Source: Bolaños and Edmeades (1996).

Table 10. Phenotypic and genetic correlations between grain yield and selected traits under severe drought stress for S_1 progenies drawn from several maize populations. All phenotypic correlations were significant at $P < 0.01$.

	No. of observ.	Phenotypic correlation	No. of trials	Genotypic correlation
Ears/plant	2,449	0.77	9	0.90 ± 0.14
Kernels/plant	2,227	0.90	8	0.86 ± 0.15
Kernel weight	2,227	0.46	9	0.14 ± 0.17
Anthesis-silking interval	2,449	-0.53	8	-0.65 ± 0.24
Leaf rolling score	2,033	-0.18	9	-0.03 ± 0.18
Leaf erectness score	2,033	-0.18	1	0.00
Leaf death score	2,449	-0.11	9	0.11 ± 0.24
Tassel branch number	1,793	-0.16	1	0.15

Note: For details, see Bolaños and Edmeades (1996).

Table 11. Effects of selection for drought tolerance on gains per selection cycle in four maize populations when evaluated at 3-6 water stressed (SS) sites, at 5-8 well-watered (WW) sites, or at two low N sites. Locations were in Mexico (Mex.) or outside (Int.).

	Yield (kg/ha)			Anthesis WW (d)	ASI SS (d)	Ears/ plant SS
Population	SS	WW	Low N			
Evaluation 1988/91						
Tuxpeño Sequía (Mex.)	100**	125**		-0.40**		
Tuxpeño Sequía (Int.)	52ns	101**		-0.24**		
Evaluation 1992/94						
La Posta Sequía (Mex.)	229**	53ns	233	-0.52**	-1.18**	0.07**
Pool 26 Sequía (Mex.)	288**	177**	207	-0.93**	-1.50**	0.08**
Tuxpeño Sequía (Mex.)	80**	38**	86	-0.32**	-0.44**	0.02**
Pool 18 Sequía (Mex.)	146**	126**	190		-2.13**	0.05**

Note: *, **, ns: significant rate of change per selection cycle at $P<0.01$, $P<0.05$, or $P>0.05$, respectively.

Are the gains obtained by screening in the dry winter season fully transferred to a normal summer season? Apparently not completely. When Byrne et al. (1995) grew cycles of selection from the population Tuxpeño Sequía at 12 international sites, mainly during the summer rainy season, they reported that gains from selection averaged 83% of those measured during the dry season when selection had occurred. Even with this loss in efficiency, improvements in yield across all sites from selection under carefully managed stress were 61% greater than those obtained from conventional multilocation progeny testing. This has been further confirmed by Chapman, Crossa, and Edmeades (1997) and by others who have used similar breeding schemes (e.g., Ortega, Valenzuela, and Cota-Agramont 1997).

In summary, selection for drought tolerance, by exposing families of populations to water deficit coinciding

with flowering, was effective at increasing grain yields under drought, well-watered conditions, and under a moderate level of N deficiency. Selection resulted in a 25-40% increase in yield for a farmer whose yields were formerly reduced from 6 t/ha to 2 t/ha by drought occurring near flowering and during grain filling. Improved yields were accompanied by an increased proportion of growth going to the ear, and by fewer, but larger, ear spikelets that had a higher success rate in forming grain under water deficits (Edmeades et al. 1993). Results indicate that ASI is an important characteristic and that it is a good indicator of the growth rate of the ear under drought *and* under low N. We believe that success in selection can be partly attributed to use of an index of traits that collectively describes a target plant with tolerance to drought.

Have these improvements in drought tolerance come at a cost to yield under unstressed conditions? Apparently not (Figure 9; Table 11), because improvements in ear growth rate are expressed in all environments. This constitutive trait requires a carefully
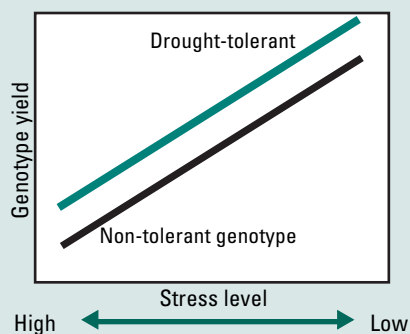
Figure 9. Idealized response to selection for improved tolerance to drought under managed stress. Source: Adapted from Bolaños and Edmeades (1993a).

managed drought stress to expose indicators (ASI, barrenness) of its genetic variation in diverse maize populations. Clearly, the occurrence of rain at flowering can greatly reduce the efficiency of selection, hence we believe that access to dry season sites with reliable irrigation systems is essential to rapid and consistent progress in the development of drought tolerance.

Marker-assisted selection: It would be very useful if the regions of the maize genome associated with improved drought tolerance could be transferred to elite, but susceptible, inbred lines and populations. Molecular markers offer a new and efficient way of accomplishing this, but first, the appropriate regions for transfer must be identified. Because of the importance of ASI, the identification of quantitative trait loci (QTL) for ASI and yield components in maize was given high priority and they have since been identified. Quantitative trait loci for ASI have demonstrated stability over stress levels (Ribaut et al. 1996). In contrast, all but two yield QTL were inconsistent in their position in the genome under different water regimes. At one important genomic position, the allele contributing to a reduction in ASI also contributed to a decrease in grain yield. Consequently, CIMMYT's marker-assisted selection strategy for drought tolerance is now based on an index of best QTL for both traits (Ribaut et al. 1997). Several marker-assisted selection projects to improve drought tolerance in maize lines and populations, based mainly on QTL for ASI and yield, are currently underway.

capable of identifying molecular markers. Efforts to breed more drought tolerant maize are likely to be helped by the development of more efficient experimental designs (Crossa, Franco, and Edmeades 1997), more accessible databases of germplasm performance, continued research on the underlying physiological mechanisms of drought tolerance, identification of the genes that control the expression of these mechanisms, and studies of genetic parallels between maize and other cereals (Beck et al. 1997b).

During the early 1990s, researchers started to look for drought stress at the seedling stage. Unfortunately, heritability for survival and biomass production under post-emergence drought stress proved low, in part because field techniques were not sufficiently precise to detect stress tolerant seedlings. Largely for this reason, progress through seedling selection has been relatively limited (Bänziger, Edmeades, and Quarrie 1997). In drought-stressed highlands of Mesoamerica, however, farmers' maize is often planted well ahead of the rains at depths of around 20 cm where residual moisture is present. This strategy is effective because the farmers' varieties have the ability to emerge from a much greater depth than normal maize. CIMMYT has developed elite highland germplasm with a similar capacity to emerge from deep planting (Srinivasan et al. 1997).

Planting Date, Density, Method, and Crop Establishment[18]

Planting date is a particularly important consideration for maize production in drier areas. When maize is planted

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[18] At a number of points, the next three subsections draw particularly on Waddington et al. (1995).

under appropriate soil moisture and temperature conditions, the chances of complete germination and crop establishment increase greatly. Where the length of the growing season is limited by the duration of the rainy season, early planting reduces the probability of drought during the late grain–filling stage. Delayed planting (frequently caused by labor and land preparation constraints) exacerbates agronomic problems, often resulting in a crop that is tall, prone to lodging, and with relatively fewer kernels per plant. These effects, together with the increased possibility of terminal drought stress, can result in significant yield losses (Waddington et al. 1991).

Considerable efforts have been made to develop methods that ensure that maize is planted at the best possible time. "Response farming" is based on an improved prediction of expected rainfall (including date of the onset of rains in the upcoming growing season) and establishing and managing the crop according to that prediction (Stewart 1991; Stewart and Kashasha 1984). In a dry area of Kenya, however, where many of the principles of response farming were developed, farmers had not adopted them by the early 1990s.

Another management strategy to ameliorate the effects of drought is to reduce maize plant populations in an attempt to maintain the amount of water available per plant above the minimum needed to form an ear. In South Africa, relatively late maturing maize grown under an annual rainfall of 500–600 mm is often sown at densities as low as 10,000 plants per hectare in rows up to 2 m apart. Cultivars are selected for prolificacy (and in some instances, tillering

capacity) so they can more fully exploit a high rainfall year when it occurs (Magson 1997), but they are not necessarily extremely tolerant of drought. Similar principles can be applied to some problems associated with nutrient availability per plant; reduced plant densities also are appropriate when soil fertility is low (Waddington et al. 1995; Blackie 1995; Carr 1989).

Adjusting tillage practices can allow farmers to plant at more optimal dates. Reduced tillage options include chisel plows and shallow ripper tines. Most on-farm experimentation on reduced tillage in southern Africa demonstrates equal yields over one to three years when compared with traditional moldboard plowing, but draft animal and time requirements were considerably lower (Waddington et al. 1995), which may permit earlier, more optimal planting (Shumba 1989). Another tillage operation, post-harvest or winter plowing, may contribute to earlier planting by reducing the time and energy needed to prepare the land when the next rainy season begins (Waddington et al. 1995).

Water Capture and Retention

The major goal of crop management practices in semiarid areas is to maximize the amount of water passing through the crop as transpiration. This can be achieved by increasing the amount of water available to the crop, by decreasing water losses (from evaporation, runoff, or weeds), or both. At one extreme would be the development of irrigation systems or the expansion of maize area into already irrigated land. We conclude that this is not likely to be a major source of

increased maize production or the primary contributor to the mitigation of drought stress in particularly vulnerable areas (see "Prospects for Expanding Irrigated Maize Area," p. 24). Short of full-fledged irrigation, other management options have been explored for intercepting a larger proportion of precipitation and directing it to the crop; these include tillage, water harvesting, and mulch.

Tillage. Tillage can improve the entry of water into the soil and facilitate the early growth of plant roots, enabling them to capture stored moisture. Tillage can also control weeds that compete with the crop for water. Tillage options vary by soil type. In southern Africa, sandy soils "have little or no crumb structure, are often compact when dry, and some are prone to crusting. Compaction of undisturbed subsoils tends to impede root penetration" (Waddington et al. 1995). On those soils, some form of tillage is necessary for crop production, so minimum tillage may be appropriate. However, in many semiarid areas of the region where draft animals are used, the conventional ox-drawn moldboard plow reaches a depth of only 10–15 cm; deeper plowing can improve maize yields up to 25% by permitting deeper rooting (Grant, Meikle, and Mills 1979; Willcocks 1981; Ivy 1987).

Water Harvesting. By reducing runoff or diverting runoff from other areas onto a plot, water harvesting can also contribute to increased crop yields in the semiarid tropics; however, water harvesting in maize, which is susceptible to waterlogging, can provide too much water to the crop in some seasons. Nonetheless, farmers in the semiarid Baringo District of Kenya use

Prospects for Expanding Irrigated Maize Area

Worldwide, only a small proportion of maize is irrigated. In non-temperate maize growing environments, nearly 80% of the total irrigated maize area is found in South Asia, Mexico, and Egypt. What are the medium-term prospects for expanding irrigated maize area?

The International Food Policy Research Institute (IFPRI) (Rosegrant 1997) and the United Nations' Food and Agriculture Organization (FAO) (Alexandratos 1995) forecast that expansion of irrigation, measured at the global level, will slow considerably over the next 20–30 years, to an annual rate of 0.7–0.8%. The International Water Management Institute (IWMI) takes a different tack, contending that *per capita* net irrigated area will be the same in 2025 as it was in 1990, which infers that irrigation will expand at the same rate as population growth, perhaps around 1.5% annually. Despite, or perhaps partially because of this more optimistic forecast of growth in irrigated cropland, IWMI projects that by 2025, growing domestic and industrial water requirements in some countries, notably those in the West Asia and North Africa, will imply reducing water withdrawals for irrigation (Seckler et al. 1998). All projections concur that Asia will continue to account for most of the world's irrigated area.

Very little global information is available on irrigated maize. Three areas (Asia, Mexico, and sub-Saharan Africa), however, are worth observing for future trends in irrigated maize area.

Asia. As stated earlier, Asia accounts for most of the world's irrigated area and is expected to outpace other regions in growth in irrigated land. For the most part, maize will be affected very little by these trends. In parts of South and Southeast Asia, however, there may be potential for small areas already under irrigation to be shifted to cool season (sometimes referred to as "spring" or "winter") maize production, in response to growing demand for maize as livestock feed. Such shifts will depend on two factors: 1) the interactions and relationships among production costs for alternative crops in potential spring maize areas, production costs in alternative areas for maize expansion (such as the rainfed uplands), transport costs, and the price of maize imports, and 2) the progress scientists make in developing maize cultivars and management practices suited to cool season maize production.

Mexico. Total irrigated area in Mexico is unlikely to expand much beyond its current levels. During the past 30 years, irrigated maize area in Mexico has expanded overall, with some contraction noted during the last few years. A closer examination reveals two growth periods in irrigated area—from the early 1970s to around 1980, and the early 1990s. During the intervening years, irrigated area stayed roughly constant. In the early 1990s, irrigated maize area grew from about 1 million hectares to 1.8 million hectares in 1994, but fell back to 1.2 million hectares in 1996. Given strong constraints to the expansion of total irrigated area, irrigated maize area in Mexico is likely to fluctuate between 1 million and 2 million hectares for the foreseeable future, with variations caused mainly by changes in the price ratios of maize compared with alternative crops.

Sub-Saharan Africa. Almost no maize area is currently irrigated in sub-Saharan Africa. In areas where small-scale irrigation is practiced and maize is a major staple, irrigation is often directed at high value crops such as vegetables, occasionally including green (immature) maize, but not maize as a staple (Reij, Scoones, and Toulmin 1996; Tiffen, Mortimore, and Gichuki 1994). Africa is thought to have much less irrigation potential than Asia. The cost of irrigation with full water control is believed to be two to three times higher in Africa than in India. Furthermore, irrigation schemes in Africa have had a history of problems with management and operation (Barghouti and Le Moigne 1990). Nonetheless, technical studies suggest that total area suitable for irrigation could potentially exceed 30 million hectares, up from about 5 million hectares in 1982 (Seckler 1992).[19] In addition, a general comparison of the areas suitable for irrigation development (Seckler 1992) with the areas most suitable for maize production (USDA 1981) indicates a high degree of overlap.

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[19] Currently, irrigated area accounts for just under 140 million hectares in developing countries in Asia other than West Asia, around 25 million hectares in West Asia and North Africa, and over 17 million hectares in Latin America.

Predicting the future course of irrigation in Africa and the extent to which it will be directed to individual crops is very risky. Alexandratos (1995), for example, predicts that irrigated area in sub-Saharan Africa will grow to about 7 million hectares by 2010, implying a considerably higher growth than Asia in percentage terms, but a much lower expansion in absolute terms. The expansion of irrigation in Africa is likely to be based on small-scale projects and to employ a variety of technologies. For the most part, it will probably continue to be devoted to the production of higher value crops. When those crops reach a certain point of market saturation, however, relative prices may shift to the point that some production of staples on irrigated land becomes profitable. Therefore, there is the possibility that in the medium term, a small amount of maize could be produced on irrigated land in sub-Saharan Africa, but its contribution to total maize production in the region would most likely be small.[20]

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[20] For a discussion of some of the principles in evaluating irrigation investment in Africa, see Seckler (1992) and Barghouti and Le Moigne (1990).

handmade, tied contour ridges for both maize and sorghum (Critchley, Reij, and Seznec 1992). Similar interventions also have demonstrated clear yield advantages in semiarid areas of West Africa (Rodriguez 1987).

In Machakos District, Kenya, excess runoff is diverted to tree crops or channeled to the top of terrace systems. The presently preferred bench terrace is formed by throwing soil uphill from a ditch laid out on the contour. The ability of bench terracing to produce higher maize yields in dry years and dry areas has provided strong incentives for farmer adoption (Tiffen, Mortimore, and Gichuki 1994).

In southern Africa, researchers have experimented with a variety of ridge-furrow systems, including tied ridges and potholes, to concentrate runoff and allow it to infiltrate slowly into the soil (Waddington et al. 1995). Ridging systems require draft power and human labor to construct ridges and ties. A small survey, conducted a few years after the initiation of the research, found that about 40% of the farmers near Chiredzi in the southeast region of Zimbabwe (an area where tractors are available for hire) had adopted a tied ridging system (Mazhangara 1993).

Mulch. In semiarid areas, as much as 50% of total evapotranspiration from a crop can be lost through evaporation from the soil surface (Unger and Stewart 1983). Losses are highest during early crop growth. Mulch can play an important role in reducing soil evaporation and temperature. In tropical environments characterized by episodes of high intensity rainfall, however, its major role is to reduce

runoff, increase infiltration, and minimize associated soil losses (Scopel et al. 1998).

Crop residue mulches have been shown to increase maize yields significantly in semiarid western Mexico at application rates as low as 2 t/ha, and they have been closely associated with increased water capture compared with conventionally tilled plots (Scopel, Tardieu, and Edmeades 1998). In a series of on-farm trials conducted in a semiarid area of Jalisco, Mexico, zero tillage, chemical weed control, and mulch applied at 2 t/ha increased water capture by 65% compared with a treatment that comprised two diskings and mechanical weed control. The result was an increase in grain yield of up to 100% (Scopel, Tardieu, and Edmeades 1998). In those areas and in semiarid southern and eastern Africa, however, use of maize residues as livestock feed may reduce the available mulch below the threshold level. In Africa, termite activity and fire are also important factors in diminishing residues (D. Jourdain, personal communication; Waddington et al. 1995).

Increasing the rooting depth of crops generally increases water availability. Typically, maize extracts more than 90% of its water from the upper 70 cm of its rooting profile (Mugo et al., forthcoming), but if rooting depth is restricted by compaction layers, or by rocky or acidic subsoils, drought symptoms will occur more rapidly and with greater intensity. Subsoiling and deep liming can be effective in delaying the development of drought stress, but at a cost.

Crop Management Practices that Increase Water Use Efficiency in Drought-Stressed Environments

One important characteristic of drought stress is that it interacts with other types of stresses including disease, competition from weeds and intercrops, soil acidity, and low soil fertility. Generally, dry environments have a lower incidence of foliar and ear fungal diseases. Weeds, on the other hand, compete for water that could be used by the maize plant, so drought symptoms are often more severe and prolonged in their presence. In semiarid sandy areas with animal traction, relatively inexpensive weed control using a moldboard plow has also proven beneficial for water retention (Riches, Twomlow, and Dhliwayo 1997). And, though intercrops clearly compete with maize for available water and reduce maize yields, they serve to reduce the risk of crop failure if the maize is severely affected by drought at a particularly susceptible stage of growth (see "Drought and Stages of Maize Growth," p. 6).

The most important management interaction in many drought-stressed maize environments is between soil fertility management and response to drought stress. It is widely accepted that low soil fertility and drought are the major constraints to maize production in non-temperate environments (Edmeades et al. 1997). Low soil fertility is considered to be a particularly important constraint in sub-Saharan Africa (Blackie 1995). In areas subject to drought stress, many small-scale farmers are reluctant to risk economic losses by applying fertilizer, which strengthens the linkage between drought and low soil fertility. Again, this appears to be a particular problem

in sub-Saharan Africa, where fertilizer nutrient-grain price ratios are usually considerably higher than elsewhere (Heisey and Mwangi 1997).

Breeding is one strategy for attacking the problem of low soil fertility. Research on experiment stations in the lowland tropics has shown that selection for tolerance to midseason drought stress in maize also provides increased tolerance to nitrogen (N) stress. Yield gains resulting from selection for drought tolerance, observed under N levels that reduce yields by about 50%, are remarkably similar to those observed when plants are drought-stressed at flowering (Bänziger, Edmeades, and Lafitte 1998). Recent unpublished data suggest, however, that when the yield reduction caused by N stress increases to around 70%, the benefits of improved drought tolerance that spill over into fertile environments decline.

Management of N fertilizer based on rainfall events, using response farming, could lead to increases in fertilizer efficiency and allow farmers to take advantage of wetter years (Piha 1993). Other evidence suggests that the case for response farming may not be quite so compelling. Wafula, McCown, and Keating (1992) summarized detailed economic analyses of alternative fertilization strategies in Machakos District, Kenya, and suggested that the most important first step was increased use of N, "irrespective of any formal system to forecast seasonal potential."

