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Agricultural policy, climate change and food security in Mexico

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This paper describes how variations in agricultural policy and climatic conditions have influenced maize production and food security in 20th-century Mexico. We describe the Mexican food system today and how economic policy has influenced food output in efforts to attain food security based on the goal of national self-sufficiency. We examine the impact of climate variability on agricultural production; the ways in which agricultural policy has interacted with climate to change vulnerability to environmental and social change and the implications of global warming for the future of Mexican agriculture. Finally, we discuss the implications of the changing economic environment as Mexico has opened its economy – for example, through the North American Free Trade Agreement. Our goal is to provide a context for thinking about the implications of two types of global change for Mexico – the internationalization of economies and the widespread transformation of the environment.

Keywords: Mexico, Climate Change, Agricultural Policy

As Mexico moves towards more open markets in agricultural trade, land, and water with the reprivatization of land and the initiation of a North American Free Trade Agreement, the Mexican people are facing an uncertain economic future. Food production in Mexico has always been constrained by low rainfall and at risk from frequent droughts, and is now threatened by climatic changes associated with global warming and regional land use transformation. Yet 20th century Mexico has experienced great increases in agricultural production associated with government policies to develop irrigation, increase the use of chemical inputs, and subsidize prices paid to farmers. At the same time, rapid population growth, urbanization, and export expansion have increased and restructured overall demand for agricultural products so that imports of basic grains have risen significantly in recent years (Sanderson, 1986; Wellhausen, 1976; Yates, 1981). Although Mexico no longer experiences the famines of previous centuries, and several indicators suggest that food security has been attained at a national level, studies show that as much as one-fifth of the population of 85 million are hungry or malnourished (Calva, 1988; Mexico INEGI, 1991).

National and individual food security is very vulnerable to year-to-year variations in climate, domestic agricultural policy, and international economic conditions. Domestic agricultural policy is variable and complicated because different population groups have contradictory interests as to the orientation of food policy. The urban poor, rural landless wage-workers, and employers who wish to pay low wages, all demand cheap food. In the absence of subsidies, low food prices are a disincentive to agricultural production, hurting peasants and farmers dependent on growing staples. National policy has varied from protectionism and economic self-sufficiency to free trade and export expansion; from free or common access to land and water to private ownership; and from large price subsidies and rampant inflation to withdrawal of government financing and controls on wages and prices (Appendini, 1992; Austin and Esteva, 1987).

This paper describes how variations in agricultural policy and climatic conditions have independently influenced food production and security in 20th century Mexico, and attempts to show how economic policy increases vulnerability to climatic variation and vice versa. We focus on maize (corn), the most significant crop in the Mexican food system and an important basis of food security. Maize is the target of government food policy and is grown by many of the poorest farmers in Mexico on rainfed, drought-prone land. Our aim is to provide a content for thinking about the implications of two types of global change for Mexico – the internationalization of economies and the widespread transformation of the environment – through a discussion of how the North American Free Trade Agreement (NAFTA) and global warming may affect Mexican agricultural production.

First we describe the general situation of the Mexican food system today. Then we review how economic policy has moulded food output during the 20th century in decade-long efforts to attain food security based on the goal of national self-sufficiency. This is followed by an examination of the impact of climate variability on agricultural production, and the ways in which agricultural policy has interacted with climate to increase or reduce vulnerability to environmental and social change. Then we consider the implications of global warming for the future of Mexican agriculture. Finally, we discuss the implications of the changing economic environment as Mexico has opened its economy to trade and is seeking its integration into the world economy. This has changed the concept of food security as domestic supply becomes less important because grain can be bought cheaper on the world market. This policy has differential impacts on different groups because the urban poor may secure access to cheap food, but poor, already malnourished, rural smallholders may be worse off.

The Mexican food system

Mexican agriculture provides most of the food for a population of around 85 million. During the 20th century, feeding this growing population – which has more than doubled in the last 30 years – has been a great challenge. Food security for the nation has always been a policy priority. Until recently the government has heavily subsidized food staples through supports for both producers and consumers. For example, high maize prices for farmers have been guaranteed to encourage production, while the price of the consumer food staple made from maize – the tortilla – has also been subsidized to guarantee cheap food, especially for urban dwellers who buy ready-made tortillas. The balance of subsidies have changed over time, sometimes leaning on the production side, most often benefiting consumers. These policies are now reforming with the current deregulation and liberalization of the Mexican economy (Appendini, 1992).

In recent decades, importing grain has become a key component of food policy. Mexico became a net food importer in the early 1970s, and imports of maize, in particular, grew to 20 to 25 per cent of total supply during the 1980s. Maize imports are largely distributed to the tortilla processing industry in the large cities where more than half of Mexico's population now live.

Despite, and in some cases because of, government food policies, household and individual food insecurity is widespread in Mexico and has accelerated with the economic crisis of the 1980s. Calva (1988) suggests that up to 20 million people in Mexico have caloric or protein deficiency. A 1990 study of children under five found that 21 per cent were malnourished. The hungry include many rural people whose food security is dependent on growing their own food on small plots of drought-prone land; earning a reasonable income from selling crops or working as wage labourers; or obtaining access to government welfare programmes or entitlements to food within households. Environmental degradation, mechanization, economic crisis, and reduced government spending are some of the factors that have restricted the entitlements of many poor people to food.

