ADAPTATION TO DROUGHT IN MEXICO

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The country of Mexico has a long and varied experience with drought, whether described by early historical chronicles or contemporary climatic data and disaster declarations. With more than 85% of the Mexican land area defined as arid or semi-arid (Reyes Castañeda 1981), interannual rainfall is highly variable. The experience of drought has resulted in a wide range of adaptations to climate variability, yet today many Mexicans are still extremely vulnerable to lower than average rainfall.

This chapter provides an overview of the nature, causes and consequences of drought in Mexico focusing on how vulnerability and adaptations vary over time and space. Some preliminary results of a case study of the recent drought in northern Mexico illustrate the state of vulnerability and the limits of adaptation in contemporary Mexico.

The climatic origins of drought in Mexico

Mexican climate spans from the hot, dry conditions of the northwestern Sonoran desert (annual average rainfall less than 100 mm) to the wet, tropical climates that characterise the forest regions of southern Mexico, especially Chiapas and the Gulf coasts (average annual rainfall can reach 2000mm). These climates originate in latitudinal belts of atmospheric circulation which shift seasonally and range from the westerlies which bring precipitation to northern Mexico in winter, through the sub-tropical highs associated with stable, dry conditions, to the intertropical convergence zone (ITCZ) and trade winds which deliver summer rainfall to the central and southern regions of the country. Other key influences on precipitation are fall hurricanes on both Caribbean and Pacific coasts, the summer monsoons in the north, and summer high pressure which disrupts the flow of moist air and creates a period of dry conditions known as the *canicula* or midsummer drought. The mountainous and varied topography of Mexico dominates many other climatic influences, producing cooler temperatures and higher rainfall in the highlands and central plateau, and rain shadows behind coastal mountains (Metcalfe 1987; Mosino and Garcia 1973).

Meteorological data is available for some parts of Mexico since the 19th Century (Servicio Meteorologico 1980), and centuries of Mexican climatic history have been reconstructed using tree rings, pollen and lake levels. Marine and pollen records suggest much dryer periods prior to 9000 BP, and around 2000 BP (Brown 1985). Analysis of tree rings from northern Mexico (where narrower annual growth rings are associated with dryer conditions) indicates some intense periods of drought during the last 500 years. For example, Figure 2 shows a tree ring chronology from the northern Mexico that indicates severe drought in the latter part of the 16th century (1545-1600), 1752-1768, 1801-1813, 1859-1868, and, most recently, the 1950s[1].

For the period of reliable instrumental records, Douglas (Douglas 1996) has calculated the Palmer Drought Severity Index (PDSI) for 18 climatological divisions in Mexico. PDSI plots for selected regions are shown in Figure 3. Severe drought is usually identified with PDSI values of -2 and below. In region 3, roughly contiguous with the northwestern state of Sonora, several extended periods of severe drought are apparent, particularly the intense drought of 1942, the 1950s, 1973-74, 1983 and 1987-88. The mid-1980s were relatively wet. In region 11, which includes parts of the important agricultural states of Guanajuato, Jalisco and Michoacan in west-central Mexico, severe droughts occur in the early 1950s, 1969-79, and in the summers of 1976, 1979, 1982 and 1988. In region 16, which includes the state of Oaxaca in southern Mexico, there were intense droughts in 1934-35, 1940-41, 1949, 1957-58, 1977, 1982-83

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[1] Tree ring data from the Laboratory for Tree Ring Research, University of Arizona. See also (Cleaveland, Cook, and Stahle 1992; Scott 1966).

and 1987.   Several of these droughts coincide with the variations in Pacific sea-surface temperatures associated with El Niño. El Niño conditions (warmer Pacific) correlate with the 1957-58, 1977, 1982-83, and 1987 droughts in Oaxaca. La Niña conditions (colder Pacific) seem to correspond to droughts in the 1950s, 1974 and 1988 in northern Mexico. Significant correlation between El Niño years and drought have also been observed in Oaxaca, associated with a southward displacement of the ITCZ and diminished hurricane frequency in the Gulf of Mexico during El Niño years (Dilley 1996). Cold events have been linked to lower than average winter rainfall in northern Mexico, and higher than average summer rainfall in central Mexico because of northward shifts in the ITCZ and weaker trade winds (Cavazos and Hastenrath 1990).

The human and ecological impacts of drought in Mexico

Drought has played a significant role in the human history of Mexico. Archaeologists have investigated the impacts of drought on pre-Columbian populations, and have debated the possibility that drought may have played a role in the collapse of Mayan and other MesoAmerican civilisations (Culbert 1973; Dahlin 1983; Deevey 1944; Hodell, Curtis, and Brenner 1995).   The evidence is inconclusive and it is likely that, although drought-induced harvest failures and water shortages may have stressed regions such as the Yucatan and central Mexico, the reasons for political and demographic decline were more complex. Nevertheless, it is clear that drought was a concern in pre-Columbian Mexico. Several important deities - such as the Aztec god of rain Tláloc - were worshipped to insure that rainfall would be timely and abundant, astronomical observatories were built to help predict the weather, and extensive irrigation works and reservoirs were constructed to store and transport water.   The Codex Ramirez documents a terrible drought from 1450-1454 causing famine and out-migration from the valley of Mexico. Although the Aztec empire distributed maize from central granaries in times of hunger, the drought of 1454 was so severe that people sold themselves or their children into slavery and human sacrifices were made to the gods of rain (Musset 1991; Sancho y Cervera and Pérez-Gavilán Arias 1981).