Smallholders' use of inorganic fertilizer in dry areas of sub-Saharan Africa remains even lower than the low rates applied in more favorable areas of the continent, probably because of limited knowledge of fertilizer use, and cash

and supply constraints (Muhammad and Parton 1992; McCown and Keating 1992). The necessity of adopting several management changes simultaneously with fertilizer (Sanders, Shapiro, and Ramaswamy 1996) adds complexity to management. Price shocks as policy regimes change, together with inadequate institutional support, also constrain fertilizer use (Heisey and Mwangi 1997).

Integrating Technological Options

In considering technological options for improving maize production under drought stress, it is important not to lose sight of several key points. First, genetic improvement for tolerance to both drought and low N cannot eliminate the gap between current and potential yields (as determined by radiation and temperature). Conventional wisdom holds that genetic improvement could make up about 15–25% of this gap in severely stressed areas.[21] More effective crop management, using available sources of N and water, could possibly close the gap by an additional 15–25% (Edmeades and Bänziger 1997), although a full consideration of field spatial variability and its effects could raise this figure somewhat. The remaining 50–70% can only be filled by adding fertilizer and water to the crop.

Second, crop management practices, including the addition of irrigation and fertilizer, cannot close all of the gap if economic considerations are taken into account. Most analysts probably do not consider the possibility of irrigating the

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[21] Total research benefits for genetic improvements in tolerance may be underestimated because gains in better-watered environments that accompany improvements for drought tolerance are often overlooked (see "Methods for Selecting Maize for Tolerance to Drought Stress," p. 20).

maize crop. If they do, irrigation development is usually ruled out as too costly (a more expanded evaluation is presented in "Prospects for Expanding Irrigated Maize Area," p. 24). Opinion is sharply divided on the use of inorganic fertilizer. Some believe the price of fertilizer, along with the risks inherent to its use, will make it unattractive to the majority of small-scale farmers in drier areas for the foreseeable future, especially in sub-Saharan Africa. Others conclude that productivity in dry areas will never improve significantly and, in fact, is likely to deteriorate if means are not found for dramatically expanding the supply of inorganic fertilizer to the crop. There is a general consensus about the need to improve the supply of organic nutrients, but disagreement remains over how technically and economically feasible this will be.

Many observers suggest that in dry areas, crop management interventions, including the use of inorganic fertilizers, could play a more important role than improved varieties in increasing yields (Rohrbach 1995; Waddington and Heisey 1997). Some go so far as to argue that in many instances management is the limiting factor, as opposed to the lack of water *per se* (Angus 1991). This may be the case where moderate rather than severe dry spells are commonly encountered. On the other hand, the genetic improvement resulting from plant breeding is in the seed itself, and the benefits of improved varieties may be applicable over a much wider area than any single crop management practice. As a result, improved varieties often provide a better alternative for poor farmers "who cannot afford additional inputs or are simply unable to get access to them" (Edmeades and Bänziger 1997). In maize, however, the particular technological and

institutional complexities associated with the development of viable seed industries imply that relying on maize seed as an agent of technological change also presents difficulties (Morris 1998).

Finally, technological change in dry areas may not be able to reduce income variability. Because drought-tolerant cultivars show positive yield gains in both dry and better-watered environments, their use implies that variability (as measured by yield variance) may remain unaltered, while variability measured as the CV should fall. Certainly the frequency of declines in farm family income below a given threshold should be reduced when drought-tolerant cultivars are deployed in drought-prone areas where maize is a major component of the cropping system. However, crop yield variability often has little correlation with income variability. Reviewing the potential for technological change to mitigate risk in the semiarid tropics, Walker (1991) concludes that the scope for risk reduction through technological change is limited, and that "researchers should be more concerned with longer-term average productivity or cost savings, and place less emphasis on potential risk benefits."

The Difficulty of Introducing Technological Change into Drought-Stressed Environments

Even discounting attempts to reduce yield variability, increasing mean yields in drought-stressed maize production environments is difficult. In large part this is because "for many farmers, successful technology introduction requires the simultaneous adoption of up to four different technology components . . . . Four simultaneous input changes are difficult for

researchers to study, for extension agents to promote, and for farmers to undertake" (Sanders, Shapiro, and Ramaswamy 1996). Farmers tend to adopt new technologies in a stepwise fashion (Byerlee and Hesse de Polanco 1986), and gradually, in the case of divisible inputs. Many proposed changes involve management components, which are more difficult to promote than simple input adoption. This contrasts with the pattern of technological change in areas where the Green Revolution began, where relatively simple technological changes based on seed and fertilizer only later gave way to more complex management changes (Byerlee 1987, 1992; Pingali, Hossain, and Gerpacio 1997).

Despite the extreme difficulties in developing and promoting technological change in dry areas, such change is necessary in many cases simply to help support farm family incomes and to reduce, if only slightly, the pressure placed on more favorable land. In some instances, technological change may be necessary to preserve present yield levels or to prevent further resource degradation. None of the promising current or future scientific developments discussed in this section will bring economic returns unless they result in technologies that are adopted by farmers. How can such complex change be promoted?

No single, overarching answer to this question exists, but several considerations should guide efforts to foster technological change in drought-stressed areas. Most farmers are interested in profitability and risk, and not yield *per se*. Field studies to determine the profitability of technologies under farmers' actual

circumstances will have to be significantly more widespread than at present. Participatory research to elicit this information must concentrate on real activities in farmers' fields, in many cases employing cultivars that farmers already use in combination with newer, stress-tolerant alternatives under development. Better information sharing across different drought-stressed environments can help. Carefully planned infrastructure development and greater integration of dry areas into larger markets can play important roles in technological change (Walker 1991; Smith et al. 1994, 1997; Fan and Hazell 1997).[22]

Finally, time horizons need to be lengthened considerably beyond the three to five year planning period of the typical donor-financed development project. A case in point is that genetic improvements in yield of around 50% under midseason drought stress were achieved only after six to eight years of selection (see "Methods for Selecting Maize for Tolerance to Drought Stress," p. 20). The Machakos case in Kenya is also instructive. Soil and water conservation technologies in that district were often developed based on agricultural recommendations from the colonial past. They did not begin to make an impact until much later, *after* they had been modified by farmers, and *after* farmers' circumstances had changed to make them profitable (Tiffen, Mortimore, and Gichuki 1994).

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[22] Binswanger, Khandker, and Rosenzweig (1993) provide an important analysis of whether infrastructural investment is endogenous, in other words, partially influenced by the natural potential of a region.

Research Policy and Marginal Environments

Drought stress is the most important abiotic constraint to maize production in developing countries. Its significant interaction with the other major abiotic stress, soil infertility, greatly increases the challenges confronting farmers, researchers, and policymakers. We have reviewed ways of measuring the effects of drought stress in maize production, the possible links between marginal maize environments and poverty, and scenarios of future maize supply and demand in marginal and favorable areas of the developing world. We then outlined many of the technological options for reducing the effects of drought stress in maize.

This discourse may seem to have taken us far afield from the "favored vs. marginal" debate that was highlighted at the beginning of this report. In reality, examination of these topics is essential for analyzing several of the questions at the heart of the debate. What can be said about research resource allocation to marginal or favorable agricultural areas? What economic principles can be used to guide expenditures of research funds? If research is directed at drought-stressed environments, what prescriptions can be employed to guide the direction of research activities between, say, crop improvement and crop management?

This section begins with a review of the economic surplus approach to research resource allocation, with a particular focus on marginal and favorable areas. Additional considerations will then be discussed, both within the context of the economic surplus paradigm and in light of other goals such as poverty

alleviation and environmental benefits. Although the analysis is general, clearly drought stress will be a very important component of most indices of marginality in maize, as it has been in previous studies of wheat (Byerlee and Morris 1993; Renkow 1993).

Analyzing the Regional Impacts of Technological Change Using Economic Surplus Methods

The concept of economic surplus underlies most of the methods used by economists to estimate both the benefits and costs of agricultural research and to assess agricultural research priorities. This approach, based on areas measured below the demand curve and above the supply curve for a particular commodity, has often proven to be the most defensible method for evaluating returns to research. One advantage of the economic surplus approach is that it can be used to determine how the benefits of agricultural research are divided between consumers and producers, and among different geographical areas. The measures of changes in consumer and producer surplus can be interpreted in terms of cost reductions, yield enhancements, effects on the total quantities produced and consumed, effects on prices, and so on (Alston, Norton, and Pardey 1995).

Surprisingly, the economic surplus approach has rarely been used to explore the question of how research benefits are distributed among favorable and marginal areas. Renkow (1994) provides a good summary of the most important issues involved in assessing the welfare effects of regionally differentiated technological change. To understand how agricultural innovations are likely to affect different types of households in different

production environments, it is necessary to analyze:

♦ the innovation's direct impacts on output, labor demand, and input use on different types of farm households;

♦ spillover effects mediated through product and labor markets that change the relative prices faced by different types of households (which may include landless households, depending on the empirical context);

♦ the relative numbers of different types of households within a particular area or production environment;

♦ the share of agriculture-based income in total household income for different types of households; and

♦ policy and other variables, particularly those determining the extent to which markets are best characterized as open or closed.

The building blocks of our analysis include the markets for labor, markets for the commodity in question, and three regions (a favorable agricultural region, a marginal agricultural region, and urban areas). It is relatively easy to analyze different household types in both favorable and marginal areas. It is also straightforward to include the effects of technological change in marginal and favorable areas. Simultaneous changes in all markets can be analyzed by expanding the "partial equilibrium" economic surplus approach into a general equilibrium analysis.[23]

In "Measuring Benefits of Technological Change to Consumers and Producers" (p. 30) and in the following discussion,

maize will serve as the commodity. We implicitly assume that maize is consumed as human food, though the model could be modified to include the explicit consideration of separate food and feed markets. The importance of such a modification for particular maize producing countries may be judged from the data on food and feed consumption in Part 3. We also assume that the favorable area is a surplus region and that the marginal area is a deficit region.

In modeling the distributional impacts of technological change, a crucial assumption is whether the region or country is "open" or "closed" with respect to the price of the commodity in question. If open, the maize price is set outside the region by conditions in a larger market (often the world market). If the economy is closed, the maize price is determined by supply and demand within the region. Characterizing economies as open or closed requires care, although general trends towards liberalization suggest that in the future, more markets may best be regarded as open. Even within open economies, significant price wedges resulting from high transportation costs may exist. Taking these into account can considerably alter estimates of the size and distribution of research benefits (Mills 1997).

In the open economy case, technological change only in the favorable region does not affect prices; all the benefits from a research-induced shift in supply go to producers in that region, whose production costs decline. Producers in the marginal area, where no technological change is assumed, neither gain or lose. Consumers in any area, including urban areas, do not gain

or lose either, because the maize price remains set by the world market. It is easy to extend this case to situations of technological change in both regions.[24] In such situations, producers in both regions would benefit, and consumers' welfare would be unchanged.

In the closed economy case, technological change in the favorable agricultural region would lead to a decline in the maize price. Welfare changes in the favorable area would be ambiguous because consumers in that area would benefit, but producers could either gain or lose, depending on whether the advantages of greater yield were outweighed by the negative impact of lower prices. The net benefits to the region as a whole could be positive or negative. In the marginal region, producers would lose because they would receive lower prices for their maize; consumers would gain for the same reason. The net welfare change in the marginal region would be positive. In the urban areas, consumers would clearly gain.

If technological change takes place in both marginal and favorable regions, the decline in maize prices would be greater than if the change occurred only in the favorable area. Likewise, gains to consumers in all three regions would also be greater than if the supply curve shifted only in the favorable area. In both producing areas, impacts on producers would be ambiguous. The net overall gains (by consumers and producers) in the favorable area would be less (or net losses greater) than under the status quo. The marginal area as a

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[23] For examples of both of these modifications, see Renkow (1991, 1993) and Coxhead and Warr (1991).

[24] To capture the possibility that technical change might be more difficult to achieve in the marginal region, the supply curve in the marginal region might be assumed to shift out less than the supply curve in the favorable region.

Measuring Benefits of Technological Change to Consumers and Producers

The basic assumptions behind the measurement of economic benefits from technological change through economic surplus measures have been outlined and reviewed by Harberger (1971) and Alston, Norton, and Pardey (1995).[25] Here we follow Renkow's (1994) treatment of some of the basic principles in applying those concepts to the question of research benefits in favorable and marginal agricultural areas. In a graph showing supply and demand, with quantity on the horizontal axis and price on the vertical axis, producer surplus is measured as the area above the supply curve and below the line depicting the prevailing price. Consumer surplus is measured as the area underneath the demand curve and above the line indicating price.

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[25] Alston, Norton, and Pardey (1995) also provide an extensive bibliography of technical discussions of the topic.

In the open economy case, the price of the commodity (say maize) is set exogenously; the increase in supply is too small to create a measurable fall in price in the country being analyzed. This could be because the country produces a small amount relative to the world total and is a net exporter or net importer. Alternatively, in countries where the government has substantial control over producer and consumer prices, impacts of technological change could also be modeled using these assumptions.

Figure 10 depicts the maize market in the open economy case; the country is assumed to be a net importer. Technological change is represented by an outward shift in the supply curve in the favorable area (first panel). Before the shift, producer surplus was PAD; afterwards, it is PBC. The shaded area ABCD represents the net increase in producer surplus. In both the marginal agricultural region and urban areas

(second and third panels) there are no changes in either producer or consumer surplus. In the national market (fourth panel), the supply curve (a horizontal sum of the supply curves in the favorable and marginal agricultural regions) shifts outward. The quantity of imports required falls by Q_1–Q_0, as it is substituted by production from the favorable region. In summary, producers, specifically producers in the favorable region, benefit and imports fall. Welfare in both the marginal agricultural region and in urban areas is unchanged, as the same price prevails and the quantities demanded (and supplied, in the case of the marginal region) are also unchanged.

In the closed economy case, prices are determined by the intersection of aggregate supply and demand curves (Figure 11). An outward shift in the supply of maize in the favorable
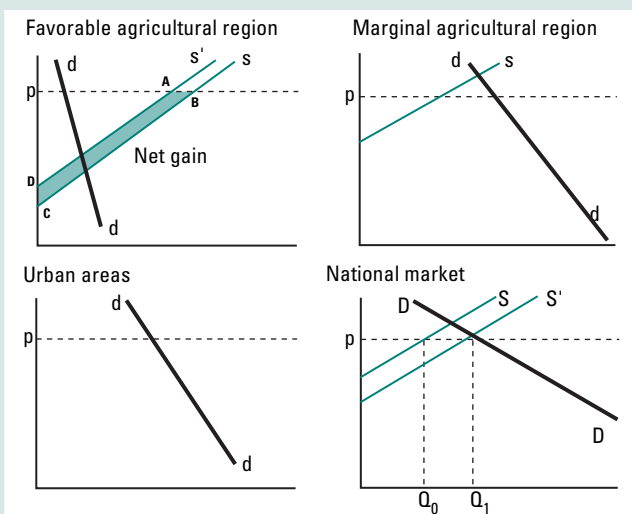
Figure 10. Commodity market impacts of technological change: Open economy case.
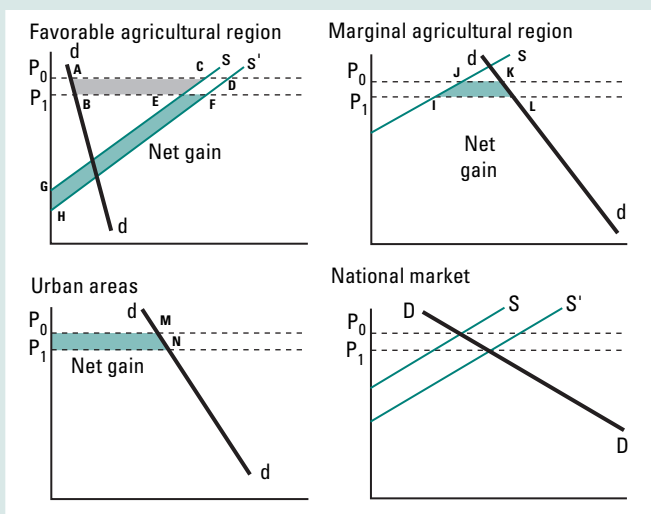
Figure 11. Commodity market impacts of technological change: Closed economy case.

agricultural region from s to s' leads to an outward shift in the national market from S to S', and as a result the price falls from P_0 to P_1 (fourth panel). In urban areas, consumers gain unambiguously as consumer surplus increases by the area P_0MNP_1. In the marginal area, consumers gain by the amount P_0KLP_1, and producers lose by the amount P_0JIP_1. There is a net gain for the region of IJKL. Results are more ambiguous in the favorable agricultural region. Before the technological change, producer surplus was P_0CG. Afterwards, it is P_1FH. As a result, producers lose P_0CEP_1 and gain GEFH; thus the overall change in their welfare is ambiguous. Consumers in the favorable area unambiguously gain P_0ABP_1. The welfare change for the region as a whole is therefore given by GEFH–ABEC, which could be positive or negative.

This basic framework can be modified in many ways. In all of these modifications, the basic concepts of consumer and producer surplus outlined here are still operative.

whole (consumers and producers) would benefit more if technological change occurs in both regions, rather than only in the favorable area.

Many small-scale farm households in developing countries consume a substantial part of their own agricultural output and cannot be regarded as pure producers. Although the size of welfare changes varies between semisubsistence households, pure producers, and consumers, the direction (positive or negative) of the effects is the same for both net and pure producers, depending, of course, on whether they adopt the innovation. The direction of welfare changes is also the same for both net and pure consumers.

Technological change in agriculture can also affect the income of households in areas where the new technologies are adopted. If the labor supply curve slopes upward, a labor-using technology will put upward pressure on wage rates. This affects the income of labor-supplying households, landless or not, and households "for whom the implicit return to their on-farm labor will have changed" (Renkow 1994). These conclusions could be modified, however, if the technological change is labor-saving or if reductions in output price accompanying a supply shift lead to a net reduction in the demand for labor.

A new labor-using technology may also have impacts in areas outside of the region where it is adopted. If real wages in the adopting area rise enough to cover the cost of moving, people may migrate from the non-adopting area to the adopting area. Furthermore, this labor withdrawal will put upward pressure on wages in the non-adopting

areas. The empirical record concerning the relationship between technological change in agriculture and wage rates is mixed. Lipton and Longhurst (1989) found that in Green Revolution areas, real wages stagnated or increased very slightly. Singh (1990) found more evidence of rising real wages in parts of South Asia. Simple analysis also understates the long-term impacts and costly nature of interregional migration. Finally, rural-rural migration is probably a much less important phenomenon than rural-urban migration (Renkow 1994).

In sum, empirical studies of the impacts of technological change in agriculture on regions and on different types of households may need to take into account a number of factors in both the grain and labor markets. Models that encompass a full range of questions about differential impacts generally come to different conclusions, depending on the empirical context. For example, in Pakistan, it was agriculture's share of household income that appeared to exercise the dominant influence on the welfare effects of technological change (Renkow 1991, 1993). In Southeast Asia, labor mobility and the responsiveness of agricultural workers to wage changes have been key factors (David and Otsuka 1994; Coxhead and Warr 1991).

Analyzing the Costs of Research

A full determination of whether net economic benefits can be gained from reallocating resources from marginal to favorable areas requires not only measures of the economic surplus to be obtained under each scenario, but also estimates of the costs of research, the length of time over which research occurs, the time lag between research

and adoption by farmers, the speed of that adoption, the ceiling adoption rate, and something generally referred to as the "probability of success" (Alston, Norton, and Pardey 1995). This last parameter is important because research outcomes are uncertain; possible yield increases, for example, are distributed over a range of values.

These are the standard parameters for studies of returns to research. Occasionally they have been used in *ex ante* priority setting exercises. The few studies that focused on the question of research resource allocation to marginal vs. favorable environments (e.g., Coxhead and Warr 1991; Renkow 1993; Byerlee and Morris 1993), however, did not begin with an attempt to allocate research expenditures to the two areas until economic returns to the last dollar invested had been equated for marginal and favorable regions.[26] Researchers tend to take current allocations to research as given and explore changes from the status quo (e.g., Mutangadura and Norton 1997), because policymakers want to start with the status quo when determining where the system should be moving. Still, a comparison of research costs, time lags, diffusion paths, and so on, under alternative scenarios, is as essential to discussions of "optimal" resource allocation as the analysis of net benefits and their distribution. Similar analysis can be applied to the question of marginal and favorable areas and to research within marginal areas; for

example, the relative emphasis to give to crop breeding and crop management.

