LAND DEGRADATION

IN

MEXICAN MAIZE FIELDS

by

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ABSTRACT

This study seeks answers for two simple yet elusive questions: a) is land degradation a real threat to the productivity of the Mexican maize field? and b) can the application of fertilizer compensate for the losses of production due to fertility depletion by soil erosion?

The thesis is based on an integrated examination of empirical evidence. International literature, national statistics, regional surveys, and greenhouse and field experiments are pursued in order to answer the above questions. In each case conclusions are drawn, but these conclusions vary with the level of analysis.

Statistics of maize production in Mexico show net gains in productivity in the last thirty years. After correcting for the technological improvements in that period, it appears that the intrinsic productivity of the land has not declined. This is contrary to predictions in the literature on soil erosion and soil fertility depletion, particularly in the tropics. According to this literature, these maize fields are not only threatened, but they should already exhibit significant losses in productivity.

To examine this conflicting evidence, a case study on three contrasting soil types was conducted in central Veracruz. Greenhouse experiments with erosion and fertilization of these soils suggest that fertilizers can compensate for losses of productivity resulting from erosion. Field experiments leave no doubt that the opposite is true: erosion dramatically reduces

maize productivity and fertilizers do not compensate.

In conclusion, the thesis offers an explanation for this paradox. As levels of analysis are abstracted from the field to the national level, or projected from the greenhouse to the field, critical information is lost. Measures of land productivity are too aggregated at the national level and too disaggregated in the greenhouse. This confuses the assessment of land degradation which requires the detection of small changes in land productivity. When land is properly considered, as in the literature reviewed and the field experiments included in this thesis, the result is clear. The productivity of the Mexican maize field will suffer from continuous land degradation, and this notwithstanding better management inputs.

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CHAPTER I: INTRODUCTION

Mexican maize production is geared to feed her own population. Every day, Mexicans eat almost half a kilo of this grain in _tortillas_, _tamales_, _atoles_, _gorditas_, _pozole_, _enchiladas_ or in any other of the six hundred maize dishes known to Mexicans (Anon., 1982a). Maize contributes half the volume of all foodstuffs consumed in Mexico. It provides almost half of the calories and a third of the proteins of the average diet (Chavez, 1973; CECODES, 1980).

Maize fields can be found almost everywhere in Mexico: from north to south and across the country; from high in the mountains to low in the coastal plains; from the back-country to the back-yards of human settlements; winter or summer and in all climates and soils.

There are approximately two and a half million maize fields throughout Mexico (CDIA, 1980, p. 44) totalling seven to eight million hectares. The average maize field measures close to three hectares in size. Considering an average maize yield of 1.4 tonne per hectare per year, the average field produces 4.2 tonne per year.

Ten and a half million tonnes of maize could feed sixty million Mexicans adequately, but today the country has seventy million people and they are increasing at the rate of two million per year (see Table 1.3, Appendix 1).

Not surprisingly, the equilibrium between supply and demand of maize is one of the most sensitive issues of Mexican politics. Recent governments have been concerned with securing adequate supplies of maize to meet the nation's demands. To this end, a number of policies have been designed: price controls to protect consumers; agricultural development programs to stimulate producers; and imports to bridge the gaps.

It is difficult, however, to solve such a multifarious problem in a matter of years. An almost perfect coordination of government, millions of producers and millions of consumers will be required to simultaneously raise the productivity of the maize field, upgrade the nutritional standards of the population, and obtain foreign currency from a badly shaken balance of payments (Walsh, 1983). But concern for the production of maize is hardly a new phenomenon in Mexico.

Enter the Mexicans of old. They were, most probably, the very people that domesticated (invented?) maize some seven thousand years ago (Iltis, 1983). Moreover, the Mexica knew that continuous cultivation on sloping terrain was bound to degrade the productivity of the land. There is ample historical and archaeological evidence of terraces in Mexico before the Spanish conquest (Donkin, 1979). Check-dam terraces, maguey hedges, sloping-field terraces, and bench terraces were widespread over all regions of the country. Today, many of them have been abandoned or completely destroyed (Denewan, 1980).