Cropland in Mexico is limited by dry climates and steep topography to about 16 per cent of the total land area. The basic staples – maize and beans – tend to be grown on the 80 per cent of the cropland that is rainfed. Irrigated land (20 per cent) has largely been devoted to other cash crops ranging from grains and fibres such as wheat and cotton, to high-value export crops such as fruits and vegetables. Irrigated land is spatially concentrated in northwest and central Mexico. The use of chemical fertilizers, and, to a lesser extent, hybrid seeds, is fairly widespread in Mexico, but poorer farmers cannot afford to use them in some regions. Average productivity of maize is low at about two tons per hectare, but ranges from more than 10 tons per hectare under irrigation to less than half a ton in drier and less fertile areas.

Seventy per cent of maize is grown on rainfed land, mostly by the 90 per cent of the maize producers who live on small landholdings of five hectares or less. Although the majority of these small farms consume most of the grain within their households, at an aggregate level they contribute about one-third of the total domestic output which goes to the market. The rest of the maize comes from larger farmers, including about 30 per cent of irrigated areas in 1991 (SARH, 1993). Cropping patterns and yields are highly differentiated and polarized according to the natural endowments of regions as well by the ability of farmers to obtain capital and purchase agricultural inputs.

Mexican food and agricultural policy in the 20th century

The most important policies affecting agricultural production and food security in 20th century Mexico include land reform, infrastructural and technological development, credit availability and subsidies. The early decades of the 20th century were characterized by the social unrest and economic uncertainty of the Mexican Revolution – which was partly driven by the aspirations of poor rural people for land to grow food. Although food production declined in the immediate aftermath of the revolution, the mid-1930s brought massive agrarian reform and increases in food production as peasants on small and collective landholdings gave priority to growing food staples for self-consumption. One important form of land distribution was the *ejido* – land held collectively by a group of farmers which could not be sold or rented under Article 27 of the constitution.

From the 1930s to the mid-1960s, one key source of increased food production was the new cropland distributed to peasants through agrarian reform, and this land contributed food to the market as the peasantry became incorporated into the national economy and began to sell their products. For a time, the main supply of maize and beans was provided by these farmers without requiring large public investment in modernizing agricultural in the *ejido* sector. The extent to which the *ejidos* have continued to contribute to local and national food security has been a subject of heated debate. Whilst some authors argue that *ejdos* provide a sustainable livelihood for millions in rural Mexico, others suggest that they are inefficient and contribute little to national agricultural production (Dovring, 1979; Eckstein, 1966; Mueller, 1970; Nguyen, 1979).

Another important factor in increasing agricultural production was the prodigious investment in irrigation infrastructure beginning in the late 19th century. Agricultural development was concentrated in the large irrigation districts on which cash and export crops such as cotton and vegetables were being grown. Food staples were grown on rainfed land with traditional technology and unable to face the pressing demand of population growth and urbanization.

By the mid-1950s, it became clear that agrarian reform was tending to redistribute mostly marginal and rainfed land, and irrigation policy, together with a general agricultural policy favouring private landholdings, was producing a highly unequal agricultural structure. Increasing overall agricultural productivity became an issue because irrigation was not ensuring the security of basic grain production or of the peasant sector. This was important because at the time, Mexico reaffirmed a development strategy of industrialization through import substitution based on a protected domestic market. Controlling inflation was one of the main factors in guaranteeing stable development, and food price control became a key issue in this policy.

Price support for basic crops was established in 1953, both aiming at regulating the grain market and giving stable conditions to farmers, as well as putting a ceiling on food prices. But from 1963, nominal support prices on basic grains were frozen until 1973. Incentives for growing basic crops were to come from productivity increases rather than prices. This was attained with the Green Revolution which emphasized the use of improved seeds, fertilizer and pesticides to increase yields. The use of inputs was encouraged through state agencies for the distribution of fertilizer, pesticides, seeds and credit, and by the establishment of Conasupo, a state agency which purchased crops at support prices and sold them at lower, subsidized costs to consumers. By many measures the Green Revolution was a tremendous success. Maize output grew steadily at an annual rate of 7.6 per cent until 1967 and Mexico became self-sufficient in food crops (Figure 1). The Green Revolution in Mexico was particularly successful for hybrid wheat and maize on irrigated land, but less so in the case of rainfed maize. Thus, the use of hybrid seeds and chemical inputs was most advantageous on the best land and for the better-off peasantry who could afford the cash expenditures for the new inputs. While peasants continued to grow maize in conditions of low productivity, commercial farmers in certain regions now found it profitable to grow grains on irrigated and more productive rainfed lands. Export crops, such as cotton, were no longer profitable owing to international prices, and the government was giving strong support to the adoption of the Green Revolution technology. This again led to

