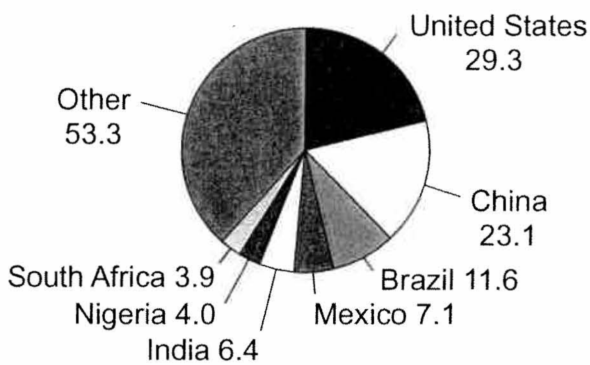
Corn (Maize) *Zea mays*

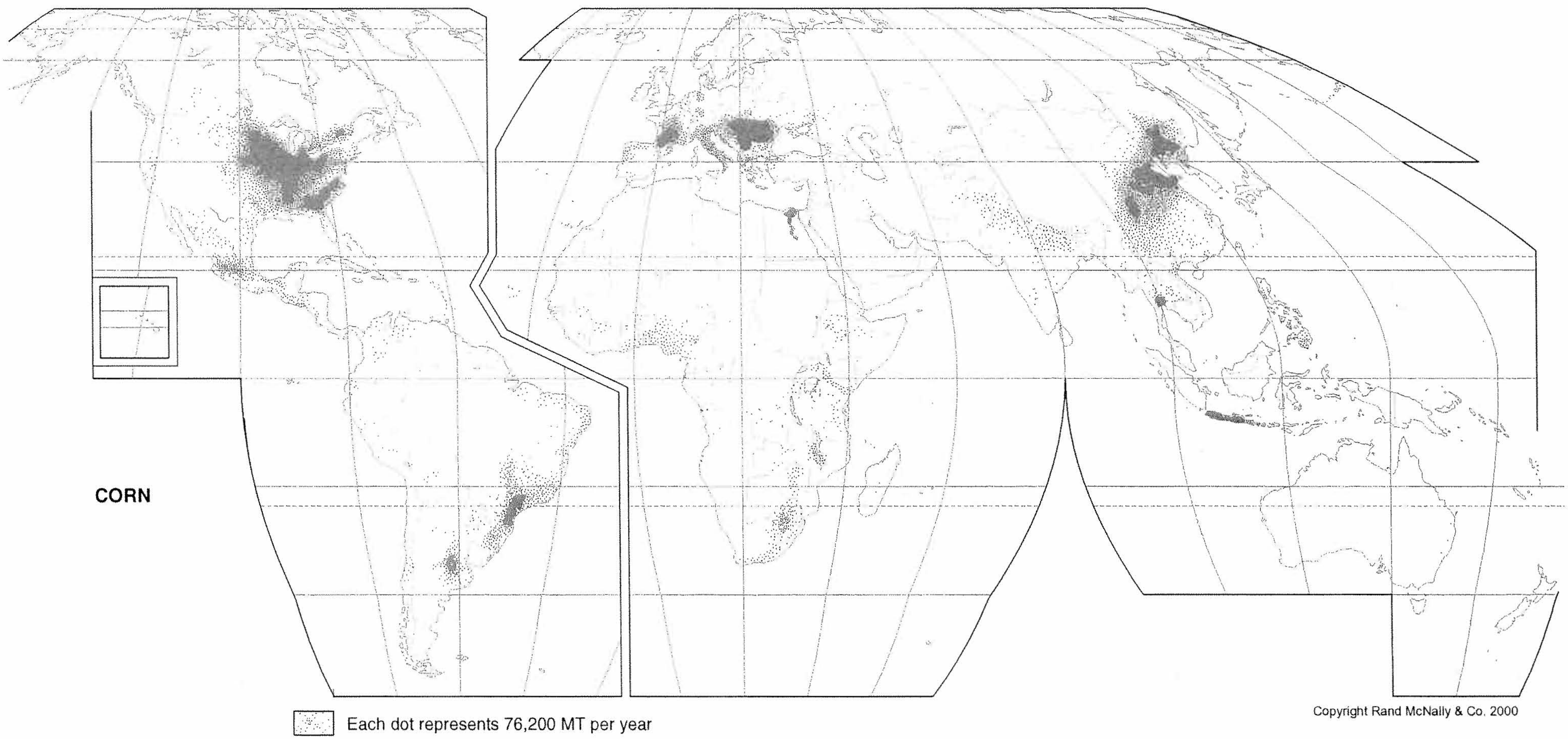
Production	
Area Under Cultivation	138.7 million ha
Global Production	593.0 million MT
Average Productivity	4,274 kg/ha
Producer Price	$111 per MT
Producer Production Value	$65,837 million
International Trade	
Share of World Production	14%
Exports	81.8 million MT
Average Price	$107 per MT
Value	$8,733 million
Principal Producing Countries/Blocs (by weight)	United States, China, Brazil, Mexico, Argentina, France, India
Principal Exporting Countries/Blocs	United States, Argentina , China, France
Principal Importing Countries/Blocs	Japan, South Korea, Mexico, Egypt, China, Spain, Malaysia
Major Environmental Impacts	Habitat conversion Soil erosion and degradation Agrochemical inputs Water use and pollution
Potential to Improve	Good for commercial and subsistence agriculture BMPs are known that reduce impacts for a wide range of production systems BMPs save money and increase profits Conservation tillage reduces inputs and impacts Plant breeding can reduce impacts

Source: FAO 2002. All data for 2000.

Maize

Area in Production (MMha)




CORN
Each dot represents 76,200 MT per year

Chapter 18

Corn (Maize)

Overview

Corn (known as maize in much of the world) was domesticated by indigenous peoples some 7,000 to 10,000 years ago in Mexico or Central America. It is still consumed throughout the region, usually in the form of tortillas, and very often at three meals a day. Sometimes corn with a little salt is the entire meal. At the time of European conquest, corn was produced throughout North and South America in longitudes from 58 degrees north to 40 degrees south in virtually all areas with sufficient growing seasons and rainfall. The Europeans first took corn home to plant and then spread it throughout their colonies.