Research for Marginal Areas, Poverty, and the Environment

We began this report by contrasting the argument that production intensity should be reduced in more fragile ecologies with the contention that research is necessary to provide livelihoods and minimize adverse environmental impacts in fragile lands. A better characterization of the essential questions would be: Given current levels of investment for agricultural research, what would be the effects on agricultural output, income distribution, and the environment of shifting more resources toward marginal lands? What would be the effects of shifting more resources toward favorable environments? How would the answers change if total research resources increased? If they decreased?

Analysis of the costs and benefits of research is an important part of priority setting, even when objectives other than economic surplus, such as poverty reduction or environmental protection, are deemed important. Although quantifying the effects of research on poverty and the environment is highly desirable, it is often difficult to do so. By carefully measuring the gains in economic surplus revealed by research, an analyst can indicate more precisely what must be sacrificed to attain other societal objectives (Alston, Norton, and Pardey 1995).

Several points are clear. Until now, the rate of technological progress in favorable agricultural lands has far exceeded the rate in more marginal areas. This strongly suggests that when

agricultural research in developing countries was initiated, returns to research were higher in areas with better resource bases. It says less, however, about what returns might be today. As noted, serious economic analysis has tended to start with the status quo, in which some resources are directed towards research for marginal areas. This indicates that few analysts are overtly proposing that research for marginal areas should be eliminated. Furthermore, some of the difficult questions about allocating research resources have only begun to be posed. For the most part, neither side to the debate has provided hard quantitative answers to such questions.

The economic surplus approach suggests that in open economies, agricultural research directed at marginal environments leads to unambiguous benefits for households that produce the commodity in question. In closed economies, net consumers fare better with additional technological change in marginal areas than if technological change is confined to favorable areas, whether or not they adopt the technology. The effects on net producers in the marginal area who adopt the technology are ambiguous, while net producers who do not adopt it are worse off. In many instances the majority of farm households in marginal areas are likely to be net consumers, thus making a strong case that agricultural research can benefit many farm households in these areas.

Despite those benefits, however, there are several reasons to believe that such research is unlikely to make a profound impact on poverty. As demonstrated earlier, the linkage between the marginality of an agricultural environment and poverty appears to be

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26 In other words, given a fixed research budget, the "optimal" allocation of resources would be determined by considering what would happen if one more dollar became available. If that dollar would earn the same amount regardless of whether it were invested in a marginal or in a favorable area, the allocation would produce the greatest economic surplus for the entire region under consideration.

tenuous at best, particularly at disaggregated levels. Poverty in marginal areas has many causes; an inhospitable agricultural environment is only one of them. Moreover, in some cases, the incidence and severity of poverty in more favorable areas are similar to that found in marginal areas. Many students of agricultural research policy conclude that agricultural research is only one of many instruments that might be used to achieve distributional objectives, and a fairly blunt one at that. For example, although agricultural research has often led to reduced food prices, with presumed benefits to the poor, there may be "more effective and less costly ways to pursue a cheap food policy . . . than a distorted research policy" (Alston, Norton, and Pardey 1995).

The sobering reality is that sweeping pronouncements about poverty and research resource allocation are usually not very helpful. Useful policy information can come only through detailed analyses of specific cases— analyses that can track the impacts of different research strategies on different groups of interest, without necessarily assuming that research will single-handedly lift many of these groups out of poverty.

A good example of such analysis is the work of Mutangadura and Norton (1997). Focusing on Zimbabwe, they applied a combination of economic surplus and mathematical programming methods. Their starting point was the current (1995/96) allocation of resources within the Department of Research and Specialist Services. Among other points, they demonstrated that under current funding levels, maize research

generates, by far, the largest share of aggregate economic benefits (just under 40% of the total); research on all other commodities accounted for the remaining benefits. Their findings also suggest that: 1) within a fixed research budget, allocating more resources to maize would be justifiable on economic criteria; 2) given the resource endowments and the importance of maize production in Zimbabwe, an optimal research portfolio would include resource allocations to both marginal and favorable maize production areas, and to both small-scale and large-scale farmers; and 3) at current levels of research expenditure, there is a relatively small loss in research benefits from placing extra weight on smallholders, but this loss would increase if the research budget was cut. In an earlier analysis of this topic in El Salvador, the efficiency-equity trade-off appears to have been steeper (Walker 1980).[27]

Providing accurate measures to assess potential environmental benefits of agricultural research for marginal areas is more difficult and problematic than for assessment of distributional impacts. But as with poverty reduction, agricultural research should generally not be considered the sole policy instrument available for tackling problems of environmental degradation and intergenerational equity (Alston, Norton, and Pardey 1995). All agricultural research, particularly that targeted at marginal areas, is likely to have consequences for unpriced natural resources, including soil fertility, air or water quality, or even populations of natural predators that control pests. If

information on the external environmental costs of production could be developed, it would serve as a vitally important component of agricultural research evaluation (Crosson and Anderson 1993).

Policymakers should consider several important environmental issues and interactions before attempting to increase maize production in less favorable environments. First, should agriculture be practiced in the area in question at all? If the answer is yes, the optimal use of the land resource (livestock? cropping? a mixed system?) must be determined. If cropping is involved, the suitability of maize compared to other major cereal species must be examined. Such a review should pay close attention to evidence that: 1) farmers generally grow maize in marginal areas only if it is a profitable cropping alternative and 2) maize does not seem to have spread widely into drought-prone areas in recent years. Second, policymakers must also consider that one of the most pressing resource issues in developing country maize production (in areas both more and less severely affected by drought stress) is soil infertility and land degradation (Blackie 1995; Waddington and Heisey 1997; Scherr 1998). Addressing such concerns will require research directed at halting or reversing land degradation, a difficult objective given that little is known about the long-term consequences of alternative agricultural strategies in drought-stressed environments. Finally, policymakers must be aware that there are interactions between equity, environmental issues, and economic growth, and that large-scale economic change usually affects all three objectives simultaneously (Vosti and

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[27] Conclusions about efficiency-equity trade-offs in public sector research might also be revised if alternative sources of research, such as the private sector, were considered.

Reardon 1997). Research will find it especially challenging to develop technologies that benefit individual farmers in the short run and also contribute to longer term social objectives.

Many commentators on the linkages between production, poverty, and the environment are hopeful of finding "win-win" (or "win-win-win") technologies that can successfully address more than one objective at the same time (Hazell and Fan 1998). This optimism runs counter to the cautious economist's presupposition that there are usually trade-offs between different objectives. However, examples of potential changes that benefit both production and poverty (or production and the environment) can be found under certain circumstances.

♦ In some instances, institutional and informational inefficiencies within a research system may prevent a nation or region from reaching a frontier where trade-offs between societal objectives must be made. Under these circumstances, the system might achieve greater success in meeting diverse societal objectives by changing its mix of research projects.

♦ In other situations, more favorable outcomes might be obtained on several fronts by scaling back other objectives; for instance, increased production and less poverty might be obtained by sacrificing environmental objectives.

♦ In certain cases, committing more resources to agricultural research could result in obtaining both higher production and societal objectives. Nonetheless, *given* the larger research budget, trade-offs among these objectives would still be necessary.

♦ Finally, employing additional policy instruments (e.g., price and income policy or infrastructure development) might produce a better mix of higher production, lower poverty, and environmental conservation for the same policy cost as relying solely on agricultural research (Alston, Norton, and Pardey 1995). Both analysts and research policymakers must recognize that there are alternative ways to reach complex social objectives and that finding the appropriate role of research will require considerable thought.

Four Specific Decisions for Research Resource Allocation to Drought-Stressed Maize

Before deciding whether to allocate additional resources to maize grown in drought-stressed environments, research managers should carefully look at four key points: the appropriateness of maize; the balance between crop management and plant breeding; the balance between breeding for less favorable and more favorable maize environments; and the roles of different research institutions.

The appropriateness of maize in drought-stressed areas. Many observers (e.g., Lipton and Longhurst 1989) consider sorghum and millet to be "safer" than maize in drought-stressed environments. The data presented in the first section, however, suggest that down to a certain rainfall threshold, maize is often economically preferable to sorghum or millet. The maize crop may fail with slightly higher frequency, but its superior productivity in good years makes this risk acceptable to most farmers. There is very little evidence that maize is spreading into environments where rainfall drops below those thresholds. Matlon (1990),

after reviewing the potential for sorghum and millet in semiarid Africa, concluded that "both efficiency and equity goals would suggest that larger shares of research and development resources should be allocated to higher potential zones and crops, with relatively declining shares allocated to sorghum and millet in the medium and long run."

The balance between crop management research and plant breeding. Another widely held belief is that the drier the area, the larger the potential gains from crop management research, compared to gains from crop improvement research. Although this may in fact be true, our discussion about the difficulty of introducing technological change into marginal environments suggests that this would be a good question to study using the basic tools of economic analysis. Even if the benefits from crop management research are potentially higher, they must be balanced against potentially higher research costs, longer time lags between research and adoption by farmers, lower adoption rates and ceiling adoption rates, and lower probabilities of success.

Although economic analysis might suggest some reallocation of research resources between breeding and management, it is important to consider that improved cultivars will often complement crop management changes (Sanders, Shapiro, and Ramaswamy 1996). In Zimbabwe, when maize research components aimed at smallholders in low potential areas were ranked, agronomy/chemistry and soils research both placed ahead of plant breeding, but all three were considered "high priority" research activities (Mutangadura and Norton 1997).

The balance between breeding for less favorable and more favorable environments. How should resources within a maize breeding program be divided between research for less-stressed and more-stressed areas? Improvements in drought tolerance in maize have not come at the expense of yield under unstressed conditions (Edmeades et al. 1997a; see also "Methods for Selecting Maize for Tolerance to Drought Stress," p. 20). In absolute terms, gains from selection in drought tolerant germplasm that is grown under better-watered conditions appear to be only slightly less than gains from selection in regular breeding programs (López-Pereira and Morris 1994). There is also little evidence that maize yield gains (in percentage terms) in farmers' fields in drier areas have been generally lower than yield gains in better-watered locations. Thus, there seems to be an empirical difference between maize and wheat. In wheat, both genetic progress and yield gains in farmers' fields appear lower, in percentage terms, in dry areas than in more favorable environments (Morris, Belaid, and Byerlee 1991; Byerlee and Moya 1993). This same trend may eventually become apparent in maize as new technologies are more widely diffused among farmers in non-temperate areas.

From the perspective of theoretical genetics, breeding costs increase for each additional trait used in selection. The lower the genetic correlation between traits, the more it costs to incorporate them. One of the reasons gains in drought-tolerant material under better-watered conditions appear similar to historical breeding gains in "normal" germplasm may be that in the latter case, yield was not the sole

breeding objective. In selection for drought tolerance, the primary objectives were yield under drought and yield *per se*. Adding drought tolerance to materials being improved for other traits would add to breeding costs, but continued attention to drought tolerance in plant breeding and technology extension efforts seems well justified. It is evident that: 1) continued maize production from severely drought-stressed areas is necessary; 2) drought stress can significantly affect production even in better areas; 3) selection methodologies must be extended to production ecologies other than the lowland tropics; and 4) considerable work will be required to move drought-tolerant material into farmers' fields.

Economic analysis of individual components of plant breeding programs could conceivably provide insights into whether resources allocated to drought tolerance should be reallocated in relation to total breeding resources. Such analysis, however, is still in its infancy.[28] Future refinement of this type of analysis will require a methodology that ensures that returns aggregated over different components of a breeding program are not significantly different than conventional estimates of returns to the entire program.

The roles of different research institutions. Finally, public sector maize research programs are more likely than private sector research entities to concentrate on the problems of marginal areas, because payoffs are

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[28] For examples of analyses of individual components of plant breeding programs in other contexts, see Galt and Stanton (1979); Unnevehr (1986); Brennan (1992); Bänziger, Betran, and Lafitte (1997); and Smale et al. (1998).

perceived as being lower and more uncertain than in other areas (López-Pereira and Filippello 1994). Similarly, the costs of research directed at marginal areas may mean that agricultural research at the international level is necessary to complement public national research programs. Institutional analysis from an economic perspective can help illuminate the relative roles of different research actors and how these roles change over time (Morris 1998).

Summary and Conclusions

Drought stress is a major and ubiquitous constraint to maize production in developing countries. In non-temperate maize environments, annual losses to drought may be responsible for about a 15% reduction in production. Drought stress clearly results in lower yields, especially when it occurs near maize flowering. Although it is apparent that maize yields in areas particularly subject to stress are lower and more variable than yields in irrigated areas that are or that have more reliable rainfall, much more work is necessary to accurately quantify the economic impacts of drought.

During the past 25 years, considerable progress has been made toward partially alleviating the effects of drought stress through technological advances in crop management and the development of germplasm with greater drought tolerance. Unlike other cereals, in maize there seems to be little difference between the genetic advances achieved in better-watered environments and those achieved in drier conditions. Crop management interventions may possess greater potential for significant impact on maize

production than genetic solutions; however, they may be costlier to develop and diffuse, and ultimately they may reach fewer farmers than more drought tolerant germplasm. Since germplasm and management interact strongly, the most successful technological interventions in drought-stressed areas will probably involve changes in both crop management and germplasm.

One point, however, is quite clear: Agricultural research for marginal environments, and particularly for maize in drought-stressed environments, will continue to be justified. The most promising course for increasing maize production to meet projected demand to 2020 requires a combination of large yield increases in favorable areas, smaller yield increases in marginal areas, and some growth in area planted to maize. Furthermore, given the usual circumstances under which technological progress continues in favorable areas, additional agricultural research directed specifically at marginal environments would probably benefit the majority of households in these locations. Such research, however, may not significantly reduce poverty. The relationships between the marginality of agricultural environment and level of poverty are complex, and agricultural research is a relatively blunt instrument for reducing poverty. Infrastructural investment, in some cases, may be a superior approach.

Agricultural research for drought-stressed maize environments probably will have consequences for unpriced natural resources. Unfortunately, little is known about the long-term consequences of alternative agricultural strategies in drought-stressed environments. One of the most pressing resource issues in developing country maize production, in both more and less drought-stressed areas, is soil infertility and land degradation. The need for more technological and economic research on this issue is acute.

So far, little analysis appears to have focused on whether additional research resources should be allocated to favorable environments, from marginal ones or vice versa, or on whether current allocations are nearly optimal given the present size of research budgets. These are important and unresolved economic research questions. Apart from the need to meet production objectives, policymakers are likely to continue targeting research resources to marginal environments for political reasons, preferring to focus on visible equity concerns rather than less obvious issues of efficiency. Economic analyses can help clarify the value of production forgone by following such strategies. In some cases, "win-win" situations may exist where the same research strategy can address more than one objective. This may involve choosing a better combination of individual research projects, sacrificing other societal objectives, devoting additional resources to research, or combining research with other policies aimed at the same objectives. More attention must also be paid to the special role of public sector agricultural research for less favorable areas, as the private sector increasingly provides research for more favorable regions.

The analyses in this report reveal the complexities inherent in attempting to clarify aspects of the favorable vs. marginal debate at the global or regional level. Despite the many broad assertions that have accompanied this debate, the truth of the matter is that there are no easy answers to the questions we posed at the beginning of our report. Although additional research and new research methods should help us make progress in determining the best approach to research resource allocation for favorable and marginal areas, our knowledge will probably have to become deeper before it can become broader. More careful, thorough case studies that analyze the implications of alternative allocations of research resources to marginal and favorable areas are essential before sweeping statements about such allocations on a global basis can be made. Using data from case studies together with more accurate assessments and definitions of marginal areas (provided by the combination and integration of GIS data, crop modeling, and refined economic measures) would enable researchers to provide sound information and options on research resource allocation to policymakers. While the marginal vs. favorable debate may continue, few will argue the value of better understanding agriculture in marginal areas, agriculture's relationship to the people who live there, and its effects on the local and regional ecosystems.

Part 2

The World Maize Economy: Current Issues

Ricardo Calvo, Federico Carrión, Pedro Aquino, and Paul W. Heisey

Production

Forecasts of high harvests for the 1998/99 cycle and their impact on final inventory levels allow us to make an optimistic calculation of the world cereal supply. The FAO forecasts that world cereal production for 1998 will be 1.911 billion tons. This level of production would bring world cereal stocks back to the FAO's minimum security level of 17-18% of output.

Global maize production continues to rise, despite fluctuations over the past five years, totaling more than 580 million tons in 1997. Erratic trends within the industrialized nations, which began in the early 1980s and prevailed throughout the 1990s, continue to affect global production. In industrialized countries, the 1997 maize output of 321 million tons surpassed the 1985 total by less than 5%. In contrast, developing nations' maize output increased by 45% over the same period. Developing countries produced more maize than industrialized countries in 1993 and almost as much in 1988 and 1995. Although maize production in industrialized countries rebounded somewhat in 1996, developing countries produced a record 278 million tons that year (Figure 12).

Increases in both yields and cultivated area contributed to maize output growth in developing countries during 1961–70. This contrasts to 1971–80, when production grew primarily because of increased yields. Since then,

annual growth in maize area and growth in maize yields in developing countries have remained fairly stable. In the industrialized nations, maize output growth chiefly comes from increased yields. The average annual growth rate in the total area under cultivation was negative during 1961–70 and 1981–90, but the impact was greater in the latter period because increased yields did not compensate as much for the drop in cultivated area. In the current decade, the rate of growth in cultivated area in industrialized countries has once again been positive but relatively low (Figure 13). Maize area fluctuations in industrialized countries are particularly influenced by world market conditions and shifting agricultural policies. Comparing Figures 12 and 13 suggests that for industrialized nations, output growth, and to a certain extent yield growth, were more stable in the 1960s and 1970s than they have been in subsequent decades.

Figure 14 shows yield growth rates for different periods in different groups of developing countries. In sub-Saharan Africa, yields grew at around 1% during the first three decades (1961–90) but grew much more rapidly from 1991–97. Part, but by no means all, of this recent acceleration in yield growth could be accounted for by the recovery in production that followed the devastating drought in southern Africa in 1991–92. In the most recent season, despite the occurrence of El Niño-related weather phenomena in some countries, the effects were less
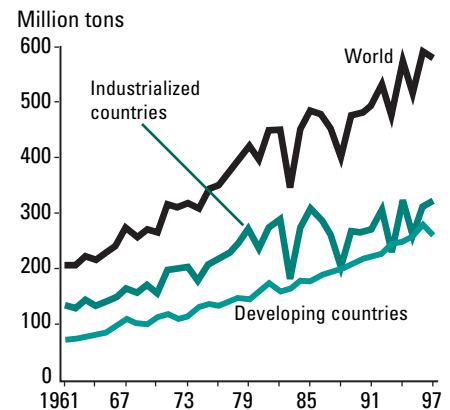
Figure 12. World maize production, 1961–97.
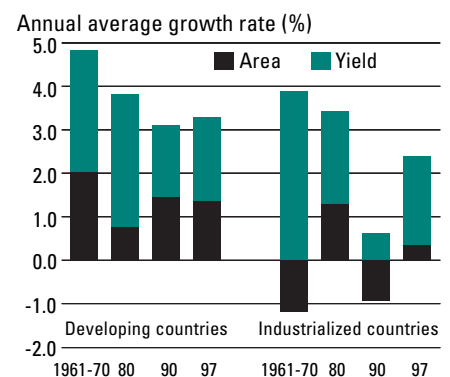
Figure 13. Sources of growth in world maize production in developing and industrialized countries, 1961–97.
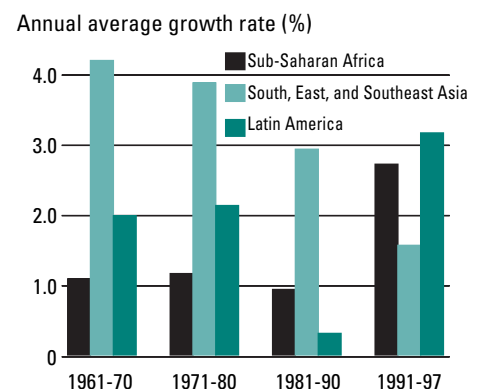
Figure 14. Growth rate in maize yield in developing countries, 1961–97.

devastating than expected. Within southern Africa, conditions in the 1997/98 season were relatively favorable in Angola, Malawi, and Mozambique; in contrast, fluctuating rainfall was partially responsible for below-average yields in Botswana, Namibia, Lesotho, and Zimbabwe. Maize yields in both Zambia and Ethiopia also appear to have declined since the late 1980s.