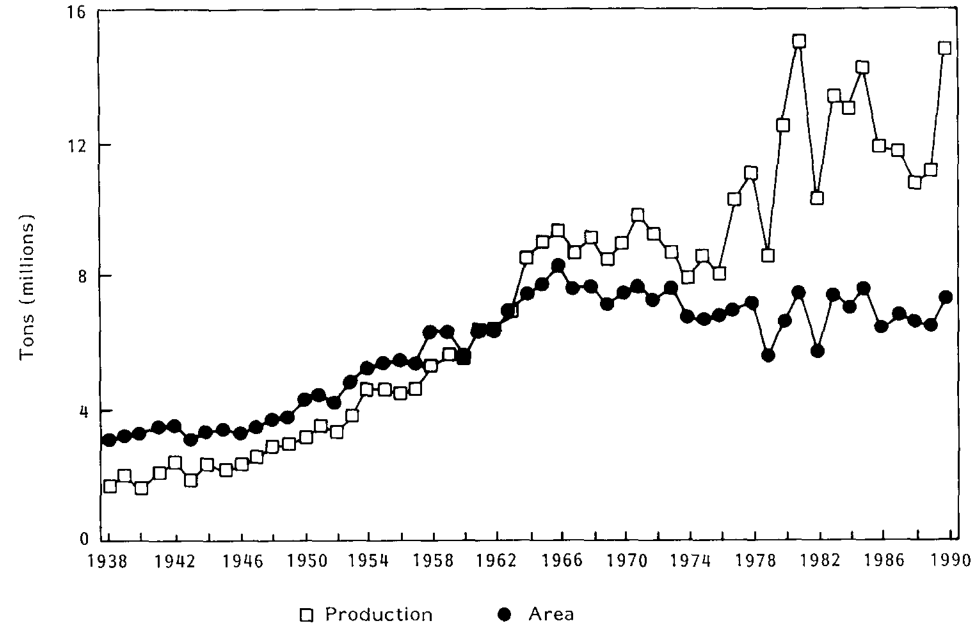

Figure 1 Maize area and production Mexico 1938–1990

Source: Appendini 1992

widening the gap between 'modern' agriculture and 'peasant' agriculture (Hewitt, 1976).

But by the end of the 1960s, basic food crops again became unprofitable relative to other cash crops. Maize prices became particularly unfavourable compared to sorghum, which was becoming a competing crop both on irrigated and rainfed land as demand for animal products increased in Mexico. Maize output in the 'modern' sector of agriculture began to decrease and by the early 1970s maize became a 'peasant crop' of the regions of Mexico land that had been largely marginalized from the Green Revolution's technological change and had low productivity. This sector was unable to ensure an increasing supply of this basic food for Mexico's still growing population.

The 1970s witnessed the constraints of Mexico's development policies as inflationary pressures, the balance of payment deficit and external debt began to build up. In the countryside the contradictions of bimodal development resulted in the stagnation of staple food production due to the marginalization of peasant agriculture. During this period, state intervention in the countryside expanded in the attempt to increase production of basic food crops. Subsidies increased through the expansion of the rural public credit system (Banrural), the distribution of inputs, the purchase of crops through Conasupo at revised support prices, and investment in rural infrastructure. Crop insurance through a government-sponsored agency was promoted as a response to climatic and other risks.

Domestic supply did not respond to these policy incentives. From 1970–1978 foodgrain output grew at an annual rate of only 2.1 per cent while feedgrains grew at 7.4 per cent. Maize output grew at only 0.4 per cent from 1964–66 to 1976–78 and harvested area diminished by 1.5 million hectares (Figure 1). Maize imports began to supplement domestic output from the early 1970s, and have continued to do so ever since. Feedgrains and other commercial crops remained more profitable for larger farms and peasant agriculture remained largely stagnated (Appendini, 1992; Sanderson, 1986).

The use of fertilizers was adopted by a large proportion of peasants during this decade, but it was often to compensate for declining fertility from erosion and continuous – rather than fallow cycle – cultivation, and did not necessarily reflect any increase in yields. Also, subsidies on inputs were not equally accessible to all producers, benefiting those who purchased inputs. The productivity gap between farmers using Green Revolution type technology and 'traditional' peasants increased, so that from 1972, support prices did not cover production costs of traditional technology on rainfed land. If peasants continued to grow and sell maize it was because they squeezed their income even below minimum salary levels.

The supply of maize to the tortilla industry became of increasing concern to the state, especially in the big cities, such as Mexico City where cheap and secure food reduced risks of political unrest and kept down demands for higher wages. In 1974, the maize processing industry for tortillas was decreed 'of public interest' and was taken under complete state control. Those who processed grain and made tortillas (millers and torillerias) were assigned supply quotas of subsidized grain distributed through Conasupo. This agency now purchased about 20 per cent of domestic supply and was the only agency allowed to import grain (Appendini, 1992). Thus, the big cities were increasingly supplied by imported grain – which was disliked by consumers because it produced lower quality tortillas. But the real price of the tortillas diminished during the decade, and the goal of feeding the urban population cheaply was achieved by both putting a ceiling on producer prices and subsidizing the tortilla industry.

It is important to note that the difficult and expensive task of balancing subsidies, and making decisions on who should benefit and who should pay for the food system, was made much easier by the inflow of Mexican oil revenues in the late 1970s and early 1980s. During 1980–82, Mexico embarked upon the most ambitious food policy scheme in recent history. A special programme called SAM – the *Sistema Alimentario Mexicano*, or Mexican Food System – was launched in order to increase produce of staple crops and attain national food self-sufficiency, while ensuring cheap food for the cities and poor rural population (Austin and Esteva, 1987). Public expenditure increased substantially, channelling funds to support peasants and farmers through subsidies to costs, prices and marketing. In order to promote new technologies among small farmers, a special risk-sharing programme – *Programa de Riesgo Compartido* – was introduced in which the state would compensate for any loss due to costs of new technology. Subsidies to consumers also increased to maintain the cheap food policy. Maize output hit a record of 14.0 million tons in 1981.

The policy of resolving the price and food security dilemma by public expenditure was, of course, unsustainable when the debt crisis struck in August 1982. Basic grain production fell dramatically in that year, especially maize which dropped by almost one-third (Figure 2). As we discuss later, this was as much as result of climate variability as economic crisis or government policy, but was blamed on a failure of the SAM. The SAM programme was completely dismantled and food policy was subdued to macroeconomic policy focused on managing the debt crisis and restoring macroeconomic equilibrium.

