GLOBAL DEVELOPMENT AND ENVIRONMENT INSTITUTE

WORKING PAPER NO. 03-06

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June 2003

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Abstract

The North American Free Trade Agreement (NAFTA) had a profound impact on corn trade between the United States and Mexico. Negotiated tariff reductions and the Mexican government's decision not to charge some tariffs to which it was entitled resulted in a doubling of US corn exports to Mexico. This paper examines the environmental implications of this change on both sides of the border.

For the US, increased exports to Mexico due to trade liberalization represent one percent of total US production and should therefore be considered responsible for one percent of the environmental impacts of corn production. These are considerable, including: high chemical use; water pollution due to runoff; unsustainable water use for irrigation; the expansion of genetically modified corn; soil erosion; and biodiversity loss. Trends in these areas are presented. For Mexico, the principal potential environmental impact of the loss of a significant share of its domestic corn market to the US is the threat to agro-biodiversity. Preliminary evidence is presented on the extent to which imports and declining prices are reducing the production of native corn varieties. The authors conclude that shifting corn trade under NAFTA is having significant negative environmental effects on both sides of the border and could have even more profound impacts in the future if it results in the loss of significant agro-biodiversity in Mexico.

[1] A version of this paper appears in a forthcoming collection from the North American Commission for Environmental Cooperation, which commissioned the research: *Trade and Environment in North America: Key Findings for Agriculture and Energy* (Montreal: CEC, 2003). It is reprinted here with permission.

1. Introduction

It has been nearly ten years since the North American Free Trade Agreement (NAFTA) took effect, and many questions about its environmental and social impacts have not yet received definitive answers. Indeed, it is not always clear where to look for answers. Aggregate assessments covering all the impacts of NAFTA on one or more of the member nations raise complex methodological problems, involving major economic models that are far from transparent (Gallagher et al. 2003). At the other extreme, journalistic accounts present only anecdotal evidence on the most visible impacts, which are often difficult to evaluate due to lack of comprehensiveness. An attractive alternative is to examine impacts at an intermediate level of aggregation, focusing on a single industry or commodity. This study attempts to pursue that alternative.

One of the largest and most environmentally significant changes since the implementation of NAFTA was the shift in the corn trade between the US and Mexico. US exports to Mexico rose from 3.1 million metric tons in 1994 to 5.2 million tons in 2000, or from 1.2% to 2.1% of the US corn crop. [2] From Mexico's perspective, imports from the US rose from 14% to 24% of total corn consumption between 1994 and 2000 (FATUS 2001). In monetary terms, US corn exports to Mexico were worth just over $500 million in 2000, which is 0.5% of all exports, or 8% of agricultural exports, from the US to Mexico (BEA 2001a). But the unique nature and significance of corn production in the two countries make it of central importance in evaluating the impacts of NAFTA.

This study explores the environmental impacts of the changes in the US-Mexico corn trade under NAFTA. Section 2 briefly describes the significance of corn production and consumption in the two countries. Section 3 presents positive and negative impacts on the US, and Section 4 does the same for Mexico. Section 5 offers conclusions and recommendations.

2. The Importance of Corn

Corn is an extremely important agricultural product in both countries. In the US corn is a huge crop, with annual sales around $17 billion, or 9% of the value of all agricultural output (NASS 2000). It is the most valuable agricultural product and accounts for more than a quarter of all farm receipts in the states of Iowa, Illinois, and Indiana, in the heart of the "corn belt"; it is among the top two or three farm products in many neighboring states (ERS 2001).

[2] This is not an artifact of the choice of years: exports to Mexico averaged 0.9% of US corn production in 1990-94, and 1.9% in 1995-2000. Note that this report uses metric units throughout, e.g. metric tons or kilograms for weight, and hectares for area. Unless otherwise noted, monetary amounts are in current US dollars.

In terms of total acreage nationwide, corn is similar to soybeans and far ahead of all other crops:corn occupies 28 million hectares, more than 20 percent of all US harvested acreage, or about 3.7 percent of the total area of contiguous 48 states. Corn and soybeans are often grown in rotation; together they account for more than 40 percent of harvested acreage, or 7.5 percent of the area of the contiguous US (Anderson et al. 2000).

Corn exports account for roughly 20% of the corn crop, or $5 billion in sales (FATUS 2001). The US is by far the world's largest corn producer and exporter, accounting for 40% of world production and 66% of world exports in 1999; in the same year Mexico accounted for 3% of world production and 7% of world imports (FAOSTAT 2001). In 2000 Mexico was second only to Japan as a market for US corn, absorbing 11% of US exports (see Figure 5 in section 3.2, below).

In Mexico corn production accounts for over two thirds of the gross value of agricultural production. Corn covers half of the total area under cultivation for all crops (DIAGRO). Roughly 3 million people are employed in the cultivation of corn, more than 40 percent of the labor force involved in agriculture or about 8 percent of Mexico's total labor force (Nadal 2000).

Mexico has the world's second highest annual per capita corn consumption (127 kg), after Malawi (Morris 1998). The pattern of consumption in Mexico is distinct from the US and other industrial countries since 68% of all corn is directly used as food. In the world as a whole, just 21% of total corn production is consumed as food. In industrial countries, including the US, corn is more often used as livestock feed or as an industrial input – a trend that is just beginning to appear in Mexico.

In Mexico maize is the basic staple food for human consumption. One study found that on average about 59% of human energy intake and 39% of protein intake was provided by maize grain in the form of "tortilla" (cooked corn dough) (Bourges, 1992 in Turrent-Fernandez et al. 1997). Five thousand years of maize domestication has generated more than 40 races of maize specialized for direct human consumption. By contrast, in the last hundred years, the industrialized countries have specialized in developing maize for animal consumption and industrial use (CIMMYT 2001).

Mexico is the ancestral home of maize, and possesses a unique and irreplaceable genetic diversity of varieties, or landraces. Most of the country's corn production comes from traditional landraces cultivated by peasant farmers from seeds that they preserve from their own crops and from the exchange of seeds with neighbors in their communities (Serratos-Hernández et al. 2001; Wilkes et al. 1981). Such *in situ* conservation of maize genetic resources is considered essential to the long-term security of this important food crop, which has particular economic value because it serves as the basis for crop breeding (Brush 2000).

3. Impacts on the United States

As noted in Section 1, the changes since the adoption of NAFTA have resulted, in round numbers, in an increase in exports to Mexico from 1% to 2% of total US corn production. Thus the growth in trade amounts to an additional 1% of the US corn crop, and can be credited with 1% of the impacts of corn production, both positive and negative, in the US. For this paper, we use a broad approach in assessing NAFTA's impact, which is based on the assessment that NAFTA cannot be usefully separated from the set of trade liberalizing policies of which it is a part. Indeed, NACEC in its analytical framework calls for a broad interpretation of NAFTA's economic and environmental impacts, noting that even where the agreement did not have a direct effect it may have stabilized and reinforced trends already underway (NACEC 1999). Some analysts attribute a smaller portion of rising US exports to NAFTA, arguing that some of these increases would have occurred even without the tariff reductions under NAFTA. (See, for example, Zahniser and Link 2002; Porter 2003.) While recognizing the usefulness in some instances of isolating those impacts that are directly attributable to NAFTA's provisions, we adopt the broader approach in this study.