Recall the Mexican Revolution of the second decade of this century. It was war between peasants and landlords. In the end, the peasants got a better share of the land, but the losses in human life, economic infrastracture, and even in maize production were huge and felt for many years to come.

Consider the following words written thirty years ago:

> "...corn (maize) is the ' staff of life ' to the Mexican people and it will grow and give some returns under a tremendous variety of conditions of climate and soil. But it is a soil depleting crop, and its cultivation induces erosion even on gentle slopes. Thus corn culture is both a blessing and a curse to the country; but, blessing or curse, it is a necessity."[1]

Finally, notice that the Green Revolution was modeled in Mexico some thirty years ago. The International Maize and Wheat Improvement Center, near Mexico city, developed the wonder seeds which yielded unprecedented amounts of grain per hectare of land. But, even one of the fathers of this revolution has acknowledged that these seeds only fitted large commercial farms, not the small and numerous maize fields (Wellhausen, 1976).

This thesis examines the following questions: Is land degradation a real threat to the productivity of the Mexican maize field? Can the application of fertilizer compensate for the losses of production due to fertility depletion by soil erosion?

To approach these questions, the thesis takes a twofold view of the productivity of the Mexican maize field: 1) the study examines the current productive structure as well as recent

[1] FAO, 1954, p. 161

technological improvements; 2) it assesses the impact of soil erosion and soil fertility depletion on the productivity of the land.

Evidence is presented from various levels of analysis: national, regional, field, and greenhouse, and tests for the above questions will be proposed in each case. Such an encompassing view is needed for effective communication among the many people, institutions, and disciplines involved in land use planning.

The thesis is organized as follows: after this general introduction, Chapter II deals with the production of maize in Mexico. It considers two main aspects: national production trends and current production in the maize field. The chapter concludes with a test of long term productivity decline for the Mexican maize fields. Appendix 1 contains raw data used in this chapter.

Chapter III offers a review of the literature on erosion and fertility depletion in continuous cultivation systems, with emphasis on maize cultivation in tropical soils. It also presents data on the impact of soil erosion and soil fertility depletion on maize yields.

Chapter IV introduces a case study in central Veracruz concerning three different soils. Climate and maize field management in the region are also described. The chapter concludes with an estimation of the risks of erosion for all three soils. Raw soil data are presented in Appendix 2.

Chapter V describes greenhouse and field experiments which test the main questions of the thesis. Through simulated erosion and fertilization, maize yields are studied in the soils referred to in Chapter IV.

Chapter VI concludes the thesis with a review of the main findings and a discussion of their implications for maize field management in Mexico.

CHAPTER II: MAIZE PRODUCTION IN MEXICO

They shall never take
from our pantries
the produce of our land,
maize, our sustenance,
the bearer of life[1]

In order to get a general picture of Mexican maize production, it is necessary: 1) to review trends in production and consumption of maize in Mexico and 2) to describe the function of the unit of production, the maize field. In conclusion, the chapter discusses long-term trends in maize field productivity.

