Environmental Impacts of the Changes in US – Mexico Corn Trade Under NAFTA

Frank Ackerman, Luke Ney, Kevin Gallagher, and Regina Flores
Global Development and Environment Institute
Tufts University
Medford MA 02155, USA

email contact: Frank.Ackerman@tufts.edu

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1. Introduction

As NAFTA enters its eighth year, 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 2001). 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. This study attempts to pursue that alternative.

One of the largest and most environmentally significant changes under 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. [1] 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

[1] 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.

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).

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 the 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 graph of leading US export markets in section 3.3, 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 (SAGARPA/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 2001).

3. Impacts on the US

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. In some respects, exports to Mexico assume a greater importance than their size alone would indicate, particularly since Mexico continues to accept genetically modified corn when other countries are resisting it.

For the most part, the expansion of production has positive economic and social effects, and neutral to negative environmental impacts. We begin with a brief review of the good news, before turning to a more detailed look at the environmental problems.

3.1 Economic benefits

The economic benefits of increased corn production include income growth, preservation of rural communities, and reduced pressure for government subsidies.

It is difficult to measure the exact dollar benefits to US farmers from NAFTA, although the fact that additional markets were created means that income increased at the margin. Farmers' cash receipts from selling corn were slightly lower in real terms at the end of the 1990s than at the beginning, as the growth in volume was outweighed by the decline in price. In this context, the additional 1% of the crop sold to Mexico prevented the decline from being even worse.

The reduction in the US farm population and the associated decline of rural communities are long-term trends. Consolidation of small farms into larger units, and the resulting decrease in the number of farmers, occurred most rapidly from the 1930s through 1970s, and have continued at a more moderate pace since then. (Hoppe et al 2001) Anything that boosts farm incomes, such as increased corn exports to Mexico, helps to slow these trends.

Rural population and incomes have continued to decline in the Corn Belt. In the top 12 corn-producing states the non-metropolitan population averaged 34.5% of the total in 1990, and 33.3% in 2000. The ratio of non-metropolitan to metropolitan per capita incomes declined from 77% in 1990 to 75% in 1999 in the same states (BEA 2001b; unweighted averages of the 12 state ratios). Without additional markets for corn, the decline would have likely been even faster.

Increased farm incomes also reduce the pressure for government subsidies to farmers, a costly but politically well-protected program that is viewed as undesirable by many observers. The Federal Agriculture Improvement and Reform (FAIR) Act of 1996 offers a recent example of how increased exports to Mexico have reduced pressure to augment federal commodity support programs. At the time this bill was debated, farm prices were high and exports were expanding; 1996 was the year of record exports to Mexico, and was also the year prior to the fall in exports to Europe. The outlays for the Commodity Credit Corporation (CCC), the USDA's financing mechanism for farm assistance, had fallen from an average of $15 billion annually during the 1980's to about $10 billion annually for fiscal years 1990-95.

Prosperity on the farm, combined with a Congressional effort to make price and income support programs more market-oriented, decoupled farm payments from market prices and instead instituted a system of "production flexibility contracts" that entitled corn (and other grain) producers to a fixed but declining annual payment through 2002. Although farm price and income declines since 1996 have led Congress to enact more subsidies, increased Mexican consumption of US corn helped to offset the degree to which this aid was needed for corn producers (Becker 2001).

3.2 Environmental Impacts: Fertilizer, herbicides, 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 is responsible for 1% of the environmental impacts, as well as the economic benefits, 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 significant other markets have rejected GM grains.

The environmental impacts of corn production have been extensively studied; see Runge and Stuart (1997) for a thorough 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 (except pesticides), while Section 3.3 examines the use of genetically modified corn, pesticides, and issues of biodiversity.

Agrochemical Impacts

U.S. 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 groundwater supplies in farm areas. The great quantities of nitrogen carried by the Mississippi River, coming heavily from corn-growing areas, annually kills ocean life throughout a huge “dead zone” in the Gulf of Mexico (Keeney and Muller 2000; Runge and Stuart 1997).

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, another leading herbicide about which we will say more below, is also a possible human carcinogen (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

Three 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 and insecticide intensities of corn production have dropped sharply since 1994.

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.

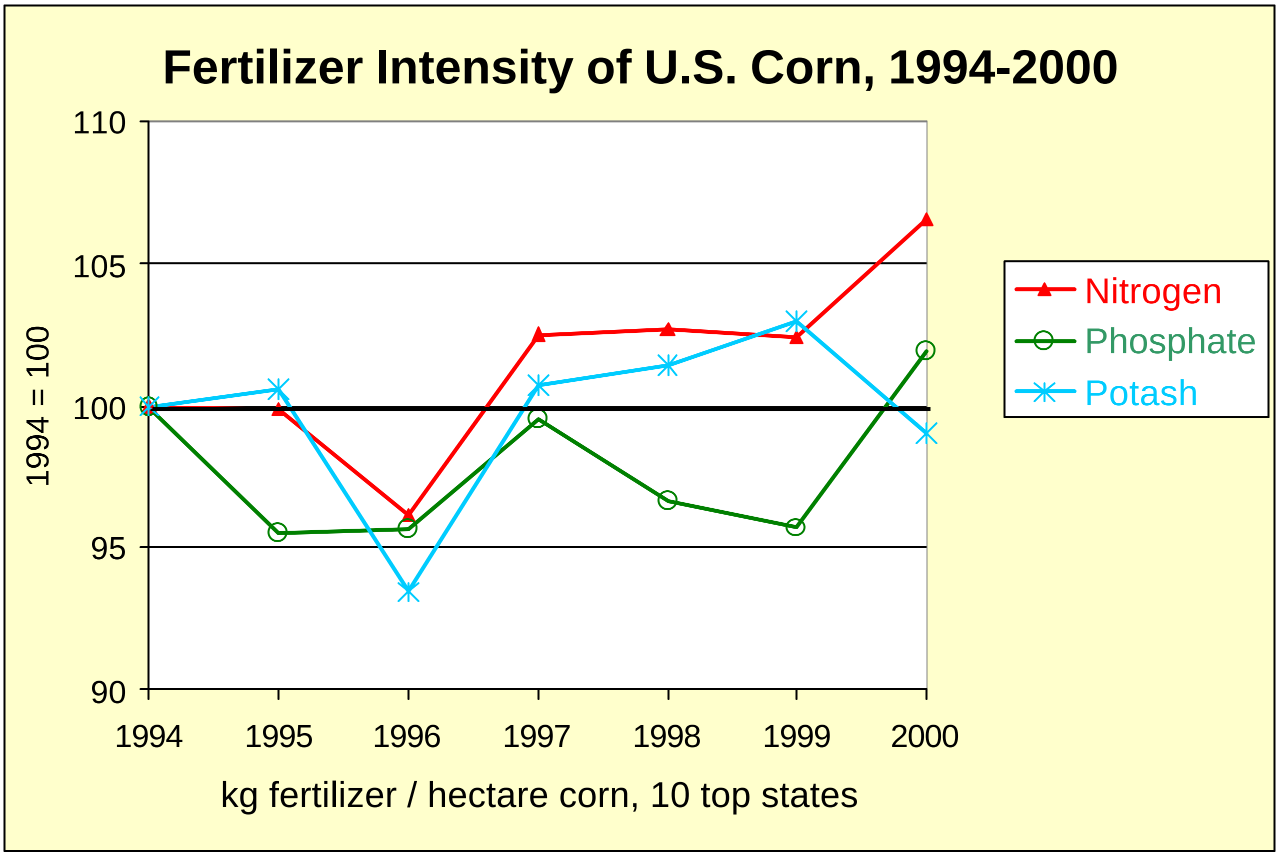
More precisely, Table 2 compares chemical intensity, by state and chemical. Intensity is measured as the state average chemical use – for example, the total quantity of nitrogen fertilizer applied to corn in Iowa, divided by the total planted area of corn in Iowa. Crops are compared within the same state 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.