For many Indian societies in North and South America, corn was a sacred food. Its cultivation and consumption was the stuff of rituals. Corn was not planted, harvested, or eaten the first time each year without paying proper respect to the gods that provided it. Different varieties were often cultivated. Some were used every day, others only for special occasions. Some societies preferred yellow, others white, still others red or blue varieties. Some 30,000 varieties are thought to have existed. Corn allowed many indigenous societies throughout the Americas to develop surpluses of food that could be stored, thus freeing their time to do other things. Many of the first indigenous villages and settlements as groups ceased being nomads both in order to cultivate corn and because of the surplus it provided.

Over time, however, corn has lost its luster as a "choice" food in many parts of the world. While it is still a major source of food for many people on the planet, particularly poor people, as soon as they can afford it, corn consumers abandon it in favor of a diet containing more fruit, vegetables and protein. At this time, corn is used not as a "gift of the gods" food but rather as animal feed.

Producing Countries

The Food and Agriculture Organization of the United Nations (FAO 2002 reports that 158 countries produced corn in 2000. Seven countries account for nearly 61.6 percent of all land planted to corn and 73.5 percent of the 593 million metric tons of corn produced in 2000, as shown in Table 18.1.

Table 18.1 Major Corn Producing Countries in 2000

	Area Cultivated (million ha)	Total Production (million MT)
United States	29.3	251.9
China	23.1	106.2
Brazil	11.6	31.9
Mexico	7.1	17.6
India	6.4	11.6
Nigeria	4.0	5.6
South Africa	3.9	10.9
Global total	138.7	593.0
Percentage of total	61.6	73.5

Source: FAO 2002.

The main producers by weight are the United States and China. These two countries account for 60.4 percent of the corn produced globally. Only 13.8 percent of corn produced each year is traded internationally. The main exporters are the United States and Argentina, with the United States accounting for half to two-thirds of all corn exports each year.

The United States grows nearly 40 percent of the world's corn. More than half of that production comes from only 20 percent of corn producers. Production is also concentrated in only a few states; the six leading corn-producing states account for more than 80 percent of the corn produced in the United States annually. Iowa alone is responsible for 9 percent of global corn production (Kimbrell 2002).

Geographically, corn is the most widely grown cereal crop in the world. Globally, average yields are approximately 4,274 kilograms per hectare per year. Kuwait has the highest yields for corn in the world, averaging more than 17,400 kilograms per hectare per year, or more than four times the global average, but such production comes at a very high price in terms of irrigation and other inputs. Belgium, Chile, France, Germany, Greece, Israel, Italy, Jordan, New Zealand, Qatar, Spain, Switzerland, and the United States all produce corn at twice the yields per hectare of the global average.

Corn production has been increasing steadily throughout the world. From 1974 to 1994, for example, global production increased by 86 percent. Though the area under corn cultivation is less than that for wheat or rice, corn produces more tons of food than any other single crop. Unlike many other food crops, most corn is used for animal feed and not for direct human consumption. The exception to this occurs in parts of Mexico and Central America and Africa. Table 18.2 shows which countries devote the most land to corn production, as a percentage of available agricultural land (FAO 1996).

Table 18.2 Percentage of Agricultural Land Devoted to Corn, 1994

50 percent or more	25–49 percent	10–24 percent
El Salvador	Belize	Angola
Guatemala	Benin	Austria
Malawi	Bhutan	Bolivia
Philippines	Brazil	Bulgaria
São Tomé/Príncipe	Côte d'Ivoire	Burundi
Tanzania	Ecuador	China
Zimbabwe	Egypt	Colombia
	Haiti	Congo
	Honduras	Ghana
	Kenya	Guinea
	Lesotho	Hungary
	Mexico	Indonesia
	Mozambique	Nicaragua
	Nepal	Panama
	North Korea	Togo
	Somalia	United States
	South Africa	Venezuela
		Zambia

Source: FAO 1996.

Corn production is increasing in parts of the world where it was not significant before. In the past three decades, for example, corn production has more than doubled in the Middle East and Asia. Those regions combined now produce twice as much corn as Latin America, the genetic home of corn. In Africa demand exceeds supply, and corn is rapidly replacing other basic food crops for direct human consumption (FAO 2002).

Consuming Countries

Most corn is consumed in the country of origin. The main corn consuming countries are the United States, China, Brazil, and Mexico. The main importing countries, by contrast, are Japan, South Korea, Mexico, Egypt, China, Spain, and Malaysia. Japan purchases nearly 20 percent of the corn traded internationally, while South Korea purchases about 11 percent. In both cases these countries use corn to feed animals to meet increasing demand for animal protein. Due to economic growth over the past fifty years, both countries' consumption of animal protein has exceeded their ability to produce sufficient feed grain. While it might be more efficient to import meat rather than feed, there is a cultural preference for fresh meat (FAO 2002).

Many policies can affect the relationship between corn producing and consuming countries. As a result of the North American Free Trade Agreement (NAFTA), roughly one-quarter of corn consumed in Mexico, generally considered the birthplace of corn, is produced in the United States. Small-scale producers in Mexico (some 90 percent of corn farmers, cultivating less than 2 hectares each) cannot compete against the mechanized and subsidized giant American producers (Weiner 2002). Under NAFTA, limits on the amount of corn the United States can export to Mexico will be eliminated by 2008, and this will further reduce the Mexican-produced share of that market. Mexico had long subsidized the price of corn as a social net for the rural poor and as a tool to discourage rural-to-urban migration. Under NAFTA Mexico agreed to let the price of corn fall to the level of the international price. However, the international price of corn is greatly influenced by the United States, which subsidizes corn producers.

Corn is used for many different purposes. Over the last fifty years, however, corn has increasingly been used to feed animals. Of all cereal grains, corn provides the highest levels of conversion of dry feed to meat, milk, and eggs, making it the feed ingredient of choice in formulated feeds (Runge and Stuart 1998).