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. Historians have blamed drought for famine and social unrest during the colonial period. Between 1521 and 1821, 88 droughts were recorded with the worst in 1695, 1749, 1771, 1785 and 1809. Production declines were accompanied by price increases in corn and meat, death of livestock, and reduction in subsequent planting because of lack of draft animals. There is also evidence of large-scale migration, epidemics, unemployment, deaths of indigenous and farming peoples, and social unrest (Sancho y Cervera and Pérez-Gavilán Arias 1981). In 1785, drought triggered the starvation of more than 300,000 people - mostly members of the indigenous Indian population (Florescano 1980). Florescano has linked variations in the price of maize in the 16th and 17th centuries to droughts and other climatic events (Florescano 1969). He claims that the majority of price rises were preceded by a severe drought, but he also notes the role of speculation and economic arrangements in triggering price rises and associated famines. He suggests that the economic and land tenure relations imposed by the Spanish crown and church created a tremendous vulnerability to drought among the poorer and indigenous *campesino* populations. The colonial political economy allowed the larger landholders and merchants to manipulate the price of staples in drought years to the disadvantage of poor consumers and small producers.

The impacts of drought in twentieth century Mexico can be seen in declines in production and exports of crops and livestock and corresponding increases in imports; reductions in yields and area in production; declines in livestock production; and increase in forest fire and losses. For example, the impacts of drought, interacting with other factors such as economic conditions and prices, can be seen in the variations in overall maize production and imports for Mexico since 1960 (Figure 4). Production was low in 1973-76, 1979, 1982, and 1986-1989, partly due to droughts in those years, but exacerbated by economic crises. Imports have grown steadily in response to increasing population demand, but increase sharply following the drought and production decline in the early 1970s, 1982, and late 1980s. Government responses have included grain imports, extension of credit payments, dam construction, and, in 1969, a Drought Combat Plan to provide jobs in disaster zones.

The geography of drought impacts is also revealed in the reports of crop losses in Mexican agricultural censuses and statistics. In 1930 the agricultural census reported a total of 1.2 million hectares lost to natural disasters, a total of 17% of the area planted, with the most serious losses in northern and north-central states such as Nuevo Leon (40% loss) and San Luis Potosi (50%). A similar area was lost in 1940, with northern states losing 20-40% of their planted area. The 1950 census was the first to report loss from specific hazards, and of the 1.43 million hectares lost, 1.1 million suffered from drought in regions such as the Bajio and Quintana Roo. The 1960 census reports a drought loss of 0.8 million hectares, lower than previous census reports, with states averaging only about 10% losses. However the 1970 census, which separates winter and summer growing seasons, includes some very high drought losses with 22% of the growing area lost to drought in summer (2 million hectares). The drought impacts were most severe in Aguacalientes (70% loss), Zacatecas (65%), and Chihuahua (53%) (Figure 5). General patterns emerging from this historical analysis suggest that drought impacts are frequent and often severe in Mexico, with 10-20% of the total planted area lost especially in northern Mexico. The states of Aguascalientes, Nuevo Leon and San Luis Potosi seem particularly vulnerable.

Vulnerability

Vulnerability to drought in Mexico is determined by both biophysical and social conditions (Liverman 1994). Biophysical vulnerability is greatest in the northern and north-central regions of the country where rainfall is most variable, and in the highlands where frost limits the growing season and the timing of rainfall and the extent of the mid-summer drought are critical. Biophysical vulnerability to drought may also be increasing as a result of deforestation and overgrazing which result in increased temperatures and reduced soil moisture (Bahre and Bradbury 1978; Balling 1988; Bryant, Johnson, and Brazel 1990; Medellin-Leal and Anaya-Garduno 1978). And, of course, anthropogenic greenhouse gas emissions to the atmosphere are likely to result in global warming that would bring warmer, drier conditions to much of Mexico (Liverman and O'Brien 1991).

Social vulnerability to drought varies greatly by region and social group, and has altered over time as a result of technological, economic and demographic changes. Mexico's rapid economic and population growth has increased demand for both food and water, especially as consumption increased in urban areas and irrigated agriculture expanded. For example, the states bordering the United States saw an expansion of their irrigated acreage from about 700,000 hectares in 1930 to 2.4 million hectares in 1980 (Figure 6). Mexico's overall population grew from 16 to over 80 million people during the same 50-year period. One estimate projected a doubling of water use between 1970 and 2000.

The restructuring of agriculture has resulted in increased water use as producers' shift from basic grains, such as maize, to forage and vegetable production. In the irrigation districts of northern Mexico, acreage has shifted from maize and wheat to crops such as alfalfa and tomatoes that consume more water (Liverman 1995). In the valley of Oaxaca, some farmers have purchased mechanical pumps to irrigate alfalfa for dairy cows and cheese production and this has resulted in a drop in the groundwater levels. Poorer farmers have found it increasingly difficult to reach water using traditional manual techniques to irrigate their subsistence crops. Groundwater supplies have also declined as a result of the deforestation of hill slopes surrounding the valley and urban pumping for the expanding city of Oaxaca (Dilley 1993; Lees 1976; Liverman 1995).