II.1. Supply and Demand

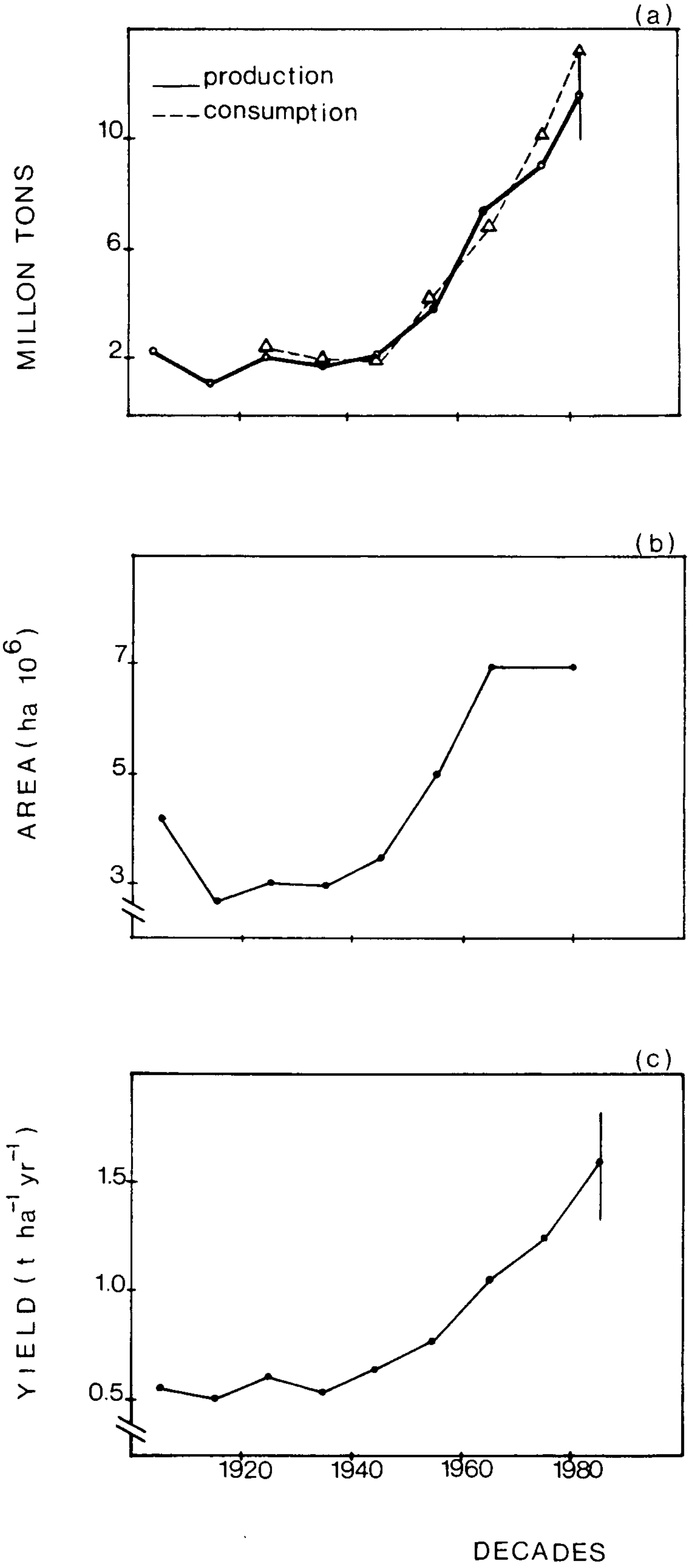
This section contains a review of the modern history of maize production and consumption in Mexico. The original series of data is included in Appendix 1.

II.1.1 Trends in production

This century has seen two patterns of maize production in Mexico: standstill and growth. Figure 2.1a shows that total production, during the first forty years of this century, oscillated around two million tonnes per year. In this period

[1] Anonymous, near Tenochtitlan, 1528.

Figure 2.1. Trends in maize production in Mexico. 2.1a, production and consumption; 2.1b area harvested; 2.1c maize yields. Data are 10 year averages. Source: DGEA,USDA series (tables 1 and 2, Appendix 1). Bars indicate disparity between estimates.



(a)
production
consumption
MILLON TONS
10
6
2
(b)
AREA (ha 10^6)
7
5
3
(c)
YIELD (t ha^{-1} yr^{-1})
1.5
1.0
0.5
1920
1940
1960
1980
DECADES

internal armed conflicts (1910-1917) and the world-wide economic depression (1930) marked the ups and downs of production.

Quite a different story began in the 1940's. Production started a continuous upward swing which lasted at least twenty-five years. Between the 1930's and the 1960's the national harvest quadrupled. In the 1950's and 1960's, production was increasing consistently at five to six per cent annually (Appendix 1, Table 2, Col 5 & 6).

These were the golden years of Mexican agriculture (Hewitt de Alcantara, 1980; Lamartine Yates, 1981). Much of what has been said about post-war agricultural development in the Third World is based on these impressive achievements of the Mexican farmers. The production of foodstuffs--and maize was no exception--was growing much faster than the Mexican population (Apendix 1, Table 3).