Roughly two-thirds of global corn production is consumed by animals, 20 percent directly by humans, 8 percent in industrial use for food and nonfood products, and 6 percent is used as seed (Runge and Stuart 1998). In addition to its primary use as a feed grain, corn by-products include corn oil, cornstarch, corn syrup, and a few thousand other products. When used as a source of hydrocarbons, corn-based products can be substitutes in any of several chemical processes. Corn can be used to make ethanol as a substitute for petroleum-based fuels or plastics.

Production Systems

The productivity of corn depends on the climate, the fertility of the soil, and the availability of water. Hybrid seeds, fertilizers, pesticides, and improved production methods have also combined to increase productivity as well as the range where corn can be planted. In the United States, production has increased from an average yield of 1,250 kilograms per hectare in 1900 (Runge and Stuart 1998) to more than 8,591 kilograms per hectare by 2000 (FAO 2002). Over the past forty-four years, for example, corn yields have increased on average 49.78 kilograms per year (USDA 1996, as cited in Runge and Stuart 1998).

Plant breeding and hybrids account for 58 percent of yield gains. Hybrid seeds allow corn to be grown in different geographical areas, provide resistance to different corn pests, and permit good yields with different inputs. Mechanical production improvements (e.g. soil preparation, cultivation, no-till, and/or irrigation), as well as herbicides, have allowed individual producers to cultivate ever-increasing areas while reducing labor needs. Pesticides have increased yields by 23 percent by permitting earlier planting dates and season-long weed control. Improvements in fertilizers and their application are responsible for 19 percent of yield increases since 1958 (Runge and Stuart 1998).

Virtually all corn growers in the United States use agrochemical inputs. Synthetic nitrogen fertilizers are applied to 98 percent of the crop. Nitrogen can be applied as manure, ammonium nitrate, anhydrous ammonia, or urea as well as in compound with other nutrients such as potassium or phosphorus. In cooler regions, nitrogen is applied alongside seeds to start and stimulate growth. It can be added later in the middle of rows so that it does not "burn" the crop. Phosphate (the most common form of phosphorus) is added to 85 percent of the crop, and potash (the most common form of potassium) to 73 percent. In addition, some 97 percent of cornfields receive herbicide treatments—the most common is atrazine—and a third are sprayed with insecticides (Kimbrell 2002). Commercial producers throughout the world use similar inputs, and small farmers are using increasing quantities of inputs as well.

In the United States, more than 90 percent of fields are sprayed with herbicide whether the corn is grown as a continuous crop or in rotation with other crops or fallow. By contrast, insecticides are used on some 60 percent of corn grown continuously on the same field, but less than 25 percent of acres receive insecticides when the crop is grown in rotation. In fact when grown in rotation with row crops and other small grains, less than 5 percent of corn acres are sprayed with insecticide (Runge and Stuart 1998).

A number of factors are beginning to reduce yields. As a result of continuous planting in some areas, the crop is susceptible to European corn borer and soil erosion. This has resulted in a 23 percent decline in production. A similar decline is thought to have resulted from several other factors. As the number of genetic varieties of corn planted is reduced, seed corn is increasingly susceptible to diseases and insect pests. For example, in 1970 U.S. corn production was decimated by corn blight. More than $1 billion of corn was lost, and in some places yields were reduced by as much as 50 percent (Kimbrell 2002). In addition, the average input costs have been increasing somewhat in real prices over the last four decades. While fertilizer costs have gone down, the costs of other chemicals have gone up somewhat. Energy costs have increased the most, by more than 50 percent (Runge and Stuart 1998). Considering overall declines in the real price of corn, this has led to greater producer interest in reducing operating costs through a more efficient use of inputs.

Recent breeding improvements of corn have allowed the expansion of the cultivated area by reducing the number of days to harvest, reducing the sunlight and mean temperature requirements, changing the disease resistance, and reducing the overall fertility or water requirements. Almost all of these improvements were done with conventional breeding programs rather than through the development of transgenic varieties. In general such changes have allowed the spread of corn production into colder climates with shorter growing seasons, which is the focus of the United States and European corporate plant breeders.

In the past in dedicated corn production areas, corn was planted after plowing, disking, and harrowing the fields to pulverize the soil. In some cases plowing was done in the fall as a way to allow farmers to plant earlier in the year, to reduce the workload in the spring or to begin the decomposition of the stubble from the year before. Now it is widely known that fall plowing is not good. It leads to soil erosion from wind and water, kills many beneficial soil organisms, and degrades soil structure (Runge and Stuart 1998).

Conservation tillage and no-till planting have become much more common within the last fifteen years or so in the United States, Brazil, and Europe. Drill planters deposit seeds in fields that have been only lightly tilled or not tilled at all. Crop residues are purposely left on the surface as a mulch that gradually decomposes and adds organic matter to the soil. The organic matter holds water and reduces the leaching of fertilizers. A critical constraint to the adoption of such practices is that the farm implements required are different from traditional ones. Therefore the front-end investments needed may be beyond the capacity of undercapitalized producers (Runge and Stuart 1998).

In some parts of the world traditional multicropping and nonmechanized production of corn still dominates the landscape. Increasingly, however, producers plant corn mechanically in monocrop stands. Today corn is the staple food crop for 350 million people living primarily in Latin America and Africa. Corn production is expanding most rapidly in Africa, where it is becoming a basic subsistence crop that also has strong markets for any surpluses.

Globally, about half of the corn produced each year is from hybrid seeds, which must be purchased each year. The rest is from seeds retained each year by farmers. Corn planted from hybrids is more productive, so less land is needed for hybrid corn than for traditional varieties. Most land devoted to hybrid corn is planted as a monocrop using machinery and other inputs. The mechanized production of corn tends to take place on fields that are less hilly and marginal. However, because the mechanized production takes place on such large areas and with few waterways retained, it still causes considerable erosion.

Much nonhybrid corn is planted on highly erodible soils. It is usually interplanted and/or sequentially planted with other crops. Hand cultivation that takes into account the nuances of the lay of the land and quality of the soil in conjunction with polycultural planting systems can reduce the overall erosion from the production of traditional corn varieties. While it is not clear which type of production causes the most soil erosion in absolute terms, it is possible that the traditional production systems create more erosion per kilogram of total production from all crops than more specialized, higher-input production systems.