Some groups are sectors are much more vulnerable to drought than others. More than 50% of Mexican cropland is operated by *ejidos* , a form of cooperative land tenure established to allocate land in the aftermath of the Mexican Revolution. A comparison of drought losses on *ejidos* and private farms at national and state levels using data from the agricultural census for 1950, 1960 and 1970 suggests that *ejidos* tend to experience much higher crop losses to drought than private landowners of more than five hectares (Figure 7). At the state level the differences are even larger. In Nuevo Leon in 1950 drought losses were 11% on private land and 29% on *ejido*s; in 1960 the loss was 20% on private land and 28% on ejidos. In winter 1970, private land in Nuevo Leon lost 14% of the crop area to drought and *ejidos* 39%; and in summer 1970 the loss on private land was 26% and on *ejidos*, 50%.

Several factors explain the relative vulnerability of *ejido* land. Land reforms tended to give less productive and drier land to the new cooperative sector, except in regions where those claiming land were particularly aggressive in their demands. In many regions, the ejidos do not have as much irrigated land and also have problems in getting access to credit, improved seeds or other resources (Liverman 1990; Nguyen 1979).

Adaptation and response to drought

Local communities in Mexico developed many traditional technologies for coping with drought. As in many semi-arid regions, sophisticated irrigation systems have developed over centuries to store and transport water to settlements and agriculture. Archaeologists and others have described prehispanic water control systems such as the *chinampas* - the highly productive raised fields in the wetlands around Mexico City - and the *galeria* tunnels which bring water from the hillside aquifers to the valley of Tehuacan, Puebla (Enge and Whiteford 1989; Wilken 1987).

The heterogeneity of the Mexican landscape and the high interannual climate variability also promoted a diversity of crop varieties, especially of maize, and many farmers still plant several different varieties to minimise risk from drought, frost and diseases (Altieri and Trujillo 1987; Bellon 1991; Brush, Corrales, and Schmidt 1988; Mangelsdorf 1974). Traditional farmers in Oaxaca adjust to drought by selecting a maize variety appropriate to expected rainfall conditions, altering the ratio of beans and maize planted and adjusting the planting density of crops (Kirkby 1973).

Indigenous social institutions and traditions also served as drought adaptations and risk management strategies. Rituals following the agricultural calendar invoke rain and other key influences on harvests. Traditional weather prediction techniques monitor the first days of January or phases of the moon as ways to predict growing season weather (Eakin 1997; Signorini 1994). The harvest can be redistributed through social events such as the *guelaguezta* of Oaxaca where local leaders are responsible for sharing food with other members of the community (Kirkby 1973; Murphy 1991). In drought years some communities rely on traditional sources of famine food and liquid such as cactus, agave and mesquite fruit (Minnis 1991).

Many of these traditional drought adaptations survived the ecological and social transformations associated with the arrival of the Spanish although, as noted earlier, some scholars believe that drought vulnerability increased as a result of Spanish changes in land use and economy.

In the twentieth century, new forms of adaptation have accompanied the expansion and intensification of Mexican agriculture. Irrigation reduced short-term vulnerability to drought, whilst increasing water use and vulnerability to multiyear droughts such as occurred in the 1950s and 1990s in northern Mexico and brought reservoirs to very low levels. For example, three years of drought resulted in reservoirs at only 10% of capacity across most of northern Mexico at the beginning of the 1995 growing season (Figure 8).

In those districts that rely on groundwater, increased demand and sustained drought have contributed to declines in the water table and saline intrusion (Aceves-Navarro 1985; Cummings 1972 ; Cummings and al. 1989). Over the longer term, improvements in irrigation efficiency have reduced drought vulnerability in some irrigation districts, and new proposals for decentralised management and water pricing may allow more flexible adjustment to water supply variations (Casasus 1994).

In the 1950s the "Green Revolution" brought improved seeds, fertiliser and mechanisation to Mexican agriculture. Plant breeders developed new, higher yielding varieties of maize and wheat that increased production, especially for those farmers with irrigation and access to credit and fertiliser. Although some new varieties were drought resistant, there are some indications that the Green Revolution increased the sensitivity of agricultural production to climatic variations and drought (Michaels 1979). In Puebla, where development projects focused on increasing yields of rainfed maize, drought and economic crisis interacted to bring the yields of those using the new technologies below those of traditional farmers in some years (Diaz-Cisneros 1994). Because the new commercial technologies sometimes require farmers to go into debt to purchase them, drought induced harvest failure can be more serious for these farmers than those using traditional techniques without purchased inputs (Appendini and Liverman 1994).

Urban areas have responded to drought and increased demand by constructing storage reservoirs and rationing water. Mexico City now pumps water at great expense from an area 100 miles distant and a thousand feet lower (Aguilera Gomez 1989; Zenteno and Benigno Morelos 1988). Many northern cities compete for water with agriculture and had severe water rationing during the recent drought. Many rural communities required water to be trucked in at considerable expense. In Chihuahua 42 deaths were attributed to the lack of drinking water because of drought and poverty (Correspondents 1996).