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**

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.

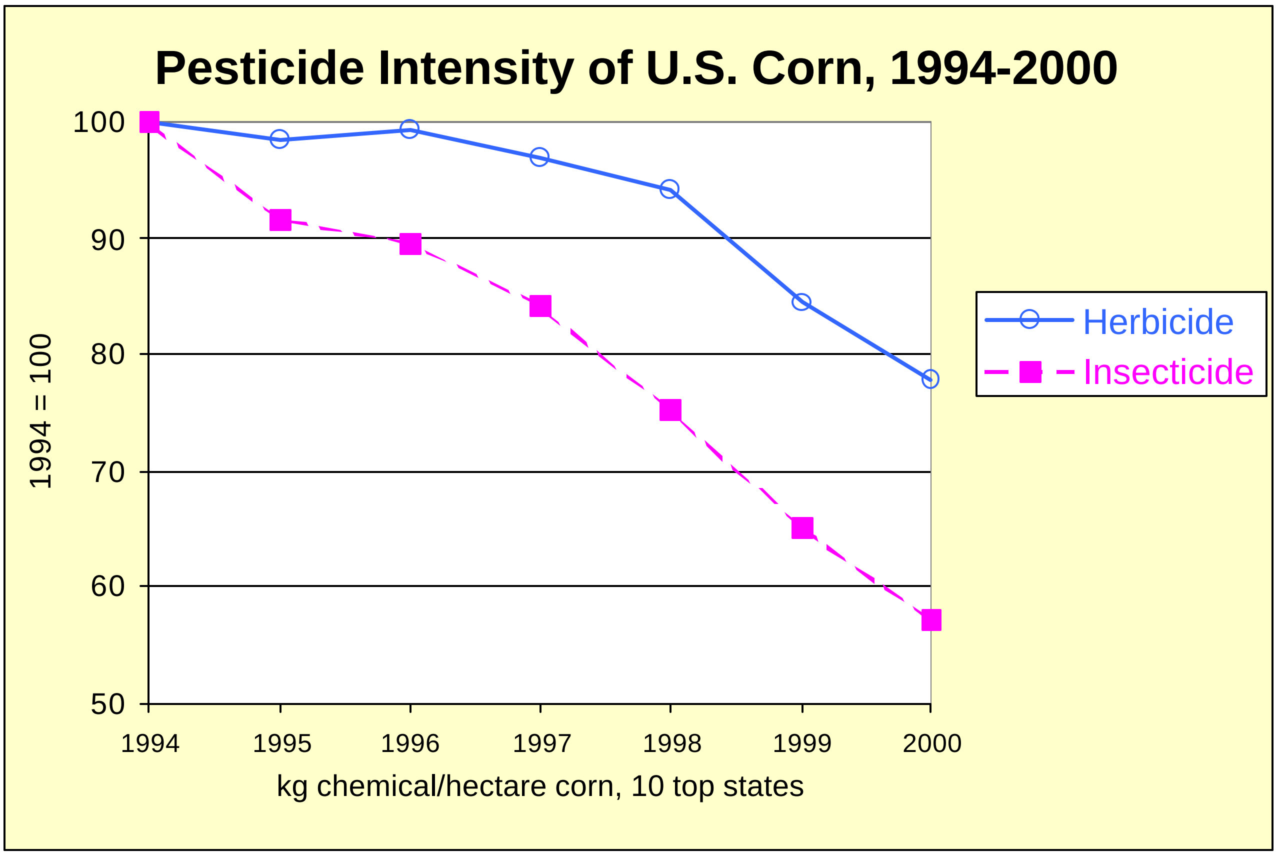
Turning to changes over time, consistent data on chemical use are available for every year from 1994 to 2000 for the top 10 corn producing states. Changes in fertilizer intensity for the 10 states as a whole are shown in Figure 1. The nitrogen intensity of corn production is increasing by about 1% per 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 and Stuart 1997). 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. There are other problems related to runoff from farms, such as erosion; some historical studies suggest that erosion has become less serious than in past decades (Runge and Stuart 1997), but there are apparently no standard sources of data on the problem.



The picture is quite different for pesticides, as seen in Figure 2. The intensity of use of both types of pesticides has dropped steadily and sharply, with the intensity as of 2000 falling just below 80% of the 1994 value for herbicides, and below 60% for insecticides.[2] However, different factors are at work in the case of the two varieties of pesticides.

[2] 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

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.



Most of the reduction in the quantity of corn herbicides in the 1990s is due to the replacement of one of the leading acetanilides, metolachlor, by S-metolachlor. This tongue-twisting change has a simple and important meaning. Old metolachlor contains equal quantities

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.

of an S-isomer and an R-isomer. Both have similar 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.

However, these gains have been threatened by the protests of other chemical companies. Cedar Chemical and SipCam have applied for permits to produce low-cost, generic versions of old metolachlor, disparaging the environmental benefits of the new product and claiming that Syngenta's introduction of S-metolachlor is an anti-competitive maneuver to protect its patents and its monopoly position. As of the end of 2001, EPA had not reached a decision on whether production of generic old metolachlor will be allowed; if it is allowed, some of the gains in herbicide reduction in the 1990s might be rapidly reversed (Benbrook 2001; Cedar Chemical 2001).

The reduction in pesticide use has quite different causes, linked to the introduction of Bt corn; therefore it is discussed in connection with genetically modified corn in Section 3.3.

Irrigation

Many parts of the U.S., 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 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.

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%

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. The four irrigation states accounted for roughly the same proportion of US output in 1998 and 1999 as in 1997; their share dropped slightly in 2000. Thus there is no rapid movement toward greater irrigation. There was a slight increase in the mid-1990s, and no obvious trend since then.

3.3 Environmental impacts: Genetically modified corn, pesticides, and biodiversity

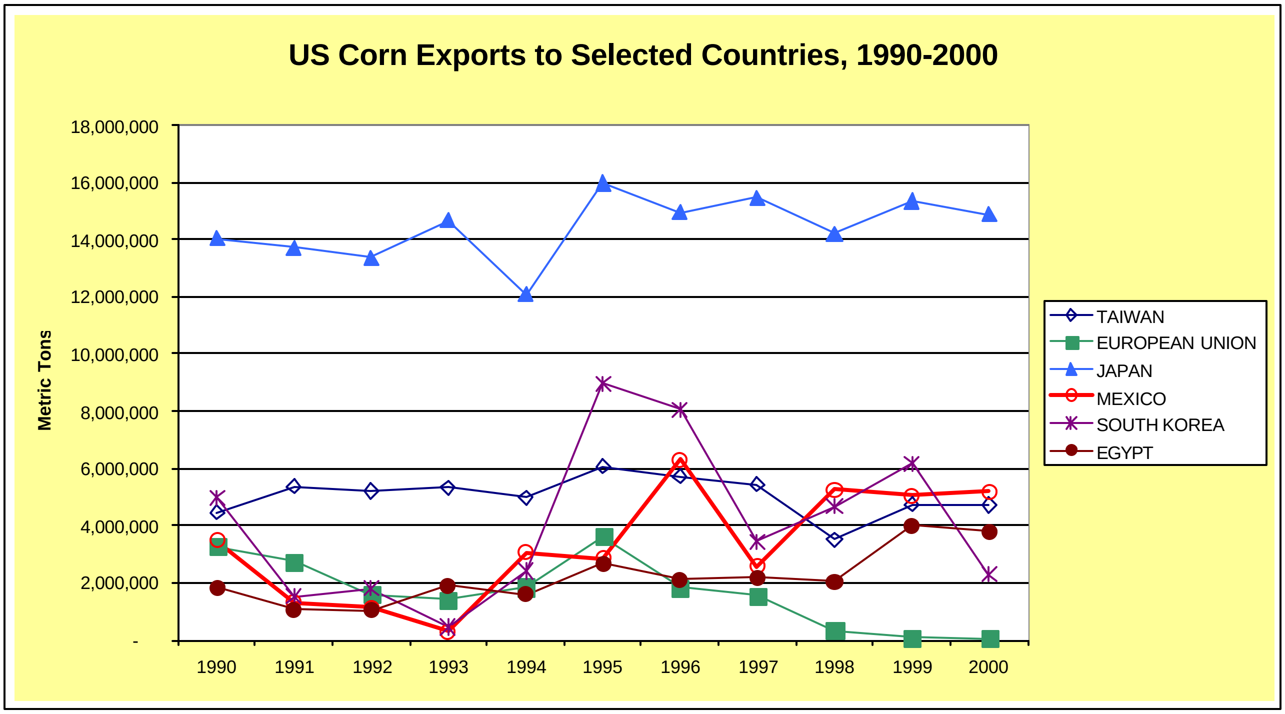
The most widely discussed recent change in US corn production is the introduction of genetically modified (GM) corn, also called Bt corn. This variety of corn contains genes from the soil bacterium *Bacillus Thuringiensis* (Bt) that produce toxins that kill certain insect pests, particularly the European corn borer and the Southwestern corn borer. Planting Bt corn therefore offers an alternative to heavy applications of insecticides; as we will see, it has been associated with sharp reductions in insecticide use.