There are some outstanding questions with regard to the impacts of the different corn production systems. For example, are larger producers, with more animals and more hectares of cropland, able to integrate and manage residual waste streams better than smaller ones? Does the combination of animal and cropping agriculture offer more opportunities for this integration than concentrated and specialized animal and/or cash grain farming alone? While smaller operations may generate fewer wastes in total, the per-hectare generation of wastes on such operations may be larger than those of larger farms capable of greater efficiencies. Opportunities for reuse, such as spreading manure on fields or more precise fertilizer application equipment, may require a larger scale to be economical (Runge and Stuart 1998).

Processing

There are no significant environmental problems on or near farms posed by the processing of corn or corn products. With the exception of parts of Central America where so much corn is consumed directly by humans, processing takes place well away from corn-producing areas and is generally regulated by the laws and regulations that apply to any industry in the country in question.

When fed to animals, corn is normally cracked or ground into flour to aid digestion. While this process produces dust and uses energy, there are few other issues involved in such processing. Such processing is generally done close to feeding sites so that transportation is not a major issue.

Technological innovations over the past twenty-five years or so continue to increase the versatility of corn, not only as food and animal feed but also as an ingredient in a large variety of industrial products and processes. While corn's uses as ethanol, corn starch, and corn syrup are well known, less well known are its uses as a source for xanthan gum, vitamin C, biodegradable packing materials, lactic acid, corncob fuels, automobile paint, plastics, tires, chewing gum, foot powder, surgical dressings, adhesives, and whiskey (Runge and Stuart 1998).

The value of corn is ultimately determined by the demand for the end uses to which its products can be directed. For example, 25.4 kilograms of corn can be used to extract 14.5 kilograms (32 pounds) of cornstarch, or 14.5 kilograms(32 pounds) of corn sweeteners, or 9.5 liters (2.5 gallons) of ethanol. In addition, the remaining by-products can be used to make 5.2 kilograms (11.4 pounds) of gluten feed (at 20 percent protein) and 1.4 kilograms (3 pounds) of gluten meal (at 60 percent protein), plus .73 kilograms (1.6 pounds) of corn oil (National Corn Growers Association 1997, as cited in Runge and Stuart 1998).

Substitutes

Because corn has so many uses, it has substitutes and is a substitute for many products produced from other crops. Similarly, depending on prices or climatic conditions corn is often grown in rotation with other crops such as soybeans.

Ground corn is used in feeds for cows, pigs, and chickens. It is mixed in varying concentrations to either substitute for or to complement soybean meal, sorghum, wheat, fish meal, and cassava.

Sorghum is one of the main substitutes for corn used in animal feed. Sorghum is an excellent feed for animals and is used increasingly for chicken production, especially in the United States (see sorghum chapter). Because sorghum grows in slightly drier conditions and on poorer soils, it is an excellent crop substitute in many countries. In many less-developed countries, particularly in Africa, sorghum is used directly for human consumption, so there is already familiarity with it and the substitution process proceeds more quickly. Seed companies in the United States have developed strains of sorghum that are adapted to drought and to growing conditions in many parts of the world. These companies see production emphasis shifting to sorghum as the world becomes a drier place and as human populations expand into more arid regions.

Soybean meal and cake, cottonseed cake, and wheat are all used to complement or to substitute for corn in animal rations depending on overall price and on the nutritional levels required. (See the chapters on soybeans, cotton, and wheat for more complete discussions of these crops.)

There are several vegetable oil substitutes for corn oil. These include palm, palm kernel, coconut, cottonseed, soybean, sunflower, and canola (rapeseed) oil to name but a few. Developed countries are experiencing a shift from the first five oils listed above, which contain more saturated fats, toward less-saturated oils such as canola and olive oil. Olive oil has a limited market because of its price, so canola production has been increasing rapidly to provide a low-cost alternative. The FAO reported that globally more than 25 million hectares were planted to canola in 1999. The largest producers were China (7.5 million hectares), India (6.0 million hectares), and Canada (4.9 million hectares). These three producers accounted for more than 70 percent of all land devoted to canola production and more than 60 percent of all production (FAO 2002).

Finally, ethanol produced from corn is a substitute for gasoline. The U.S. Renewable Fuels Act of 2000 required that a certain level of all gasoline sold in the United States be from renewable sources. This could increase the yearly demand for ethanol from 6.8 billion liters (1.8 billion gallons) to more than 20.4 billion liters (5.4 billion gallons) per year by the year 2010 (American Corn Growers Association 2000a).

Market Trends

Between 1960 and 2000 corn production increased by 189 percent while the amount of corn traded internationally increased by 484 percent. Corn yields increased by 121 percent during the same period, and prices declined by 57.9 percent (FAO 2002).

In 1900 farmers received 70 cents of every food dollar spent. Today they receive less than 5 cents, and that figure is falling, especially for manufactured products. For example, a farmer receives less than 2 cents for the corn in a $4.00 box of corn flakes. Over the past twenty-five years the prices paid to farmers have remained relatively constant, while consumer food prices have increased by 250 percent.

One of the main issues currently affecting the market for corn is the production and sale of transgenic or genetically modified corn, known as "Bt corn" because it produces *Bacillus thuringiensis* (Bt), a bacterium that acts as a pesticide. At issue is whether Bt corn should be produced, and if so, whether it or products containing it should be labeled. The issue of ingredient labeling is complicated since corn is used in thousands of products.

Ultimately, however, consumers and governments will decide what consumers need to know from packaging. Producers are beginning to catch on as well. As Gary Goldberg, the chief executive officer of the American Corn Growers Association (ACGA), testified before the U.S. Department of Agriculture (USDA) in April 2000,

> For agricultural producers, this debate over GMOs [genetically modified organisms] is not a safety, environmental, or health issue. It is an economic issue. GMOs have become an albatross around their necks, catching them in the middle of a debate between chemical companies, seed dealers, grain exporters, foreign and domestic customers, and U.S. and foreign government officials. Simply put, can farmers afford to grow a crop they may not have a market for? If we had to categorize this debate in one word it is "uncertainty." The uncertainty of not knowing whether our foreign customers will continue to purchase our products because we are dictating to them what they should buy; uncertainty over the issue of segregation and the responsibility for farmers to segregate on the farm, adding considerable expense; uncertainty over liability and who is liable for cross-pollination and contamination; and the uncertainty over corporate concentration and whether only a small handful of companies will control the production and distribution of seeds. These are the issues that concern farmers and they are the reasons that so many farmers have made the conscious decision to reject GMOs for this [2000] planting season.