Institutional response to drought in contemporary Mexican agriculture includes a complex set of agricultural subsidies and emergency relief measures. Mexican agricultural policy has varied quite dramatically in terms of guaranteed support price and year to year crop area is very sensitive to relative prices for different crops. In 1981, for example, prices for growing basic grains were increased to promote national food self-sufficiency, and production increased (Appendini 1992). In the last decade, however, financial restructuring and the liberalisation of trade have resulted in a decline in the guaranteed prices for producers (Figure 9), and this has increased the economic uncertainty and associated environmental risks (Appendini and Liverman 1994). In the early 1980s, subsidies for agricultural inputs were reduced from 27.5% of the cost of grain production in 1985 to only 6.5% in 1990 (De Janvry and al 1995). The fertiliser parastatal FERTIMEX was privatised in the early 1990s and fertiliser prices are now near those of the international markets.

Less than 10% of Mexican producers have crop insurance, although some coverage is increasingly required as government credit declines and producers turn to provide loans. But the recent collapse of the peso and associated surge in interest rates has made access to both credit and insurance difficult for the majority of farmers.

The 1996 drought in northern Mexico

Four years of below normal rainfall produced severe drought conditions in northern Mexico by 1996. By June, reservoirs were at 50 year lows, below 5% of capacity in some cases, more than 4.6 million hectares of cropland was damaged and 6 million hectares remained unplanted because of the drought. Ranching, important to the economy and culture of states like Sonora, was suffering great losses as herds died off or were sold at prices 40% lower than in 1996. An estimated 300,000 cattle died and 700,000 were sold at very low prices. By the end of the year, Mexico's livestock herd had declined 1/3 from 1990 levels. The Federal Agricultural department estimated farm losses at more than 1 billion dollars (U.S.) and planned to import an extra 4 million metric tons of basic grains for a total grain import of about 11.25 million metric tons in 1996 compared to 6 million metric tons in 1991. Farmers groups estimated the loss to producers at nearer 2.5 billion (SourceMex 12 June 1996; Agricultural Trade Office). The drought provoked interstate political conflict with Sonora and Sinaloa competing for the water from the Huites Dam, Nuevo Leon and Tamaulipas competing for the remaining water in the El Cuchillo dam, and even Mexico, as a nation., requesting Rio Grande water from Texas, and being refused (Patterson 1996).

The government responded to the drought with 1.147 billion pesos ($155 million US) in drought aid for feed purchases, drinking water supplies, and jobs in infrastructural improvements as well as with ongoing price support programs such as Procampo which made direct cash payments to farmers for area planted. State government and local producer's organizations also provided drought relief. For example, in Sonora, the state government joined with irrigators to invest $500,000 (US) in cloud seeding, and also provided feed to ranchers (Notimex 1996).

Individual responses to the drought varied widely with some farmers planting and then praying for rain or government relief, and others deciding to abandon their land and migrating to find work in other regions of Mexico or in the U.S. (Velasco 1996). Many ranchers and rainfed crop producers found the combined impact of the drought and economic crisis overwhelming, with the low rainfall, high input prices, low producer prices, and high interest rates placing them at great risk. Smaller landholders were disproportionately affected, especially those who were in debt, or who farmed or ranched more biophysically marginal land (Liverman and Rosenberg 1996).

Conclusion

The 1996 drought in northern Mexico drew attention to the overall and differential vulnerability of Mexican agriculture and society to climate variability. Although agriculture contributes less than 10% to Mexico's Gross National Product, it is important to rural stability and national political strategy. Drought exacerbated the effect of economic crises in the agricultural sector and stressed the water supplies of rapidly growing cities and communities. Partly as a result of the drought, the Mexican government is now undertaking major review of water resources management including decentralisation of management, improvements in infrastructure, and potential for seasonal climate forecasting. Agricultural production in many irrigation districts increased in 1997 and overall, the Mexican economy was recovering (American Embassy 1997). But the future of the most vulnerable farmers and ranchers on rainfed and marginal land is less clear in the face of the decline in support prices, the continuing difficulties in access to input and credits, and the unequal participation in economic recovery (Quintana S. 1996).