3.1 Environmental Impacts: Fertilizer, pesticides, irrigation

Increased exports to Mexico after NAFTA have affected the environment, as well as the economy, of the US farm states. The additional 1% of the crop sold to Mexico after NAFTA – and after the broader set of trade liberalizing policies of which the trade agreement is a part – can be considered responsible for 1% of the environmental impacts, as well as the economic impacts, of US corn production. The principal exception to this "1% rule" is the complex question of genetically modified (GM) corn, where sales to Mexico assume a greater importance because Mexico has remained open to GM grains while significant other markets have rejected them.

The environmental impacts of corn production have been extensively studied; see Runge (2002) for a thorough presentation and literature review. Major issues of concern examined in this report include:

- agrochemical impacts resulting from fertilizers, herbicides, and pesticides;
- potentially unsustainable levels of irrigation; and
- the introduction of genetically modified organisms and effects on biodiversity.

This section addresses the first two categories, while Section 3.2 examines the use of genetically modified corn. In Section 3.3 we briefly note two additional areas of environmental impact: soil erosion and biodiversity.

Agrochemical Impacts

US agriculture in general, and corn production in particular, rely on intensive application of fertilizers, herbicides, and insecticides. While these chemicals make a major contribution to agricultural productivity, they also create problems of water pollution, with risks to human health and natural ecosystems. In particular, runoff of excess nitrogen and phosphate fertilizer contaminates surface and groundwater supplies, by promoting algal growth which reduces the dissolved oxygen content (hypoxia) in the water making it difficult for fish or other wildlife to survive. The great quantities of nitrogen carried by the Mississippi River have been implicated in the large "dead zone" in the Gulf of Mexico where ocean life has been killed off (Keeney and Muller 2000; Runge 2002; Goolsby et al. 1999). Corn production is a major contributor to this effect both through direct nitrogen runoff from fertilizer application on farms and through the use of corn as a feed for livestock whose manure contributes to water pollution.

Atrazine, the most common herbicide used in corn production, among other crops – and the most common pesticide detected in groundwater nationwide – is an endocrine disrupter and possible human carcinogen (it causes cancer in rats). Exposure to atrazine creates risks for farm workers, consumers of corn products, and users of groundwater downstream from farm areas (EPA 2001a; Repetto and Baliga 1996; Ribaudo and Bouzaher 1994; Briggs 1992). Metolachlor and S-Metolachlor, both leading herbicides that will be discussed later, are possible human carcinogens (EPA 2000; Briggs 1992). Chlorpyrifos, the most common insecticide used on cornfields, is a neurotoxin that poses risks for children who are exposed to it at high levels; it is also used on other foods, and for residential cockroach and termite control (EPA 2001b; Briggs 1992).

USDA's National Agricultural Statistical Service (NASS) publishes annual reports on the use of agricultural chemicals by state, with coverage varying by crop and year. For 2000 the report covered the 18 top corn-growing states, accounting for 93% of production. It found that nitrogen fertilizer was applied to 98% of planted corn acreage, compared to 84% for phosphates and 66% for potash, the three major varieties of fertilizer. Herbicides were applied to 97%, and insecticides to 29%, of corn acreage. Total quantities of chemical use, and chemical intensities (total quantity of chemical divided by total planted area), are shown in Table 1.

Table 1
Chemical Use in US Corn Production, 2000

	Total Use (thousand metric tons)	Intensity (kg/hectare)
Nitrogen	4,423.7	148.18
Phosphate	1,577.4	52.84
Potash	1,716.3	57.49
Herbicides	69.6	2.33
Insecticides	4.5	0.15

Source: USDA, National Agricultural Statistics Service

Four important conclusions emerge from these reports, and are explained below:

- Corn is more chemical-intensive than soybeans or winter wheat, by every available measure;
- The fertilizer intensity of corn production has been constant or increasing since 1994;
- The herbicide intensity of corn production has dropped sharply since 1994;
- The insecticide intensity of corn production has changed little, despite the introduction of GM corn which was expected to result in declining insecticide use.

The USDA reports on agricultural chemical use allow a comparison of corn with soybeans and winter wheat, the other two leading field crops. If somewhat less corn had been grown, it is possible (though of course not certain) that the same land might have been used to produce more soybeans or wheat. In every case where a comparison is possible, a switch to soybeans or wheat would have reduced chemical use, as shown in detail in Table 2. The point of this large table is simply that the ratio of chemical use in soy or wheat to chemical use in corn is always less than 1.0.

Table 2: Kg/hectare of agricultural chemicals
Ratio of other leading crops to corn in leading corn states

	Ratio: soy/corn				Ratio: wheat/corn			
	nitrogen	phosphate	potash	herbicides	nitrogen	phosphate	potash	herbicides
CO					0.25	0.07		0.10
IL	0.01	0.11	0.30	0.40	0.53	0.89	0.75	0.01
IN	0.01	0.15	0.33	0.35				
IA	0.06	0.25	0.25	0.61				
KS	0.02	0.20		0.44	0.36	0.65	0.11	0.02
KY	0.04	0.40	0.45	0.49	0.52	0.58	0.63	0.04
MI	0.05	0.48	0.89	0.39				
MN	0.01	0.06	0.31	0.66				
MO	0.04	0.40	0.31	0.54	0.56	0.79	0.95	0.02
NE	0.03	0.28	0.53	0.63	0.29	0.63		0.07
NC	0.08	0.90	0.47	0.31	0.92	0.43	0.59	0.12
ND	0.15	0.37		0.91				
OH	0.03	0.25	0.54	0.35	0.59	0.91	0.82	0.02
SD	0.06	0.42	0.33	0.82	0.46	0.55	0.11	0.23
TX					0.32	0.35	0.70	0.08
WI	0.05	0.32	0.67	0.43				
Average	**0.05**	**0.33**	**0.45**	**0.52**	**0.48**	**0.58**	**0.58**	**0.07**

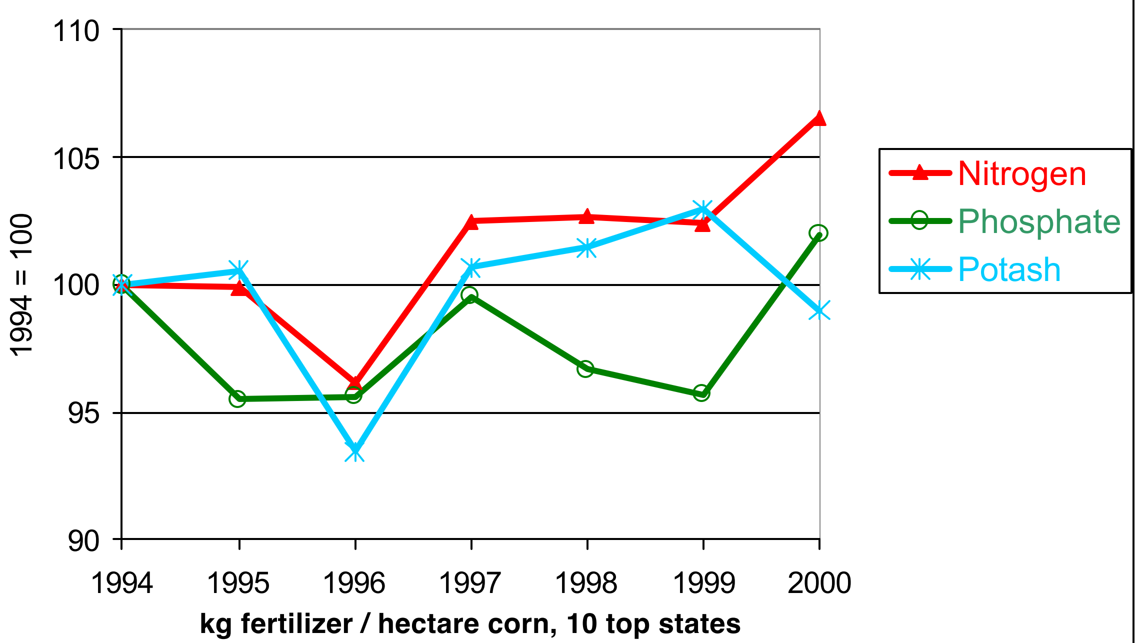
Source: USDA. National Agricultural Statistics Service