Goldberg reported that the ACGA, in its own independent survey of members, found that there was a 16 percent reduction in Bt corn planted in 2000 compared to the previous year. A USDA survey found a 25 percent reduction in acres planted to Bt corn for 2000 compared with the previous year.

In short, a minority of producers in the United States, and their political and corporate supporters, are jeopardizing the marketplace for conventional corn producers. The issue is really about markets. In 1997–98 the United States exported 2 million metric tons of corn to Europe. In 1998–99, corn exports to Europe totaled only 137,000 metric tons. U.S. competitors (Argentina, Brazil, and China) not planting GMOs captured the difference. Once again, the issue is complicated. Argentine corn producers are beginning to plant more Bt corn; Brazilians are reportedly planting a great deal of Bt corn illegally; and China may be exporting non-GM corn, but it is importing lower cost transgenic Bt-corn (and transgenic soybeans as well).

Contrary to corporate claims, it is not clear that GMOs actually net more income for producers because seed and technology fees are higher than for conventional corn. On the other hand, producers believe they are saving money on reduced herbicide and insecticide use. They also see higher yields and production efficiencies.

The yield issue is interesting. To date, it appears that Bt corn yields may be 10 percent higher than non-Bt corn yields (American Corn Growers Association 2000b). If all farmers in the United States had planted Bt corn in 1999, the 10 percent increase would have added 238,760,000 kilograms to the U.S. inventory. In all likelihood this would have pushed the average price down to less than 4 cents per kilogram. What financial impact would this have had on farmers who are already finding it hard to survive financially? This situation has the feel of the commodity treadmill that producers throughout the world know so well. Farmers are also concerned that the technology is monopolized by a few companies that will be able to raise prices after producers have converted to the technology and are unable to convert back to other seed varieties.

One thing is clear: Many consumers, particularly outside the United States, do not want to purchase Bt corn or products that contain it. Consequently, on-farm segregation is becoming an important issue. Japanese purchasers (in 1999 the largest purchaser of the United States corn with 398.9 million kilograms) have already warned American producers that they must segregate their crop if they want to continue to sell to Japan (American Corn Growers Association 2000c). This will be very difficult. In addition, many grain elevators are not physically prepared to handle two distinct grain flows. Whoever segregates the crop is likely to incur substantial costs for testing and certification as well as the time to clean out the combine and grain augers every time the product flow shifts from Bt corn to non-genetically modified corn.

Concerns about Bt corn are also found in the United States. Gerber and Heinz baby foods, Wild Oats supermarkets, Seagram's, IAMs pet foods, Genuardi's Family Markets, and Frito-Lay have moved to stop the purchase of Bt corn either in response to or in anticipation of consumer concerns about the product (American Corn Growers Association 2002).

An increasing number of consumers have turned to organic corn products to ease their concerns about food quality in general and to avoid genetically modified products in particular. Certified organic products guarantee that the chain of custody must be traceable from the producer to the consumer. This is much harder to do for traditional versus Bt corn. This is one of the reasons the price of organic corn is high, often twice the price of conventional corn.

But, is organic corn the solution to concerns about genetically modified, Bt corn or even the more sustainable production of traditional corn? It is not clear that the higher price for organic corn offsets its lower production levels and necessary crop rotations with lower-valued crops. While organic may make sense as a long-term strategy, it may not make sense in the short to medium term. It might also be more difficult to produce organic corn if a producer has existing debts for machinery or land. Thus, transitions to organic production may be very difficult to absorb financially.

Finally, it is now clear that for corn (and other genetically-modified crops) pollen can drift very large distances and contaminate even organically grown crops. Some researchers estimate that due to pollen drift very little organic seed, much less organic produce, exists in countries such as the United States.

Environmental Impacts of Production

Most of the environmental impacts associated with corn production occur at the farm level. The most important problems are habitat conversion, soil erosion and overall degradation, leaching of agrochemicals, and pollution of fresh water and groundwater.

Habitat Conversion

Corn is produced in a wide range of settings. In developed countries, corn tends to be produced on the same fields year after year or in rotation with other crops. In these countries any expansion of corn production tends to correspond with a decline in areas used for other crops. There is little habitat conversion for the production of corn at this time, although that was very common during the last 200 years in areas like the United States. Even where major habitat conversion took place decades or even generations ago, corn production is still changing the landscape. As machinery gets bigger, fields get bigger. This means the loss of fencerows and hedges that often were a safe haven for biodiversity. Larger machinery makes it more difficult to disengage to avoid grass-covered waterways. Tilling these areas in the past thirty years has led to increased erosion.

In developing countries corn production is gaining at the expense of other crops. Production is also becoming increasingly mechanized. In addition, however, habitat conversion for corn cultivation is also occurring. This is true of the planned colonization schemes in the greater Amazon region as well as the more generalized displacement of people in Central and South America (e.g. when labor-intensive crops such as cotton, coffee, and other crops were abandoned in favor of cattle). Perhaps the greatest impact of corn production on natural habitats at this time is occurring in Central and Southern Africa, where corn production is expanding more rapidly than anywhere in the world (due to government subsidies) and demand still far exceeds supply.

Soil Erosion and Degradation

Studies in the United States have shown that environmental susceptibility to erosion may or may not be related to overall productivity (Larson et al. 1988). In corn-producing areas of Minnesota, soils vulnerable to erosion and those low in productivity were often not the same lands. In fact, these two types of land were not correlated. However, land that is vulnerable to erosion eventually loses productivity.

A study of soil erosion in the corn belt areas of Iowa, Minnesota, Wisconsin, and Illinois indicates that erosion rates have declined. In 1932 erosion rates were more than 37 metric tons per hectare per year when corn production amounted to only 2.75 metric tons per hectare per year. By 1982 average erosion rates were down to 19.5 metric tons per hectare per year. By 1992, after 18 percent of all arable cropland had been taken out of production (including the most highly erodible areas) through the Conservation Reserve Program (CRP), erosion in the United States was estimated at 14 metric tons per hectare per year while corn production was about 8.6 metric tons per hectare per year (Runge and Stuart 1998).