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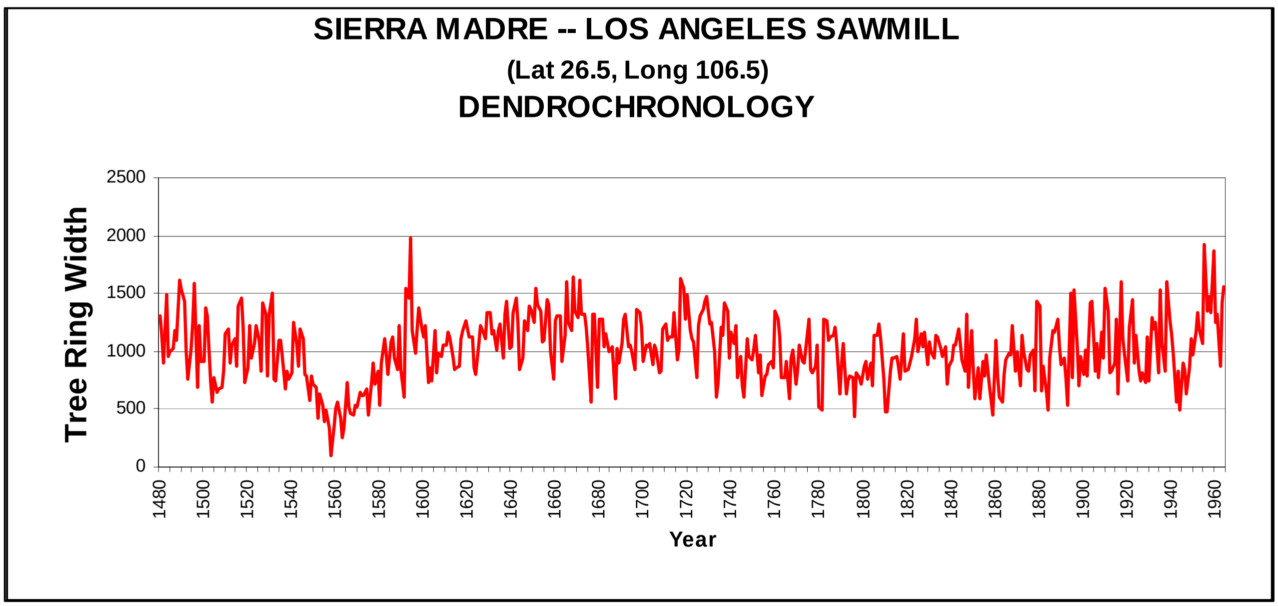
Mexico
BAJA CALIFORNIA
SONORA
CHIHUAHUA
COAHUILA DE ZARAGOZA
NUEVO LEON
BAJA CALIFORNIA SUR
DURANGO
SINALOA
TAMAULIPAS
ZACATECAS
SAN LUIS POTOSI
NAYARIT
AGUASCALIENTES
GUANAJUATO
YUCATAN
QUERETARO
JALISCO
HIDALGO
TLAXCALA
MEXICO
CAMPECHE
QUINTANA ROO
MICHOACAN
COLIMA
VERACRUZ
PUEBLA
TABASCO
GUERRERO
OAXACA
CHIAPAS


SIERRA MADRE -- LOS ANGELES SAWMILL
(Lat 26.5, Long 106.5)
DENDROCHRONOLOGY
Tree Ring Width
2500
2000
1500
1000
500
0
1480
1500
1520
1540
1560
1580
1600
1620
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1660
1680
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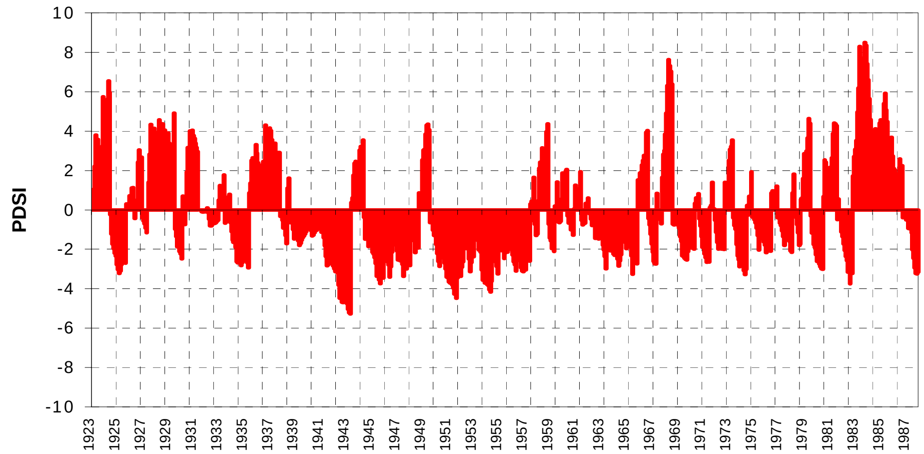
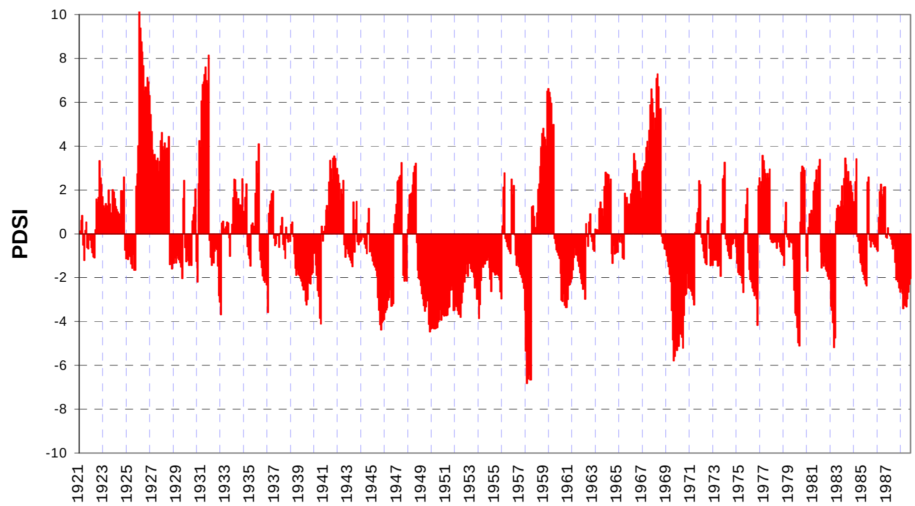
1960
Year