Reducing public deficit was one of the main policy instruments, and this had direct implications for food policy. During this period, agriculture was not a

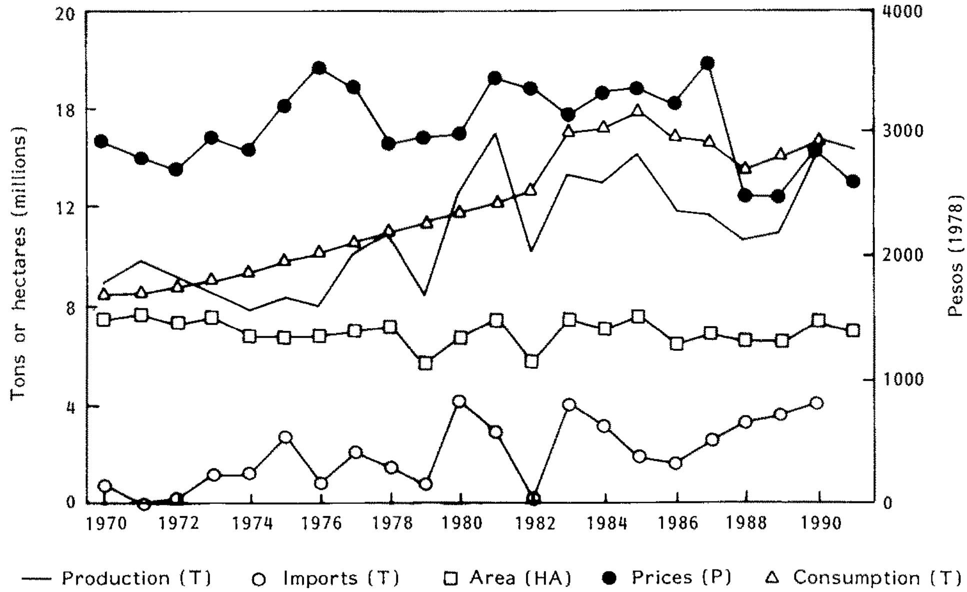

Figure 2 Maize production, area, imports, support prices and consumption

Source: Appendini 1992

priority issue on the government agenda and policy instrumentation was reduced to distributing decreasing public resources. From 1982 to the end of the decade, public expenditure in agriculture decreased at an average yearly rate of 8 per cent. This had an impact on the maintenance of infrastructure such as irrigation works and resulted in increasing inefficiency in water use and salinization. The impact was also felt on credit, where Banrural loans for maize decreased at a yearly rate of 20.2 per cent from 1983 to 1990. Fiscal constraints reduced subsidies on fertilizers and other inputs. Although economic crisis affected Conasupo's capacity to buy domestic grain output at support prices, price policy was perhaps the one instrument that remained as an incentive to farmers, especially for maize which, after a sharp decline in 1983, showed increases in real support prices up to 1987. Maize and beans were both favoured relative to other crops by credit and support prices (Myhre, 1993). Private investment remained stagnant, as it had since the 1970s.

Although maize production stayed low in 1983, better weather, an easing on adjustment policy, and support price increases, explain better performance for agriculture overall, and for maize production from 1984 to 1986 (Figure 2). From then until the end of the decade agricultural production declined. This recession was due to adverse climate (1988), the impact of contraction in sectoral expenditure, and to a change in macroeconomic stabilization policy beginning in 1987. This new anti-inflationary policy fixed nominal prices on all basic goods, including good staples, and controlled the exchange rate, making basic food imports cheaper. From 1989, trade liberalization removed import tariffs on most agricultural commodities except maize and beans.

During crises of the 1980s, distribution and consumption of staples for household food security was much more of a concern than production. The policy priority was to guarantee the population's access to cheap food as personal income contracted.

Minimum real salaries decreased 50 per cent during the period making it difficult for many families to purchase adequate food. Subsidies to food staples, particularly in big cities, were not abolished, although they were restructured throughout the decade in order to diminish the public financial burden of food subsidies. In these years, the gap between the price of imported maize and the domestic support price widened, with domestic prices ending up at double the international price. The state began to depend on cheaper imported maize, rather than domestic grain from Conasupo, to support the tortilla industry. This lowered the cost of the subsidy to this basic food and made it clear that national food self-sufficiency was no longer a goal of food policy.

By the end of the 1980s the productive capacities of peasants and farmers had been severely eroded by a decade of decreasing government support to agriculture, several years of adverse climate, and decreasing prices. After the new administration of President Salinas took office in December 1988, the agricultural crisis again became an item on the national economic agenda. But, before we summarize the most recent agricultural policy shifts and their implications for food security, we turn to examine the role of one key factor in Mexican food security at national and local scales – climate, and particularly the role of low rainfall in year-to-year variations in agricultural production.

Climate variation and food production in Mexico

Almost every year drought endangers agricultural production in some part of Mexico. With 85 per cent of the land classified as arid or semi-arid, Mexican agriculture relies on low, seasonal and variable rainfall. The dry climates, together with steep topography, are the main reason why only 16 per cent of Mexico's land area is considered suitable for crop production. As we noted earlier, only one-fifth of Mexico's cropland is irrigated and many irrigation districts rely on small reservoirs and wells which deplete rapidly in the dry years.

Throughout Mexican history, drought and climate variation have been associated with migrations, food crises, and social unrest. Climate changes have been implicated both in the rise and collapse of powerful pre-Hispanic civilizations such as those in Yucatan and in the valley of Mexico, and it is clear that management of scarce water supplies was critical to food security (Sanders *et al.*, 1979). The arrival of the Spanish in 1519 altered climatic risks in important ways. There was a tremendous expansion of irrigation which increased the range and reliability of crop production, whilst increasing competition for limited water supplies in some regions. However, the Spanish often controlled the best land and water, and their cattle and wheat replaced the more moisture conserving agriculture of the indigenous people. These changes, together with grain speculation and relentless tribute demands by the colonial powers, have been linked to subsistence crises, and to widespread famine in drought years. In 1785, drought is estimated to trigger the starvation of more than 300 000 people – mostly members of the indigenous Indian population (Florescano, 1969).