More precisely, Table 2 compares chemical intensity, by state and chemical. Intensity is measured as the state average chemical use – for example, the total quantity of nitrogen fertilizer applied to corn in Iowa, divided by the total planted area of corn in Iowa. Crops are compared within the same state to control for regional differences: for example, Kentucky and Ohio are above average in phosphate fertilizer intensity for all three crops, while South Dakota, Nebraska, and Kansas are below average for all three. Data were available for soybeans grown in 14 of the top corn states, and for wheat in 10 of the states. Insecticide use was not reported for soy or wheat production, and potash data was missing in a few cases.

In all, there are 92 comparisons in Table 2 – every one of which shows lower chemical use in soy or wheat than in corn. The averages show that there is little nitrogen fertilizer applied to soybeans, and little herbicide applied to wheat. The other ratios average from 33% to 58% -- that is, the other crops have from one-third to somewhat less than two-thirds the chemical intensity of corn.

Turning to changes over time, consistent data on chemical use are available for every year from 1994 to 2000 for the top 10 corn producing states. Changes in fertilizer intensity for the 10 states as a whole are shown in Figure 1. The nitrogen intensity of corn production is increasing by about 1% per year, while there is no discernible time trend to either phosphate or potash intensity. These patterns are consistent with longer-term trends – over several decades, nitrogen use has been rising while phosphate and potash use have been roughly constant (Runge 2002). This implies that the serious, long-term problems of nitrogen runoff and its impacts on ground water in general, and the Mississippi River and the Gulf of Mexico in particular, are only getting worse, albeit gradually.

Figure 1: Fertilizer Intensity of U.S. Corn, 1994-2000

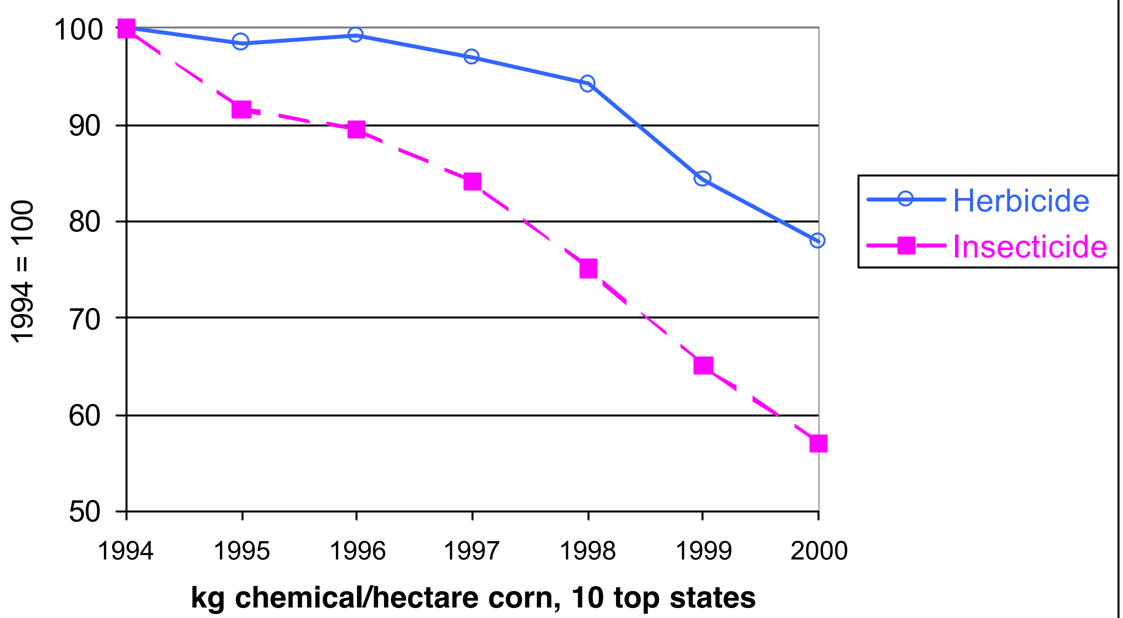


Source: USDA, National Agricultural Statistics Service
http://usda.mannlib.cornell.edu/reports/nassr/other/pcu-bb/agcs0501.txt

The picture is somewhat different for pesticides, as seen in Figure 2. The intensity of herbicide use has dropped steadily and sharply, with the intensity as of 2000 falling just below 80% of the 1994 value. For insecticides, the apparent drop to under 60% of the volume/hectare turns out to be misleading, as the toxicity of insecticides has increased, allowing lower application quantities to deliver the equivalent chemical intensities.[3]

For herbicides, the decline results from the ongoing process of innovation and change in the chemical industry (Benbrook 2001b). Of the herbicides used to treat corn, atrazine alone accounts for 35% by weight, while a group of chemicals called acetanilides account for another 40%; no other single category has nearly as large a share of the market. Innovation has occurred within the acetanilides, with new chemicals replacing similar older ones.

Figure 2: Pesticide Intensity of U.S. Corn, 1994-2000



Source: USDA, National Agricultural Statistics Service
http://usda.mannlib.cornell.edu/reports/nassr/other/pcu-bb/agcs0501.txt

Most of the reduction in the quantity of corn herbicides in the late 1990s is due to the introduction of S-metolachlor in March of 1997 and the reduction in the use of metolachlor. This tongue-twisting change has a simple and important meaning. Old metolachlor contains equal quantities of an S-isomer and an R-isomer. Both have similar

[3] Insecticide data were modified to correct an apparent error in the Illinois report for 1997, which was large enough to visibly affect the national trend. As reported, the insecticide intensity of Illinois corn in 1997 was roughly twice the level for both 1996 and 1998. The data used in Figure 2 assume that the true 1997 intensity for Illinois was the average of the 1996 and 1998 intensities.

impacts on humans and other mammals, and similar ecotoxicological properties in general, but the S-isomer is much more effective in killing weeds. S-metolachlor, as marketed today, is five-sixth S-isomer molecules, as opposed to half in old metolachlor. The manufacturer (formerly Novartis, now Syngenta following a corporate merger) worked closely with EPA to phase out old metolachlor and replace it with S-metolachlor, while informing farmers that they should use 35% less of the new chemical than the old (EPA Tolerance Report 2003).

However, these environmental gains may be undercut by the EPA's reversal on its decision to ban metolachlor. Cedar Chemical and SipCam applied for permits to produce low-cost, generic versions of the old metolachlor, disparaging environmental benefits of the new product and claiming that Syngenta's introduction of S-metolachlor was anti-competitive and monopolistic. The EPA ruled in March 2002 that Cedar Chemical could produce metolachlor even though there is a less toxic and equally effective alternative (Werner 2002). This is likely to undermine the environmental gains of the 1990s because the metolachlor produced by Cedar Chemical is expected to be cheaper than S-metolachlor while, as explained above, it is more toxic (Benbrook 2001b; Cedar Chemical 2001).