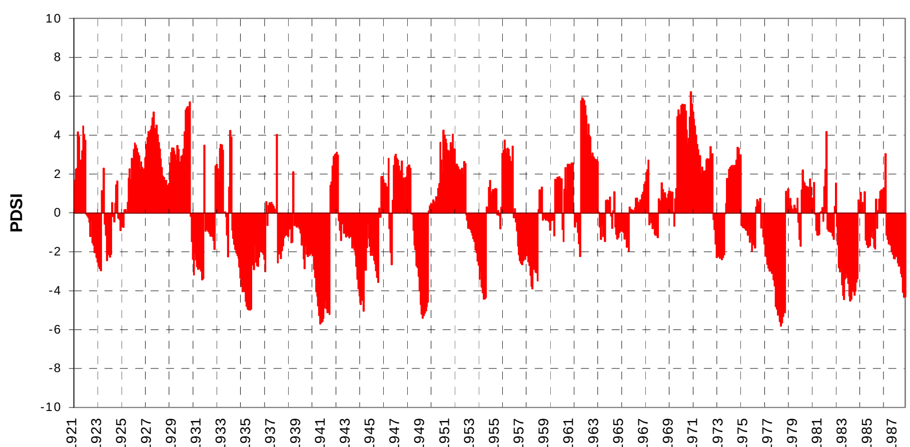
Region 3 (Sonora) PDSI

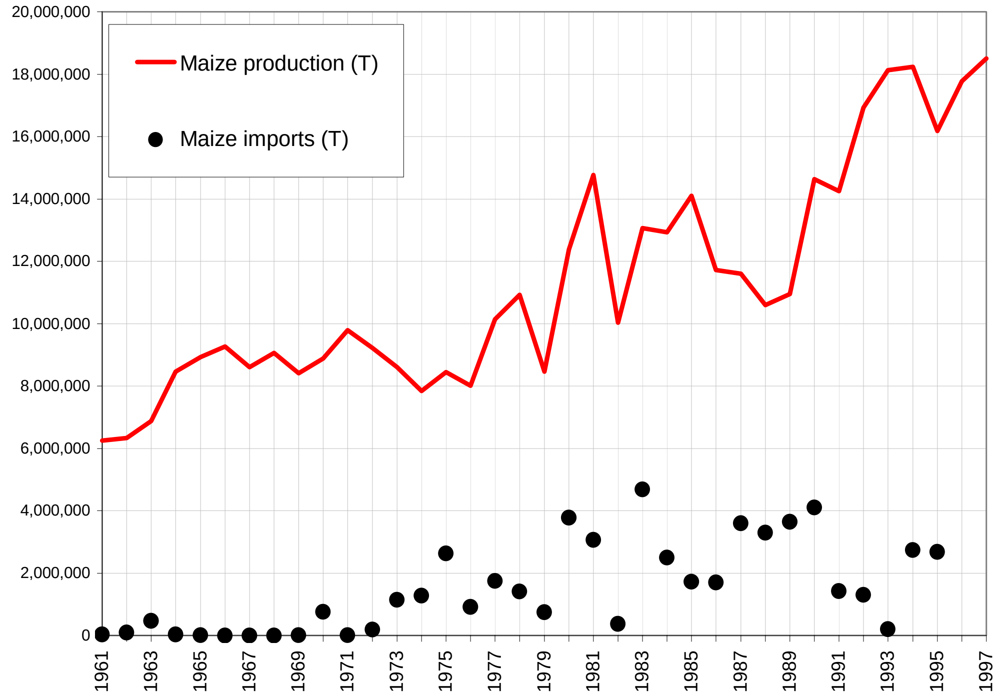


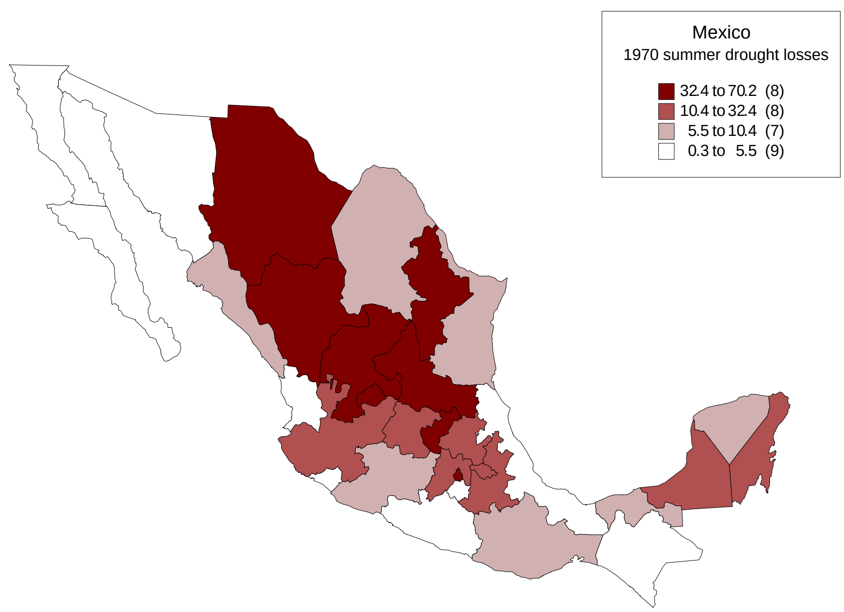
Region 11 (Guanajuato, Jalisco, Michoacan) PDSI