At the same time the introduction of Bt corn has opened debates about its long-term ecological effects, including questions, still unresolved, about its effects on other species, the possibility of crossbreeding with weeds or other wild species, and its effects on humans or animals (see Ervin et al. 2000 for a discussion of these effects). We will not attempt to examine those debates in this report, except to note them where relevant to the discussion of biodiversity in the US and particularly in Mexico.

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 21% just three years later, in 1999. However, after these three dramatic years the growth abruptly stopped, with Bt corn again covering 21% of US cornfields in 2000 and slightly less, 20%, in 2001 (Benbrook 2001a). Two factors account for the reversal:

resistance to Bt corn in major export markets, and the limited profitability of Bt corn in many areas of the US.

The next graph shows the history of US corn exports to six major markets. As recently as 1996 the U.S. exported over $305 million worth of corn to the E.U., 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, and by 2000 the E.U. consumed only $8 million of U.S. grown corn. This decline in European markets coincided with the nascent production of GM corn in the United States. 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 encouraged E.U. importers to look elsewhere for their corn. (USDA 2001; Hepher 1998; ICTSD 1998a and 1998b).



Other countries have also expressed concern over this issue and have recently lowered their import levels of US corn. There has been great concern in South Korea over the effects of Bt and herbicide resistant corn; purchases of US corn fell by more than half between 1999 and 2000. South Korea reacted to the StarLink contamination problem by recalling 32,000 of the 75,000 pounds of tortillas that had been exported there, even though the company that made the products (Mission Foods) insisted that it only sells wheat products in Korea, not corn products (CNN 2000a). South Korea implemented mandatory labeling on food products, including biotech corn and soybeans, in March of 2001.

In Japan, no significant decline had appeared as of 2000, as shown in the graph, but problems have surfaced more recently. The discovery of StarLink corn in taco shells in the US and the subsequent exposure of the inability of US elevators and shippers to maintain separation of this type of corn from non-GM strains has generated a fear among US farmers that the Japanese market may also be in danger of falling (Barboza 2000). 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). However, Japan virtually halted its purchases for the first quarter of 2001 because of fear that some StarLink corn may taint supplies. Japan has strict rules about biotech crops and does not allow StarLink even in livestock feed (CNN 2000b).

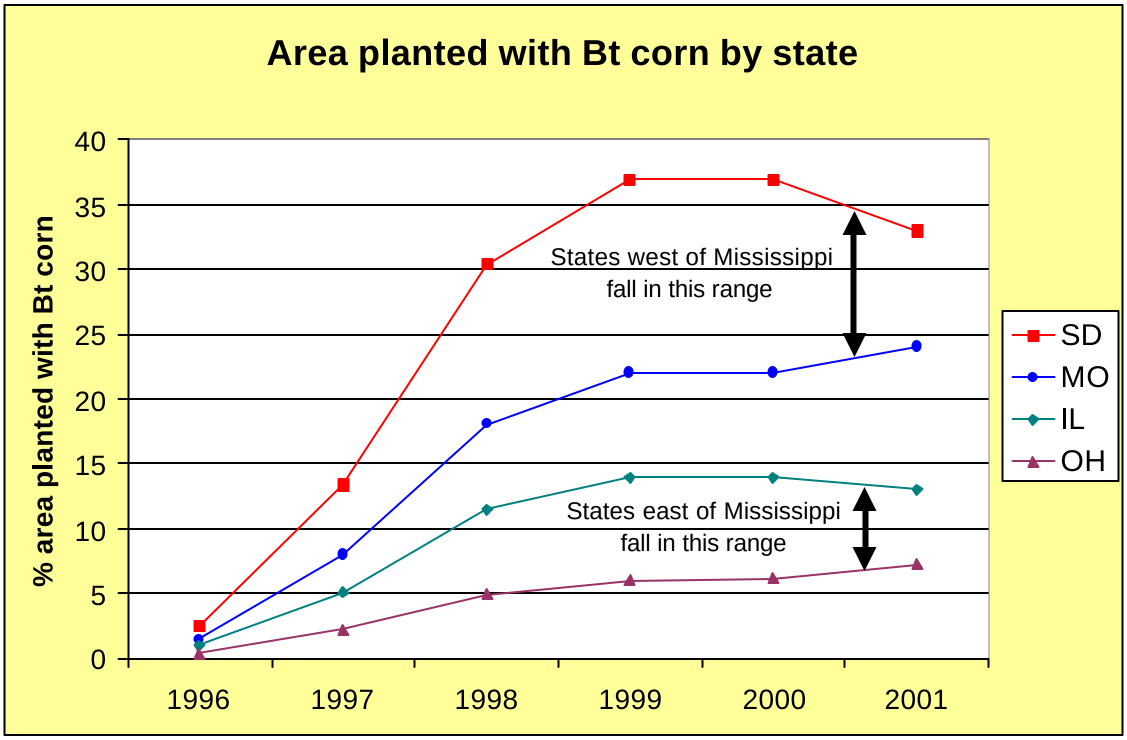
Fortunately for U.S. corn growers, the increased exports to Mexico during the same period softened the blow from other lost markets. Growing GM corn was banned in Mexico in 1998, but imports of GM corn are still allowed. In this sense, the increased sales to Mexico after NAFTA are of greater importance 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. If Europe, Japan, and East Asia all reject genetically modified grain, the remaining US export markets will be concentrated in Latin America and the Middle East, where Mexico and Egypt, respectively, are the biggest single customers.

Another limitation on the spread of Bt corn in the US has been the high cost and limited profitability of the new varieties. The seeds are much more expensive than ordinary hybrids; the additional expense is only justified from a commercial point of view in times and places of high insect infestation. In a comprehensive recent analysis, Charles Benbrook estimates that US corn growers paid a premium of $659 million (above the cost of other varieties) for Bt corn seed planted from 1996 through 2001, but got only $567 million worth of increased yields, for a net loss of $92 million (Benbrook 2001a).