The apparent dramatic decline in insecticide intensity in US corn production raises hopes that another technological innovation – the introduction of GM corn – may have resulted in some environmental benefits. The data, however, are misleading. The toxicity of leading pesticides has increased significantly over time, allowing farmers to apply lower volumes to deliver the same active ingredients. The apparent decline is largely the result of this rising toxicity. Alternative measures of insecticide use, such as number of acre-treatments, suggest that insecticide use has remained roughly the same or even risen slightly. Several studies suggest that the introduction of GM corn, in particular Bt corn engineered to control the European corn borer, has not produced the insecticide reductions seen for some other GM crops (Benbrook 2001c; Heimlich 2000; Clark 2003).

Irrigation

Many parts of the United States, including most of the leading corn states, have ample rainfall for production of crops such as corn. However, agriculture has also expanded into dry areas where irrigation is necessary. Well-publicized problems concerning irrigation include the unsustainable rate of withdrawals from the Ogallala Aquifer, and conflicts over the scarce and overused water from western rivers. A significant fraction of corn is grown in areas

Table 3
Corn: Total and Irrigated Harvested Area, 1997

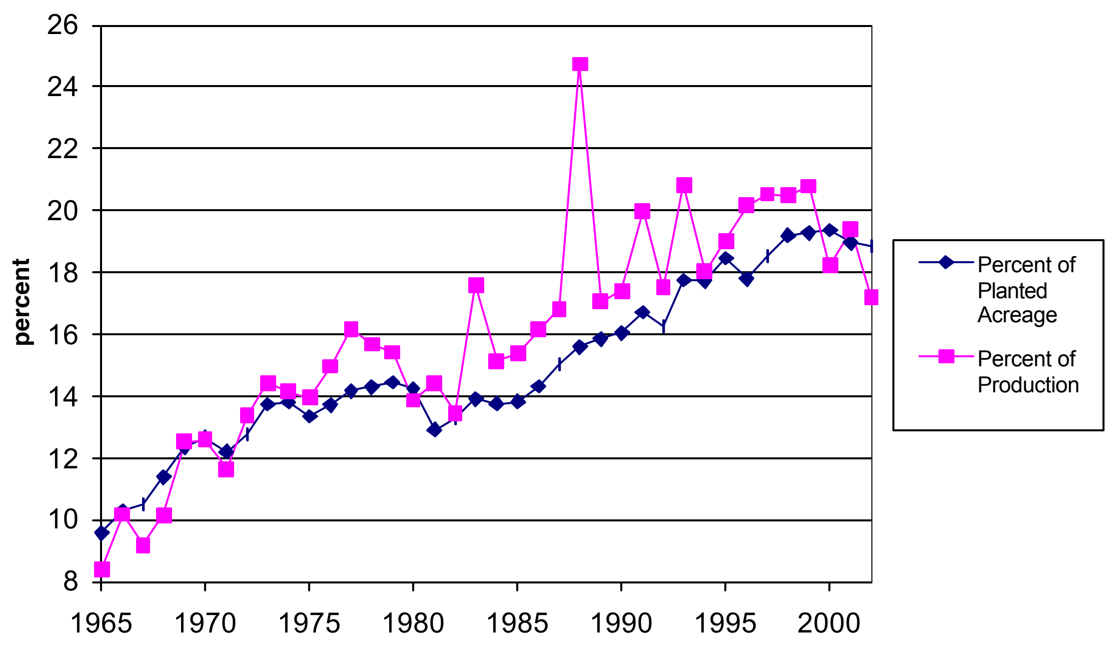
	Harvested area (thousand hectares)		
	Total	Irrigated	Percent Irrigated
Nebraska	3,351	2,010	60.0%
Kansas	1,011	593	58.7%
Texas	670	353	52.6%
Colorado	372	311	83.7%
Subtotal	5,404	3,267	60.5%
All other states	22,843	1,038	4.5%
US Total	28,247	4,306	15.2%

Source: USDA 1997 Census of Agric., www.nass.usda.gov/census/ Table 26, pages 436-437 facing these problems (Opie 2000; NRC 1996).

The 1997 Census of Agriculture found that 15% of corn (measured by harvested area) is irrigated. More than three-fourths of the irrigated corn is located in four states, as shown in Table 3. In Nebraska, Kansas, Texas, and Colorado, 60% of all corn is irrigated; in the rest of the country, the proportion is less than 5%. All four of the irrigation-intensive states are located over the Ogallala Aquifer.

Annual data on irrigated corn production are apparently not available. The 1992 Agricultural Census showed 13.9% of corn acreage was irrigated, implying a gradual rise in irrigation through the mid-1990s. For more recent estimates, Table 3 suggests that production in the four "irrigation states" is a good proxy for the extent of irrigation. Interestingly, as Figure 3 shows, between 1993 and 1998 there was an increase in the share of US corn planted in these four states, from about 16% to about 19%. (Production figures have fluctuated more widely, mainly due to climatic conditions.) Though the dry-state share leveled off at about 19%, the increase is the most recent rise in an irregular but long-term trend toward increasing corn production in the drier states. In 1965, the proportion was about 9%.

Figure 3: Dry State Corn Production and Planted Acreage CO, KS, NE, and TX as a percent of US, 1965-2002



Source: National Agricultural Statistics Service, USDA

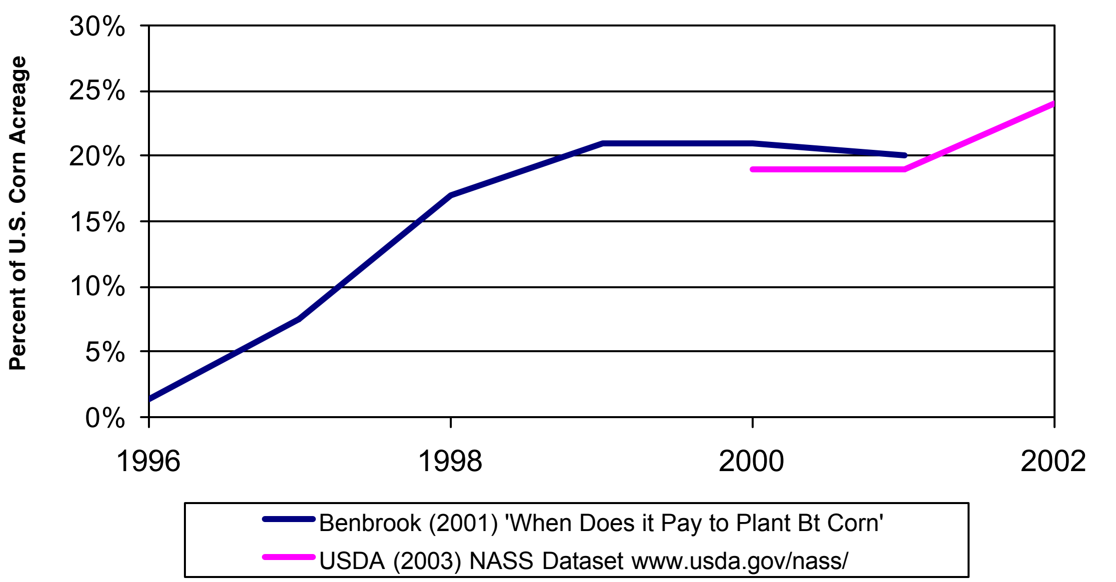
As we will see in the next section, the rising share of dry-state production may be associated not only with unsustainable water use, particularly from the Ogallala, but also higher rates of insecticide use and Bt corn adoption, since the corn borer thrives in warmer, drier climates.