Just as there is no correlation between a soil's susceptibility to erosion and its fertility, there is no correlation between row-crop cultivation and erosion. Row crops have increased considerably in the United States, for example, from 1930 to the present, precisely when erosion declined. The correlation is between mechanical row-crop cultivation and erosion. No-till and conservation tillage row crops have reduced erosion dramatically. Erosion rates, however, are still well beyond replacement values and consequently are unacceptably high.

Declines in soil erosion result primarily from investments in conservation measures that include terraces, strip cropping, crop rotations, wind breaks, and switching to conservation tillage (reduced tillage and no-till cultivation). By 1994 no-till farming techniques were practiced on about 12 percent of row crop production. Mulch-tillage (in which crop residue is left on the soil surface) and ridge-tillage (in which crop residue is collected in valleys alongside ridges of soil that are planted) were practiced on another 26 percent of planted crops in the United States. This compared with 3 percent in 1984 and zero in 1930. Yet not all reductions in erosion result from producers' practices. Between 1985 and 1992 the U.S. government's CRP program paid producers not to cultivate the most highly degradable areas (Runge and Stuart 1998). This is probably the single most important cause for declining soil erosion.

There have not been widely accepted studies on global soil erosion rates. Anecdotal evidence suggests that erosion is increasing in many areas even though producers know that it will destroy their ability to produce over time. For many, there is no other option. They do not know any alternatives.

Use of Agrochemical Inputs

A range of pesticides are used widely on corn in the United States and elsewhere. Between 1964 (when Rachel Carson wrote *Silent Spring*) and 1991, herbicide use on corn in the United States grew from just under 12 kilograms to just less than 100 kilograms of active ingredients per hectare (Runge and Stuart 1998).

In 1992 nearly 70 percent of the area planted to corn in the United States was treated with the herbicide atrazine (Ribaudo 1993). Cornfield weed suppressants (like atrazine) as a class of farm chemicals accounted for 47 percent of total agricultural pesticide use in the nation in the early 1990s. Weed suppressants were applied to about 95 percent of all corn acres (USDA 1991; 1992). Atrazine persists in soil, however, and moves in surface and ground water. Atrazine is thought to be one of the main contributors to the "dead zone" in the Gulf of Mexico and a major polluter of underground water supplies throughout the corn belt of the United States.

During the same period the rates of application of insecticides more than doubled from less than 1.5 kilograms per hectare to slightly less than 3.5 kilograms per hectare (Runge and Stuart 1998). The important point here, however, is that the composition of the insecticides changed dramatically away from some of the most hazardous chemicals.

Fertilizers are used more commonly in the production of corn than they were 50 years ago. About 95 percent of all corn planted in the United States receives supplemental nitrogen. Fertilizers containing phosphate and potash are used on 75 to 80 percent of all corn. In all, corn accounts for almost half of total fertilizer use in the United States (by comparison, wheat has 14 percent and soybeans 6 percent). Fertilizer use is one of the main causes of water pollution and eutrophication in the United States.

By 1990 the U.S. Environmental Protection Agency estimated that roughly 650 different active ingredients were for sale as pesticides, down from 1,400 previously. However, about 15 to 20 new materials are added each year in the United States (Runge and Stuart 1998).

Worst-case estimates of the impacts of eliminating the use of all agrochemicals suggest yield declines on the order of 53 percent for crops such as corn and 37 percent for soybeans (Knutson et al. 1990). However, according to Ayer and Conklin (1990) it is likely that these estimates "tend to underestimate the ability of producers to substitute other methods of pest and disease control, such as crop rotations, and to more carefully time and apply new and existing chemicals based on when and where they are most needed." Integrated pest management (IPM), cropping management, and precision agriculture are important new approaches, but current technology continues to rely on existing pesticides. Analysis also shows that reductions in the use of pesticides will affect the profits of farms of different sizes in different ways. There is good evidence that pesticides used on medium and especially larger farms are being substituted for other inputs such as labor and mechanical weeding (Runge and Stuart 1998).

A bigger issue, however, is pest resistance. By 2000, producers in the U.S. were using twenty times more pesticides and losing twice as much of their crop to pests as they were in 1950. This was one of the attractions of Bt corn. It produced its own insecticides. However, by as early as 1997, eight insect pests in the U.S. had become resistant to Bt (Conway 1997, as cited in Hawken et al. 1999).

Water Use

Because corn requires large amounts of water, it poses risks of crop failure for producers. One way to avoid the risk is to irrigate the crop. It is expensive to set up irrigation systems on the off chance that water will be needed in a bad year, however. Instead, irrigation systems tend to be set up in areas that are not suited to produce corn with the rainfall that is normally available. Unfortunately, ongoing irrigation is expensive and requires large amounts of water in areas where it draws on scarce water and energy supplies. While most corn grown throughout the world is not irrigated, in the United States corn is the second largest consumer of irrigation water (after alfalfa hay). Over half of all U.S. corn irrigation takes place in the state of Nebraska, where the crop could not be grown profitably, year in and year out, without irrigation. Unfortunately, the Ogallala Aquifer that supplies all the water for this irrigation is fossilized water. This means that the aquifer has a limestone cap, and the water being drawn from it is not being replaced. Eventually the water will run out, but before that the energy costs of bringing it to the surface may become too expensive to produce corn profitably.

Corn production is increasing throughout Asia. In China, corn is displacing other crops such as wheat and even rice. Increasingly, corn is also being grown with irrigation.

Water Pollution

Agriculture was acknowledged recently as the major source of surface water quality impairment in the United States. The USDA's Economic Research Service in 1994 found that agriculture contributed to water quality problems in 72 percent of impaired stretches of river, 56 percent of lakes and 43 percent of estuaries (Runge and Stuart 1998; Faeth 1996; USDA 1994).