This situation differs from that found in the nations of South, East, and Southeast Asia, where very rapid rates of growth in maize yields from 1961 to about 1990 fell to approximately 1.5% annually in 1991–97. In 1998, however, maize production in China was the second highest on record, despite heavy flooding in the Yangtze River basin, which did not affect China's major maize producing areas.

Latin America stands in contrast to both the African and Asian nations. Yields grew at about 2% annually during 1961–80 and virtually stagnated in the 1980s. In the 1990s, maize yields in Latin America have recovered strongly, growing at more than 3% per year. In Latin America, however, maize planting in 1997/98 was somewhat delayed by the effects of El Niño, which caused irregular rainfall and poor distribution of the rains. This affected maize cultivation and also irrigation-dependent maize crops. Most of Latin America's irrigated maize is in Mexico. Major flooding occurred in some areas of Argentina and southern Brazil, while Brazil's northern states endured a severe drought.

Trade

Between 1961 and 1980, maize trade more than tripled; however, in 1996, the most recently recorded level in the FAO long-term trade database,[29] maize trade was down more than 30% compared to its 1980 peak. In spite of two major upswings in 1988 and 1995, the volume of world maize trade has not returned to its 1980 level; its current pattern is one of fluctuation. Trade volume reached 69 million tons in 1996, which was lower than the 78 million tons recorded in 1995 (Figure 15).
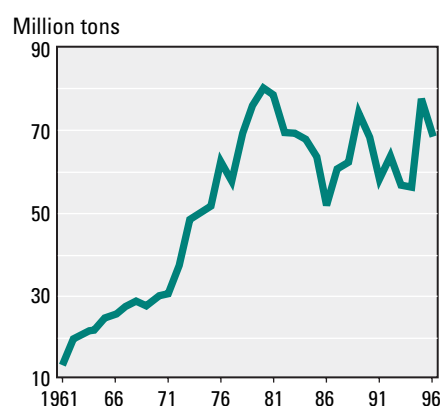
Figure 15. Volume of world maize trade, 1961–96.

The forecast for world cereal trade in the 1998/99 cycle is 201 million tons, somewhat lower than the projected figure for 1997/98. Though global imports of wheat and rice are both expected to drop, coarse grain imports are expected to remain fairly steady. Over the past 40 years, world maize imports reached their highest levels in 1980, 1981, 1989, and most recently in the 1995 trading cycle (Figure 15). Maize imports fell by 5–7% between 1995 and 1996.

The financial crisis in Asia has affected imports of feed grains and other value-added products such as meat into the region; this is due mainly to currency devaluations and the sharp decline in per capita incomes. Maize imports into Asia have continued to fall from the 1995/96 peak. Reduced imports are expected particularly in the Philippines, Malaysia, and the Republic of Korea. The European Community's maize imports fell as a result of their acceptance of genetically modified maize from the USA, which caused a reduction in purchases because of consumer resistance. In contrast, lower global prices and increased domestic demand for maize led to rising imports in Algeria, Brazil, Peru, and Uruguay. It is hoped that sub-Saharan Africa can also increase its imports during this cycle to make up for the deficits expected as a result of climatic and civil disturbances.

Only non-traditional maize-exporting countries such as China appeared to increase their export volumes in 1997/98. China tripled its maize exports thanks to its vast stocks and its ability to offer competitive prices by reason of its proximity to the Asian maize markets. In 1998/99, Chinese maize exports are expected to fall somewhat. The European Community's exports could increase. Increased export volumes from traditional exporting countries, mainly Argentina and the USA, are also expected in 1998/99. In addition to China, Australia, the Republic of South Africa, and Zimbabwe may experience decreases in maize exports.

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[29] Trade data may be reported in two ways, even within the same institution(in this case the FAO). The FAO's long-term electronic trade database is maintained on a calendar year basis. More contemporary trade data that focus on the recent past and on near-term projections are sometimes reported on a July-June "trade cycle" basis. As a result, when discussing longer-term trade comparisons we will usually employ a calendar year definition, but when presenting comtemporary shifts in trade volumes, more recent trade cycle estimates may be used.

Maize Utilization

Global maize utilization totaled 579 million tons in 1996, with the largest proportion (387 million tons) used for animal feed. Use of maize for direct human consumption has remained stable at around 100 million tons per year since 1988; 97 million tons were used for direct human consumption in 1996.

An analysis of how maize is used in the developing countries reveals interesting patterns. The rate of growth in the volume of maize used for animal feed has been rising since 1986, but since 1991, the increase has become more pronounced (see Figure 16), with utilization now totaling 180 million tons. In contrast, the volume of maize used for human consumption has fallen. The highest figure (87 million tons) was recorded in 1990, while 1996 utilization was slightly more than 82 million tons. Demand forecasts for feed maize are linked to the projected expansion of poultry and pig production in some countries; if the projections are correct, maize used for those purposes will soon reach 200 million tons. The recent economic turmoil in Asia, however, may affect the long-term rate of growth in demand for feed maize there. We explore revised forecasts at the end of this section.
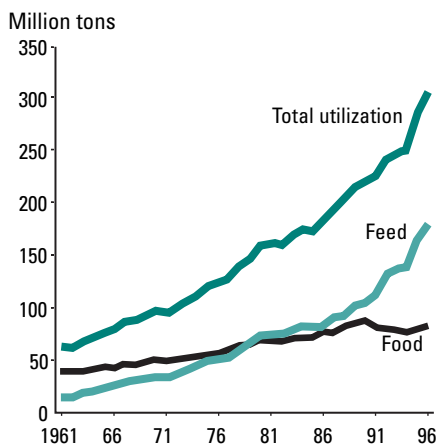
Prices

There has been a clear downward trend in real world maize prices since the mid-1970s. Figure 17 shows the magnitude of the fluctuations in real prices compared to the regression trend line. Between 1985 and 1995, real prices were below the trend, coinciding with major fluctuations in trade during the same period.
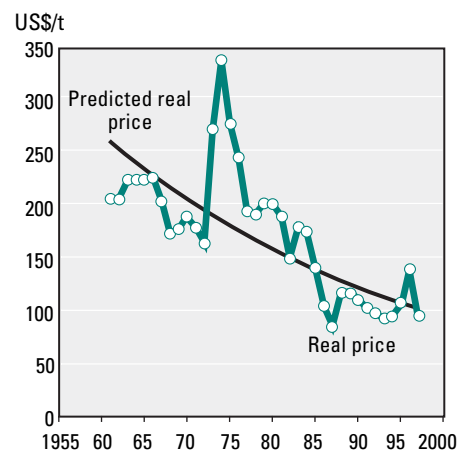
Figure 17. Export price, No. 2 yellow maize, Gulf ports.

The downward trend in global maize prices has been reinforced by the abundant harvests obtained during the 1997/98 cycle. In general, and with the exception of rice, almost all cereal prices are dropping. The prospects for good harvests in 1998/99 would indicate that the downward trend may continue for the short term. The area under cultivation, harvest prospects, and the Asian crisis could also affect the evolution of prices during the coming cycle.

Recent Cereal Policies

Cereal policy over the past few years has been aimed primarily at market-oriented reforms. The mechanisms used for this have been: 1) the reduction of subsidies for inputs and 2) the privatization of economic activities that were previously part of governments' responsibilities in this sector.

Poor harvests during the 1994/95 and 1995/96 cycles forced some countries to maintain their subsidies and to halt their price liberalization measures. Policies encouraging cereal imports were also introduced to guarantee domestic supplies. These measures were implemented primarily to benefit domestic consumers.

In the sphere of international trade, progress was made toward compliance with the trade liberalization commitments made under the Uruguay Round of the General Agreement on Tariffs and Trade (GATT), although some governments continued to grant subsidies and apply quotas, thereby limiting access to their domestic markets.

New farm legislation in the USA has potential long-term effects on international cereal trade and prices. If the USA increases the efficiency of its agricultural sector through a strong degree of market orientation—which is the purpose of the Federal Agricultural Improvement and Reform (FAIR) Act of 1996—it could become a more competitive cereal exporter. One of the major provisions of the legislation eliminates the connection between income maintenance payments and agricultural prices.

Figure 16. Maize utilization in developing countries, 1961–96.

During the coming years, many countries are expected to continue designing and implementing policies that liberalize their domestic and international cereal trade. This may have some impact on both the volume and global prices of these commodities. Neither the United States Department of Agriculture (USDA) or the Congressional Budget Office expect that recently enacted US legislation will have major effects on supply, demand, or prices; rather, farm incomes in the USA are likely to become more variable and require more risk management. This conclusion is likely to apply to other parts of the world as markets liberalize.

Projections for Maize to 2020

The International Food Policy Research Institute (IFPRI) has recently modified its forecasting model to include a scenario of reduced economic growth in Asia. In this scenario, the growth rate in non-agricultural, gross domestic products is assumed to decline by approximately 50%. For maize, the main impacts are on demand, not supply. The volume of maize used for human consumption is projected to increase faster in the "reduced growth in Asia" scenario than in IFPRI's baseline scenario; maize used for animal feed, meanwhile, will grow much less rapidly. Using the "reduced growth in Asia" scenario, by 2020, developing countries would consume roughly 30 million tons less feed maize than under the baseline scenario. Asia would account for nearly all of this decrease (Table 12).

IFPRI's revised scenario also assumes lower maize production in the developing countries. Maize imports in Asia would decrease more than 30% compared to the baseline scenario. Maize imports for developing countries overall would only decrease 11%, because developing countries outside of Asia would be expected to increase their imports to some extent. Because lower demand rather than lower supply would account for the overall reduction in consumption, the real price of maize in the "reduced growth in Asia" scenario is expected to be about 10% lower than the baseline projections (Table 12).

Table 12. Projected maize data in 2020: baseline and "reduced growth in Asia" scenarios		
	Baseline scenario	"Reduced growth in Asia" scenario
Growth rates in maize production[a]	(% per annum)	
Asia	1.7	1.5
Latin America/Caribbean	1.7	1.5
Sub-Saharan Africa	2.9	2.7
West Asia/North Africa	1.8	1.7
All developing countries	*1.9*	*1.7*
High income/transitional	*1.1*	*1.1*
World	**1.4**	**1.3**
Total maize production in 2020	(million tons)	
Asia	207.9	196.8
Latin America/Caribbean	106.6	102.2
Sub-Saharan Africa	51.3	48.8
West Asia/North Africa	14.8	14.4
All developing countries	*380.6*	*362.3*
High income/transitional	*393.9*	*392.9*
World	**774.6**	**755.2**
Developing countries' share of world maize production	(%)	
	49.1	48.0
Developing countries' share of world maize consumption	(%)	
	57.1	55.2
Growth rate of developing countries' consumption of food maize[a]	(% per annum)	
	1.1	1.3
Growth rate of developing countries' consumption of feed maize[a]		
	2.8	2.3
Total maize imports in 2020 by developing countries	(million tons)	
Asia	44.7	30.5
Latin America/Caribbean	3.1	6.3
Sub-Saharan Africa	3.1	6.6
West Asia/North Africa	10.8	11.4
All developing countries	*61.7*	*54.9*
Price of maize	(1990 US$/ton)	
	119	107

Source: IFPRI Impact Model, 1998.
[a] Growth rates calculated over the period 1993–2020.

Part 3
Selected Maize Statistics
Pedro Aquino, Federico Carrión, and Ricardo Calvo

The following tables present statistics related to maize production, trade, and utilization, as well as some basic economic indicators. These statistics reflect the latest information available at the time of publication.

Countries are classified as either "developing" or "high-income" based on the criteria used by the World Bank in its *World Development Indicators* (1998). Countries classified as "developing" had a per capita GNP lower than US$ 9,635 in 1996, whereas high income countries had a per capita GNP exceeding US$ 9,636. Countries in Eastern Europe and the Former Soviet Union (FSU) are treated separately. Traditionally included as "developed" countries in FAO statistics, most of these countries would be classified as developing countries by World Bank criteria.

Countries are also classified as either maize consumers or maize producers. Developing countries and those in Eastern Europe and the FSU are included in the individual country statistics if they consumed (or produced) at least 100,000 tons of maize per year. Developing countries are classified as "maize producers" if they produced more than 100,000 tons of maize per year, regardless of import and consumption levels. Developing countries that produced less than 100,000 t/yr, but that produced at least 50% of their total maize consumption, are also classified as producers. Other developing countries that consumed over 100,000 t/yr are defined as "maize

consumers." High-income countries are classified in the same way, using minimum levels of production or consumption of 1 million tons. A three-year average of the latest data available was used in the classification.

Unless otherwise indicated, the regional aggregates include data from all of the countries in a particular region, including those countries for which data have not been reported individually. For a list of countries belonging to each region, see Appendix A. Regional means are appropriately weighted; thus they may not exactly equal the mean of the average values presented for each country. The FSU was divided into separate countries, for which statistics were reported individually. Regional aggregates for variables 2 and 3 are based on countries in the region that have data presented in the tables.

Notes on the Variables

Variable 1: The data source is the FAOSTAT Population Statistics (1998).

Variables 2–3: Data are from the World Bank *World Development Indicators* (1998).

Variables 4, 5, 9–20, 23: The data sources are the FAOSTAT Production Statistics (1998). Growth rates were calculated using the log-linear regression model:

$$ln\ Y = \alpha + \beta t + \varepsilon\ ,$$

where *ln Y* is the natural logarithm of *Y*, *t* is time period (year), α is a constant, β is the growth rate of *Y*, and ε is the error

term. The function describes a variable, *Y*, which displays a constant proportional rate of growth (β>0) or decay (β<0). β may be interpreted as the annual percentage change in *Y*.

Variables 6–8, 21, 22: The data source is the FAOSTAT Production Statistics (1998). Yield was computed by dividing three-year average production by the three-year average area harvested, which gives an average weighted by areas in the different years.

Variables 24–25: The data source is the FAOSTAT Trade Statistics (1998). Net imports are defined as the amount of imports less exports.

Variables 26–29: The data source is the FAOSTAT Food Balance Sheets (1998). Total consumption was calculated as the sum (in kg) of the amounts used for each type of maize utilization (i.e., food, feed, seed). The growth rate was calculated using the regression model given above.

Variables 30–37: These data were collected through a general country survey of knowledgeable maize scientists. Data for the Latin American countries refer to the maize crop harvested in 1996; for other countries the reference year is 1997. The data in variables 35-37 refer to an important producing region within each country. The maize price is the average post-harvest price received by farmers. The nitrogen price is usually the price paid by farmers for the most common nitrogenous fertilizer (commonly urea).

Eastern and Southern Africa

		Producers					
		Angola	**Burundi**	**Ethiopia**	**Kenya**	**Lesotho**	**Madagascar**
General indicators	1. Estimated population, 1996 (million)	11.2	6.2	58.2	27.8	2.1	15.4
	2. Estimated growth rate of population, 1996-2010 (%/yr)	2.7	2.4	3.0	2.0	2.0	2.8
	3. Per capita income 1996 (US$)	270	170	100	320	660	250
	4. Average per capita cereal production, 1995-97 (kg/yr)	38	45	179	114	72	175
	5. Growth rate of per capita cereal production, 1988-97 (%/yr)	1.4	-3.1	10.8	-2.1	-6.4	-2.0
Production of wheat and all cereals	6. Average maize area harvested, 1995-97 (000 ha)	596	113	1,800	1,360	106	189
	7. Average maize yield, 1995-97 (t/ha)	0.5	1.4	1.6	1.9	1.1	0.9
	8. Average maize production, 1995-97 (000 t)	326	153	2,967	2,553	114	178
	9. Growth rate of maize area, 1961-70 (%/yr)	0.1	2.0	1.3	5.2	0.5	5.3
	10. Growth rate of maize area, 1971-80 (%/yr)	1.4	1.4	-0.6	1.5	-2.4	1.2
	11. Growth rate of maize area, 1981-90 (%/yr)	4.1	-0.3	4.9	3.1	3.7	3.0
	12. Growth rate of maize area, 1991-97 (%/yr)	-6.8	-2.1	18.9	-0.9	1.5	3.9
	13. Growth rate of maize yield, 1961-70 (%/yr)	0.8	1.9	2.1	0.2	-3.7	-3.2
	14. Growth rate of maize yield, 1971-80 (%/yr)	-3.7	0.4	4.3	0.9	9.5	0.2
	15. Growth rate of maize yield, 1981-90 (%/yr)	-6.5	2.6	0.3	0.2	3.6	0.7
	16. Growth rate of maize yield, 1991-97 (%/yr)	9.7	-0.4	-0.6	2.9	11.9	0.8
	17. Growth rate of maize production, 1961-70 (%/yr)	0.9	3.9	3.3	5.4	-3.2	2.1
	18. Growth rate of maize production, 1971-80 (%/yr)	-2.3	1.8	3.6	2.4	7.1	1.4
	19. Growth rate of maize production, 1981-90 (%/yr)	-2.4	2.3	5.2	3.3	7.3	3.6
	20. Growth rate of maize production, 1991-97 (%/yr)	2.9	-2.5	18.3	2.0	13.3	4.6
	21. Maize area as percent of total cereal area (average), 1995-97 (%)	76	55	21	77	72	14
	22. Average yield of all cereals, 1995-97 (t/ha)	0.6	1.4	1.2	1.8	1.0	2.0
	23. Growth rate of yield of all cereals, 1991-97 (%/yr)	8.3	0.4	-4.6	3.7	11.2	0.7
Trade and utilization	24. Average net imports of maize, 1994-96 (000 t)	193	32	28	95	100	-10
	25. Average net imports of maize per capita, 1994-96 (kg/yr)	18	5	1	4	49	-1
	26. Average per capita maize consumption, 1994-96 (kg/yr)	38	29	40	105	149	11
	27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	0.7	-2.0	-2.7	-0.6	-0.9	-1.0
	28. Average percent maize used for animal feed, 1994-96 (%)	6	2	4	4	2	5
	29. Average percent maize used for direct human consumption, 1994-96 (%)	83	91	88	91	92	86
Prices and input use	30. Area planted to improved maize as percentage of total maize area, 1997	34	++	6	56	++	++
	31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	4	52	++	++
	32. Area planted to improved OPVs as percentage of total maize area, 1997	34	++	2	4	++	++
	33. Ratio of the price of most popular hybrid to the price of grain, 1997	17.5	++	12.5	7.0	++	++
	34. Ratio of the price of commercial OPV seed to the price of grain, 1997	13.1	++	5.1	7.0	++	++
	35. Farm price of maize, 1997 (US$/ton)	57	++	63	182	++	++
	36. Ratio of farm level nitrogen price to maize price, 1997	19.5	++	7.8	7.3	++	++
	37. Farm wage in kg of maize per day, 1997	16.6	++	10.0	7.7	++	++

++ Data are not available or incomplete.