3.2 Environmental impacts: Genetically modified corn

The most widely discussed recent change in US corn production is the introduction of genetically modified (GM) corn, also called Bt corn. This variety of corn contains genes from the soil bacterium *Bacillus Thuringiensis* (Bt) that produce toxins that kill certain insect pests, particularly the European corn borer and the Southwestern corn borer.

Bt corn was developed in the 1980s, won its first regulatory approvals in 1992-93, and was first planted on a significant scale in 1996. It rose from 1.4% of planted area in 1996 to 24% in 2002. The USDA only began keeping reliable data on Bt adoption rates in 2000, but other sources suggest the adoption rates in earlier years. As Figure 4 shows, adoption rates increased dramatically in the early years, leveled off briefly, and seem to be increasing again.

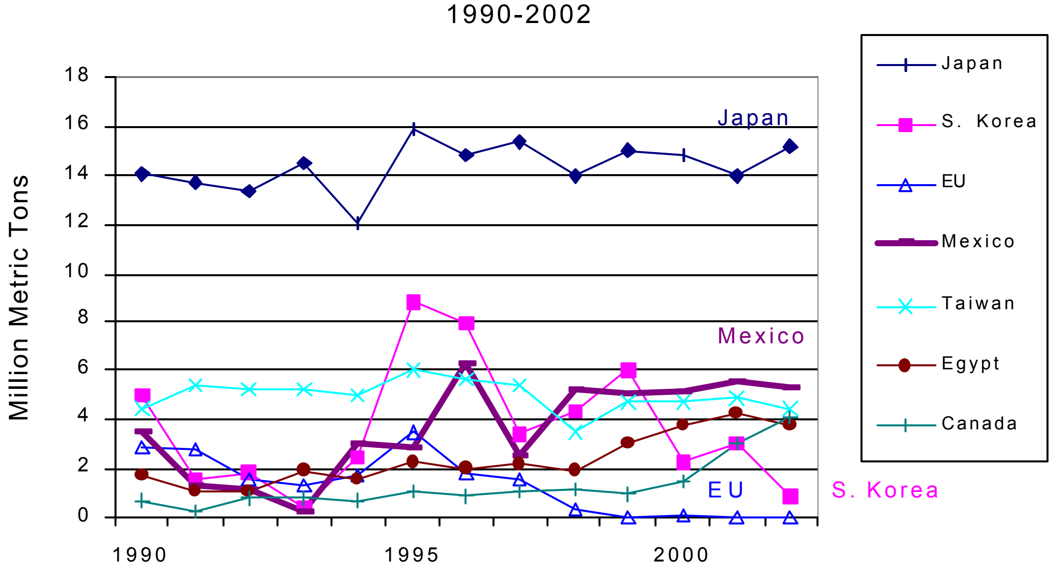
Figure 4: Bt Corn Adoption Trends 1996-2002



The debate on the safety and environmental impacts of biotechnology is still heated and unresolved. Many academic researchers, environmentalists, and GM critics have raised concerns about the impact of Bt corn on other species, on biodiversity in general and, on human and animal health. In a study for the Henry A. Wallace Center, Ervin et al. (2000) suggest that the genes may be transferred into wild relatives, which would reduce biodiversity and create herbicide, insect or viral resistance in weeds. In addition, the Bt toxin may have adverse effects on non-target organisms like butterflies or beneficial insect populations that help control pests. Matt Rand at the National Environmental Trust warns that biotechnology may have many unintended consequences which include allergic reactions and plant toxicity. In addition, he cautions that Bt produced from corn may accumulate in the soil (unlike organic spraying of Bt) and that the use of Bt corn will create pesticide resistance, thereby reducing the effectiveness of Bt as an organic pesticide (Rand 2001).

These concerns suggest the need for a precautionary approach to the commercial introduction of GM crops. The European Union applies the precautionary principle (that crops must be proven safe before being approved), whereas the US Environmental Protection Agency has a much lower burden of proof, often approving new GM crops when little information is known (Ervin et al. 2000).

Figure 5: U.S. Corn Exports to Selected Countries 1990-2002



Source: USDA, Agricultural Statistics Service (2003)
www.usda.gov/nass/

International concerns about GM safety have affected the US export markets for corn. Figure 5 shows the history of US corn exports to seven major markets. International market shifts have decreased the demand for US corn exports throughout the 1990s and early 2000s, making Mexico a more desirable market. In the early 1990s, the break up of the Soviet Union and the creation of the newly independent states caused demand to drop. This drop was temporarily offset by increases in South Korea, and Japan in 1995 and 1996. However, after 1997 exports to South Korea and to the European Union dropped off, largely due to controversy over genetically-modified corn.

As recently as 1996 the United States exported over $305 million worth of corn to the EU, mostly to Spain and Portugal. But in 1998, only two years later, that figure had fallen to $36 million or about 12 percent of the 1996 level. The trend has continued, with US exports falling to $8 million in 2000, and $2.7 million in 2002 (USDA Economic

Research Unit, FATUS database). Consumer doubts about the safety of these new corn strains, combined with the lack of adequate labeling systems to guarantee separation from the non-GM varieties, have encouraged EU importers to look elsewhere for their corn. (USDA 2001; Hepher 1998; ICTSD 1998a and 1998b). Before EU registration of a particular GM product, scientific studies must prove that it is safe and will not disrupt ecosystems. Since 1999, there has been a de facto moratorium on commercial licensing of GM products until relevant legislation is revised on labeling and registration. However, the US has recently challenged that position by requesting WTO consultation on the issue (EU Trade News 2003).

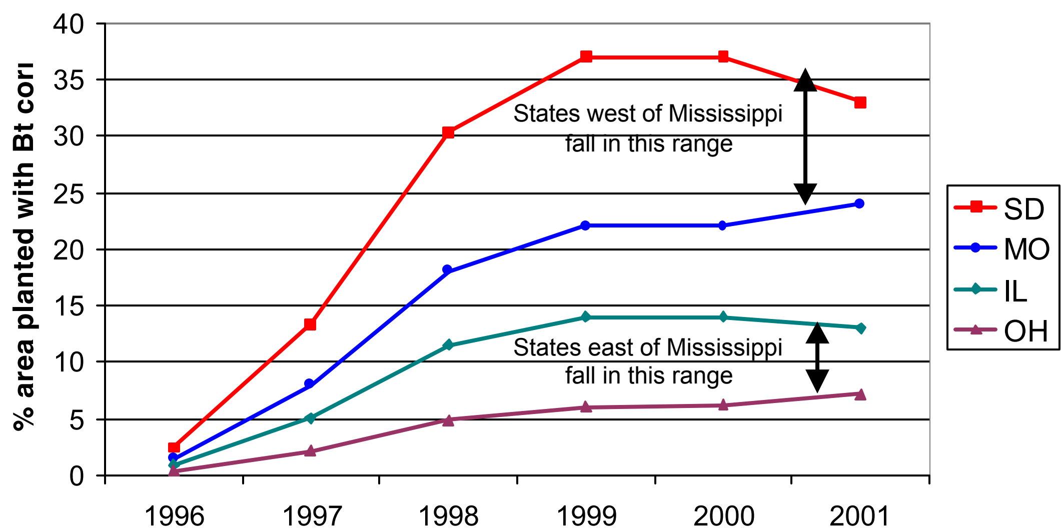
Concerns about GM safety have also eaten into the South Korean export market. South Korea strongly reacted to the Starlink incident – when corn that was not registered for human consumption appeared in food products – and exports to South Korea dropped sharply in 2000 and 2002. In 2000, South Korea recalled 32,000 to 75,000 pounds of US-made tortillas, even though the company that made the products (Mission Foods) insisted it sold only wheat products in Korea, not corn products (CNN 2000a). In 2002 South Korea implemented mandatory labeling of genetically-modified food products, including biotech corn and soybeans, which has likely caused a drop in purchases from the US (Vazquez 2003).