During the 1970's, maize production continued to grow, but at a more modest rate of 1.5 to 2.5 per cent per year (Appendix 1, Table 2, Col. 5 & 6). Population, however, grew at a faster rate during these years, and maize shortages began to appear. For the politicians, maize imports were an irritating feature of the 1970's. There were those who predicted that Mexico would never again be self-sufficient in this old and cherished staple. However, harvests in 1980 and 1981 were record ones and imports, although continued, were much less important in 1982.

During the first three years of this decade, production has again been growing at an impressive 10 per cent per year, according to one source, or at a more modest 3.6 per cent per year, according to another (see Appendix 1, Table 2, Col. 5 & 6). However, these latest maize production figures have yet to be confirmed.

II.1.2. Area harvested and yields

The area harvested is an indicator of the total area cultivated. Crop yields are usually reported as the yearly quotient between total production and area harvested, i.e., in tonnes per hectare per year ($t\ ha^{-1}\ yr^{-1}$). They indicate land productivity. A plot of these two components of production could reveal the source of progress: more land; better yields; or both.

Figure 2.1b shows that the area cultivated with maize has undergone dramatic changes during this century. When compared with the trends in production shown in Fig.2.1a, it seems that contraction and expansion of the area cultivated controlled production in the first forty years of the century. Note how the area harvested declined during the Mexican revolution (in the 1910's), and how this coincided with the worst production ever recorded in this century.

The area harvested to maize expanded continuously in the 1940's, the 1950's, and during the first half of the 1960's. As a result there was 2.3 times more land producing maize in the 1960's than in the 1930's. However, during the 1970's and early 1980's the area remained practically the same, as if it had reached a plateau.

Figure 2.1c shows the changes in maize yields in this century.[1] Until 1940 there was apparently no significant change. Thereafter, an upward-swing began. Average yields grew from little more than 0.5 t ha^{-1} yr^{-1} in the 1930's to more than 1.1 t ha^{-1} yr^{-1} in the 1970's. In these forty years, the annual rate of increase of yields fluctuated between 1.0 per cent and 3.0 per cent (see Appendix 1, Table 2, Col. 3&4)

For Mexico, this was a good achievement in improving land productivity. Preliminary data from the 1980's, however, suggest even greater increases. According to one source, yields were growing at an astonishing 11 per cent a year; according to another at 5 per cent a year (Appendix 1, Table 2, Col. 3 & 4).

<u>Table</u> <u>II.1</u>. Rates of growth for production, area, and yields by selected decades of the 20th Century

Decades	% Annual Changes Production	Yields	Areas
1930-1960	4.8	2.0	2.7
1960-1970	2.0	1.6	0.5
1970-1980 [2]	7.0	8.3	-0.7

[2] Preliminary calculation for the 1980's (based on 1980-1982 data only)
Source:DGEA-USDA series combined, see Appendix 1, Tables 1-2