Pollution from the Midwestern agricultural states (where corn is the major crop) contributes to an offshore "dead" zone in the Gulf of Mexico. The U.S. Geological Survey (USGS) investigated the sources of pollutants causing the dead zone. They concluded that 70 percent of the nitrogen delivered to the Gulf came from above the confluence of the Ohio and Mississippi Rivers (Alexander, Smith and Schwarz 1995). An estimated 90 percent came from nonpoint sources, primarily agricultural runoff and atmospheric deposition (EPA 2001).

Corn production has had a significant impact on groundwater quality from the agrochemical inputs used in production. The impacts are not well documented. However, half of the U.S. population uses groundwater for its main source of drinking water. It is the sole source for many rural communities.

Cross-Pollination and Contamination by GM Corn

The issues of cross-pollination and contamination by genetically modified corn, and the associated liability issues, will probably drive some farmers away from transgenic seeds. The seed companies claim that corn pollen can drift 107 to 185 meters (350 to 600 feet). However, Neil Harl, an agricultural economist from Iowa State University, has said that pollen can drift over 8 kilometers (5 miles) (American Corn Growers Association 2001). Who is right? Perhaps more importantly, who will be liable? If the seed industry is confident that the distance is 185 meters (600 feet), then they should assume liability for any crossing or contamination beyond that.

GMOs are expected to be a continuous source of concern, but it is their uncontrolled introduction and proliferation that is especially disturbing. Perhaps one of the most important issues is the potential impact of GMOs on microorganisms, upon which so much of sustainable agriculture will depend. Can GMOs change landscapes? Can GMOs pose hazards to the fragile habitats and to wildlife itself? These, too, may ultimately be questions about liability.

Better Management Practices

Given what is already known about reducing the environmental impacts of corn production, it should be possible for conservation strategies to reduce production impacts significantly as well as to increase long-term profits. However, the strategies will have to be site-specific and tailored to different types of production. What will work with capital-intensive, market-oriented producers will be quite different than what will work most effectively with subsistence producers and small farmers who sell surpluses into local markets. Since both types of producers can have significant impacts and since both types of production could be improved, it would be wise to determine which type of production is most common in a biodiverse area before proceeding.

Understanding better management practices (BMPs) for corn cultivation should be the cornerstone of any strategy to reduce the impacts of production. Research on BMPs should identify not only the practices and their social and environmental impacts but also their financial implications. For example, integrated pest management generally improves profits while reducing pesticide applications. Many, if not most, BMPs are being identified, adopted, and promoted primarily to solve a problem for producers or due to market-based incentives to lower producer costs. Reduced environmental impacts are added benefits. For example, the overall reductions in erosion in the United States were not accomplished by growing less corn or other crops. Rather, they came about through investments in a variety of BMPs that include a wide range of conservation measures (Runge and Stuart 1998).

For many producers, however, the critical constraint to the adoption of BMPs may well be that many farm implements are expensive and require up-front investments. Well-capitalized producers must first amortize their existing investments. By contrast, under-capitalized producers may neither be able to adopt new, better machinery or abandon older, obsolete technology for which they have not yet paid.

BMPs could also provide guidance for both what is important to measure and how one might measure nonpoint source pollution, nutrient balances, ground and surface water contamination, as well as other specific measures such as nitrogen use and runoff. In addition, they could be the basis for identifying targets and policies aimed at changing incentives as well as producer practices. All too often, policies are changed after a problem has been discovered rather than implemented earlier in the process in order to prevent problems.

Ideally, BMPs could be the basis for a certification program. However, they would have to be evaluated with measurable targets and indicators to monitor progress in achieving them. Such practices and the measurable impacts could serve both as the target and the yardstick by which to develop and measure policies.

Government can encourage the adoption of BMPs whether the goal is to change the use of specific chemicals or to change land-use patterns. The CRP program is a case in point. Taking some of the most highly erodible land in the United States out of production had two impacts: soil erosion was reduced immediately, and biodiversity increased almost immediately. Government does not need to buy land to ensure conservation. It is far cheaper to buy conservation easements. For example, a program in the state of Minnesota has purchased permanent conservation easements along threatened watersheds to protect critical wetland habitat (Larson et al. 1988).

Finally, it is conceivable that global markets could push for the development of perennial corn varieties that could produce multiple corn crops in tropical areas while at the same time reducing their overall environmental impacts. Given that there would be less private sector interest in such varieties, development would need to be supported by governments. Such developments would certainly not only reduce the overall impacts of corn production but also change what are presently understood to be the better practices.

Adopt Conservation Tillage

Many BMPs save producers time and money. Conservation tillage saves on fuel, labor, and depreciation of farm equipment while improving soil structure and fertility (USDA 1995). Producers reduce mechanical cultivation, and the savings are substantial. A farm of 400 hectares saves 450 person-hours per year, more than U.S.$800 for machinery use and wear and tear, and U.S.$3,250 in fuel savings per year (CTIC 1997). Producers seem to be interested in switching to conservation tillage or no-till production if they do not have huge existing capital investments in machinery and if their land tends to be erodible.

Recent research regarding the impacts of conservation tillage suggests that it can have a significant positive impact on soil biodiversity while reducing erosion and increasing water retention in soil. Studies indicate that it increases earthworm populations two to three times above those in no-till fields, bringing the associated benefits of improved water infiltration, better crop rooting, and increased soil fertility (Scardena 1996). One of the key remaining questions about conservation tillage is: What are its overall impacts regarding herbicide use? One form, no-till, substitutes herbicide use for mechanical cultivation to prepare fields for planting and to control weeds.

BMPs are not found only in high-input forms of agriculture in developed countries. In the humid tropics, corn is cultivated on steep slopes and more marginal areas in the Andes, Belize, and mountainous areas of Mexico. Use of conservation tillage methods there is reducing impacts and increasing producers' yields and income. In Belize, for example, producers are now planting native nitrogen-fixing legumes simultaneously with corn. These plants overtake the corn after it is harvested, protecting the soil from exposure, reducing erosion, fixing nitrogen, and actually reseeding themselves for the next season's crop.

Increase Organic Matter in the Soil

The key to sustainable agriculture is the maintenance or rehabilitation of the soil. Organic matter in the soil is perhaps the single most important issue, as many other factors stem from it. For example, organic matter in the soil can trap or detain major water pollutants and chemicals.