Japan has also shown a strong reaction to the Starlink incident and to GM corn in general, but negotiations have prevented the erosion of the United States' most important export market. Japan severely limited US imports of corn in the first quarter of 2001 because of fear that StarLink tainted supplies. Japan has strict rules about biotech crops and does not allow StarLink even in livestock feed (CNN 2000b). To allay widespread concern over the issue, the United States and Japan agreed on testing procedures to ensure that corn being shipped to Japan to be used in food contains no StarLink (CNN 2000a). In April 2001, mandatory labeling took effect for all approved food products containing recombinant DNA. However (to the dismay of many Japanese consumers), labels are only required on foods containing more than 5% GM products, and certain food categories, like cooking oil and baby food, are entirely exempt from labeling. Moreover, more than two-thirds of US corn sold in Japan is used for livestock feed. These factors have prevented declines in US corn exports to Japan (Vazquez 2003).

Fortunately for US corn growers, increasing exports to Mexico during the same period softened the blow from other lost markets. Mexico banned the cultivation of GM corn in 1998, but imports are still allowed. In this sense, the increased sales to Mexico after NAFTA are of greater importance to the US than their size alone would suggest. While the post-NAFTA increase in exports to Mexico amounts to 1% of the US corn crop, it is more than 1% of the markets that still accept GM corn. Adoption of Bt corn during 1996-99 was not uniform throughout the country. Benbrook (2001a) presents estimates of Bt corn as a percentage of corn acreage for leading states; by 1999 Bt corn was between 22% and 37% of state acreage in all the leading corn producing states west of the Mississippi, and between 6% and 14% in leading states east of the Mississippi (see Figure 6, which shows only the highest and lowest use states in each region).

Estimates of production gains from Bt corn – that is, avoided corn borer losses due to use of Bt corn – are even more geographically skewed: Colorado and Texas, with only 6% of the nation's Bt planting, had 45% of the production gains from Bt corn in

Figure 6: Area planted with Bt corn by state



Source: Calculated from data from USDA, National Agricultural Statistics Service http://www.nass.usda.gov:81/ipedb/

1998. It is no accident that these were also among the high irrigation states identified in Section 3.1 above: corn borers thrive in dry climates with long growing seasons, and the insect pressures are consistently greatest in those areas. In the wetter areas of rain-fed corn production, Bt corn is less useful, and therefore less reliably profitable (Benbrook 2001a). Colorado and Texas, the states where Bt corn is most obviously profitable, are also the states with the highest insecticide intensity in most years.

3.3 Other environmental impacts

There are additional environmental impacts from US corn production that are worth noting even though we do not review them in detail in this study. Two areas of concern are soil erosion and biodiversity impacts. A more detailed analysis of these issues is presented in Runge (2002), which we draw on here.

Conversion to cropland has carried with it rising problems with soil erosion. Some historical studies suggest that conservation tillage practices have significantly reduced erosion rates since the 1930s. This would suggest that expanding corn production has little impact on soil erosion rates (Runge 2002).

Biodiversity impacts are still of concern with expanded corn production. In sharp contrast to the situation in Mexico, biodiversity in the corn crop itself is long gone in the United States. Commercially distributed hybrid varieties have been the norm in US production for decades. In addition to the dangers of Bt contamination and rising pesticide resistance among insects, there is one other way in which US corn production can impact biodiversity within the US. The long-term expansion of cultivated area in the US has reduced the area of grasslands and wetlands, while the growth in average farm size has cut down many field edges that have been important habitats for birds and other species (Runge 2002). While proponents of biotechnology argue that increased yields from transgenic crops would reduce the need for cultivated land, this is an oversimplification: higher yields will not automatically lead to the return of existing cropland to wild habitat (Batie and Ervin 2001).

4. Impacts in Mexico

The impacts of Mexico's increased corn imports have been extensively studied by Alejandro Nadal, in an earlier report for NACEC (Nadal 1999), a related later study (Nadal 2000), and a follow-up paper for NACEC (Nadal 2002). We do not attempt here to summarize this work, and the extensive work on the topic carried out by other researchers. In this section we present a brief overview, drawing heavily on Nadal and other secondary sources, and then analyze state data on production and cultivated area in order to place the rise in US corn exports to Mexico – with their commensurate environmental impacts – in the broader context of North American corn production and trade. As Nadal and others have noted, the significant negative environmental impacts of expanding US corn production for export are compounded by the potention for such exports to undermine positive environmental services in Mexico, particularly the stewardship of genetic diversity.

4.1 Overview

The changes in corn production and consumption in Mexico in the 1990s are highlighted in Figure 7 and Table 4 below. While consumption continued to grow after 1994, the earlier increases in production, cultivated area, and harvested area were all reversed after the middle of the decade. Increases in consumption later in the 1990s were supplied by imports, more than 99% of which come from the US. Yield grew in both periods, although more slowly in the later years; prices fell, reducing farm incomes.

Table 4: Changes Mexican Corn in the 1990s

	1994 vs 1990	2000 vs 1994
Consumption	+17%	+8%
Production	+25%	-3%
Cultivated Area	+16%	-8%
Harvested Area	+12%	-13%
Yield	+7%	+6%

Source: SAGARPA

Powerful market and political pressures were at work, encouraging corn production in the early 1990s and discouraging it later in the decade; however, it is a mistake to attribute all of the later pressures to NAFTA. Rather, the adoption of NAFTA was one of several changes that affected corn production, as the neo-liberal or open economy model became increasingly dominant in Mexican policy. In the early 1990s, while import quotas and high agricultural support prices were still in effect, one form of market liberalization benefited corn producers, namely the elimination of the ban on feeding corn to livestock.