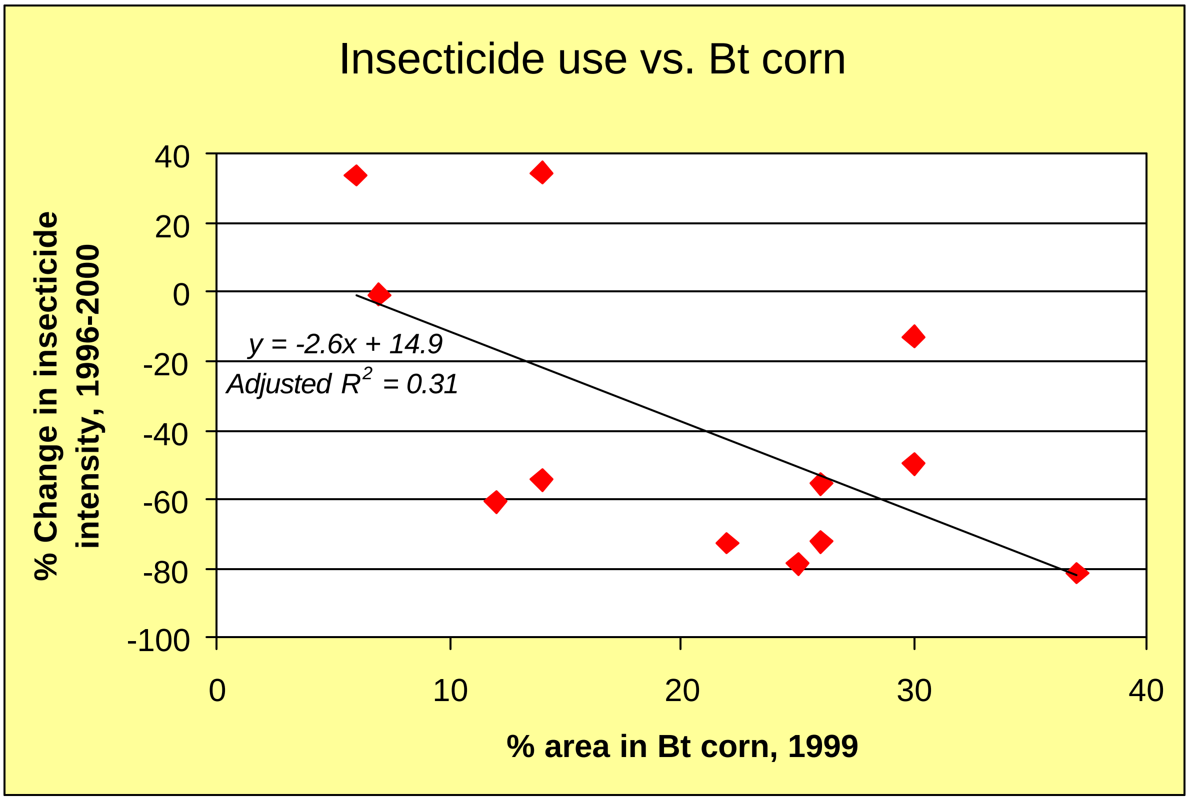
The gradual realization that Bt corn is not economical in most of the country, combined with the evidence of resistance from export markets, could have led to the slowdown in adoption since 1999.

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 next graph, 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 1998. It is no accident that these were also among the high irrigation states identified in Section 3.2 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, Benbrook's analysis suggests that Bt corn is profitable only in the occasional years of the worst insect problems. He concludes that "farmers who know and understand corn borer dynamics can almost surely find ways to more profitably deal with [corn borer] pressure than planting most of their acreage every year to Bt corn." (Benbrook 2001a, 2)



The introduction of Bt corn is, not surprisingly, connected to the reduction in insecticide use noted in Section 3.2. Colorado and Texas, the states where Bt corn is most obviously profitable, are also the states with the highest insecticide intensity in most years. Some observers have argued that Bt corn does not reduce the use of insecticides; debate on this topic continues. However, we have seen that the pesticide intensity of US corn production dropped sharply in exactly the years when Bt corn was introduced. Our examination of state-level data adds to the impression that there is a relationship between these trends. Data are available for insecticide use by state in 12 leading corn states for 1996-2000 (from NASS reports); the next graph compares the states' change in insecticide use over that four-year period to the percent of area planted with Bt corn in 1999, the peak year for most of the leading states. There is a significant negative relationship, as expected, although it explains only about one-third of the variance. An increase of one percentage point of Bt corn planting was associated, on average, with a 2.6 percent reduction in insecticide intensity (measured as kg insecticide/hectare corn).



A final point about corn in the US concerns its relationship to biodiversity. In sharp contrast to the situation in Mexico, biodiversity in the corn crop itself is long gone in the US. Commercially distributed hybrid varieties have been the norm in US production for decades. There are, however, three ways in which US corn production could impact biodiversity within the US, as well as the potential impacts on Mexico discussed below. First, 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 and Stuart 1997). 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).

Second, some observers believe that the Bt genes introduced in corn could cross over to weeds and other plants, with unpredictable but potentially serious biological impacts (Ervin et al. 2000). Third, the use of insecticides and Bt corn can produce pesticide tolerant insects, with adverse effects for conventional and organic farmers alike, not to mention the potential problems for the rest of the food chain (Batie and Ervin 2001).

4. Impacts in Mexico

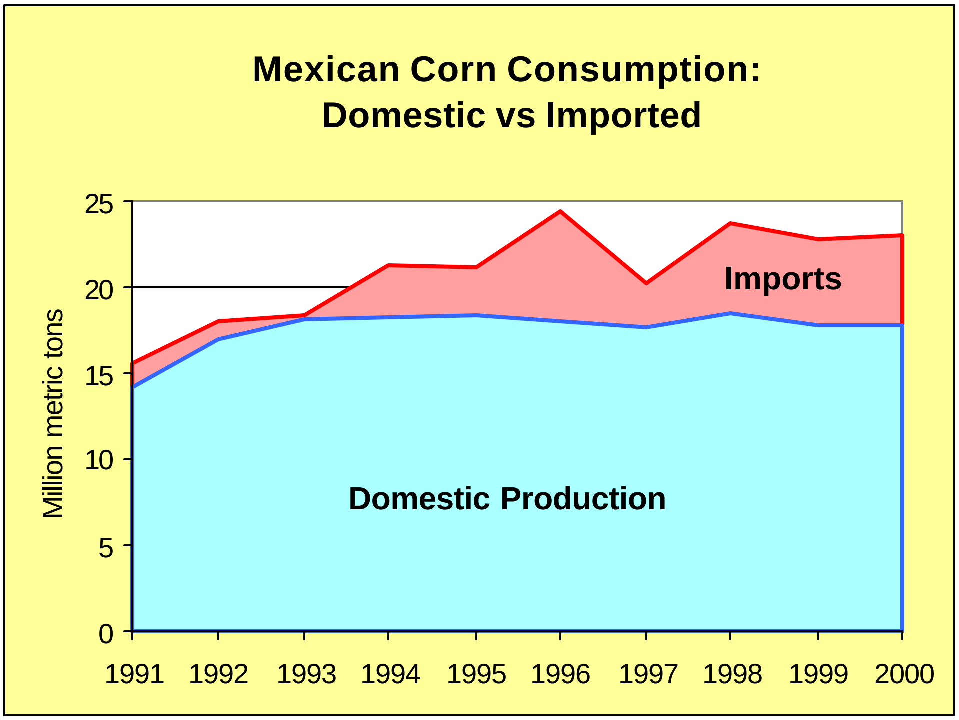
The impacts of Mexico's increased corn imports have been extensively studied by Alejandro Nadal, in an earlier report for the CEC (Nadal 1999) and a related later study (Nadal 2000). In this section we present a brief overview, drawing heavily on Nadal and other secondary sources, and then analyze state data on production, cultivated area, and technology in an effort to understand the impacts of market liberalization on genetic diversity.