Because potential evaporation exceeds precipitation in most of Mexico, even slightly below average rainfall can place crops at risk. On average, more than 90 per cent of losses in Mexican agriculture are from drought. In 1990, with favourable weather, about 7 per cent of the crop area that was planted was lost to natural hazards. In 1979, with less favourable weather, drought losses alone devastated 19 per cent of the area planted. A large region of central and northern Mexico lost more than 50 per cent of the area planted (Liverman, 1993).

Rainfed maize production is particularly sensitive to any delay in the start of the summer rainy season (May–June) and to the severity of the midsummer drought called the *canicula*. During the 1980s, dry years had significant impacts on national and local food production. Figure 1 shows the dramatic drop in maize production in 1982, which was more a result of low rainfall than of agricultural policy, as the critics of SAM claimed. In Puebla, east of Mexico City, rainfall in 1982 was more than 25 per cent below normal (Walsh, 1993). In Oaxaca, to the south, both 1982 and 1983 saw rainfall more than 30 per cent below normal (Dilley, 1993). Yields and production fell correspondingly. In Puebla, yields fell from more than 3000 kg/ha in 1981, to 1200 kg/ha in 1982 and 1050 kg/ha in 1983. In Oaxaca, maize production dropped from 80 000 tons in 1981 to only 15 000 tons in 1982 and 20 000 tons in 1983. Similar drought-driven production declines at the national level occurred in 1979 and 1988.

When production drops precipitously due to climate there are local and national impacts on food security: some peasants do not grow enough to eat and go hungry; others become temporary migrants and wage labourers. The state usually tries to bring grain into the regions, at least to major cities. When national supplies are inadequate, grain is usually purchased from the United States, but in 1988 it was difficult to make up the shortfall from imports because of weather related losses in US agricultural production.

Changes in demand for land and water can make some people more vulnerable to climatic variability and drought. For example, population growth has meant more people trying to make a living from the land and has been one of the causes of deforestation, erosion, competition for water resources and increased flood and drought vulnerability. In the valley of Oaxaca, for example, population has quadrupled in the last 30 years, especially around the city of Oaxaca. In some areas of the valley, per capita demand has increased as farmers purchase mechanical pumps and shift from growing maize to alfalfa or vegetables for domestic and international markets. A growing population of middle class urban dwellers and tourists is increasing per capita water use in the city. As a result, competition for surface water has intensified, and groundwater levels have fallen from one to ten metres, especially in low rainfall years (Dilley, 1993).

Another example of urban growth and pressure on water resources is that of the northwestern valley of Toluca. In rural districts, underground water has been drained to supply the metropolitan area of Mexico City – which now has a population approaching 20 million – with water since the early 1970s. Rural communities must now alternate one year with water supplied by wells and one year cultivating on rainfed land. Peasants switched from rye, wheat and livestock activities – requiring humid soil and suited to the colder climate of the high central plateau – to maize, which can be grown under both irrigated and rainfed conditions. But they also adopted new technologies to ensure good yields, mainly using chemical inputs. This, together with a credit policy favouring maize, turned the region to almost exclusive maize production, in spite of the fact that maize is more vulnerable to early frost and heavy winds than the former grains. Small landholding peasants were drawn into the market and abandoned the multiple variety of the *milpa* farming system for self-consumption. The valley has become an important region for supplying Mexico City with maize, but at the same time underground water extraction has made agriculture more vulnerable to climate change (Appendini, 1992).

Both these examples of increasing water demand also show potential interactions between agricultural policy – credit, input use, export orientation – and vulnerability to climate. To what extent have agricultural policies described earlier changed vulnerability to drought and reduced climatic threats to food security in Mexico?

The interaction of food policy and climate variability

One of the most significant responses to uncertain rainfall has been massive Federal investment in irrigation works. This resulted, for the most part, in much more reliable and higher volume production, especially in northwest Mexico. In other regions, farmers are still using the traditional irrigation systems built in pre-hispanic or colonial times. Unfortunately the ability of irrigation to buffer producers against low rainfall is threatened by growing demand, widespread salinization, falling groundwater levels, and inadequate reservoir supplies, especially when rainfall is low. Although the Comision Nacional del Agua has formal procedures for allocating water in dry years, and *ejidos* and certain high value crops are supposed to receive priority, in practice it is often the wealthier and more powerful farmers that get the water.

Of the basic grains, wheat is grown mainly on irrigated land. Maize has been grown on irrigated land at certain times as a response to high support prices and thus contributed to self-sufficiency. This was the case during the mid-1960s when the Green Revolution and price incentives made the crop profitable on high-yielding land. At present, when maize remains the only crop left with support price and relatively higher than other basic crops, farmers on irrigated land have again switched to maize, accounting for self-sufficiency from 1990–93.

The Green Revolution can be seen as a partial response to climate risk in that some new seeds were bred for drought and disease resistance. Wilken (1987) has argued that the new techniques have replaced some traditional hazard prevention strategies, such as mixed cropping and microclimate modification, and have enabled agriculture to expand into areas of high hazard risk such as deserts, mountains, coastal regions, and the disease-susceptible humid tropics. In favourable weather conditions, improved seed and fertilizer give much higher yields of crops such as wheat and corn, especially with irrigation. However, when drought, frost or flood destroys the crop, farmers are often left in debt because of the cost of the technical inputs (Walsh, 1993). Previously farmers did not purchase inputs, they kept seed from one year to another and perhaps used some green or animal manure as fertilizer. They might lose their crop to drought, and be hungry, but would not be making a major financial risk.