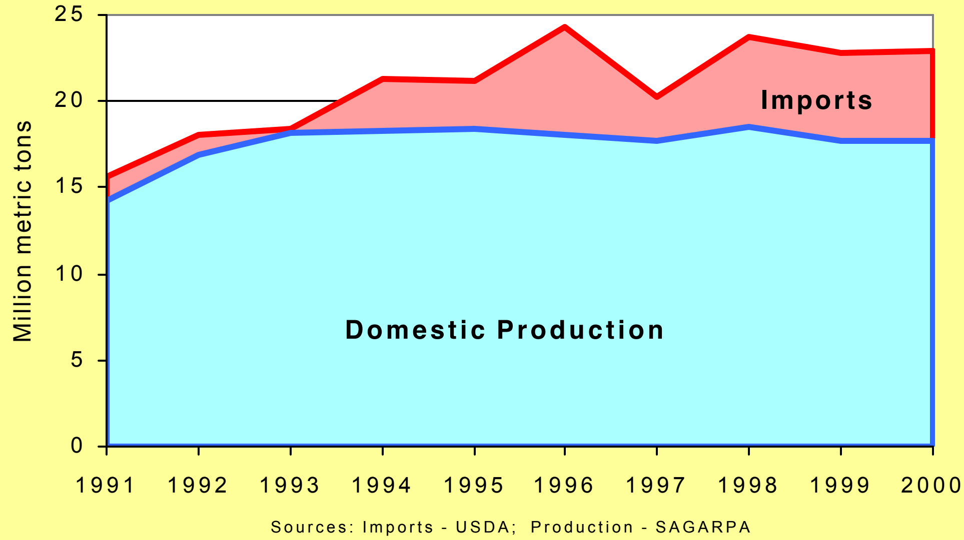


Figure 7
Mexican Corn Consumption: Domestic vs Imported

Later in the 1990s, further stages of liberalization removed trade protection and support prices, pushing prices farther down and creating a disincentive for corn production. NAFTA was only part of a process of opening the Mexican economy to international trade, involving removal of import controls and licenses, and tariff reductions, on many fronts. NAFTA itself called for a very gradual reduction in tariffs and quotas on corn imports; a separate, subsequent decision of the Mexican government led to the abrupt elimination of essentially all limits on imports in 1996 (Nadal 2000). As a result, the planned 15-year transition to open competition was shortened to three years. US exports to Mexico doubled and producer prices have declined 48% in real terms.

Other key changes included the elimination of the parastatal organization CONASUPO (Comision Popular de Subsistencias Populares), which had previously purchased large quantities of basic crops from producers at guaranteed prices. CONASUPO bought ten different crops in the 1980s, then was restricted to only corn and beans in the early 1990s; it began to cut back even on those crops in the mid-1990s, and ceased purchasing altogether in 1998.

Finally, there was a revision of the constitutional constraints on land tenure, carried out in the restructuring of the laws regulating *ejidos* and communal lands. These changes allowed for the private sale of some collectively held agricultural lands. This provided an additional vehicle for the withdrawal of land from biodiverse corn farming.

4.2 Benefits and Costs of Imports

The impacts of the expanded post-NAFTA corn trade in Mexico are in many (not all) ways the mirror image of the US: Mexico has experienced the benefits and costs of less production just as the US has experienced the effects of more. Increased imports into Mexico bring the benefits of lower prices to corn-using industries such as livestock production and processed foods. However, the economic benefits of lower corn prices have not been passed on directly to consumers due to monopoly pricing of tortillas, a principal form in which corn is consumed (Nadal 2000).

The costs of increased trade and lower prices include economic losses to producers both from the lower prices and from sales lost to imports, and the social effects on rural communities whose existence revolves around growing corn. Given the importance of corn to Mexico's rural economy and society, these are enormous and well-documented impacts. Supplying the growing industrial and livestock-feeding uses of corn in Mexico after 1994 was a missed opportunity for a creative rural development strategy.

In addition to these impacts, there is a unique area of concern due to Mexico's (pre)historic role as the country of origin for corn: are contemporary corn imports a threat to the ultimate reservoir of genetic diversity for this important species? Has the combination of market liberalization, increased imports and lower prices undermined the use and preservation of traditional seed varieties?

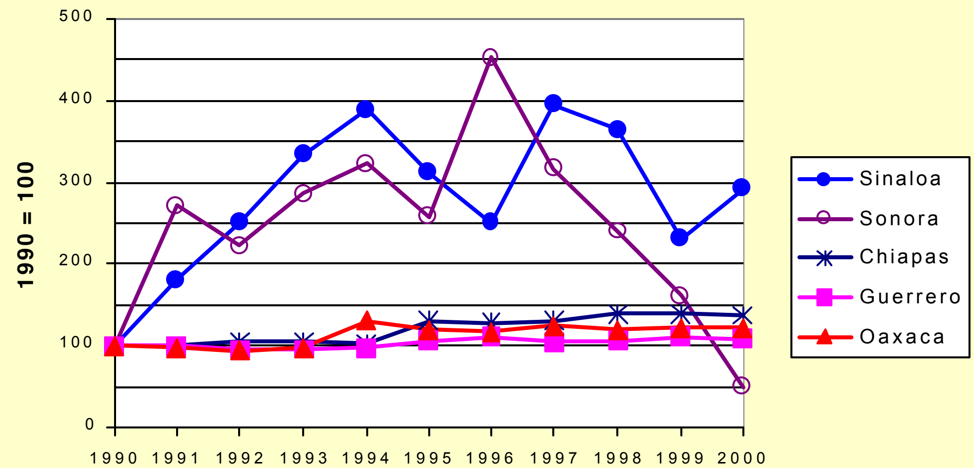
4.3 Market Pressures and Biodiversity

Traditional cultivation practices, evolved over centuries of corn growing, involve the use and preservation of many natural varieties (landraces) of corn that are adapted to varying local conditions. It is this traditional style of production that preserves the genetic diversity of Mexican maize in practice. Threats to traditional cultivation and its living repository of biodiversity come in two distinct, widely discussed forms.

The more dramatic and recent threat was highlighted by the discovery, in September 2000, of transgenic corn with Bt genes growing in a remote area of rural Oaxaca known for its diverse indigenous varieties of corn (Quist and Chapela 2001; de Ita 2001). It is conceivable that this resulted from the limited amount of Bt corn planted in Mexico before it was prohibited in 1998. It seems more likely, however, that it is a consequence of recent imports of Bt corn from the US, which are still allowed. US corn bought for food or feed could have been planted or accidentally released, and could have crossbred with local varieties. There is now considerable attention being paid to the implications of this contamination.[4]

This potential mechanism of literal genetic contamination is an important warning about the implications of Bt corn consumption, and the uncertainty that still surrounds the very new technology of genetic modification of crops. Less dramatic, but also serious, is the other mechanism that may lead to the loss of genetic diversity: market pressures can reduce the extent of traditional cultivation, either through outmigration of farmers with traditional farming knowledge and experience, or through displacement of traditional corn varieties with other crops or with commercial hybrid seeds. It is now a subject of intense research to determine the extent to which this shift away from genetically diverse corn production is taking place.