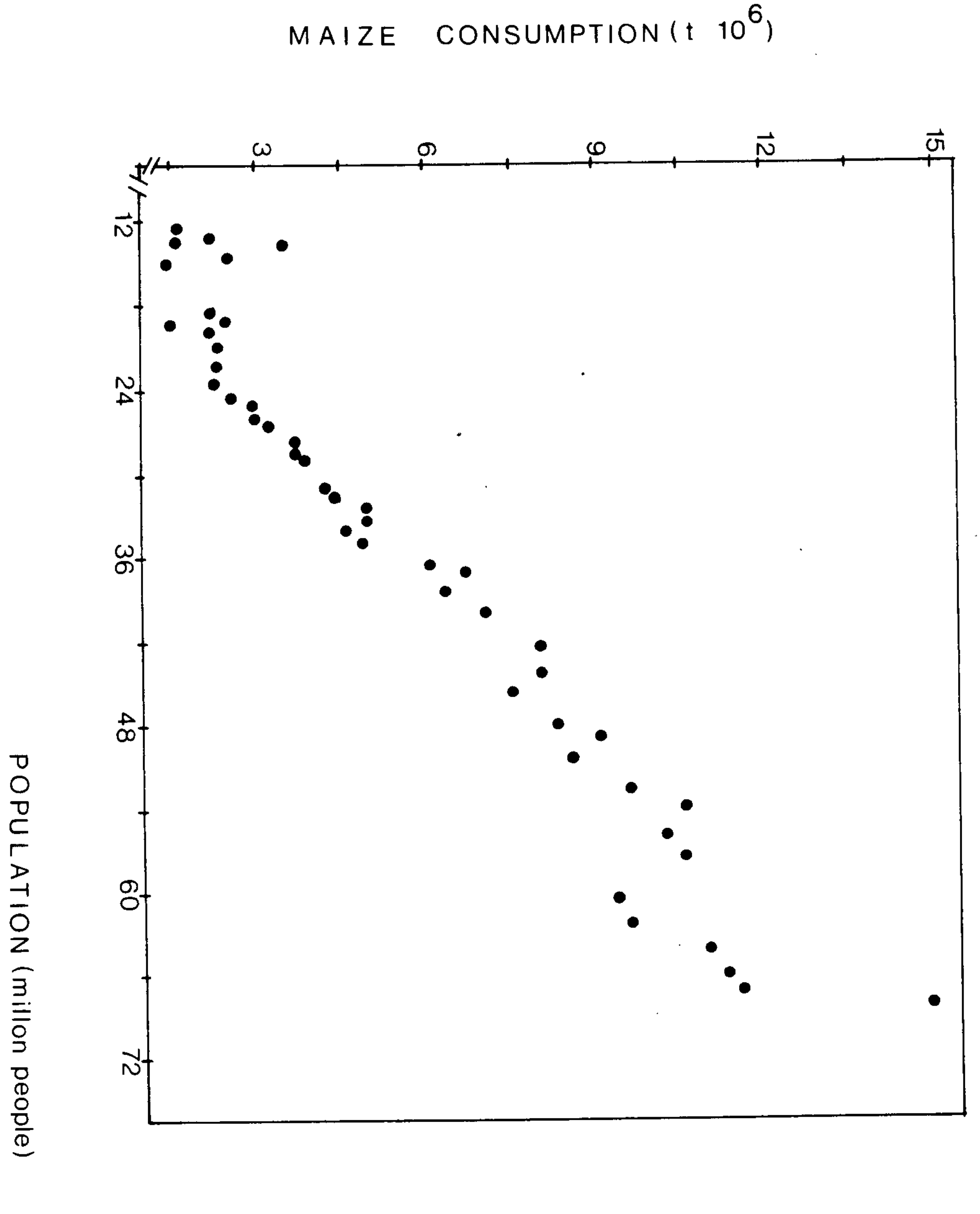
Table II.1 summarizes the rates of growth of the three variables discussed so far. The following conclusions can be drawn: a) during the first forty years of the century, Mexican maize production was basically controlled by the amount of land harvested; b) from the 1940' until the 1970's a combination of more land and better yields resulted in significant production gains; c) during the 1970's, the area harvested did not change; instead, increasing maize yields sustained the growth of production, but at a slower pace; d) preliminary data from the 1980's suggest a net decrease in the area harvested but a tremendous increase in yield, which drove production to unprecedented levels.

II.1.3. Trends in consumption

Figure 2.2 shows a strong historical correlation between apparent consumption of maize and population in Mexico. As population grew so did consumption, apparently at a constant rate. For each new Mexican, about 168 kg of maize were supplied every year. But the linear relationship suggested by these data is deceptive. A closer look at the extremes of this curve indicates non-linearity; in fact, the slope changes as population increases: flat first, steep at the middle, deflated at the end.