There is a problematic relationship between land reform and drought vulnerability in Mexico. On the one hand, land distribution reduced the vulnerability of significant numbers of landless and poor by providing the opportunity for subsistence food production on their own plot of land. But a large proportion of land that was distributed was of poor quality and in hazard prone areas. Irrigated land has tended to stay in the private sector. The vulnerability of *ejidos* is borne out in statistical studies of agricultural losses to natural hazards based on census data. For example, in 1970 the average drought loss on the *ejidos* in the summer growing season was 17 per cent as compared to 14.5 per cent on private landholdings over five hectares (Liverman, 1990). In winter the average *ejido* loss was 11.6 per cent compared to 8.6 per cent in the private sector. Many *ejidatarios* experience this loss in the form of both income from the crops and nutrition from those they eat. These patterns can be explained through a combination of physical, technical and social factors. Explanations of this increased vulnerability are that more biophysically marginal land was given to *ejidos* in the land reform, and that *ejidatarios* are socially vulnerable because they cannot get access to irrigation, credit, improved seeds, or other resources (Liverman, 1993).

Increasingly important for climate vulnerability are the changes brought about by the integration of Mexico into a national and international market and financial system. Subsistence production of corn has been replaced by wheat, dairy, sugar, feedgrain and fibre production for domestic industrial and urban markets. Overall, in the latter years, the agricultural system has increasingly been oriented to export production – of fruit, vegetables and livestock – although there have been periods where the state has intervened with subsidies to encourage basic grains.

The increased acreage under fruit, vegetable and feedgrains has furthered the demand for water both within and outside the irrigation districts. Alfalfa, tomatoes and lettuce, for example, have a much higher consumptive use of water than maize. As the crop mix becomes more water-demanding, rainfall deficits are more critical. For example, water demand in the irrigation districts of northern Mexico has doubled in the past 20 years. In drought years, reservoir and groundwater resources are increasingly insufficient and water allocations are reduced. Increased production of water intensive export crops has also increased the potential for international conflict over the waters of the Colorado and Rio Grande, and for competition between agriculture and the industrial and domestic consumers of the rapidly developing border cities (Borza, Leichenko and Liverman, 1993). Mexico's broader economic conditions are also important to rural climate vulnerability. For example, the growth of debt in the 1980s reduced the availability of the state to provide or subsidize rural infrastructure such as dams, credit and inputs.

Despite overall increases in agricultural production, and the ability of irrigation and insurance to reduce climate risks, it is clear that Mexican agriculture is quite vulnerable to climatic variations, especially drought. In some years and regions, drought is a real threat to the food security of households, especially when economic conditions raise overall prices and unemployment, and shift government policy away from subsidy and import programmes for basic foods. Thus, any climate change towards warmer, drier conditions could have very serious implications for food security in Mexico.

Global warming and Mexican agriculture

Many scientists believe that an increase in atmospheric CO_2 is likely to result in warmer global temperatures and altered precipitation patterns. Research on the impacts of global warming in Mexico indicates that climate change may bring warmer and drier conditions to much of Mexico (Liverman and O'Brien, 1991). We have used the results of the major climate models – General Circulation Models – to project what may happen to Mexican climate if concentrations of carbon dioxide in the atmosphere double over pre-industrial levels. There is a considerable debate about the accuracy and validity of these models because of limitations in their ability to simulate some cloud and ocean processes, their coarse spatial scale, disagreements between the models, and their poor ability to reproduce observed climates. The estimates of precipitation are particularly dubious and immediate improvements in the regional projections of climate models are unlikely. We have used the results of five different climate models, as well as extensive sensitivity analyses, in order to try to capture some of the uncertainty in current global warming studies.

On average, the models project that global warming will bring annual temperature increases of two to five degrees celsius in Mexico, depending on the model

Table 1. Climate changes projected by General Circulation Models for Mexico (averaged change across country)

Model	Temperature °C	Precipitation (%)
GFDL	3.11	−1.75
GISS	3.92	2.74
NCAR	2.38	−23.01
OSU	3.15	−1.05
UKMO	5.44	−0.09

Source: Liverman and O'Brien (1991)

(Table 1). For rainfall, however, the NCAR model predicts a 23 per cent decrease, and the GISS model a 3 per cent increase, dramatically illustrating the uncertainty in precipitation forecasts under global warming. Although all parts of Mexico are projected to have temperature increases, and many regions could see rainfall decreases, there are a number of places where rainfall could increase.

In cases where both rainfall and temperature increase, it is not immediately obvious what the effects on soil moisture may be. Will higher rainfall compensate for the increased evaporation brought by higher temperatures? Table 2 shows some estimates for the increased evaporation and water availability in Puebla, an important maize growing area east of Mexico City. Using relatively simple calculations we estimate that potential evaporation may increase by 7 to 16 per cent and the annual deficit of water could increase by 17.5 to 44.7 per cent. That is, all models project that soil moisture and water availability in the valley of Puebla may decrease. This has serious implications for agricultural production. Our main conclusion, based on climate model projections, is that Mexico is likely to become warmer and drier. All models show increases in potential evaporation, and, in most cases, indicate that moisture availability will decrease, even where the models project an increase in precipitation. Sensitivity analysis of moisture deficit calculations indicate that water availability could increase only if the models simulated much higher rainfall and relative humidities, or significantly less solar radiation and wind.