4.1 Overview

The changes in corn production and consumption in Mexico in the 1990s are highlighted in the graph and table 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.

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.

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).



Source: Calculated from data from SAGARPA, except imports from USDA

Corn in Mexico: Changes 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%

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, which had a tremendous impact on the legal status of small producers (Josling 1992).

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 environmental benefits of reduced production could include reduced demand for irrigation, and reduced use of agricultural chemicals. A smaller proportion of corn is irrigated in Mexico than in the US, so a shift of production from Mexico to the US may not reduce total irrigation requirements; nonetheless, it may provide a local benefit if irrigation capacity is scarce in Mexico's producing regions.

In terms of agricultural chemicals, we have found only one source with data for fertilizer in Mexico’s corn production: fertilizer intensity (kg/ha) in the 1999-2000 agricultural year is shown in Table 5 (CIMMYT 2000). The original source of the data is not made clear in the published report.

Table 5: Fertilizer Intensity of Corn Production in Mexico

Percent of area receiving fertilizer	43%
Nitrogen (kg/ha)	157
Phosphorus (kg/ha)	61
Potassium (kg/ha)	3

Source: CIMMYT World Maize Facts and Trends 1999/2000

These figures are similar to – in fact, slightly higher than – the fertilizer intensity in the top US corn states, as shown in Table 1 above, for nitrogen and phosphates, but substantially lower for potash (potassium). However, these intensity values are calculated per hectare, while the yield per hectare is much greater in the US than in Mexico. Therefore, if these numbers are accurate, the nitrogen and phosphate fertilizer per ton of corn is much greater in Mexico; potassium fertilizer use remains lower in Mexico even on a per-ton basis. Further investigation is needed to explore this remarkable finding.

The environmental problems caused by runoff of excess nitrogen fertilizer, discussed in connection with US impacts, are not necessarily proportional to the quantities of fertilizer applied. It could be that more, or less, of the nitrogen fertilizer is absorbed in Mexico than in the US. Soil conditions, crop rotation patterns and other factors differ between the two countries, and indeed between regions within each country. Despite these caveats, the numbers presented in Table 5 imply that when a ton of corn is produced in the US instead of Mexico, the two countries' total use of nitrogen and phosphate fertilizer declines.

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 – as it turned out, it became a rural development strategy for the US corn belt, not for Mexico.

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? We present a statistical exploration these questions, using the limited source of available data, in the next section.

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 accidentally released, and could have crossbred with local varieties. If the Bt genes are beneficial to plant survival, that is if natural selection or farmer selection favors them over other varieties, they could rapidly spread and displace indigenous corn races.

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, replacing it either with other crops or with modern production methods using commercial hybrid seeds. This latter question, regarding the surviving scope of traditional cultivation, is more amenable to economic analysis.

Development of new hybrids and other improved varieties for use in Mexico, as an alternative to local landraces of corn, dates back more than 60 years. Early government initiatives occurred in 1938, when the Ministry of Agriculture established an Office of

Experimental Stations to promote maize breeding, and in 1940, when an agreement with the Rockefeller Foundation led to the creation of an Office of Special Studies in the Ministry, to perform research on breeding hybrid varieties. The gradual adoption of such improved varieties, while still representing a minority of production nationwide, has had an effect on genetic diversity: by one estimate, only 20% of the maize varieties reported in Mexico in 1930 are still known (GRAIN 1996).

Description of data

Our analysis of production techniques in Mexico relies on state-level data; Mexico's states are far more diverse in technology, cultivation practices, and yields than the states of the US. Annual data are available on maize production and cultivated area by state; we use data from 1990 to 2000. All 32 states, including the urban Federal District, report some maize production, but some states produce only tiny amounts; our analysis below uses all 32 observations, but the results are substantially the same if the 8 smallest producers are omitted. We also use data by state on four indicators of modern vs. traditional practices from the 1991 Agricultural Census, the latest available (via Nadal 1999): the percentage of producing units (farms) using improved varieties rather than landraces; the percentage of cultivated area that is irrigated; the percentage of units with tractors, and the percentage of units with less than 5 hectares of land.

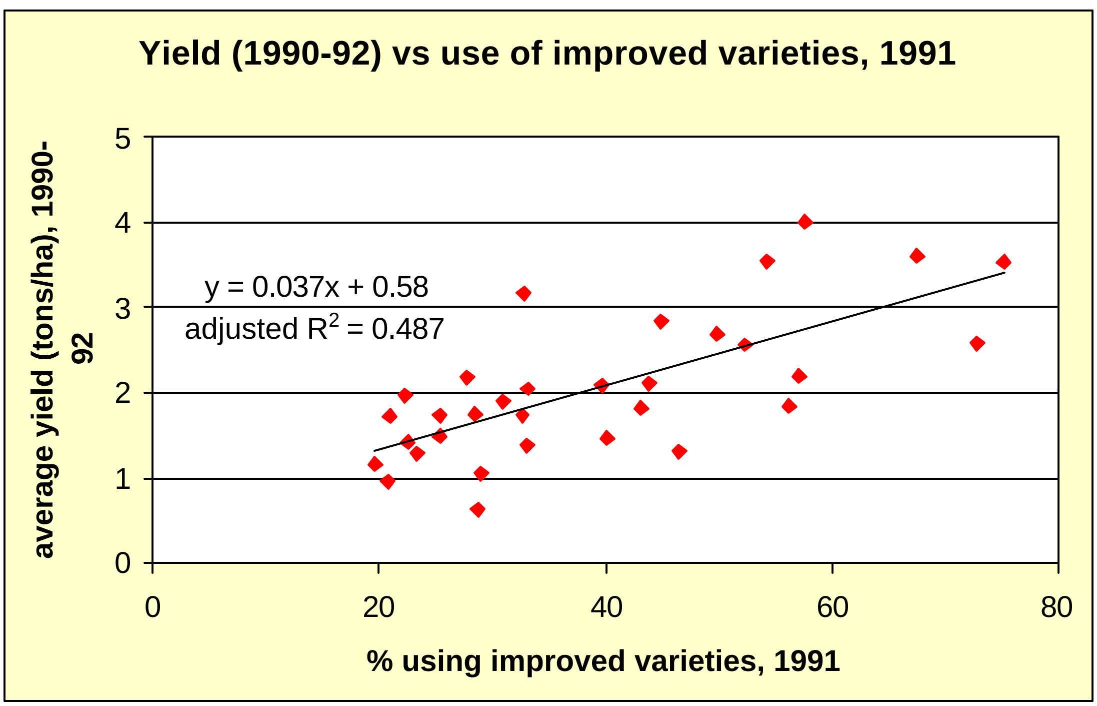
There is a high degree of correlation among the four indicators, as shown in the correlation matrix; the percent with less than 5 hectares is slightly less correlated with the other three measures, but all are significantly related to each other.