Figure 8: Cultivated Area in Selected States



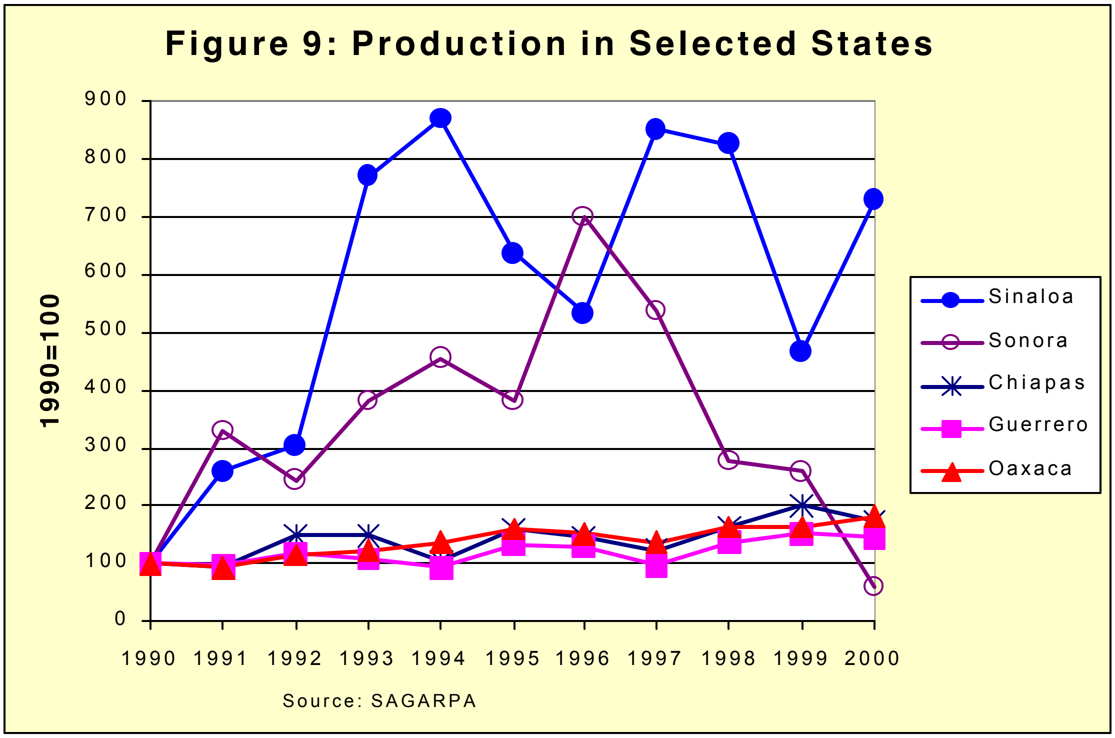
Source: SAGARPA

Annual data are available on maize production and cultivated area by state. In figures 8 and 9, we present some of the data from 1990 to 2000, contrasting the trends in the more commercial corn-growing states with those in three states in which more traditional practices predominate. Among major producing states, Sonora and Sinaloa were the most modern, with more than half of farm units using improved varieties rather than landraces, more than half having tractors, and more than one-third of the cultivated area irrigated. At the traditional extreme, in Oaxaca, Guerrero, and Chiapas roughly one-fourth or less used improved varieties, even fewer had tractors, and less than 2% of the area was irrigated. (Data are from Mexico's 1991 Agricultural Census via Nadal 1999.)

Figures 8 and 9 show the changes in production and cultivated area in these states, with all data scaled to 1990 = 100.

[4] The North American Commission for Environmental Cooperation has commissioned a comprehensive set of papers on the issue, some of which can be found on its web site: http://www.cec.org/maize/index.cfm?varlan=english

The modern states, Sonora and Sinaloa, both expanded corn production very rapidly in the first half of the decade. Sonora then moved even more rapidly out of corn production, falling to half its 1990 level by 2000. In Sinaloa the trend since the mid-



1990s appears to be slightly downward, though with large variation from year to year. These trends reflect the policy changes discussed earlier, including the continuation of corn support prices in the mid-1990s after support for most other crops was withdrawn, followed by loss of corn support prices later in the decade. In general, these trends highlight the difficult challenge, even for Mexico's most modern farmers, of competing with more technologically developed and more highly subsidized US producers.

Of greater interest in terms of the threats to genetic diversity, the increasing economic pressure on corn farmers from declining prices and reduced government support seem not to have produced an exodus from corn in the three more traditional states. In fact, the three traditional states continued to expand cultivated area and production after 1994; Oaxaca's corn production expanded at similar rates before and after 1994, while Guerrero and Chiapas saw more rapid expansion in the later period.

The more modern, irrigated states appear to respond to market incentives in the manner anticipated by economic theory: positive incentives in the early 1990s led to rapid expansion, while negative incentives in the late 1990s led to contraction. The more traditional states did not respond in this manner, at least in the 1990s. (It is worth noting, however, that generalizations from state-level data can be misleading, since all states contain both traditional and more modern producers. Further research using more disaggregated data is needed to clarify these trends.)

This finding has several possible explanations. Nadal (1999) notes that prices for other traditional crops suffered declines similar to or greater than that of corn, making a shift to other crops less viable. Pointing to evidence of expanding cultivation and declining yields in some traditional areas, he attributes the apparent persistence of traditional corn production to survival strategies of peasant farmers, who bring more marginal lands under cultivation in order to grow for subsistence. Yúnez-Naude and Dyer (2003) suggest that a significant proportion of corn farmers still grow for subsistence and are likely to remain isolated from market forces, reducing the impact of falling prices and decreasing the threat to corn genetic diversity.

A great deal depends on how Mexico's more traditional corn farmers respond over time. At least through 2000, the data show that the feared exodus from traditional corn had not yet occurred. However, that dire outcome could paradoxically still occur with future improvements in the Mexican economy. Better opportunities elsewhere could offer traditional corn farmers viable alternatives to either producing for subsistence or selling corn in the market at the prevailing low prices.

5. Conclusions

The goal of this study is to contribute to the evaluation of the impacts of trade liberalization on corn production in the US and Mexico. Since the adoption of NAFTA, US exports of corn to Mexico have increased by an amount equal to roughly 1% of US production, or equivalently 10% of Mexico's consumption. In this concluding section we summarize our findings on the impacts of this large change in trade on the two societies.

The environmental balance sheet is complex, because of the varied nature of the environmental impacts and potential problems associated with corn in the two countries. In the US, since increased exports to Mexico accounted for 1% of production, they should be considered responsible for 1% of overall environmental impacts; in the case of Bt corn and related issues, exports to Mexico are of greater importance, since Mexico still accepts Bt corn but some other export markets do not. Given the high levels of corn production and its resulting environmental damage, this can be significant. For example, a 1% increase in fertilizer used on US corn amounts to 77,000 addition tons of nitrogen, phosphorous and potassium – or the equivalent of 11% of the fertilizer used on corn in Mexico.

One of our more interesting findings is the complex of environmental problems associated with corn production in the drier states. These include unsustainable water use for irrigation and the need for greater use of either pesticides or Bt corn to fight more prevalent pests. To the extent that increases in demand for US corn push corn production onto this less sustainable frontier – and the rising proportion of US corn coming from the drier states suggests this is a long-term trend – increasing export markets such as Mexico's under NAFTA are contributing to the expansion of unsustainable agricultural practices. This is even more the case with Mexico remaining open to GM corn exports from the United States.

At the risk of oversimplification, it may be possible to sketch two regional sets of problems: “wet” problems such as nitrogen runoff, and “dry” problems including overuse of irrigation, and the need for high levels of insecticide and/or Bt corn. There is no possibility of significant reduction of production in the extensive “wet” areas; cleaner production techniques for wet states are definitely needed. The smaller quantity of production in the driest areas is less obviously essential; if it is particularly damaging, it is worth exploring the costs of reducing production in dry states, and shifting back to the traditional, wetter corn belt.

Using a similar methodology for Mexico, imports should be credited with the avoided environmental impacts of producing another 10% of the nation’s corn; as the marginal, rapidly expanding source of supply, imports are responsible for more than 10% of the change in market conditions. Given the limited availability of comparable data on chemical and water use, and given the great variation in Mexican production between traditional and modern corn production, it makes little sense to attempt such a calculation.

The complex story of threats to genetic diversity, which are bound up with poverty levels in the Mexican countryside, suggests that we should also examine the positive environmental impacts of traditional corn production in Mexico. As noted, many traditional producers maintain Mexico’s rich stocks of genetic diversity in corn. It remains to be seen whether declining corn prices and reduced government support programs result in significant losses in that production and in that genetic pool. Rising Mexican demand for corn poses a still more intriguing question: Would a different set of trade arrangements and government policies allow rising demand in Mexico to serve as the economic stimulus to improve the livelihoods and long-term economic prospects of traditional corn farmers? If so, one of the environmental costs of changing corn trade under NAFTA is the lost opportunity to secure Mexico’s genetic wealth for our common future.

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