Overall water use in corn production is related directly to the poor water retention of the soils devoted to its production. The main cause for reduced water retention is the depletion of organic matter in the soil where corn is produced. Thus, any buildup of organic matter in the soil will result in a net water savings. The buildup in organic matter will also result in a net savings in fertilizer and pesticide use, because organic matter also reduces nutrient leaching and makes plants more vigorous and thus more pest-resistant. This means that organic debris from the harvest should be the returned to the fields rather than removed for any other purpose. There are now techniques, including adding decomposer microorganisms that can make crop residues decompose very quickly into organic matter within the field itself. Conservation tillage, described above, is one of the ways to increase soil organic matter in corn production.

Use Microorganisms to Break Down Waste and Excess Nutrients

With organic matter present, microbial biodiversity can begin to decontaminate pollutants in the soil. It may be possible to undertake limited bioremediation using effective microorganisms in freshwater systems, but care should be taken before releasing alien microorganisms into such environments. They do, however, have the ability to convert nitrates into other forms of nitrogen that could become useful nutrients for other organisms. Pesticides can also be acted upon by microorganisms to change their toxicities or to detoxify them entirely. Sulfur and iron radicals can be converted by these organisms to become useful substances for other life forms.

Reduce Use of Fertilizers and Pesticides

In the cases of both pesticides and fertilizers, application timing and methods can greatly influence total use levels. More precise application of pesticides, and their increased efficiency, has resulted in continual increases in yields in the 1990s even as total pounds applied of active ingredients per area of land cultivated has fallen. Lin et al. (1995) report that switching from preplanting to after-planting applications and from broadcast to band applications can reduce nitrogen use by 4.5 to 64.8 kilograms per hectare.

The recommended use of nitrogen, for corn and for other crops, is often based on monocrop trials rather than on crop rotation systems of production. Researchers have found that with typical crop rotations, nitrogen applications can be reduced as much as 34 kilograms per hectare (30 pounds per acre) below the manufacturer's recommended rate (Vanotti and Bundy 1994, as cited in Runge and Stuart 1998). Not only is this a savings to farmers, it means that less fertilizer will be put into the ecosystem to pollute it.

In a study of continuous corn cultivation in Iowa, it was found that the herbicide atrazine was less concentrated in drain tiles under fields if it was applied in narrower bands than if it was spread over the entire crop. Banding allowed producers to apply one-third less (Kanwar and Baker 1994).

Biological substitutes for chemical pesticides (e.g. sex-linked insect attractors) can also be effective. These should be added to the options of producers around the world as well as encouraged by the various groups that work with them. As such measures become more common, their costs are far cheaper too. Microorganisms, for example, have proven to be a valuable disease control solution that is becoming cheaper as well. PlantShield (Trichoderma harzianum) and Mycostop (Streptomyces griseoviridis), manufactured by BioWorks, Inc. and Kemira Agro, respectively, are labeled for control of a number of vegetable crop diseases (Reid 2002). All these approaches can be developed further and applied more broadly. The application of some of these approaches can even reduce the use of some chemical inputs by making them more effective by reducing pest resistance to them.

Use Crop Rotation

The same crop cannot be grown continuously on the same piece of land year after year without causing serious damage and serious problems. The most successful low-cost, long-term corn production systems include crop rotation. Such rotations should include not only cash crops but also nitrogen-fixing legumes and high-biomass-producing plants as well so as to introduce more organic matter into the soil. Rotations are normally three to four years, but in some cases with organic producers, corn rotations can be five or six years and involve corn, soybeans, oats, hay, and fallow. In these systems corn is produced only every five years. The overall profitability of such operations depends not only on the value of all the different crops, averaged over the rotation, but also on the reduced input costs associated with continual monocropping of the same crop.

Crop rotations can be shortened if clover or other legume cover crops are sown when oats or wheat are planted and then allowed to grow for the remainder of that crop year, effectively getting two crops in one year. In the tropics, two to three sequential crops (e.g. those grown in the same year) are normally part of multiyear rotations.

Such rotations are not only undertaken by organic producers. In Brazil corn producers regularly have corn-soybean-cotton rotations. Within any given year, grass or other off-season crops are planted to increase the biomass. These crops are sprayed with weed killer, but the total amount of pesticides and fungicides used on such crops is half that of traditional producers in the area. In addition, these production systems are allowing smart, forward-looking producers to buy up degraded pasture land and rehabilitate it within four to five years. In effect, they are making as much money rehabilitating land as they do from growing marketable products.

Outlook

The projections for increased consumption of animal protein, particularly in developing countries, imply an increase in demand for animal feed. At this time, no other feed is as important as corn for increasing the production of beef, pork, or poultry. Since most of the demand is coming from developing countries, it is possible, if not likely, that many producers in developing countries will abandon the production of traditional food crops in an attempt to capture some of the increasing market for corn for animal feed. With current price supports and subsidies for U.S. corn, it will be hard for producers in most developing countries to compete even on domestic markets in their own countries, unless their countries erect market barriers of their own.

The one possible bright spot for producers in this scenario is that current demand projections indicate that developing countries will need supplies of corn that are equal to the total current annual U.S. production. However, this most likely means that increased corn production may well reduce the production of traditional food crops. This will have a disproportionate impact on those who cannot afford to eat meat or other animal proteins on a regular basis.

Corn is grown throughout the world in both temperate and tropical areas, coastal areas and highlands. As a consequence, the production of corn causes a wide range of environmental impacts. These can include soil erosion and degradation as well as intense use of pesticides, fertilizers, and water. In all likelihood, global corn production will increase dramatically as demand increases for animal feed grains. At the same time, increasing efforts will be made to reduce pollution from corn production, first in developed countries but later in developing countries as well. It is not obvious that the attempts to reduce the impacts of corn production will be sufficient or timely enough to offset rapidly expanding production.

Resources

Web Resources

maize.agron.iastate.edu
www.corn.org
www.grains.org
www.acga.org

Additional resources can be obtained by searching on "corn" or "maize" on the WWF International Intranet:
http://intranet.panda.org/documents/index.cfm

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