Correlations among technology indicators, 1991

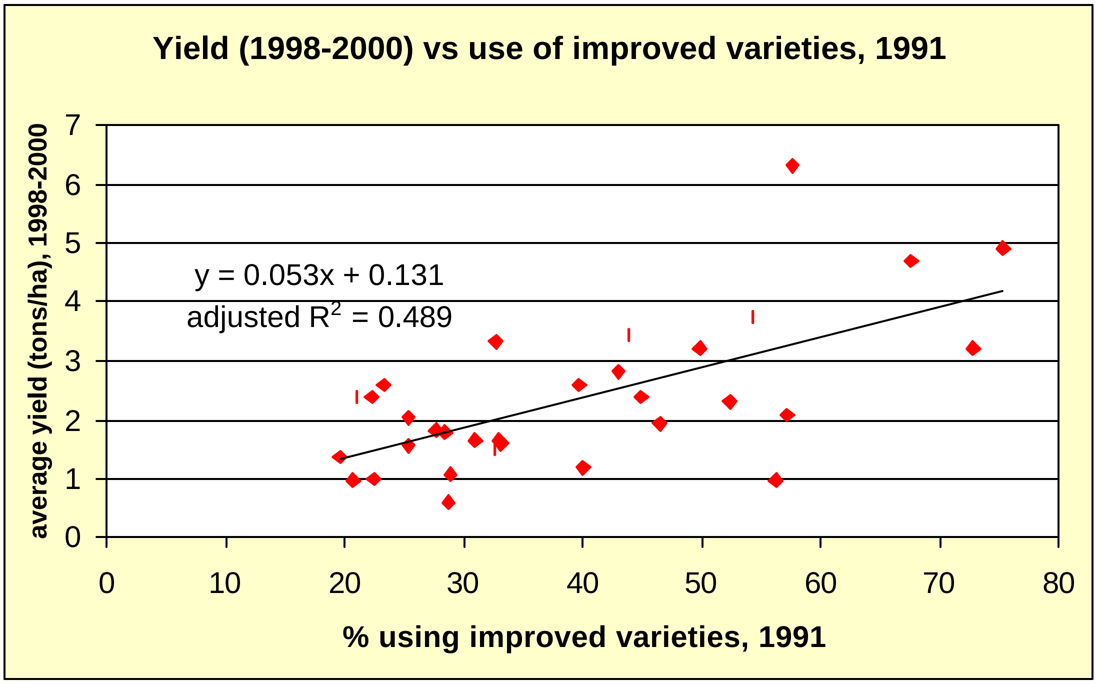
	Percent using improved varieties	Percent with tractors	Percent of area irrigated	Percent with under 5 ha
Percent using improved varieities	1.00			
Percent with tractors	0.76	1.00		
Percent of area irrigated	0.78	0.64	1.00	
Percent with under 5 ha	-0.55	-0.49	-0.42	1.00

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.

The average yield (tons per cultivated hectare) for 1990-92 is strongly correlated with each of the variables; the relationship is strongest with improved varieties.



The relationship is still strong at the end of the decade – that is, average yield in 1998-2000 is related to the percent using improved varieties in 1991:

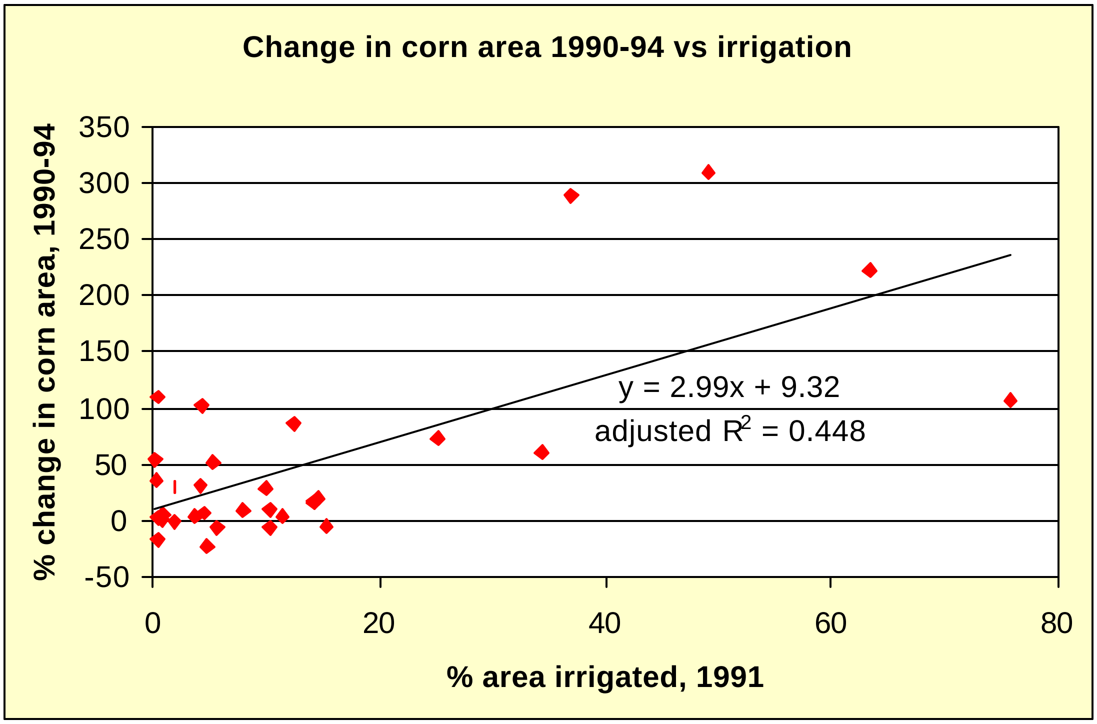


State data and biodiversity: a statistical exploration

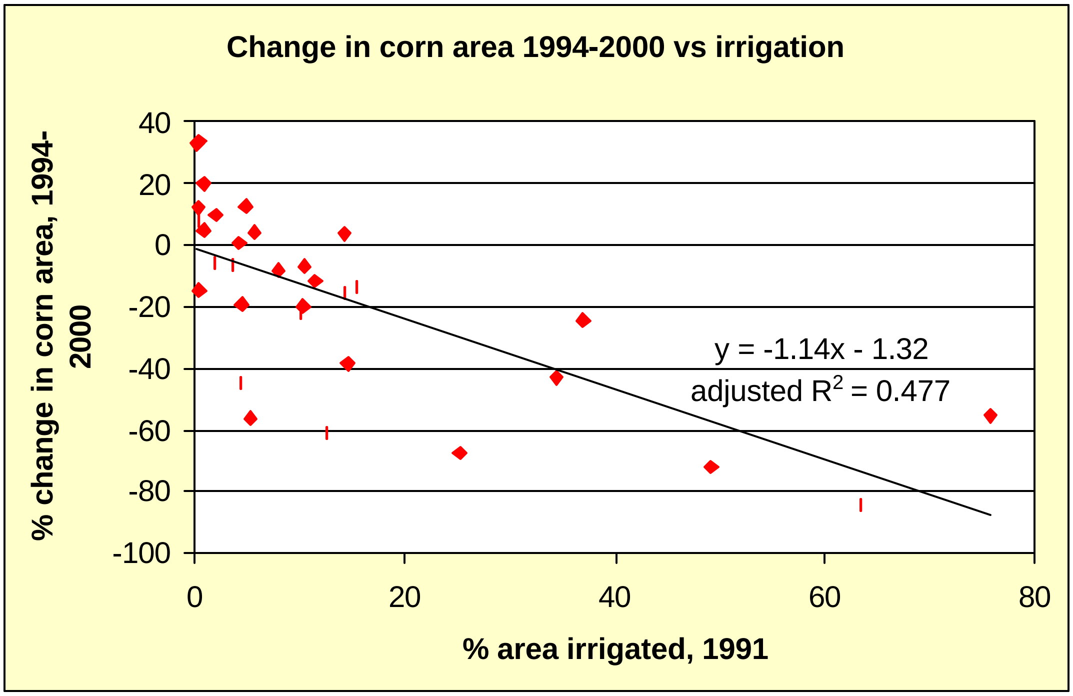
Market pressures could affect biodiversity in either of two ways. It could cause shifts between states, moving production from more traditional to more modern states. Or it could cause shifts within states, modernizing production within the traditional states and thus leading to abandonment of landraces (or loss of traditional knowledge about their use, which could in turn lead to loss of the varieties).