Eastern and Southern Africa

		Producers					
		Malawi	**Mozambique**	**Rwanda**	**Somalia**	**South Africa**	**Swaziland**
General indicators	1. Estimated population, 1996 (million)	9.8	17.8	5.4	9.8	42.4	0.9
	2. Estimated growth rate of population, 1996-2010 (%/yr)	2.3	2.4	3.5	++	1.4	++
	3. Per capita income 1996 (US$)	180	80	190	++	3,520	++
	4. Average per capita cereal production, 1995-97 (kg/yr)	172	76	34	30	256	120
	5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-0.4	8.3	-3.4	-10.8	-2.4	-5.3
Production of wheat and all cereals	6. Average maize area harvested, 1995-97 (000 ha)	1,235	1,081	51	350	3,770	60
	7. Average maize yield, 1995-97 (t/ha)	1.3	0.9	1.4	0.4	2.1	1.7
	8. Average maize production, 1995-97 (000 t)	1,560	931	72	142	7,897	103
	9. Growth rate of maize area, 1961-70 (%/yr)	3.4	-0.4	9.6	-2.5	0.5	3.9
	10. Growth rate of maize area, 1971-80 (%/yr)	-0.4	5.2	4.2	3.1	0.2	-1.2
	11. Growth rate of maize area, 1981-90 (%/yr)	1.5	4.1	-0.8	3.9	-1.9	6.2
	12. Growth rate of maize area, 1991-97 (%/yr)	-2.3	3.7	-6.3	27.6	2.9	-2.6
	13. Growth rate of maize yield, 1961-70 (%/yr)	-0.1	2.6	-0.4	-0.2	1.0	5.1
	14. Growth rate of maize yield, 1971-80 (%/yr)	0.9	-4.9	1.6	-2.5	2.9	-2.5
	15. Growth rate of maize yield, 1981-90 (%/yr)	-1.0	-3.7	2.3	4.8	2.8	1.0
	16. Growth rate of maize yield, 1991-97 (%/yr)	6.5	24.8	-0.4	-19.6	3.7	4.3
	17. Growth rate of maize production, 1961-70 (%/yr)	3.4	2.2	9.2	-2.8	1.5	9.0
	18. Growth rate of maize production, 1971-80 (%/yr)	0.5	0.3	5.8	0.6	3.0	-3.7
	19. Growth rate of maize production, 1981-90 (%/yr)	0.5	0.4	1.4	8.7	0.9	7.2
	20. Growth rate of maize production, 1991-97 (%/yr)	4.2	28.5	-6.7	8.1	6.6	1.7
	21. Maize area as percent of total cereal area (average), 1995-97 (%)	89	61	36	44	61	96
	22. Average yield of all cereals, 1995-97 (t/ha)	1.2	0.8	1.3	0.4	1.8	1.7
	23. Growth rate of yield of all cereals, 1991-97 (%/yr)	5.7	21.3	1.6	-8.1	4.0	3.6
Trade and utilization	24. Average net imports of maize, 1994-96 (000 t)	294	228	22	3	-1,401	20
	25. Average net imports of maize per capita, 1994-96 (kg/yr)	30	13	4	< 1	-35	23
	26. Average per capita maize consumption, 1994-96 (kg/yr)	181	57	41	16	195	138
	27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	0.2	4.6	13.9	-12.7	-0.7	-3.8
	28. Average percent maize used for animal feed, 1994-96 (%)	6	3	++	++	41	22
	29. Average percent maize used for direct human consumption, 1994-96 (%)	81	90	62	86	53	30
Prices and input use	30. Area planted to improved maize as percentage of total maize area, 1997	13	10	++	++	++	++
	31. Area planted to hybrids as a percentage of total maize area, 1997	7	6	++	++	++	++
	32. Area planted to improved OPVs as percentage of total maize area, 1997	6	4	++	++	++	++
	33. Ratio of the price of most popular hybrid to the price of grain, 1997	9.5	4.6	++	++	++	++
	34. Ratio of the price of commercial OPV seed to the price of grain, 1997	3.8	++	++	++	++	++
	35. Farm price of maize, 1997 (US$/ton)	76	164	++	++	++	++
	36. Ratio of farm level nitrogen price to maize price, 1997	11.4	11.0	++	++	++	++
	37. Farm wage in kg of maize per day, 1997	21.9	4.2	++	++	++	++

++ Data are not available or incomplete.

Eastern and Southern Africa	Producers				Regional total or average
	Tanzania	Uganda	Zambia	Zimbabwe	
General indicators					
1. Estimated population, 1996 (million)	30.8	20.3	8.3	11.4	313.9
2. Estimated growth rate of population, 1996-2010 (%/yr)	2.2	2.4	1.9	1.5	2.3
3. Per capita income 1996 (US$)	170	300	360	610	765
4. Average per capita cereal production, 1995-97 (kg/yr)	134	89	144	198	146
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-3.5	-0.7	-6.9	-3.7	-0.8
Production of wheat and all cereals					
6. Average maize area harvested, 1995-97 (000 ha)	1,602	585	599	1,528	15,117
7. Average maize yield, 1995-97 (t/ha)	1.5	1.4	1.7	1.2	1.5
8. Average maize production, 1995-97 (000 t)	2,347	837	1,037	1,880	23,199
9. Growth rate of maize area, 1961-70 (%/yr)	2.8	8.2	1.8	1.0	1.8
10. Growth rate of maize area, 1971-80 (%/yr)	4.2	-0.9	-6.9	0.1	0.4
11. Growth rate of maize area, 1981-90 (%/yr)	4.8	4.4	7.0	-2.0	1.6
12. Growth rate of maize area, 1991-97 (%/yr)	-3.6	6.3	-1.2	8.7	2.5
13. Growth rate of maize yield, 1961-70 (%/yr)	-4.7	0.9	-1.4	4.1	0.7
14. Growth rate of maize yield, 1971-80 (%/yr)	7.9	< 1	7.8	-3.1	1.9
15. Growth rate of maize yield, 1981-90 (%/yr)	0.9	0.9	-0.1	3.3	0.5
16. Growth rate of maize yield, 1991-97 (%/yr)	2.7	-0.6	4.7	5.8	3.6
17. Growth rate of maize production, 1961-70 (%/yr)	-1.9	9.1	0.4	5.1	2.4
18. Growth rate of maize production, 1971-80 (%/yr)	12.1	-0.9	1.0	-3.0	2.3
19. Growth rate of maize production, 1981-90 (%/yr)	5.7	5.3	6.9	1.3	2.1
20. Growth rate of maize production, 1991-97 (%/yr)	-0.9	5.7	3.5	14.5	6.1
21. Maize area as percent of total cereal area (average), 1995-97 (%)	51	44	80	75	38
22. Average yield of all cereals, 1995-97 (t/ha)	1.3	1.4	1.6	1.1	1.2
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	1.3	-2.3	3.6	5.1	0.8
Trade and utilization					
24. Average net imports of maize, 1994-96 (000 t)	118	-82	60	-426	-588
25. Average net imports of maize per capita, 1994-96 (kg/yr)	4	-4	7	-39	-2
26. Average per capita maize consumption, 1994-96 (kg/yr)	88	40	168	153	79
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	-2.0	5.9	-1.7	-0.4	-0.7
28. Average percent maize used for animal feed, 1994-96 (%)	5	11	5	13	18
29. Average percent maize used for direct human consumption, 1994-96 (%)	84	64	84	77	73
Prices and input use					
30. Area planted to improved maize as percentage of total maize area, 1997	2	70	19	70	++
31. Area planted to hybrids as a percentage of total maize area, 1997	1	10	19	68	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	1	60	++	2	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	12.0	8.9	8.3	5.7	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	7.0	4.4	8.1	++	++
35. Farm price of maize, 1997 (US$/ton)	200	180	167	80	++
36. Ratio of farm level nitrogen price to maize price, 1997	32.6	6.8	6.0	4.9	++
37. Farm wage in kg of maize per day, 1997	5.0	5.6	25.1	20.8	++

++ Data are not available or incomplete.

Western and Central Africa

		Producers					
		Benin	**Burkina Faso**	**Cameroon**	**Congo, Dem. Rep. of (formerly Zaire)**	**Côte d'Ivoire**	**Ghana**
General indicators	1. Estimated population, 1996 (million)	5.6	10.8	13.6	46.8	14.0	17.8
	2. Estimated growth rate of population, 1996-2010 (%/yr)	2.7	2.4	2.4	3.0	2.1	2.3
	3. Per capita income 1996 (US$)	350	230	610	130	660	360
	4. Average per capita cereal production, 1995-97 (kg/yr)	121	222	92	34	122	100
	5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-0.6	0.2	1.7	-1.8	1.9	3.8
Production of wheat and all cereals	6. Average maize area harvested, 1995-97 (000 ha)	479	180	317	1,349	692	667
	7. Average maize yield, 1995-97 (t/ha)	1.1	1.3	2.1	0.8	0.8	1.5
	8. Average maize production, 1995-97 (000 t)	517	242	668	1,090	583	1,014
	9. Growth rate of maize area, 1961-70 (%/yr)	-1.4	-3.4	-0.6	2.2	5.6	6.0
	10. Growth rate of maize area, 1971-80 (%/yr)	1.5	2.4	0.5	2.3	6.3	-3.3
	11. Growth rate of maize area, 1981-90 (%/yr)	0.7	6.4	-10.5	5.7	3.7	3.3
	12. Growth rate of maize area, 1991-97 (%/yr)	-0.3	-3.1	6.6	0.7	0.2	1.6
	13. Growth rate of maize yield, 1961-70 (%/yr)	1.5	1.3	1.9	0.9	1.9	2.7
	14. Growth rate of maize yield, 1971-80 (%/yr)	3.5	4.0	-2.0	0.9	-3.3	-1.2
	15. Growth rate of maize yield, 1981-90 (%/yr)	3.7	5.9	7.9	-0.4	-2.2	6.0
	16. Growth rate of maize yield, 1991-97 (%/yr)	2.2	-2.7	2.9	-0.5	2.3	1.7
	17. Growth rate of maize production, 1961-70 (%/yr)	0.1	-2.2	1.3	3.0	7.5	8.7
	18. Growth rate of maize production, 1971-80 (%/yr)	5.0	6.4	-1.4	3.2	3.0	-4.5
	19. Growth rate of maize production, 1981-90 (%/yr)	4.4	12.3	-2.6	5.3	1.6	9.3
	20. Growth rate of maize production, 1991-97 (%/yr)	1.9	-5.8	9.4	0.2	2.5	3.3
	21. Maize area as percent of total cereal area (average), 1995-97 (%)	72	6	34	65	45	52
	22. Average yield of all cereals, 1995-97 (t/ha)	1.0	0.8	1.3	0.8	1.1	1.4
	23. Growth rate of yield of all cereals, 1991-97 (%/yr)	2.0	-1.1	2.7	-0.7	3.4	3.6
Trade and utilization	24. Average net imports of maize, 1994-96 (000 t)	5	++	4	48	< 1	1
	25. Average net imports of maize per capita, 1994-96 (kg/yr)	1	++	< 1	1	< 1	< 1
	26. Average per capita maize consumption, 1994-96 (kg/yr)	97	28	48	27	40	57
	27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	1.7	3.3	3.5	-0.1	< 1	3.0
	28. Average percent maize used for animal feed, 1994-96 (%)	3	++	1	2	10	6
	29. Average percent maize used for direct human consumption, 1994-96 (%)	67	92	90	80	68	75
Prices and input use	30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++	++	++
	31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++	++	++
	32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++	++	++
	33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++	++	++
	34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	++	++
	35. Farm price of maize, 1997 (US$/ton)	++	++	++	++	++	++
	36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++	++	++
	37. Farm wage in kg of maize per day, 1997	++	++	++	++	++	++

++ Data are not available or incomplete.

Western and Central Africa

		Producers				Regional total or average
		Mali	**Nigeria***	**Senegal**	**Togo**	
General indicators	1. Estimated population, 1996 (million)	11.1	115.0	8.5	4.2	290.1
	2. Estimated growth rate of population, 1996-2010 (%/yr)	2.8	2.6	2.3	2.5	2.6
	3. Per capita income 1996 (US$)	240	240	570	300	306
	4. Average per capita cereal production, 1995-97 (kg/yr)	225	189	122	156	140
	5. Growth rate of per capita cereal production, 1988-97 (%/yr)	1.9	0.1	-1.3	0.3	0.1
Production of wheat and all cereals	6. Average maize area harvested, 1995-97 (000 ha)	237	4,702	91	354	9,425
	7. Average maize yield, 1995-97 (t/ha)	1.2	1.3	1.1	1.1	1.2
	8. Average maize production, 1995-97 (000 t)	290	6,316	97	377	11,521
	9. Growth rate of maize area, 1961-70 (%/yr)	-3.8	0.5	6.0	1.1	0.9
	10. Growth rate of maize area, 1971-80 (%/yr)	-7.1	-12.0	6.9	1.9	-0.8
	11. Growth rate of maize area, 1981-90 (%/yr)	11.4	27.2	4.6	5.9	10.2
	12. Growth rate of maize area, 1991-97 (%/yr)	4.2	-3.1	-2.0	6.8	-0.9
	13. Growth rate of maize yield, 1961-70 (%/yr)	1.6	1.5	-1.2	7.6	1.9
	14. Growth rate of maize yield, 1971-80 (%/yr)	8.3	6.4	0.7	-1.7	0.4
	15. Growth rate of maize yield, 1981-90 (%/yr)	4.4	< 1	1.8	1.8	3.3
	16. Growth rate of maize yield, 1991-97 (%/yr)	-1.0	4.0	-1.6	1.7	2.5
	17. Growth rate of maize production, 1961-70 (%/yr)	-2.2	1.9	4.8	8.7	2.8
	18. Growth rate of maize production, 1971-80 (%/yr)	1.2	-5.5	7.6	0.2	-0.4
	19. Growth rate of maize production, 1981-90 (%/yr)	15.8	27.1	6.4	7.7	13.4
	20. Growth rate of maize production, 1991-97 (%/yr)	3.2	1.0	-3.6	8.5	1.7
	21. Maize area as percent of total cereal area (average), 1995-97 (%)	8	26	7	45	22
	22. Average yield of all cereals, 1995-97 (t/ha)	0.8	1.2	0.8	0.8	0.9
	23. Growth rate of yield of all cereals, 1991-97 (%/yr)	0.3	1.7	0.1	0.6	1.1
Trade and utilization	24. Average net imports of maize, 1994-96 (000 t)	1	< 1	17	2	119
	25. Average net imports of maize per capita, 1994-96 (kg/yr)	< 1	++	2	1	< 1
	26. Average per capita maize consumption, 1994-96 (kg/yr)	27	60	15	85	43
	27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	1.5	2.0	-3.6	4.3	1.7
	28. Average percent maize used for animal feed, 1994-96 (%)	20	7	++	13	++
	29. Average percent maize used for direct human consumption, 1994-96 (%)	91	55	84	78	65
Prices and input use	30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++	++
	31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++	++
	32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++	++
	33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++	++
	34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	++
	35. Farm price of maize, 1997 (US$/ton)	++	++	++	++	++
	36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++	++
	37. Farm wage in kg of maize per day, 1997	++	++	++	++	++

* Maize statistics for Nigeria have been particulary erratic in recent years.
++ Data are not available or incomplete.

North Africa		Producers		Consumers			Regional total or average
		Egypt	Morocco	Algeria	Libya	Tunisia	
General indicators	1. Estimated population, 1996 (million)	63.3	27.0	28.8	5.6	9.2	134.1
	2. Estimated growth rate of population, 1996-2010 (%/yr)	1.6	1.6	1.9	2.3	1.4	1.7
	3. Per capita income 1996 (US$)	1,080	1,290	1,520	++	1,930	1,230
	4. Average per capita cereal production, 1995-97 (kg/yr)	265	197	91	57	167	198
	5. Growth rate of per capita cereal production, 1988-97 (%/yr)	3.7	-7.8	-0.8	-2.3	6.2	0.6
Production of wheat and all cereals	6. Average maize area harvested, 1995-97 (000 ha)	774	327	< 1	1	++	1,102
	7. Average maize yield, 1995-97 (t/ha)	6.5	0.7	1.6	1.1	++	4.7
	8. Average maize production, 1995-97 (000 t)	5,010	220	< 1	1	++	5,231
	9. Growth rate of maize area, 1961-70 (%/yr)	-1.6	1.9	++	++	++	-0.1
	10. Growth rate of maize area, 1971-80 (%/yr)	2.5	-1.7	++	++	++	0.9
	11. Growth rate of maize area, 1981-90 (%/yr)	0.1	-0.1	++	++	++	< 1
	12. Growth rate of maize area, 1991-97 (%/yr)	-2.8	-6.0	++	++	++	-3.8
	13. Growth rate of maize yield, 1961-70 (%/yr)	5.3	1.9	++	++	++	3.7
	14. Growth rate of maize yield, 1971-80 (%/yr)	0.8	0.7	++	++	++	2.0
	15. Growth rate of maize yield, 1981-90 (%/yr)	3.6	11.6	++	++	++	4.1
	16. Growth rate of maize yield, 1991-97 (%/yr)	3.0	5.6	++	++	++	4.0
	17. Growth rate of maize production, 1961-70 (%/yr)	3.8	3.8	++	++	++	3.6
	18. Growth rate of maize production, 1971-80 (%/yr)	3.3	-1.0	++	++	++	2.8
	19. Growth rate of maize production, 1981-90 (%/yr)	3.7	11.5	++	++	++	4.1
	20. Growth rate of maize production, 1991-97 (%/yr)	0.2	-0.4	++	++	++	0.2
	21. Maize area as percent of total cereal area (average), 1995-97 (%)	29	7	< 1	< 1		9
	22. Average yield of all cereals, 1995-97 (t/ha)	6.3	1.1	1.0	0.7	1.3	2.2
	23. Growth rate of yield of all cereals, 1991-97 (%/yr)	2.4	-0.1	-1.7	-0.2	-5.2	2.8
Trade and utilization	24. Average net imports of maize, 1994-96 (000 t)	2,305	485	953	182	299	4,223
	25. Average net imports of maize per capita, 1994-96 (kg/yr)	37	18	34	34	33	32
	26. Average per capita maize consumption, 1994-96 (kg/yr)	116	24	34	34	34	71
	27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	0.9	0.9	-4.2	-7.8	2.5	0.2
	28. Average percent maize used for animal feed, 1994-96 (%)	38	5	83	93	98	43
	29. Average percent maize used for direct human consumption, 1994-96 (%)	50	83	10	2	++	45
Prices and input use	30. Area planted to improved maize as percentage of total maize area, 1997	59	++	++	++	++	++
	31. Area planted to hybrids as a percentage of total maize area, 1997	58	++	++	++	++	++
	32. Area planted to improved OPVs as percentage of total maize area, 1997	1	++	++	++	++	++
	33. Ratio of the price of most popular hybrid to the price of grain, 1997	11.3	++	++	++	++	++
	34. Ratio of the price of commercial OPV seed to the price of grain, 1997	3.8	++	++	++	++	++
	35. Farm price of maize, 1997 (US$/ton)	156	++	++	++	++	++
	36. Ratio of farm level nitrogen price to maize price, 1997	2.2	++	++	++	++	++
	37. Farm wage in kg of maize per day, 1997	28.3	++	++	++	++	++

++ Data are not available or incomplete.

West Asia

		Afghanistan	Iran, Islamic Rep. of	Iraq	Syrian Arab Republic	Turkey
				Producers		
General indicators	1. Estimated population, 1996 (million)	20.9	70.0	20.6	14.6	61.8
	2. Estimated growth rate of population, 1996-2010 (%/yr)	++	1.9	2.8	2.3	1.3
	3. Per capita income 1996 (US$)	++	++	++	++	++
	4. Average per capita cereal production, 1995-97 (kg/yr)	123	239	125	376	470
	5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-6.8	1.6	-1.0	5.6	-1.4
Production of wheat and all cereals	6. Average maize area harvested, 1995-97 (000 ha)	230	120	61	72	538
	7. Average maize yield, 1995-97 (t/ha)	1.6	4.8	1.8	3.3	3.7
	8. Average maize production, 1995-97 (000 t)	360	582	112	236	1,967
	9. Growth rate of maize area, 1961-70 (%/yr)	-1.1	6.3	11.2	-5.2	-0.6
	10. Growth rate of maize area, 1971-80 (%/yr)	-0.4	12.4	14.9	12.6	-0.9
	11. Growth rate of maize area, 1981-90 (%/yr)	-5.2	-4.9	17.9	12.3	-1.5
	12. Growth rate of maize area, 1991-97 (%/yr)	-0.4	21.5	-14.6	3.2	0.9
	13. Growth rate of maize yield, 1961-70 (%/yr)	1.7	6.3	2.0	5.9	1.8
	14. Growth rate of maize yield, 1971-80 (%/yr)	1.3	-2.8	5.1	6.6	3.2
	15. Growth rate of maize yield, 1981-90 (%/yr)	0.5	7.4	0.2	2.0	8.0
	16. Growth rate of maize yield, 1991-97 (%/yr)	0.2	2.3	-1.8	-0.6	-3.5
	17. Growth rate of maize production, 1961-70 (%/yr)	0.6	12.6	13.2	0.7	1.2
	18. Growth rate of maize production, 1971-80 (%/yr)	0.9	9.6	20.1	19.3	2.3
	19. Growth rate of maize production, 1981-90 (%/yr)	-4.7	2.5	18.0	14.3	6.6
	20. Growth rate of maize production, 1991-97 (%/yr)	-0.3	23.7	-16.4	2.6	-2.7
	21. Maize area as percent of total cereal area (average), 1995-97 (%)	10	1	2	2	4
	22. Average yield of all cereals, 1995-97 (t/ha)	1.2	1.8	0.8	1.6	2.1
	23. Growth rate of yield of all cereals, 1991-97 (%/yr)	0.3	2.2	1.7	8.1	-1.1
Trade and utilization	24. Average net imports of maize, 1994-96 (000 t)	++	936	++	344	483
	25. Average net imports of maize per capita, 1994-96 (kg/yr)	++	14	++	24	8
	26. Average per capita maize consumption, 1994-96 (kg/yr)	18	23	8	39	39
	27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	-9.4	6.1	-20.0	10.5	-1.3
	28. Average percent maize used for animal feed, 1994-96 (%)	20	91	40	92	44
	29. Average percent maize used for direct human consumption, 1994-96 (%)	74	3	55	4	43
Prices and input use	30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++	51
	31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++	47
	32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++	4
	33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++	27.6
	34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	5.2
	35. Farm price of maize, 1997 (US$/ton)	++	++	++	++	159
	36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++	2.4
	37. Farm wage in kg of maize per day, 1997	++	++	++	++	32.8

++ Data are not available or incomplete.