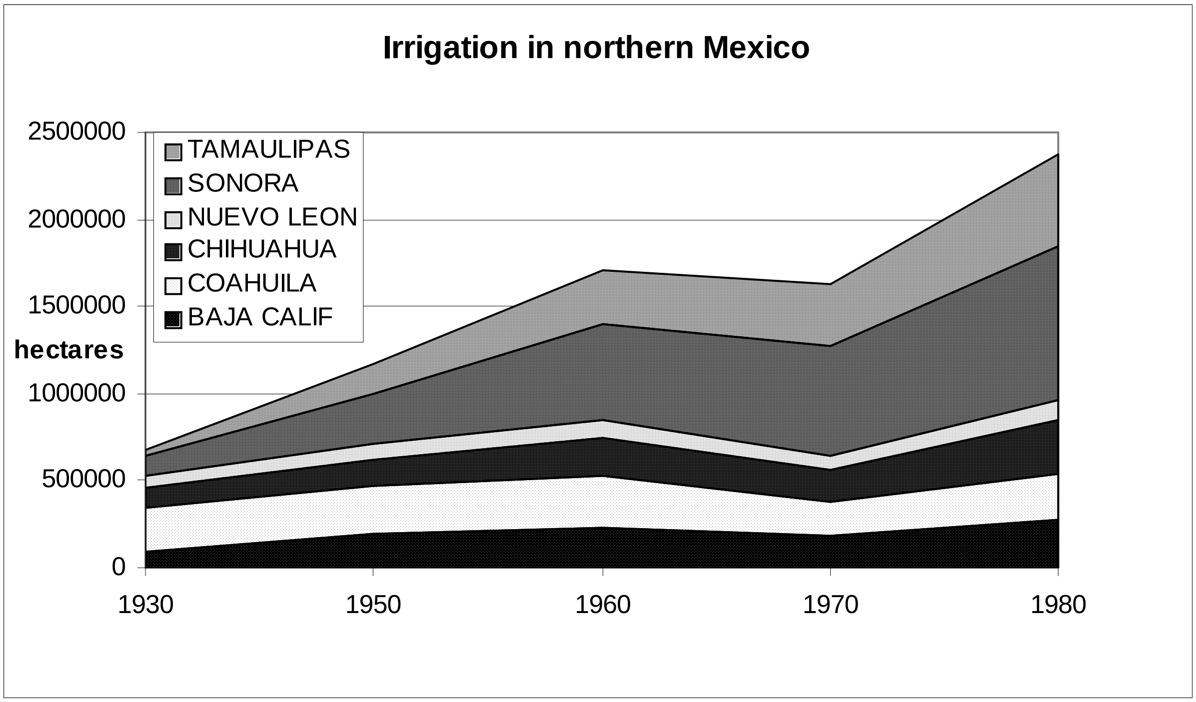


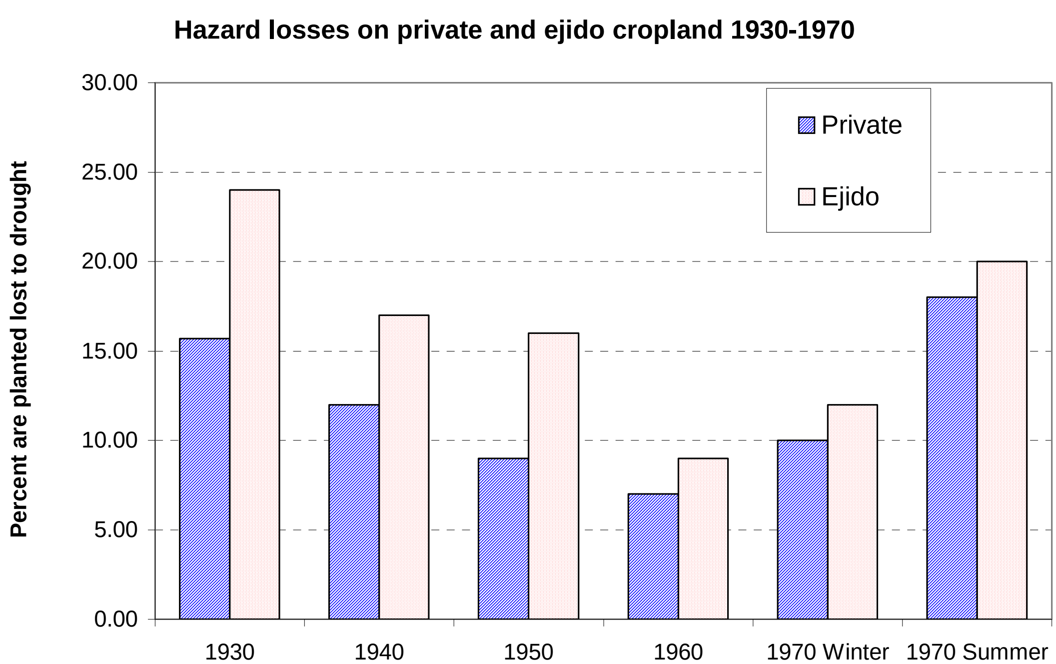
Region 16 (Oaxaca) PDSI

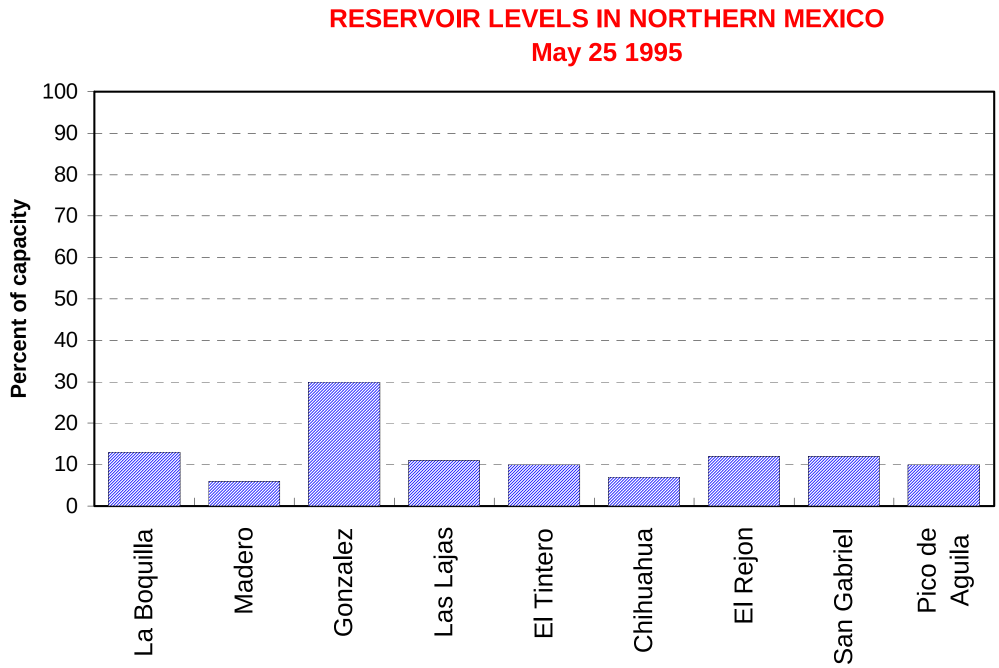


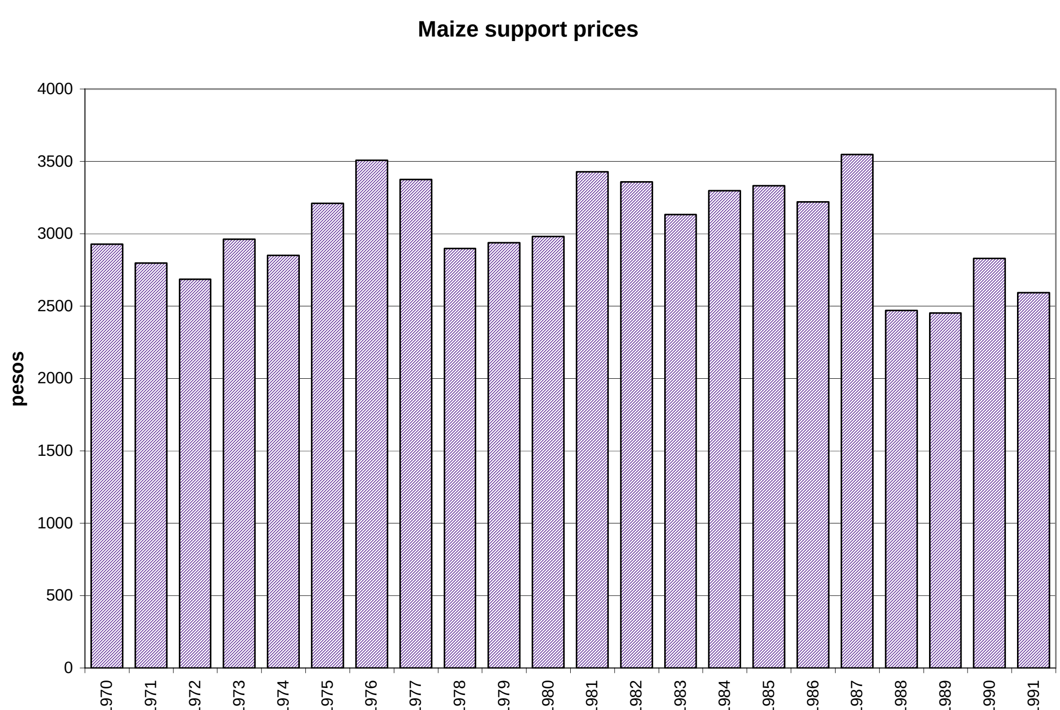

Maize production (T)
Maize imports (T)
20,000,000
18,000,000
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
0
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997


Mexico
1970 summer drought losses
32.4 to 70.2 (8)
10.4 to 32.4 (8)
5.5 to 10.4 (7)
0.3 to 5.5 (9)


Irrigation in northern Mexico
2500000
2000000
1500000
hectares
1000000
500000
0
1930
1950
1960
1970
1980
TAMAULIPAS
SONORA
NUEVO LEON
CHIHUAHUA
COAHUILA
BAJA CALIF


Hazard losses on private and ejido cropland 1930-1970
Percent are planted lost to drought
30.00
25.00
20.00
15.00
10.00
5.00
0.00
1930
1940
1950
1960
1970 Winter
1970 Summer
Private
Ejido


RESERVOIR LEVELS IN NORTHERN MEXICO
May 25 1995
Percent of capacity
100
90
80
70
60
50
40
30
20
10
0
La Boquilla
Madero
Gonzalez
Las Lajas
El Tintero
Chihuahua
El Rejon
San Gabriel
Pico de Aguila


Maize support prices
pesos
4000
3500
3000
2500
2000
1500
1000
500
0
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991