To test the first possibility, we examined the changes in cultivated area by state, both in the period before 1994 when maize production was expanding, and in the years since 1994 when it has contracted. Our conclusion, in brief, is that the change in both periods was concentrated in the more modern states.

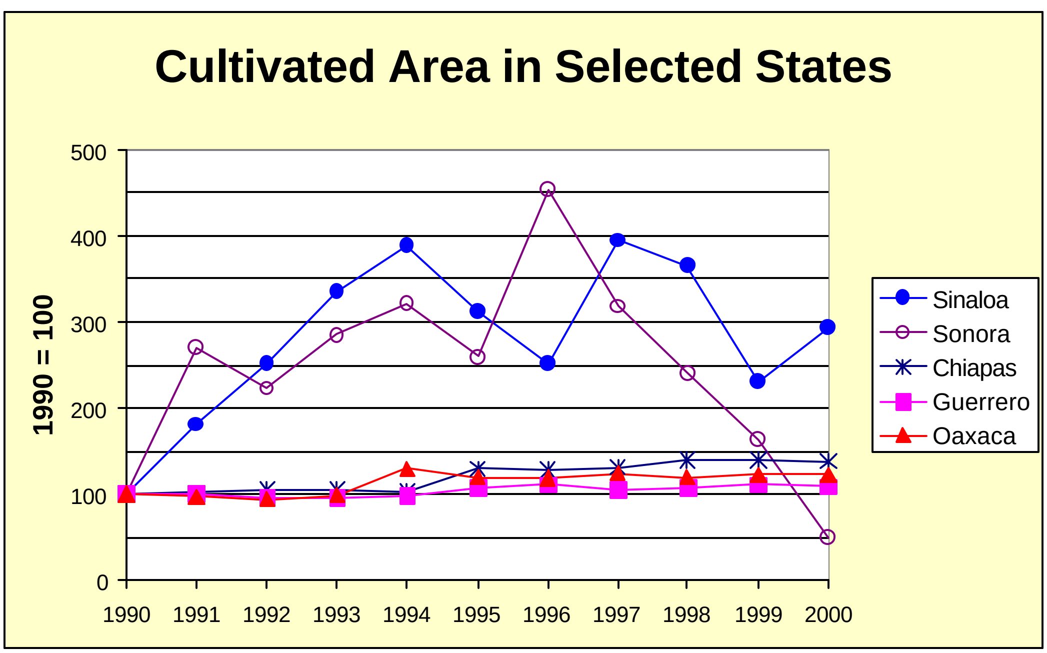
From 1990 to 1994, the change in cultivated area is positively related to the use of irrigation. That is, states with more irrigated corn production saw more expansion of cultivated area.

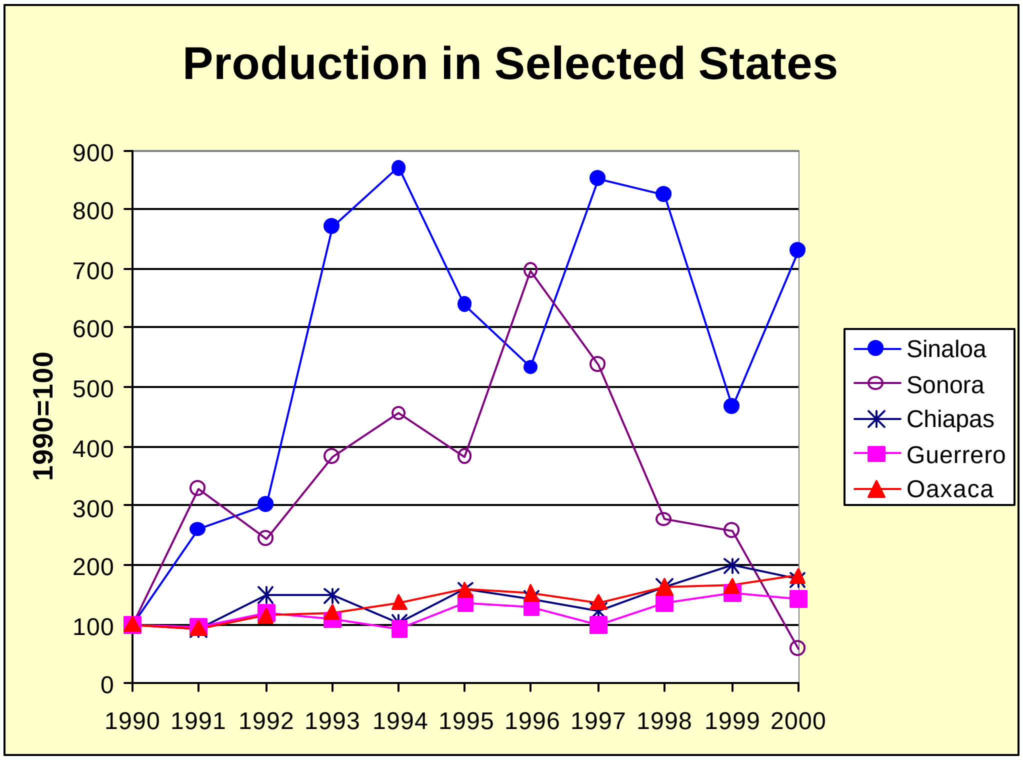


Exactly the opposite occurred after 1994: there is again a strong relationship to irrigation, but this time it is negative, implying that more irrigated states cut back more on area as market conditions worsened.



The dramatic changes of the 1990s thus appear to have been concentrated in the more modern (irrigated) states, both in the expansion early in the decade and in the contraction in later years. This can be seen clearly for the five states mentioned above: Sinaloa and Sonora are among the most modern, while Chiapas, Guerrero, and Oaxaca are among the most traditional. The next two graphs show the changes in production and cultivated area in these states, with all data scaled to 1990 = 100.





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. Cultivated area as a whole did not decline in Sinaloa; rather, land withdrawn from maize and other basic grains (except sorghum) was shifted into vegetables, oilseeds, other specialty crops, and pasture:

SINALOA
Change in Area Cultivated (Hectares)
Selected Crops, 1994-2000

Increased Production		Decreased Production	
Crop	**Area (ha)**	**Crop**	**Area (ha)**
Sorghum	80,642	Corn	-105,821
Chickpeas	68,675	Soy	-77,967
Pasture	33,773	Wheat	-22,413
Beans	26,798	Rice	-7,916
Sesame	19,949	**Total**	**-214,118**
Horticulture*	18,996		
Safflower	12,473		
Peanuts	7,182		
Total	**268,488**		

* Includes eggplant, squash, onion, peas, chili, green beans, lettuce, strawberries, melon, cucumber, watermelon, tomato, and tomatillo

Source: http://www.sin.sagarpa.gob.mx/

(This table presents changes in average cultivated area from 1993-95 to 1999-2000. Problems with the SAGARPA website have so far prevented a similar analysis of the much larger change in cultivated area in Sonora, which we hope to add in later revisions.)

In contrast, 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. Their growth is substantial, although overshadowed by the big changes in the modern states – Chiapas doubled its 1990 production in 1999.

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 traditional states did not respond in this manner, a finding that has several possible explanations. Reports of large-scale out-migration from traditional agricultural areas might imply that formerly small farm units are being consolidated into larger, somewhat more modern farms – or that a decline in output is about to begin, a few years after market conditions worsened. Another possibility is that producers in the traditional states are remote from urban markets and lack opportunities to switch to more profitable crops. Yet another possible story is that the high price of tortillas means that the value of production for local consumption (i.e., the avoided cost of commercially produced tortillas) is greater than indicated by the price of corn. There is clearly a need for more detailed analysis of the changes in corn production in the traditional states.