West Asia

		Consumers				Regional total or average
		Jordan	Lebanon	Saudi Arabia	Yemen	
General indicators	1. Estimated population, 1996 (million)	4.4	3.1	18.8	15.7	233.5
	2. Estimated growth rate of population, 1996-2010 (%/yr)	2.6	1.4	3.3	3.3	2.1
	3. Per capita income 1996 (US$)	1,650	2,970	++	380	2,152
	4. Average per capita cereal production, 1995-97 (kg/yr)	27	24	162	45	258
	5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-5.2	-3.3	-7.5	-6.2	-1.3
Production of wheat and all cereals	6. Average maize area harvested, 1995-97 (000 ha)	< 1	2	3	41	1,069
	7. Average maize yield, 1995-97 (t/ha)	11.4	2.0	2.0	1.3	3.1
	8. Average maize production, 1995-97 (000 t)	4	4	6	54	3,325
	9. Growth rate of maize area, 1961-70 (%/yr)	++	++	++	11.3	0.3
	10. Growth rate of maize area, 1971-80 (%/yr)	++	++	++	2.5	-1.4
	11. Growth rate of maize area, 1981-90 (%/yr)	++	++	++	-1.0	0.8
	12. Growth rate of maize area, 1991-97 (%/yr)	++	++	++	-0.8	1.7
	13. Growth rate of maize yield, 1961-70 (%/yr)	++	++	++	-0.8	2.3
	14. Growth rate of maize yield, 1971-80 (%/yr)	++	++	++	-1.8	5.8
	15. Growth rate of maize yield, 1981-90 (%/yr)	++	++	++	-0.9	-0.8
	16. Growth rate of maize yield, 1991-97 (%/yr)	++	++	++	0.6	1.0
	17. Growth rate of maize production, 1961-70 (%/yr)	++	++	++	10.5	2.6
	18. Growth rate of maize production, 1971-80 (%/yr)	++	++	++	0.7	4.4
	19. Growth rate of maize production, 1981-90 (%/yr)	++	++	++	-1.9	0.1
	20. Growth rate of maize production, 1991-97 (%/yr)	++	++	++	++	++
	21. Maize area as percent of total cereal area (average), 1995-97 (%)	< 1	5	< 1	6	3
	22. Average yield of all cereals, 1995-97 (t/ha)	1.1	1.9	4.0	1.0	1.8
	23. Growth rate of yield of all cereals, 1991-97 (%/yr)	-2.8	-2.1	-2.2	1.5	0.6
Trade and utilization	24. Average net imports of maize, 1994-96 (000 t)	363	250	871	62	3,345
	25. Average net imports of maize per capita, 1994-96 (kg/yr)	86	83	47	4	15
	26. Average per capita maize consumption, 1994-96 (kg/yr)	89	76	48	8	29
	27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	0.9	3.5	9.3	3.1	0.4
	28. Average percent maize used for animal feed, 1994-96 (%)	95	94	97	39	69
	29. Average percent maize used for direct human consumption, 1994-96 (%)	1	2	< 1	54	23
Prices and input use	30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++	++
	31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++	++
	32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++	++
	33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++	++
	34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	++
	35. Farm price of maize, 1997 (US$/ton)	++	++	++	++	++
	36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++	++
	37. Farm wage in kg of maize per day, 1997	++	++	++	++	++

++ Data are not available or incomplete.

South Asia	Producers				Consumer	Regional total or average
	India	**Myanmar**	**Nepal**	**Pakistan**	**Sri Lanka**	
General indicators						
1. Estimated population, 1996 (million)	944.6	45.9	22.0	140.0	18.1	1,292.7
2. Estimated growth rate of population, 1996-2010 (%/yr)	1.3	1.3	2.3	2.5	1.0	1.4
3. Per capita income 1996 (US$)	380	++	210	480	740	382
4. Average per capita cereal production, 1995-97 (kg/yr)	230	383	286	178	140	229
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	0.1	1.6	-0.9	0.1	-0.2	0.0
Production of wheat and all cereals						
6. Average maize area harvested, 1995-97 (000 ha)	6,083	163	805	872	33	8,004
7. Average maize yield, 1995-97 (t/ha)	1.5	1.4	1.7	1.4	1.0	1.5
8. Average maize production, 1995-97 (000 t)	9,367	236	1,354	1,264	34	12,296
9. Growth rate of maize area, 1961-70 (%/yr)	3.5	-2.9	< 1	4.2	5.2	3.2
10. Growth rate of maize area, 1971-80 (%/yr)	< 1	4.5	0.1	1.6	-0.6	0.3
11. Growth rate of maize area, 1981-90 (%/yr)	0.1	-2.9	5.6	1.5	2.6	0.6
12. Growth rate of maize area, 1991-97 (%/yr)	0.6	5.0	1.4	0.3	2.0	0.7
13. Growth rate of maize yield, 1961-70 (%/yr)	1.7	0.7	-0.9	0.6	1.1	1.1
14. Growth rate of maize yield, 1971-80 (%/yr)	1.4	5.7	-2.1	1.3	3.9	1.1
15. Growth rate of maize yield, 1981-90 (%/yr)	2.5	-0.5	0.5	1.3	2.3	2.1
16. Growth rate of maize yield, 1991-97 (%/yr)	0.8	-0.8	0.7	0.8	-1.1	0.7
17. Growth rate of maize production, 1961-70 (%/yr)	5.1	-2.2	-0.9	4.8	6.3	4.3
18. Growth rate of maize production, 1971-80 (%/yr)	1.4	10.2	-2.1	2.9	3.4	1.3
19. Growth rate of maize production, 1981-90 (%/yr)	2.6	-3.4	6.1	2.7	5.0	2.7
20. Growth rate of maize production, 1991-97 (%/yr)	1.4	4.2	2.1	1.1	0.9	1.4
21. Maize area as percent of total cereal area (average), 1995-97 (%)	6	3	25	7	4	6
22. Average yield of all cereals, 1995-97 (t/ha)	2.2	2.8	1.9	2.0	3.3	2.3
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	2.8	< 1	1.6	2.1	3.0	2.3
Trade and utilization						
24. Average net imports of maize, 1994-96 (000 t)	-13	-79	< 1	4	65	-20
25. Average net imports of maize per capita, 1994-96 (kg/yr)	0	-2	++	< 1	4	0
26. Average per capita maize consumption, 1994-96 (kg/yr)	10	5	61	9	6	10
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	1.3	-0.4	0.9	-1.5	6.7	1.0
28. Average percent maize used for animal feed, 1994-96 (%)	2	37	2	20	42	5
29. Average percent maize used for direct human consumption, 1994-96 (%)	77	53	86	60	56	76
Prices and input use						
30. Area planted to improved maize as percentage of total maize area, 1997	45	++	45	34	++	++
31. Area planted to hybrids as a percentage of total maize area, 1997	30	++	++	8	++	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	15	++	45	26	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	8.9	++	14.1	33.3	++	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	3.3	++	3.5	1.7	++	++
35. Farm price of maize, 1997 (US$/ton)	122	++	139	128	++	++
36. Ratio of farm level nitrogen price to maize price, 1997	3.9	++	1.9	2.5	++	++
37. Farm wage in kg of maize per day, 1997	11.1	++	5.9	16.7	++	++

++ Data are not available or incomplete.

Southeast Asia and the Pacific

	Producers				Consumer	Regional total or average
	Indonesia	Philippines	Thailand	Viet Nam	Malaysia	

General indicators

	Indonesia	Philippines	Thailand	Viet Nam	Malaysia	Regional total or average
1. Estimated population, 1996 (million)	200.5	69.3	58.7	75.2	20.6	446.8
2. Estimated growth rate of population, 1996-2010 (%/yr)	1.3	1.8	0.6	1.6	1.6	1.4
3. Per capita income 1996 (US$)	1,080	1,160	2,960	290	4,370	1,335
4. Average per capita cereal production, 1995-97 (kg/yr)	297	221	438	364	104	302
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	0.8	-0.7	-0.4	3.1	-0.8	0.6

Production of wheat and all cereals

	Indonesia	Philippines	Thailand	Viet Nam	Malaysia	Regional total or average
6. Average maize area harvested, 1995-97 (000 ha)	3,737	2,724	1,343	596	24	8,506
7. Average maize yield, 1995-97 (t/ha)	2.4	1.6	3.2	2.4	1.8	2.2
8. Average maize production, 1995-97 (000 t)	8,959	4,262	4,292	1,417	44	19,106
9. Growth rate of maize area, 1961-70 (%/yr)	0.1	2.8	9.8	-1.6	1.4	1.8
10. Growth rate of maize area, 1971-80 (%/yr)	0.5	3.5	4.2	7.2	2.6	2.6
11. Growth rate of maize area, 1981-90 (%/yr)	2.1	2.0	1.4	2.9	10.5	1.9
12. Growth rate of maize area, 1991-97 (%/yr)	3.9	-5.3	0.8	5.6	3.8	0.1
13. Growth rate of maize yield, 1961-70 (%/yr)	-0.1	3.0	2.5	-0.2	5.5	1.9
14. Growth rate of maize yield, 1971-80 (%/yr)	4.1	2.3	0.3	-0.7	-8.4	2.3
15. Growth rate of maize yield, 1981-90 (%/yr)	3.8	2.9	0.7	4.1	5.2	2.7
16. Growth rate of maize yield, 1991-97 (%/yr)	2.4	3.7	2.7	9.4	0.9	4.0
17. Growth rate of maize production, 1961-70 (%/yr)	< 1	5.8	12.3	-1.8	6.9	3.7
18. Growth rate of maize production, 1971-80 (%/yr)	4.6	5.7	4.5	6.5	-5.8	4.9
19. Growth rate of maize production, 1981-90 (%/yr)	5.9	5.0	2.0	6.9	15.7	4.6
20. Growth rate of maize production, 1991-97 (%/yr)	6.2	-1.7	3.5	15.0	4.7	4.1
21. Maize area as percent of total cereal area (average), 1995-97 (%)	25	41	13	8	4	20
22. Average yield of all cereals, 1995-97 (t/ha)	4.0	2.3	2.4	3.6	3.1	3.1
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	0.7	2.4	1.4	3.2	0.2	1.8

Trade and utilization

	Indonesia	Philippines	Thailand	Viet Nam	Malaysia	Regional total or average
24. Average net imports of maize, 1994-96 (000 t)	854	205	95	-34	2,184	3,311
25. Average net imports of maize per capita, 1994-96 (kg/yr)	4	3	2	< 1	108	8
26. Average per capita maize consumption, 1994-96 (kg/yr)	46	68	74	17	112	49
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	4.3	-1.4	11.0	7.6	4.3	3.9
28. Average percent maize used for animal feed, 1994-96 (%)	6	72	97	21	91	48
29. Average percent maize used for direct human consumption, 1994-96 (%)	79	15	< 1	74	3	41

Prices and input use

	Indonesia	Philippines	Thailand	Viet Nam	Malaysia	Regional total or average
30. Area planted to improved maize as percentage of total maize area, 1997	94	23	100	100	++	++
31. Area planted to hybrids as a percentage of total maize area, 1997	23	19	60	46	++	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	71	4	40	54	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	20.6	12.3	17.2	16.7	++	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	4.8	4.0	2.3	3.3	++	++
35. Farm price of maize, 1997 (US$/ton)	138	156	121	127	++	++
36. Ratio of farm level nitrogen price to maize price, 1997	2.8	2.9	3.5	2.9	++	++
37. Farm wage in kg of maize per day, 1997	15.9	24.0	27.5	10.0	++	++

++ Data are not available or incomplete.

East Asia	Producers			Consumer	Regional total or average
	China*	Taiwan	Korea, D.P.R.	Korea, Republic of	
General indicators					
1. Estimated population, 1996 (million)	1,216.9	21.4	22.5	45.3	1,308.6
2. Estimated growth rate of population, 1996-2010 (%/yr)	0.7	++	0.9	0.7	0.7
3. Per capita income 1996 (US$)	872	++	++	10,610	1,219
4. Average per capita cereal production, 1995-97 (kg/yr)	358	116	184	162	344
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	1.2	-2.5	-7.5	-3.4	0.9
Production of wheat and all cereals					
6. Average maize area harvested, 1995-97 (000 ha)	23,571	70	650	18	24,309
7. Average maize yield, 1995-97 (t/ha)	4.9	5.6	2.6	4.1	4.8
8. Average maize production, 1995-97 (000 t)	114,819	389	1,679	74	116,961
9. Growth rate of maize area, 1961-70 (%/yr)	1.4	3.2	0.8	7.0	1.4
10. Growth rate of maize area, 1971-80 (%/yr)	2.7	4.7	1.8	-1.8	2.6
11. Growth rate of maize area, 1981-90 (%/yr)	1.3	10.4	-0.2	-2.9	1.3
12. Growth rate of maize area, 1991-97 (%/yr)	2.3	-1.4	-0.4	-3.7	2.2
13. Growth rate of maize yield, 1961-70 (%/yr)	6.0	3.9	1.2	9.0	5.7
14. Growth rate of maize yield, 1971-80 (%/yr)	4.4	1.0	1.5	12.8	4.3
15. Growth rate of maize yield, 1981-90 (%/yr)	3.1	5.0	0.9	1.9	3.0
16. Growth rate of maize yield, 1991-97 (%/yr)	0.7	1.8	-6.8	1.6	0.6
17. Growth rate of maize production, 1961-70 (%/yr)	7.4	7.1	2.0	16.0	7.1
18. Growth rate of maize production, 1971-80 (%/yr)	7.1	5.7	3.3	10.9	6.9
19. Growth rate of maize production, 1981-90 (%/yr)	4.4	15.4	0.7	-1.0	4.3
20. Growth rate of maize production, 1991-97 (%/yr)	3.0	0.4	-7.2	-2.1	2.9
21. Maize area as percent of total cereal area (average), 1995-97 (%)	26	16	47	2	26
22. Average yield of all cereals, 1995-97 (t/ha)	4.8	5.7	3.0	6.3	4.8
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	2.4	1.6	-3.0	2.0	2.3
Trade and utilization					
24. Average net imports of maize, 1994-96 (000 t)	-1,107	6,037	120	7,821	12,871
25. Average net imports of maize per capita, 1994-96 (kg/yr)	-1	285	5	174	10
26. Average per capita maize consumption, 1994-96 (kg/yr)	93	304	95	175	99
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	4.3	4.0	-5.7	4.3	4.0
28. Average percent maize used for animal feed, 1994-96 (%)	76	95	5	63	75
29. Average percent maize used for direct human consumption, 1994-96 (%)	12	2	49	9	12
Prices and input use					
30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++	++
31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	++
35. Farm price of maize, 1997 (US$/ton)	++	++	++	++	++
36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++	++
37. Farm wage in kg of maize per day, 1997	++	++	++	++	++

* Data for China include figures for Hong Kong.
++ Data are not available or incomplete.

Mexico, Central America, and the Caribbean

	Producers						
	El Salvador	**Guatemala**	**Haiti**	**Honduras**	**Mexico**	**Nicaragua**	**Panama**
General indicators							
1. Estimated population, 1996 (million)	5.8	10.9	7.3	5.8	92.7	4.2	2.7
2. Estimated growth rate of population, 1996-2010 (%/yr)	2.0	2.3	1.6	2.4	1.5	2.4	1.3
3. Per capita income 1996 (US$)	1,700	1,470	310	660	3,670	380	3,080
4. Average per capita cereal production, 1995-97 (kg/yr)	145	111	53	130	285	157	131
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-2.1	-4.9	-3.5	< 1	0.7	1.8	-0.6
Production of wheat and all cereals							
6. Average maize area harvested, 1995-97 (000 ha)	293	566	250	402	7,764	273	73
7. Average maize yield, 1995-97 (t/ha)	2.0	2.0	0.8	1.6	2.2	1.2	1.5
8. Average maize production, 1995-97 (000 t)	588	1,111	199	646	16,934	324	110
9. Growth rate of maize area, 1961-70 (%/yr)	1.1	0.7	0.5	0.9	1.8	5.8	-0.6
10. Growth rate of maize area, 1971-80 (%/yr)	4.1	-0.1	-0.5	4.3	-1.8	-3.7	< 1
11. Growth rate of maize area, 1981-90 (%/yr)	1.5	< 1	3.2	1.8	-0.6	0.7	1.6
12. Growth rate of maize area, 1991-97 (%/yr)	-1.2	-4.1	< 1	-1.7	2.1	6.7	-1.3
13. Growth rate of maize yield, 1961-70 (%/yr)	5.0	3.0	-0.1	1.9	2.3	0.6	0.4
14. Growth rate of maize yield, 1971-80 (%/yr)	1.8	2.2	-3.9	-2.0	3.9	4.0	2.7
15. Growth rate of maize yield, 1981-90 (%/yr)	2.1	2.8	-2.6	0.5	< 1	5.2	4.3
16. Growth rate of maize yield, 1991-97 (%/yr)	0.3	1.2	-0.2	4.1	-0.7	0.7	1.5
17. Growth rate of maize production, 1961-70 (%/yr)	6.1	3.7	0.5	2.8	4.0	6.5	-0.2
18. Growth rate of maize production, 1971-80 (%/yr)	5.9	2.1	-4.4	2.2	2.1	0.3	2.7
19. Growth rate of maize production, 1981-90 (%/yr)	3.5	2.8	0.6	2.3	-0.6	6.0	5.9
20. Growth rate of maize production, 1991-97 (%/yr)	-0.9	-2.9	-0.2	2.4	1.4	7.4	0.2
21. Maize area as percent of total cereal area (average), 1995-97 (%)	68	90	60	82	73	71	46
22. Average yield of all cereals, 1995-97 (t/ha)	1.9	1.9	0.9	1.5	2.5	1.7	2.2
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	0.8	1.2	-1.3	3.0	-0.8	2.9	4.4
Trade and utilization							
24. Average net imports of maize, 1994-96 (000 t)	165	158	28	47	3,693	23	166
25. Average net imports of maize per capita, 1994-96 (kg/yr)	29	15	4	8	40	6	63
26. Average per capita maize consumption, 1994-96 (kg/yr)	137	132	32	122	235	81	100
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	0.5	-1.3	-0.1	0.2	1.9	-1.3	8.5
28. Average percent maize used for animal feed, 1994-96 (%)	29	11	20	18	22	19	63
29. Average percent maize used for direct human consumption, 1994-96 (%)	65	83	72	74	54	70	34
Prices and input use							
30. Area planted to improved maize as percentage of total maize area, 1997	48	17	7	16	20	7	43
31. Area planted to hybrids as a percentage of total maize area, 1997	48	16	++	9	19	1	42
32. Area planted to improved OPVs as percentage of total maize area, 1997	1	2	7	7	1	6	1
33. Ratio of the price of most popular hybrid to the price of grain, 1997	7.8	8.9	++	9.6	12.7	10.4	12.7
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	6.7	5.5	2.1	3.9	7.5	5.9	4.8
35. Farm price of maize, 1997 (US$/ton)	180	190	320	170	180	150	230
36. Ratio of farm level nitrogen price to maize price, 1997	1.2	1.6	1.1	1.4	1.3	2.2	1.4
37. Farm wage in kg of maize per day, 1997	17.8	18.9	7.0	11.3	25.2	13.9	26.1

++ Data are not available or incomplete.