We have also undertaken some analysis of the impacts of global warming on the production of maize – the most important crop in Mexico – using the CERES crop growth model. At Tlatizapan, a site of Mexico City, current rainfed corn yields with low fertilizer are 3600 kg/ha. If climate changes and no adaptations are made, yields could decrease to as low as 2000 kg/ha (Table 3). Farmers, are of course, likely to

Table 2. Climate change and potential evaporation in Puebla, Mexico

Climate	Potential evaporation	Potential evaporation – Precipitation 'Water deficit'
Observed	1528 mm	694 mm
GFDL	+14.2%	+44.7%
GISS	+13.3%	+33.1%
NCAR	+7.1%	+22.8%
OSU	+10.0%	+17.5%
UKMO	+16.0%	+29.5%

Source: Liverman and O'Brien (1991)

Table 3. Potential impacts of global warming on Mexican maize yields in Morelos (CERES model)

Model	Rainfed yield kg/ha
Observed	3600
GISS	2900
GFDL	3000
UKMO	2000

Source: Liverman (1992b)

adapt to the projected warming. However, given the environmental and economic constraints on agricultural input use and water resources in Mexico, the ability to adapt to climate change may be limited, especially for poorer farmers (Liverman, 1992).

If global warming occurs as projected, it is likely to interact with some major agricultural and macroeconomic policies which are also likely to dramatically transform Mexican agriculture in the coming decades. We conclude with a discussion of some of these recent and ongoing policy changes.

New challenges and options for Mexican agriculture

Since 1989 agricultural policy under President Salinas has undergone a complete change as part of the economic restructuring of the Mexican economy towards integration into the world market. The changing policy comprises above all the reorganization of institutions with the goal of reducing state intervention in the countryside and attracting private investment in agriculture, livestock and forestry. This has led to a complete change in the framework in which peasants and farmers have operated for over two decades. It has meant uncertainty for producers, as access to resources has become more difficult and expensive. Privatization of land, trade liberalization, and new policy instruments are the core of restructuring.

The main changes in policy which have already had a profound impact on agriculture are:

- the reorganization of rural credit – reducing heavily subsidized credit for peasants farming at the small and medium scale;
- privatization of input industries such as fertilizers and seeds;
- abolishing support prices;
- liberalizing trade for all crops except maize and beans.

Small farmers have been excluded from the banking system and may receive a small loan for basic crops – covering about a third of production costs of maize per hectare – through the poverty assistance programme Pronasol (*Programa Nacional de Solidaridad*). Credit has become scarce and expensive and medium-sized farmers have become heavily indebted in the last four years. Access to crop insurance had diminished as subsidies have been abolished. As part of a transition policy, deregulation has been partial. The state still intervenes in the grain market protecting maize and beans with import licences and by buying up maize and beans at support prices through Conasupo. Other basic products, including feedgrains, have been liberalized and domestic prices have dropped to equal international prices.

A contradictory outcome has resulted. Instead of farmers substituting grains for high value crops such as certain export fruits and vegetables in which Mexico has a comparative advantage, farmers – particularly those on irrigated land who no longer find it profitable to grow feedgrains – have turned to maize, taking advantage of the relative high prices and secure market. This seems in the short run to be a safe business decision rather than to invest in export crops which require large investments and have high transaction costs. Thus in 1990 and 1991 maize production reached a record harvest of 14 million tons after several years of high imports, and self-sufficiency has been attained for the past three years.

Mexico has already negotiated the conditions for maize and beans within the North American Free Trade Agreement (NAFTA). For these staples, import licences will be abolished and protection replaced by a tariff which diminishes over a period of 15 years. A tariff-free, increasing, import quota of maize will start at 2.5 million tons per year. The issue for Mexican farmers is whether they will be able to increase productivity substantially in the long run and be able to compete with middle western US farmers on the Mexican grain market. Up to now, there are no signs of a strong government support for developing agriculture among small- and medium-sized farmers in order to reach higher productivity for food crops. A new programme for subsidizing all basic crop farmers – *Programa de Apoyos Directos al Campo* – comes very short of being an incentive to crop production and is rather a welfare programme handing a small direct payment to farmers according to the hectares they command. Support prices for maize and beans will be abolished after a year's transition period under this new programme.

These recent trends in agricultural policy clearly point to integration into the NAFTA area. It appears that Mexico will become increasingly dependent on grain imports from the US. This may mitigate some of the problems referred to in this paper – the constant struggle to increase output on poor rainfed land with a large sector of small- and medium-sized peasant producers. At current international prices and with favourable credit extended by the US government for buying grain, Mexico will be able to supply cheap grain and tortillas for its poor consumers. Thus, food security may increase at the national and local level if government maintains some sort of food subsidy for the poor and the world market for grain remains favourable.

But these trends also imply some counter effects which are already felt in the countryside. Ten per cent of Mexico's labour force are maize producers, and they and their families base their livelihoods on small farm households, combining farming with multiple-income generating activities such as wagework and petty commerce. A further deterioration of agriculture and peasant livelihoods as subsidies and supports are withdrawn will put more pressure on the rural and urban labour markets and may increase migration, especially towards and across the border with the United States. Food security at local and household levels will also be more uncertain as poor rural households no longer grow their own crops or sell their land under the new programme to privatize *ejido* land.

Land privatization and NAFTA could also increase drought vulnerability in northern Mexico. A number of economic models suggest that if NAFTA fully liberalizes trade between the US and Mexico, maize production in Mexico will drop dramatically and horticultural production will increase, as basic grains will be increasingly imported from the US. This would continue the trend towards greater water demand by agriculture in northern Mexico, and the low and variable rainfall of this arid region may eventually provide a constraint to the success of the trade agreement (Borza, Leichenko and Liverman, 1993). If, as it seems to be the goal, the privatization of *ejido* land leads to more intensive agricultural production, this too could increase water demand and drought vulnerability. The rush to private credit and new crops may create a volatile and risky financial situation especially if extreme weather brings harvest failures in the next few years. Whether water rights and water institutions will change as a result of agrarian reform is as yet unclear although there is talk of increased water prices, open water markets, and the possibility of increased water use efficiency.