Our analysis suggests that market-induced changes *between* states since NAFTA have had little effect on genetic diversity in Mexican maize. There is no discernible shift of production away from traditional low-technology areas through 2000; on the contrary, they have expanded recently despite unfavorable market conditions. It remains possible that changes *within* states have had an effect, but this is more difficult to detect at our level of analysis. We conclude with one last calculation, offering a hypothetical, and probably worst-case, estimate of changes within states.

We found that maize yield (tons per cultivated hectare) in 1990-92 was strongly correlated with the percent of farm units using improved varieties rather than landraces in 1991. The trend line (see graph above) has a slope of 0.037, meaning that, on a cross-section basis in 1991, a 1 percent increase in use of improved varieties was typically associated with an increase in yield of 0.037 tons/ha. Annual data are available through 2000 on maize production and cultivated area, showing that yield increased during the 1990s for Mexico as a whole and for most, though not all, states. Suppose, hypothetically, that the decade's changes in yield were all due to changes in the use of improved varieties – that is, no other technological, behavioral, or natural changes moved any state's yield up or down after 1991. Suppose, also, that the 1991 cross-section estimate applies on a time series basis to all states: every 0.037 tons/ha increase in yield corresponds to a 1 percent increase in use of improved varieties.

On these unlikely but indicative assumptions, we can calculate the hypothetical change in the prevalence of improved varieties. More precisely, we took the difference between each state's average yield in 1998-2000 and its average yield in 1990-92 and divided by 0.037 to obtain the hypothetical change in improved varieties. We then added that change to the actual 1991 numbers to produce the table shown below.

It is not a realistic scenario for several reasons, most obviously the estimates of more than 100 percent for two modern states, Baja California Sur and Sinaloa. Those states could not have achieved their yield gains of the 1990s solely by increasing the use of improved varieties (at our assumed rate of 0.037 tons/hectare per percentage point of improved varieties). Less obviously, a handful of states had yield declines, and are therefore shown as having decreased their use of improved varieties.

Nonetheless, the numbers may be interesting for many states and for the nation as an indicator of the maximum plausible pace of change. The national average estimate increases from 31 percent to 39 percent in 8 years, implying an additional 1 percent of farm units using improved varieties every year in our hypothetical scenario. This would imply a rapid reduction in the use of landraces, which would indeed threaten the genetic diversity of maize in Mexico. Thus our calculation emphasizes the need for real, nonhypothetical information about the changes taking place within states, particularly within the areas where traditional cultivation practices remain widespread.

Percent using improved varieties	Actual 1991	Hypothetical 1999
Aguascalientes	46.5	63.2
Baja California	72.9	90.2
Baja California Sur	75.3	112.2
Campeche	33.0	40.8
Chiapas	25.4	33.7
Chihuahua	43.9	79.2
Coahuila	56.3	33.3
Colima	52.3	45.5
Distrito Federal	33.2	21.2
Durango	40.1	32.6
Guanajuato	43.1	70.3
Guerrero	22.4	34.1
Hidalgo	21.0	38.9
Jalisco	54.3	59.8
Mexico	32.7	37.2
Michoacan	39.7	53.2
Morelos	57.2	54.4
Nayarit	49.9	64.0
Nuevo Leon	25.4	27.6
Oaxaca	19.6	25.7
Puebla	31.0	24.6
Queretaro	23.4	58.7
Quintana Roo	28.8	27.8
San Luis Potosi	22.5	11.6
Sinaloa	57.6	119.7
Sonora	67.6	96.9
Tabasco	32.6	26.5
Tamualipas	44.9	33.0
Tlaxcala	27.7	17.9
Veracruz	28.5	29.5
Yucatan	20.8	21.3
Zacatecas	29.0	29.5
NATIONAL TOTAL	**31.4**	**39.4**

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 attempt to bring together our findings on the impacts of this large change in trade on the two societies.

The economic and social impacts are easiest to describe, and have been addressed by other studies. For the US, exports to Mexico provided markets for an additional 1% of the corn crop, at a time when prices are down and some other markets are buying less. This was an obvious economic benefit to farm states and rural communities, slowing the long-term decline of rural populations and incomes and reducing, albeit only temporarily, the pressure for farm subsidies.

For Mexico, lower corn prices were a benefit only to industries that use corn as an input; monopoly pricing of tortillas meant that the savings were not passed on to urban consumers as a whole. Benefits to US corn producers were mirrored in costs to their Mexican counterparts: lower prices meant economic hardship for producers in general; the modern, irrigated sector of agriculture, particularly in the northern states, had to cut back sharply on its corn production, following its expansion in the early 1990s. More analysis is needed of the traditional producers in southern states, who expanded output despite unfavorable market conditions.

The environmental balance sheet is more 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. In Mexico, likewise, 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; and they are potentially involved in the complex story of threats to genetic diversity.

Principal US impacts include the use of chemical fertilizers, herbicides, pesticides, scarce irrigation water, and potential impacts of Bt corn.

Heavy use of fertilizers is continuing, and, in the important case of nitrogen, even growing slightly in intensity; runoff of excess nitrogen fertilizer causes problems in downstream water systems, including the pollution of the Mississippi River and the large "dead zone" around its mouth in the Gulf of Mexico. One piece of evidence, which needs further exploration, suggests that much more nitrogen is used, per ton of corn, in Mexico than in the US. If this finding is confirmed, increased US corn exports to Mexico could be seen as decreasing the two-country total use of nitrogen, although perhaps causing or exacerbating local problems in the Mississippi or elsewhere.

The use of herbicides and insecticides, per hectare planted in corn, decreased sharply in the US in the 1990s. We are not aware of comparable data for Mexico. While these trends are encouraging, they are at risk of stopping or even reversing in the near future. Herbicide reduction could be jeopardized by a challenge, still unresolved as of late December, to the regulations that removed an older herbicide, metolachlor, from the market to make way for an improved formulation that allows lower use. Insecticide reduction appears closely related to the sudden rise in Bt corn use, which may not continue (see below).

Overuse of irrigation is an important problem in large parts of the plains states, southwest, and western US. Some 15% of US corn is irrigated, the great majority of it in Nebraska, Kansas, Texas, and Colorado; the proportion is constant or slightly increasing. A somewhat lower proportion of Mexico's corn is irrigated, but given the local nature of irrigation problems and constraints, it may not make sense to consider a two-country balance sheet in this area.

Bt corn, first planted on a significant scale in 1996, spread to 21% of US cornfields by 1999, then abruptly stopped and may even have begun to contract. Bt corn faces resistance from major export markets and evidence of its lack of profitability under many circumstances. It is at the center of ongoing controversy about its potential implications for biodiversity, and its long-term impacts are of course unknown. It is quite expensive, and is clearly profitable only in times and places of high insect infestation. Bt corn is more widely used west of the Mississippi, though not unknown in eastern states. Corn growers in Colorado and Texas are by far the most consistent winners from its use (since corn borers thrive in warm, dry climates), while other states may find it profitable only in the worst years.

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.

Mexico no longer allows growing of Bt corn, and probably had very little planted before it was banned in 1998. However, imports of Bt corn are still permitted, and are likely the cause of the appearance of transgenic corn in remote rural areas. In addition to such threats of direct contamination, there is a broader problem of the impacts of the market on Mexico’s crucial reservoir of genetic diversity in corn. Our principal finding is that there is no evidence, in the state-level data, that corn production has shifted out of the traditional producing regions into more modern ones since NAFTA. The impacts of the market on genetic diversity need to be studied within, rather than between, states, particularly within the most traditional states where landraces remain in widespread use. Ongoing improvements in yield, seen in traditional as well as modern states, could imply a loss of traditional techniques and varieties, but more detailed research on this subject is needed.

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