Mexico, Central America, and the Caribbean	Consumers				Regional total or average
	Costa Rica	Cuba	Dominican Republic	Jamaica	
General indicators					
1. Estimated population, 1996 (million)	3.5	11.0	8.0	2.5	161.4
2. Estimated growth rate of population, 1996-2010 (%/yr)	1.4	0.4	1.4	0.8	1.5
3. Per capita income 1996 (US$)	2,640	++	1,600	1,600	2,855
4. Average per capita cereal production, 1995-97 (kg/yr)	62	35	70	2	198
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-6.2	-6.9	-1.7	2.0	0.2
Production of wheat and all cereals					
6. Average maize area harvested, 1995-97 (000 ha)	21	74	41	3	9,780
7. Average maize yield, 1995-97 (t/ha)	1.7	1.2	1.0	1.4	2.1
8. Average maize production, 1995-97 (000 t)	36	87	43	4	20,119
9. Growth rate of maize area, 1961-70 (%/yr)	1.6	-0.8	-2.8	-7.6	1.6
10. Growth rate of maize area, 1971-80 (%/yr)	-3.7	-5.1	5.0	-1.4	-1.3
11. Growth rate of maize area, 1981-90 (%/yr)	-1.0	++	0.4	-2.6	-0.3
12. Growth rate of maize area, 1991-97 (%/yr)	-3.9	-0.7	7.3	3.3	1.4
13. Growth rate of maize yield, 1961-70 (%/yr)	3.0	-0.9	1.1	7.9	2.2
14. Growth rate of maize yield, 1971-80 (%/yr)	4.6	6.1	-4.9	4.0	3.3
15. Growth rate of maize yield, 1981-90 (%/yr)	0.5	++	1.8	-3.2	0.3
16. Growth rate of maize yield, 1991-97 (%/yr)	0.5	-0.9	-7.8	1.1	-0.3
17. Growth rate of maize production, 1961-70 (%/yr)	4.6	-1.7	-1.6	0.3	3.8
18. Growth rate of maize production, 1971-80 (%/yr)	0.9	1.0	0.2	2.7	2.0
19. Growth rate of maize production, 1981-90 (%/yr)	-0.5	++	2.2	-5.8	< 1
20. Growth rate of maize production, 1991-97 (%/yr)	-3.4	-1.6	-0.5	4.4	1.1
21. Maize area as percent of total cereal area (average), 1995-97 (%)	30	41	27	99	72
22. Average yield of all cereals, 1995-97 (t/ha)	3.1	2.1	3.6	1.4	2.3
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	< 1	2.9	-2.9	-0.4	-0.3
Trade and utilization					
24. Average net imports of maize, 1994-96 (000 t)	378	170	649	173	5,778
25. Average net imports of maize per capita, 1994-96 (kg/yr)	110	16	83	70	36
26. Average per capita maize consumption, 1994-96 (kg/yr)	119	23	88	72	169
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	5.4	-15.3	5.1	0.9	1.5
28. Average percent maize used for animal feed, 1994-96 (%)	83	94	86	83	26
29. Average percent maize used for direct human consumption, 1994-96 (%)	11	++	10	11	53
Prices and input use					
30. Area planted to improved maize as percentage of total maize area, 1997	12	95	76	++	++
31. Area planted to hybrids as a percentage of total maize area, 1997	11	59	++	++	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	1	36	76	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	15.6	++	++	++	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	++
35. Farm price of maize, 1997 (US$/ton)	230	++	++	++	++
36. Ratio of farm level nitrogen price to maize price, 1997	1.1	++	++	++	++
37. Farm wage in kg of maize per day, 1997	34.8	++	++	++	++

++ Data are not available or incomplete.

Andean Region, South America

		Producers				Regional total or average
	Bolivia	**Colombia**	**Ecuador**	**Peru**	**Venezuela**	

General indicators

	Bolivia	Colombia	Ecuador	Peru	Venezuela	Regional total or average
1. Estimated population, 1996 (million)	7.6	36.4	11.7	23.9	22.3	103.3
2. Estimated growth rate of population, 1996-2010 (%/yr)	2.1	1.3	1.6	1.5	1.6	1.5
3. Per capita income 1996 (US$)	830	2,140	1,500	2,420	3,020	2,227
4. Average per capita cereal production, 1995-97 (kg/yr)	159	93	161	98	106	116
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	2.8	-3.9	1.9	-0.2	-1.1	-0.7

Production of wheat and all cereals

	Bolivia	Colombia	Ecuador	Peru	Venezuela	Regional total or average
6. Average maize area harvested, 1995-97 (000 ha)	290	642	550	393	443	2,321
7. Average maize yield, 1995-97 (t/ha)	2.1	1.6	1.1	2.0	2.6	1.8
8. Average maize production, 1995-97 (000 t)	604	1,033	603	783	1,133	4,160
9. Growth rate of maize area, 1961-70 (%/yr)	0.4	0.3	3.1	4.0	5.2	2.5
10. Growth rate of maize area, 1971-80 (%/yr)	3.2	< 1	-5.7	-1.1	-3.0	-1.3
11. Growth rate of maize area, 1981-90 (%/yr)	-1.1	2.9	10.3	1.8	7.6	4.3
12. Growth rate of maize area, 1991-97 (%/yr)	1.3	-4.0	2.9	4.8	1.9	0.7
13. Growth rate of maize yield, 1961-70 (%/yr)	1.3	1.2	2.2	2.8	0.4	1.4
14. Growth rate of maize yield, 1971-80 (%/yr)	0.5	1.0	3.5	0.2	3.8	1.8
15. Growth rate of maize yield, 1981-90 (%/yr)	0.1	-0.3	-3.5	1.9	4.0	0.7
16. Growth rate of maize yield, 1991-97 (%/yr)	4.5	1.2	-0.4	0.4	1.9	1.6
17. Growth rate of maize production, 1961-70 (%/yr)	1.7	1.6	5.3	6.8	5.7	3.9
18. Growth rate of maize production, 1971-80 (%/yr)	3.7	1.1	-2.2	-0.9	0.8	0.6
19. Growth rate of maize production, 1981-90 (%/yr)	-1.0	2.6	6.8	3.7	11.6	5.0
20. Growth rate of maize production, 1991-97 (%/yr)	5.7	-2.8	2.5	5.1	3.7	2.3
21. Maize area as percent of total cereal area (average), 1995-97 (%)	40	52	55	45	56	48
22. Average yield of all cereals, 1995-97 (t/ha)	1.7	2.7	1.9	2.7	3.0	2.5
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	2.7	2.2	1.2	2.3	2.7	2.0

Trade and utilization

	Bolivia	Colombia	Ecuador	Peru	Venezuela	Regional total or average
24. Average net imports of maize, 1994-96 (000 t)	-2	1,299	-34	893	970	3,139
25. Average net imports of maize per capita, 1994-96 (kg/yr)	< 1	36	-3	38	44	31
26. Average per capita maize consumption, 1994-96 (kg/yr)	66	64	48	70	122	76
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	1.3	10.3	1.2	1.3	7.0	5.5
28. Average percent maize used for animal feed, 1994-96 (%)	21	38	--	82	41	45
29. Average percent maize used for direct human consumption, 1994-96 (%)	57	59	--	15	47	42

Prices and input use

	Bolivia	Colombia	Ecuador	Peru	Venezuela	Regional total or average
30. Area planted to improved maize as percentage of total maize area, 1997	52	26	27	25	99	++
31. Area planted to hybrids as a percentage of total maize area, 1997	25	20	22	13	99	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	27	7	5	12	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	28.0	10.1	10.3	18.7	7.1	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	6.4	5.1	5.3	6.2	4.6	++
35. Farm price of maize, 1997 (US$/ton)	100	270	190	180	350	++
36. Ratio of farm level nitrogen price to maize price, 1997	4.6	1.1	1.2	1.9	0.6	++
37. Farm wage in kg of maize per day, 1997	50.6	23.9	23.3	24.2	15.4	++

++ Data are not available or incomplete.

Southern Cone, South America

		Producers				Regional total or average
	Argentina	Brazil	Chile	Paraguay	Uruguay	

General indicators

	Argentina	Brazil	Chile	Paraguay	Uruguay	Regional total or average
1. Estimated population, 1996 (million)	35.2	161.1	14.4	5.0	3.2	218.9
2. Estimated growth rate of population, 1996-2010 (%/yr)	1.0	1.2	1.1	2.2	0.6	1.2
3. Per capita income 1996 (US$)	8,380	4,400	4,860	1,850	5,760	5,033
4. Average per capita cereal production, 1995-97 (kg/yr)	830	297	190	287	655	381
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	3.9	1.0	-2.8	5.2	6.1	2.0

Production of wheat and all cereals

	Argentina	Brazil	Chile	Paraguay	Uruguay	Regional total or average
6. Average maize area harvested, 1995-97 (000 ha)	2,789	13,668	96	355	51	16,959
7. Average maize yield, 1995-97 (t/ha)	4.4	2.5	9.2	2.4	2.3	2.9
8. Average maize production, 1995-97 (000 t)	12,133	34,403	885	857	115	48,393
9. Growth rate of maize area, 1961-70 (%/yr)	4.2	3.9	-2.1	6.5	-3.5	3.8
10. Growth rate of maize area, 1971-80 (%/yr)	-4.7	1.3	4.5	3.7	-6.0	< 1
11. Growth rate of maize area, 1981-90 (%/yr)	-7.6	0.9	-2.6	-0.9	-8.3	-0.6
12. Growth rate of maize area, 1991-97 (%/yr)	6.4	1.0	-2.2	8.3	-5.1	1.9
13. Growth rate of maize yield, 1961-70 (%/yr)	2.8	0.9	6.1	-0.6	-0.4	1.7
14. Growth rate of maize yield, 1971-80 (%/yr)	3.5	1.3	-0.4	2.5	-0.2	1.5
15. Growth rate of maize yield, 1981-90 (%/yr)	< 1	1.2	9.0	4.0	3.7	0.3
16. Growth rate of maize yield, 1991-97 (%/yr)	0.4	4.1	1.8	7.4	4.9	3.7
17. Growth rate of maize production, 1961-70 (%/yr)	7.0	4.8	4.0	5.9	-3.9	5.5
18. Growth rate of maize production, 1971-80 (%/yr)	-1.2	2.6	4.1	6.2	-6.3	1.4
19. Growth rate of maize production, 1981-90 (%/yr)	-7.6	2.1	6.3	3.1	-4.6	-0.3
20. Growth rate of maize production, 1991-97 (%/yr)	6.8	5.1	-0.4	15.7	-0.2	5.6
21. Maize area as percent of total cereal area (average), 1995-97 (%)	27	70	15	57	8	54
22. Average yield of all cereals, 1995-97 (t/ha)	2.9	2.4	4.4	2.3	3.2	2.6
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	0.6	4.0	1.5	6.0	4.7	3.0

Trade and utilization

	Argentina	Brazil	Chile	Paraguay	Uruguay	Regional total or average
24. Average net imports of maize, 1994-96 (000 t)	-5,520	891	432	-131	87	-4,242
25. Average net imports of maize per capita, 1994-96 (kg/yr)	-159	6	30	-27	27	-20
26. Average per capita maize consumption, 1994-96 (kg/yr)	151	217	97	109	61	194
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	1.3	2.9	4.6	3.0	3.1	2.7
28. Average percent maize used for animal feed, 1994-96 (%)	65	79	86	43	56	77
29. Average percent maize used for direct human consumption, 1994-96 (%)	4	9	9	39	29	9

Prices and input use

	Argentina	Brazil	Chile	Paraguay	Uruguay	Regional total or average
30. Area planted to improved maize as percentage of total maize area, 1997	90	57	++	36	++	++
31. Area planted to hybrids as a percentage of total maize area, 1997	88	49	++	34	++	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	2	7	++	2	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	29.3	15.3	++	24.7	++	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	5.7	7.9	++	12.7	++	++
35. Farm price of maize, 1997 (US$/ton)	120	100	++	70	++	++
36. Ratio of farm level nitrogen price to maize price, 1997	2.4	3.2	++	6.0	++	++
37. Farm wage in kg of maize per day, 1997	169.8	96.4	++	126.1	++	++

++ Data are not available or incomplete.

Eastern Europe and the Former Soviet Union

	Producers						
	Albania	**Bosnia and Herzegovina***	**Bulgaria**	**Croatia***	**Czech Republic***	**Georgia***	**Hungary**
General indicators							
1. Estimated population, 1996 (million)	3.4	3.6	8.5	4.5	10.3	5.4	10.0
2. Estimated growth rate of population, 1996-2010 (%/yr)	0.9	++	-0.9	-0.3	-0.2	0.0	-0.4
3. Per capita income 1996 (US$)	820	++	1,190	3,800	4,740	850	4,340
4. Average per capita cereal production, 1995-97 (kg/yr)	178	173	640	627	658	111	1,177
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-6.0	-22.4	-6.4	3.6	1.4	8.4	-2.6
Production of wheat and all cereals							
6. Average maize area harvested, 1995-97 (000 ha)	62	128	501	359	30	197	1,053
7. Average maize yield, 1995-97 (t/ha)	3.5	3.0	3.0	5.3	5.0	2.0	5.4
8. Average maize production, 1995-97 (000 t)	218	378	1,519	1,898	150	394	5,690
9. Growth rate of maize area, 1961-70 (%/yr)	-4.1	++	-1.3	++	++	++	-0.7
10. Growth rate of maize area, 1971-80 (%/yr)	-2.5	++	-0.3	++	++	++	-1.1
11. Growth rate of maize area, 1981-90 (%/yr)	-4.7	++	-2.5	++	++	++	-0.6
12. Growth rate of maize area, 1991-97 (%/yr)	2.6	-16.6	-2.4	-0.8	2.4	18.4	-2.2
13. Growth rate of maize yield, 1961-70 (%/yr)	9.8	++	6.3	++	++	++	4.8
14. Growth rate of maize yield, 1971-80 (%/yr)	7.6	++	0.4	++	++	++	4.3
15. Growth rate of maize yield, 1981-90 (%/yr)	1.3	++	-5.4	++	++	++	-2.3
16. Growth rate of maize yield, 1991-97 (%/yr)	6.3	-9.3	-4.3	6.2	5.2	-5.4	2.8
17. Growth rate of maize production, 1961-70 (%/yr)	5.7	++	5.0	++	++	++	4.1
18. Growth rate of maize production, 1971-80 (%/yr)	5.1	++	0.2	++	++	++	3.2
19. Growth rate of maize production, 1981-90 (%/yr)	-3.4	++	-8.0	++	++	++	-2.9
20. Growth rate of maize production, 1991-97 (%/yr)	8.9	-25.9	-6.7	5.4	7.6	13.1	0.7
21. Maize area as percent of total cereal area (average), 1995-97 (%)	27	55	25	58	2	57	37
22. Average yield of all cereals, 1995-97 (t/ha)	2.7	2.7	2.7	4.6	4.2	1.8	4.2
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	4.1	-7.4	-5.6	3.4	1.1	-1.6	-0.8
Trade and utilization							
24. Average net imports of maize, 1994-96 (000 t)	2	4	33	-10	138	++	-293
25. Average net imports of maize per capita, 1994-96 (kg/yr)	< 1	1	4	-2	13	++	-29
26. Average per capita maize consumption, 1994-96 (kg/yr)	62	154	161	392	30	69	499
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	- 5.4	-6.9	-8.4	7.0	13.3	11.8	-4.0
28. Average percent maize used for animal feed, 1994-96 (%)	43	53	81	95	86	41	77
29. Average percent maize used for direct human consumption, 1994-96 (%)	41	32	1	1	< 1	51	< 1
Prices and input use							
30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++	++	++	++
31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++	++	++	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++	++	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++	++	++	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	++	++	++
35. Farm price of maize, 1997 (US$/ton)	++	++	++	++	++	++	++
36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++	++	++	++
37. Farm wage in kg of maize per day, 1997	++	++	++	++	++	++	++

*   Variables 5, 12, 16, 20, and 23 come from 1992–97 (Former Soviet Union and Former Yugoslavia) and 1993–97 (Former Czechoslovakia).
    Variable 27 comes from 1992–96 (Former Soviet Union and Former Yugoslavia) and 1993–97 (Former Czechoslovakia).
++ Data are not available or incomplete.

Eastern Europe and the Former Soviet Union	Producers						
	Kazakstan*	Kyrgyzstan*	Macedonia*	Moldova*	Poland	Romania	Russian Federation*
General indicators							
1. Estimated population, 1996 (million)	16.8	4.5	2.2	4.4	38.6	22.7	148.1
2. Estimated growth rate of population, 1996-2010 (%/yr)	0.1	1.1	0.7	0.0	0.2	-0.3	-0.2
3. Per capita income 1996 (US$)	1,350	550	990	590	3,230	1,600	2,410
4. Average per capita cereal production, 1995-97 (kg/yr)	655	286	286	572	650	826	485
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-19.6	-3.0	-0.2	2.8	-1.2	0.4	-6.3
Production of wheat and all cereals							
6. Average maize area harvested, 1995-97 (000 ha)	78	42	41	348	64	3,141	612
7. Average maize yield, 1995-97 (t/ha)	1.6	3.8	3.7	3.4	4.7	3.4	2.4
8. Average maize production, 1995-97 (000 t)	123	161	151	1,172	300	10,737	1,446
9. Growth rate of maize area, 1961-70 (%/yr)	++	++	++	++	-8.5	-0.4	++
10. Growth rate of maize area, 1971-80 (%/yr)	++	++	++	++	29.6	0.9	++
11. Growth rate of maize area, 1981-90 (%/yr)	++	++	++	++	16.6	-1.9	++
12. Growth rate of maize area, 1991-97 (%/yr)	-14.4	-1.6	-2.5	5.4	1.5	1.7	-6.6
13. Growth rate of maize yield, 1961-70 (%/yr)	++	++	++	++	-0.1	3.7	++
14. Growth rate of maize yield, 1971-80 (%/yr)	++	++	++	++	2.7	3.0	++
15. Growth rate of maize yield, 1981-90 (%/yr)	++	++	++	++	2.5	-2.7	++
16. Growth rate of maize yield, 1991-97 (%/yr)	-13.5	-4.8	7.5	6.1	0.6	3.5	-3.4
17. Growth rate of maize production, 1961-70 (%/yr)	++	++	++	++	-8.6	3.3	++
18. Growth rate of maize production, 1971-80 (%/yr)	++	++	++	++	32.4	3.9	++
19. Growth rate of maize production, 1981-90 (%/yr)	++	++	++	++	19.1	-4.6	++
20. Growth rate of maize production, 1991-97 (%/yr)	-27.9	-6.4	5.0	11.5	2.0	5.2	-10.0
21. Maize area as percent of total cereal area (average), 1995-97 (%)	< 1	7	18	42	1	51	1
22. Average yield of all cereals, 1995-97 (t/ha)	0.7	2.1	2.7	3.1	2.9	3.0	1.4
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	-10.6	-3.5	2.2	0.1	0.6	2.8	-3.4
Trade and utilization							
24. Average net imports of maize, 1994-96 (000 t)	-12	4	47	-9	31	-1	291
25. Average net imports of maize per capita, 1994-96 (kg/yr)	-1	1	22	-2	1	< 1	2
26. Average per capita maize consumption, 1994-96 (kg/yr)	15	33	91	196	16	418	23
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	-39.6	-12.2	10.4	6.1	4.5	2.7	-30.0
28. Average percent maize used for animal feed, 1994-96 (%)	89	96	60	69	78	83	79
29. Average percent maize used for direct human consumption, 1994-96 (%)	4	++	28	21	++	6	1
Prices and input use							
30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++	++	++	++
31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++	++	++	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++	++	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++	++	++	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	++	++	++
35. Farm price of maize, 1997 (US$/ton)	++	++	++	++	++	++	++
36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++	++	++	++
37. Farm wage in kg of maize per day, 1997	++	++	++	++	++	++	++

* Variables 5, 12, 16, 20, and 23 come from 1992–97 (Former Soviet Union and Former Yugoslavia) and 1993–97 (Former Czechoslovakia).
Variable 27 comes from 1992–96 (Former Soviet Union and Former Yugoslavia) and 1993–97 (Former Czechoslovakia).
++ Data are not available or incomplete.