At present it is difficult to predict the future of basic food production in Mexico. We are at a crossroad. Changes in land tenure, policy mechanisms, and trade liberalization will certainly have an impact on crop structure and thus food supply. The impact will be differentiated according to regions, crops and the type of farmers and peasants concerned. Poor peasant farmers who remain on the marginal rainfed land will likely grow maize for self-consumption as long as access to cheaper grain on the market is difficult. Also the degree to which peasants grow food for self-consumption will depend on the alternatives provided by the labour market and on the impacts of shifts in rural property due to privatization. As for basic food producers in regions with good rainfed land which supply the market, their future will highly depend on specific policy giving support to these farmers. Better-off farmers are able to increase productivity and supply part of the food grain on the domestic market because white maize grown in Mexico is still highly preferred as input for the tortilla and other foods, compared to imported yellow maize.

As for the role of climate in Mexican agriculture, we have tried to show the way in which climatic variation and climatic change influence food production in Mexico. Drought already poses problems for agricultural production and policy in Mexico, particularly as increasing water demands place pressure on the irrigation districts. Global warming may present a threat to local and national food security, especially if farmers are unable to adapt to a drier climate or if imports from other regions become more costly. In the long run, Mexican food security will be determined by the complex interaction of macroeconomic policy, social and demographic trends, and environmental change with the risk for individual households sharply differentiated by access to land, water and government support.

References

Appendini, K (1992) *De la Milpa los Tortibonos: La restructuración de la política Alimentaria en México*, El Colegio de México.

Austin, J E and Esteva, G (1987) *Food Policy in Mexico: The Search for Self-Sufficiency*, Cornell University Press, Ithaca.

Borza, K, Leichenko, R and Liverman, D (1993) 'The impacts of climatic and economic change on irrigation districts in northern Mexico', presentations at the Association of American Geographers Annual Conference, Atlanta, Georgia (April).

Calva, J L (1988) *Crisis Agricola y Alimentaria en México 1982–1988*, Fontamara, Mexico.

Dilley, M (1993) *Climate Change and Agricultural Transformation in the Valley of Oaxaca, Mexico*, PhD dissertation, Department of Geography, Penn State University.

Dovring, F (1970) 'Land reform and productivity in Mexico', *Land Economics*, 46, 3, pp 264–274.

Eckstein, S. (1966) *El Ejido Colectivo en México*, México, Fondo de Cultural Económica.

Florescano, E (1969) 'Precios del maíz y crisis agricolas en México 1708–1810', *México DF: Ediciones Era*.

Hewitt, Alcántara, C (1976) *Modernizing Mexican Agriculture*, Geneva: United Nations Institute for Research on Society and Development (UNIRSD).

Hewitt, de Alcántara, C (1992) Reestructuración Ecónomica y subsistencia rural. El maíz y la crisis de los ochenta', El Colegio de México/UNRISD, Mexico.

Liverman, D M (1990) 'Vulnerability to drought in Mexico: the cases of Sonora and Puebla in 1970', *Annals of the Association of American Geographers*, 80, 1, pp 49–72.

Liverman, D M and O'Brien, K (1991) 'Global warming and climate change in Mexico', *Global Environmental Change* (December) 1, 4, pp 351–364.

Liverman, D M (1992a) 'The regional impacts of global warming in Mexico: uncertainty, vulnerability and response', in Schmandt, J and Clarkson, J (eds) *The Regions and Global Warming*, Oxford University Press, pp 44–68.

Liverman, D M (1992b) 'Global warming and Mexican agriculture: some preliminary results', in Reilly, J M and Anderson, M (eds) *Economic Issues in Global Climate Change: Agriculture, Forests and Natural Resources*, Westview, Boulder, pp 332–352.

Liverman, D M (1993) *Environmental Change and Economic Transformation: Natural Hazard Vulnerability in Mexico in the Twentieth Century*, Unpublished manuscript.

Mexico, INEGI (1991) (Instituto Nacional de Estadistica, Geografia y Informaci6n). *El Sector Alimentaria en Mexico*, INEGI.

Mueller, M W (1970) 'Changing patterns of agricultural output and productivity in the private and land reform sectors in Mexico 1940–1960', *Economic Development and Cultural Change*, 18, 2, pp 262–366.

Myhre, D (1993) *The Unseen Instrument of Agricultural Restructuring in Mexico: The Growth, Crisis and Erosion of the Official Credit System*, ILET, preliminary unpublished paper, Mexico.

Nguyen, D T (1979) 'The effects of land reform on agricultural production, employment and income distribution: a statistical study of Mexican States 1959–1969', *The Economic Journal*, 89, pp 624–635.

Sanders, W T, Parsons, J R and Santley, R S (1979) *The Basin of Mexico: Ecological Processes in the Evolution of a Civilization*, Academic Press, New York.

Sanderson, S (1986). *The Transformation of Mexican Agriculture: International Structure and the Politics of Rural Change*, Princeton University Press, Princeton, NJ.

SARH (1993) (Secretaría de Agricultura y Recursos Hidráulicos) Estadisticas, SARH, México.

Walsh, J (1993) *Climate, Culture and Plan Puebla: Natural and Social Influences on Subsistence Farmers In Mexico*, Honors Thesis, Departments of Political Science and Geography, Penn State University.

Wellhausen, E (1976) 'The agriculture of Mexico', *Scientific American*, 235, 3, pp 128–50.

Wilken, G C (1987) *The Food Farmers: Traditional Agricultural Resource Management in Mexico and Central America*, University of California Press, Berkeley.

Yates, P L (1981) *Mexico's Agricultural Dilemma*, University of Arizona Press, Tucson.