Eastern Europe and the Former Soviet Union	Producers					Regional total or average
	Slovakia*	Slovenia*	Ukraine*	Uzbekistan*	Yugoslavia, Fed Rep of*	
General indicators						
1. Estimated population, 1996 (million)	5.3	1.9	51.7	23.3	10.3	414.8
2. Estimated growth rate of population, 1996-2010 (%/yr)	0.2	-0.1	-0.6	1.6	0.2	0.0
3. Per capita income 1996 (US$)	3,410	9,240	1,200	1,010	++	2,116
4. Average per capita cereal production, 1995-97 (kg/yr)	670	283	567	136	818	521
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	2.4	4.9	-6.5	5.6	2.9	-3.7
Production of wheat and all cereals						
6. Average maize area harvested, 1995-97 (000 ha)	130	48	837	61	1,417	9,219
7. Average maize yield, 1995-97 (t/ha)	5.4	6.7	3.0	3.6	3.9	3.7
8. Average maize production, 1995-97 (000 t)	701	324	2,543	219	5,521	33,763
9. Growth rate of maize area, 1961-70 (%/yr)	++	++	++	++	++	-4.0
10. Growth rate of maize area, 1971-80 (%/yr)	++	++	++	++	++	-1.0
11. Growth rate of maize area, 1981-90 (%/yr)	++	++	++	++	++	-0.9
12. Growth rate of maize area, 1991-97 (%/yr)	-0.7	-5.7	-11.6	-12.9	-0.5	-1.8
13. Growth rate of maize yield, 1961-70 (%/yr)	++	++	++	++	++	4.1
14. Growth rate of maize yield, 1971-80 (%/yr)	++	++	++	++	++	3.1
15. Growth rate of maize yield, 1981-90 (%/yr)	++	++	++	++	++	-1.5
16. Growth rate of maize yield, 1991-97 (%/yr)	6.6	14.7	5.2	0.4	6.1	1.0
17. Growth rate of maize production, 1961-70 (%/yr)	++	++	++	++	++	0.1
18. Growth rate of maize production, 1971-80 (%/yr)	++	++	++	++	++	2.1
19. Growth rate of maize production, 1981-90 (%/yr)	++	++	++	++	++	-2.4
20. Growth rate of maize production, 1991-97 (%/yr)	5.9	9.0	-6.4	-12.6	5.6	-0.8
21. Maize area as percent of total cereal area (average), 1995-97 (%)	15	45	7	4	59	8
22. Average yield of all cereals, 1995-97 (t/ha)	4.2	5.1	2.4	2.0	3.5	1.9
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	2.5	7.5	-5.2	2.9	3.6	-1.0
Trade and utilization						
24. Average net imports of maize, 1994-96 (000 t)	-84	204	32	5	< 1	483
25. Average net imports of maize per capita, 1994-96 (kg/yr)	-16	106	1	< 1	< 1	1
26. Average per capita maize consumption, 1994-96 (kg/yr)	93	288	49	15	511	82
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	1.0	4.0	-10.2	-11.3	11.6	-6.9
28. Average percent maize used for animal feed, 1994-96 (%)	88	80	67	20	83	79
29. Average percent maize used for direct human consumption, 1994-96 (%)	++	13	17	71	3	7
Prices and input use						
30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++	++	++
31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++	++	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++	++	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	++	++
35. Farm price of maize, 1997 (US$/ton)	++	++	++	++	++	++
36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++	++	++
37. Farm wage in kg of maize per day, 1997	++	++	++	++	++	++

* Variables 5, 12, 16, 20, and 23 come from 1992–97 (Former Soviet Union and Former Yugoslavia) and 1993–97 (Former Czechoslovakia).
Variable 27 comes from 1992–96 (Former Soviet Union and Former Yugoslavia) and 1993–97 (Former Czechoslovakia).
++ Data are not available or incomplete.

Western Europe, Japan, and Other High Income Countries

		Producers						
		Austria	**Canada**	**France**	**Germany**	**Greece**	**Italy**	**Portugal**
General indicators	1. Estimated population, 1996 (million)	8.1	29.7	58.3	81.9	10.5	57.2	9.8
	2. Estimated growth rate of population, 1996-2010 (%/yr)	0.0	0.6	0.2	-0.1	0.1	-0.3	-0.2
	3. Per capita income 1996 (US$)	28,110	19,020	26,270	28,870	11,460	19,880	10,160
	4. Average per capita cereal production, 1995-97 (kg/yr)	552	1766	1,026	519	450	354	161
	5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-3.0	0.8	0.2	1.2	-2.5	2.0	0.2
Production of wheat and all cereals	6. Average maize area harvested, 1995-97 (000 ha)	188	1,035	1,745	356	208	976	182
	7. Average maize yield, 1995-97 (t/ha)	8.6	7.0	8.4	7.9	9.2	9.4	4.6
	8. Average maize production, 1995-97 (000 t)	1,610	7,277	14,690	2,793	1,928	9,216	829
	9. Growth rate of maize area, 1961-70 (%/yr)	9.7	11.8	4.0	26.7	-2.0	-1.9	-1.6
	10. Growth rate of maize area, 1971-80 (%/yr)	4.7	7.5	-0.1	-0.3	-2.3	0.6	-1.7
	11. Growth rate of maize area, 1981-90 (%/yr)	0.1	-1.4	1.2	4.9	2.8	-3.3	-3.3
	12. Growth rate of maize area, 1991-97 (%/yr)	1.4	1.0	-0.5	4.4	-0.4	2.8	-1.2
	13. Growth rate of maize yield, 1961-70 (%/yr)	5.1	1.6	9.1	6.4	10.5	4.5	2.2
	14. Growth rate of maize yield, 1971-80 (%/yr)	2.2	1.6	0.7	2.2	7.2	3.6	0.3
	15. Growth rate of maize yield, 1981-90 (%/yr)	1.3	1.3	1.3	2.1	1.3	1.4	9.0
	16. Growth rate of maize yield, 1991-97 (%/yr)	2.0	2.0	2.6	2.3	-2.0	3.8	7.1
	17. Growth rate of maize production, 1961-70 (%/yr)	14.7	13.4	13.2	33.1	8.5	2.6	0.7
	18. Growth rate of maize production, 1971-80 (%/yr)	6.9	9.1	0.6	1.9	5.0	4.1	-1.4
	19. Growth rate of maize production, 1981-90 (%/yr)	1.4	-0.1	2.5	6.9	4.1	-1.9	5.7
	20. Growth rate of maize production, 1991-97 (%/yr)	3.4	3.0	2.1	6.8	-2.4	6.7	5.8
	21. Maize area as percent of total cereal area (average), 1995-97 (%)	23	5	20	5	16	23	26
	22. Average yield of all cereals, 1995-97 (t/ha)	5.4	2.7	6.8	6.3	3.6	4.8	2.3
	23. Growth rate of yield of all cereals, 1991-97 (%/yr)	0.3	1.0	1.2	2.2	-1.4	1.2	2.9
Trade and utilization	24. Average net imports of maize, 1994-96 (000 t)	-76	440	-6,850	714	106	561	349
	25. Average net imports of maize per capita, 1994-96 (kg/yr)	-9	15	-118	9	10	10	36
	26. Average per capita maize consumption, 1994-96 (kg/yr)	176	269	110	44	195	152	176
	27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	-1.0	0.9	-1.5	1.0	-1.5	3.3	3.9
	28. Average percent maize used for animal feed, 1994-96 (%)	88	78	71	61	84	93	91
	29. Average percent maize used for direct human consumption, 1994-96 (%)	2	1	12	18	1	2	4
Prices and input use	30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++	++	++	++
	31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++	++	++	++
	32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++	++	++	++
	33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++	++	++	++
	34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	++	++	++
	35. Farm price of maize, 1997 (US$/ton)	++	++	++	++	++	++	++
	36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++	++	++	++
	37. Farm wage in kg of maize per day, 1997	++	++	++	++	++	++	++

++ Data are not available or incomplete.

Western Europe, Japan, and Other High Income Countries	Producers		Consumers				Regional total or average
	Spain	United States of America	Belgium-luxembourg	Japan	Netherlands	United Kingdom	

General indicators

	Spain	United States of America	Belgium-luxembourg	Japan	Netherlands	United Kingdom	Regional total or average
1. Estimated population, 1996 (million)	39.7	269.4	10.6	125.4	15.6	58.4	848.6
2. Estimated growth rate of population, 1996-2010 (%/yr)	-0.1	0.7	0.0	0.1	0.3	0.1	0.3
3. Per capita income 1996 (US$)	14,350	28,020	26,440	40,940	25,940	19,600	27,138
4. Average per capita cereal production, 1995-97 (kg/yr)	447	1,184	240	109	101	400	729
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	-2.6	2.4	1.1	-0.6	2.0	0.4	1.6

Production of wheat and all cereals

	Spain	United States of America	Belgium-luxembourg	Japan	Netherlands	United Kingdom	Regional total or average
6. Average maize area harvested, 1995-97 (000 ha)	430	28,580	25	< 1	11	++	33,841
7. Average maize yield, 1995-97 (t/ha)	8.3	7.7	9.5	2.5	7.5	++	7.8
8. Average maize production, 1995-97 (000 t)	3,575	220,422	242	< 1	82	++	263,407
9. Growth rate of maize area, 1961-70 (%/yr)	1.7	-0.1	9.9	++	++	++	0.2
10. Growth rate of maize area, 1971-80 (%/yr)	-2.4	2.3	6.0	++	++	-11.1	2.1
11. Growth rate of maize area, 1981-90 (%/yr)	3.3	-1.1	1.7	++	++	++	-0.9
12. Growth rate of maize area, 1991-97 (%/yr)	2.1	1.0	18.1	++	++	++	1.0
13. Growth rate of maize yield, 1961-70 (%/yr)	4.1	2.9	1.3	++	++	++	3.2
14. Growth rate of maize yield, 1971-80 (%/yr)	3.4	1.4	2.0	++	++	-10.6	1.6
15. Growth rate of maize yield, 1981-90 (%/yr)	2.8	0.9	1.0	++	++	++	1.0
16. Growth rate of maize yield, 1991-97 (%/yr)	5.1	1.9	3.7	++	++	++	2.0
17. Growth rate of maize production, 1961-70 (%/yr)	5.8	2.8	11.2	++	++	++	3.4
18. Growth rate of maize production, 1971-80 (%/yr)	1.0	3.8	8.0	++	++	-21.8	3.7
19. Growth rate of maize production, 1981-90 (%/yr)	6.1	-0.2	2.7	++	++	++	0.1
20. Growth rate of maize production, 1991-97 (%/yr)	7.1	2.8	21.8	++	++	++	2.9
21. Maize area as percent of total cereal area (average), 1995-97 (%)	6	45	8	< 1	5	++	24
22. Average yield of all cereals, 1995-97 (t/ha)	2.6	5.1	7.6	6.1	8.0	7.0	4.5
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	3.6	1.8	4.0	2.5	1.8	1.7	1.4

Trade and utilization

	Spain	United States of America	Belgium-luxembourg	Japan	Netherlands	United Kingdom	Regional total or average
24. Average net imports of maize, 1994-96 (000 t)	2,335	-49,149	1,220	16,171	1,581	1,484	-29,884
25. Average net imports of maize per capita, 1994-96 (kg/yr)	59	-184	116	129	102	25	-35
26. Average per capita maize consumption, 1994-96 (kg/yr)	119	651	115	128	88	25	275
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	0.5	1.4	-0.3	-0.5	-3.6	-1.9	1.3
28. Average percent maize used for animal feed, 1994-96 (%)	85	76	60	76	56	11	76
29. Average percent maize used for direct human consumption, 1994-96 (%)	1	2	2	17	3	13	4

Prices and input use

	Spain	United States of America	Belgium-luxembourg	Japan	Netherlands	United Kingdom	Regional total or average
30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++	++	++	++
31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++	++	++	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++	++	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++	++	++	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++	++	++	++
35. Farm price of maize, 1997 (US$/ton)	++	++	++	++	++	++	++
36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++	++	++	++
37. Farm wage in kg of maize per day, 1997	++	++	++	++	++	++	++

++ Data are not available or incomplete.

Regional Aggregates

	Producers			
	Developing Countries	Eastern Europe and the Former Soviet Union	Western Europe, Japan, and Other High Income Countries	WORLD
General indicators				
1. Estimated population, 1996 (million)	4,503.2	414.8	848.6	5,766.6
2. Estimated growth rate of population, 1996-2010 (%/yr)	1.4	0.0	0.3	1.1
3. Per capita income 1996 (US$)	1,194	2,116	27,138	5,260
4. Average per capita cereal production, 1995-97 (kg/yr)	263	521	729	350
5. Growth rate of per capita cereal production, 1988-97 (%/yr)	0.3	-3.7	1.6	-0.1
Production of wheat and all cereals				
6. Average maize area harvested, 1995-97 (000 ha)	96,592	9,219	33,841	139,652
7. Average maize yield, 1995-97 (t/ha)	2.7	3.7	7.8	4.0
8. Average maize production, 1995-97 (000 t)	264,310	33,763	263,407	561,480
9. Growth rate of maize area, 1961-70 (%/yr)	2.0	-4.0	0.2	0.9
10. Growth rate of maize area, 1971-80 (%/yr)	0.8	-1.0	2.1	1.0
11. Growth rate of maize area, 1981-90 (%/yr)	1.5	-0.9	-0.9	0.6
12. Growth rate of maize area, 1991-97 (%/yr)	1.4	-1.8	1.0	1.0
13. Growth rate of maize yield, 1961-70 (%/yr)	2.8	4.1	3.2	2.7
14. Growth rate of maize yield, 1971-80 (%/yr)	3.0	3.1	1.6	2.6
15. Growth rate of maize yield, 1981-90 (%/yr)	1.6	-1.5	1.0	0.4
16. Growth rate of maize yield, 1991-97 (%/yr)	1.9	1.0	2.0	1.7
17. Growth rate of maize production, 1961-70 (%/yr)	4.8	0.1	3.4	3.5
18. Growth rate of maize production, 1971-80 (%/yr)	3.8	2.1	3.7	3.6
19. Growth rate of maize production, 1981-90 (%/yr)	3.1	-2.4	0.1	1.1
20. Growth rate of maize production, 1991-97 (%/yr)	3.3	-0.8	2.9	2.8
21. Maize area as percent of total cereal area (average), 1995-97 (%)	22	8	24	20
22. Average yield of all cereals, 1995-97 (t/ha)	2.7	1.9	4.5	2.9
23. Growth rate of yield of all cereals, 1991-97 (%/yr)	1.8	-1.0	1.4	1.5
Trade and utilization				
24. Average net imports of maize, 1994-96 (000 t)	27,937	483	-29,884	—
25. Average net imports of maize per capita, 1994-96 (kg/yr)	6	1	-35	—
26. Average per capita maize consumption, 1994-96 (kg/yr)	66	82	275	98
27. Growth rate of per capita maize consumption, 1987-96 (%/yr)	2.6	-6.9	1.3	0.9
28. Average percent maize used for animal feed, 1994-96 (%)	56	79	76	66
29. Average percent maize used for direct human consumption, 1994-96 (%)	30	7	4	17
Prices and input use				
30. Area planted to improved maize as percentage of total maize area, 1997	++	++	++	++
31. Area planted to hybrids as a percentage of total maize area, 1997	++	++	++	++
32. Area planted to improved OPVs as percentage of total maize area, 1997	++	++	++	++
33. Ratio of the price of most popular hybrid to the price of grain, 1997	++	++	++	++
34. Ratio of the price of commercial OPV seed to the price of grain, 1997	++	++	++	++
35. Farm price of maize, 1997 (US$/ton)	++	++	++	++
36. Ratio of farm level nitrogen price to maize price, 1997	++	++	++	++
37. Farm wage in kg of maize per day, 1997	++	++	++	++

++ Data are not available or incomplete.

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Appendix A

Regions of the World

Developing Countries

Eastern and Southern Africa
Botswana
Burundi
Comoros
Djibouti
Ethiopia
Kenya
Lesotho
Madagascar
Malawi
Mauritius
Mozambique
Namibia
Rwanda
Seychelles
Somalia
Sudan
Swaziland
Tanzania
Uganda
Zambia
Zimbabwe

Western and Central Africa
Angola
Benin
Burkina Faso
Cameroon
Cape Verde
Central Africa Republic
Chad
Congo, People's Rep. of
Congo, Dem. Rep. of
Côte d'Ivoire
Equatorial Guinea
Gambia
Ghana
Guinea
Guinea-Bissau
Liberia
Mali
Mauritania
Niger
Nigeria
Reunion
Sao Tome
Senegal
Sierra Leone
St. Helena
Togo

North Africa
Algeria
Egypt
Libya
Morocco
Tunisia
West Sahara

West Asia
Afghanistan
Bahrain
Cyprus
Gaza Strip (Palestine)
Iran
Iraq
Jordan
Kuwait
Lebanon
Oman
Qatar
Saudi Arabia
Syria
Turkey
United Arab Emirates
West Bank (Palestine)
Yemen Republic

South Asia
Bangladesh
Bhutan
India
Maldives
Myanmar
Nepal
Pakistan
Sri Lanka

Southeast Asia and the Pacific
American Samoa
Brunei Darussalam
Cambodia
Christmas Island (Aust.)
Cocos Island (Keeling)
Cook Islands
East Timor
Fiji
French Polynesia
Guam
Hong Kong
Indonesia
Kiribati
Laos
Macau
Malaysia
Marshall Islands
Micronesia, Federal States
Nauru
New Caledonia
Niue
Norfolk Island
Northern Mariana Islands
Pacific Island (Trust Ter.)
Palau (Pacific Island)
Papua New Guinea
Philippines
Samoa
Singapore
Solomon Islands
Thailand
Tokelau
Tonga
Tuvalu
Vanuatu
Vietnam
Wallis and Futuna Island

East Asia
China
Mongolia
Korea, Democratic Peoples Rep. of
Korea, Republic of
Taiwan

Mexico, Central America, and the Caribbean
Anguilla
Aruba
Antigua Barbados
Bahamas
Barbados
Belize
Bermuda
British Virgin Islands
Cayman Islands
Costa Rica
Cuba
Dominica
Dominican Republic
El Salvador
Grenada
Guadeloupe
Guatemala
Haiti
Honduras
Jamaica
Martinique
Mexico
Montserrat
Netherlands Antilles
Nicaragua
Panama
Puerto Rico
St. Christopher and Nevis
St. Lucia
St. Pierre Miquelon
St. Vincent Grenadines
Trinidad and Tobago
Turks Caicos Island
U.S. Virgin Islands

Andean Region
Bolivia
Colombia
Ecuador
French Guiana
Guyana
Peru
Suriname
Venezuela

Southern Cone, South America
Argentina
Brazil
Chile
Falkland Islands
Paraguay
Uruguay

Eastern Europe and the Former Soviet Union

Albania
Armenia
Azerbaijan
Belarus
Bosnia Herzegovina
Bulgaria
Croatia
Czech Republic
Czechoslovakia
Estonia
Georgia
Hungary
Kazakhstan
Kyrgyzstan
Latvia
Lithuania
Macedonia
Moldova Republic
Poland
Romania
Russian Federation
Slovakia
Slovenia
Tajikistan
Turkmenistan
Ukraine
Uzbekistan
Former Yugoslavia
Yugoslavia SFR

Western Europe, North America, and Other High-Income Countries

Andorra
Australia
Austria
Bahamas
Belgium-Luxembourg
Canada
Denmark
Faeroe Island
Finland
France
Germany
Gibraltar
Greece
Greenland
Holy See
Iceland
Ireland
Israel
Italy
Japan
Leichtenstein
Malta
Monaco
Netherlands
New Zealand
Norway
Portugal
San Marino
South Africa
Spain
Sweden
Switzerland
United Kingdom
United States