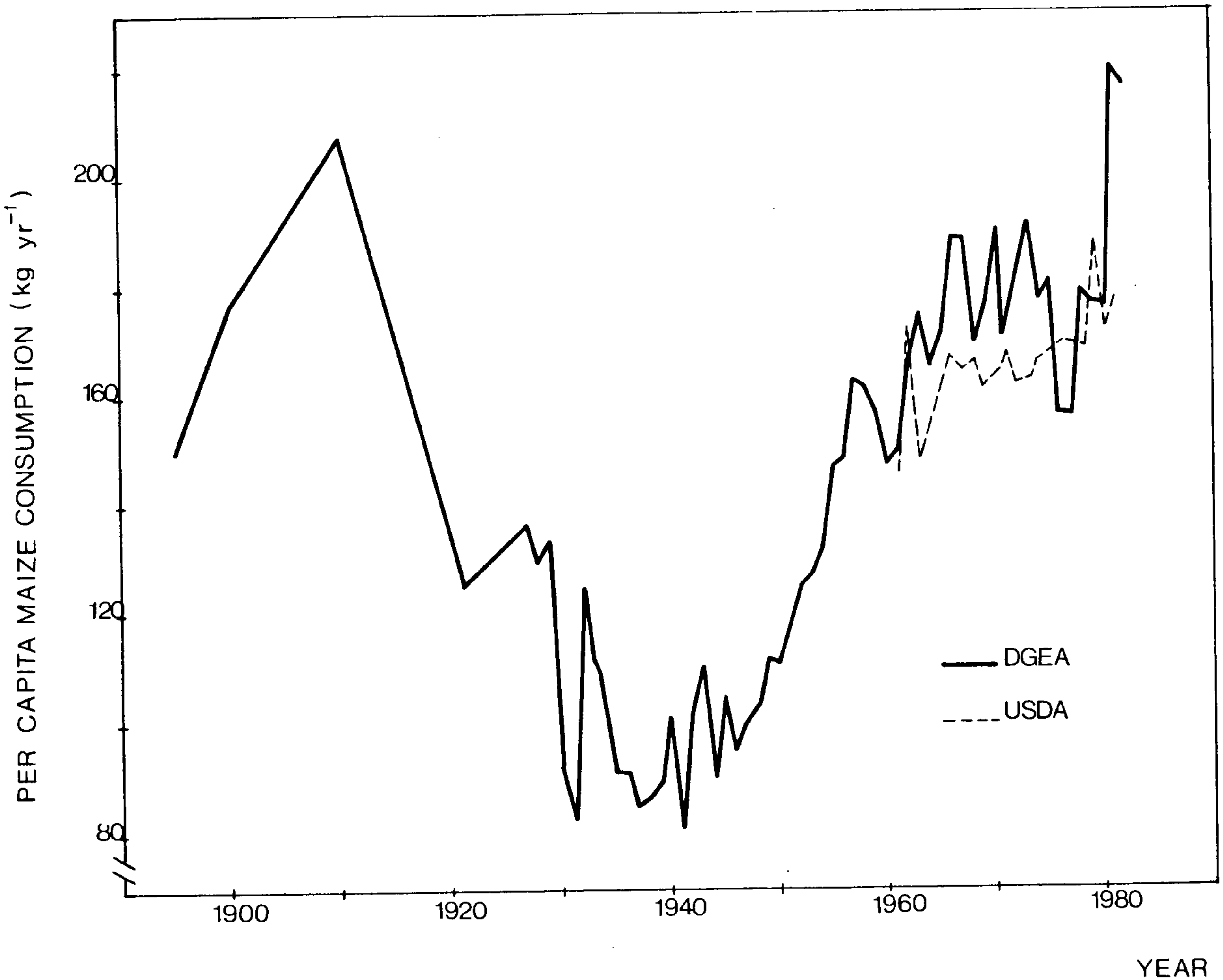
Figure 2.3 plots maize per capita consumption versus time, which offers a new perspective to the previous problem. Per capita consumption of maize decreased dramatically and then increased in this century in Mexico. In 1940, Mexicans were eating half the amount of maize they ate forty years before and forty years later!

Figure 2.2. Consumption of maize and population in Mexico (1895-1981). Regression equations (1) Tot. Cons.(10^6 T) = -2.026 (time in years) + 0.215 Pop. (people 10^6); r^2 = 0.96, SE = 0.74 10^6; (2) Tot. Cons.(10^6 T) = 0.168 (people 10^6); r^2 = 0.96, SE = 1.098 10^6.



MAIZE CONSUMPTION (t 10^6)
3
6
9
12
15
12
24
36
48
60
72
POPULATION (millon people)

Figure 2.3. Per capita consumption of maize (1895-1981). 10 years averages until 1925; yearly data later. Source: DGEA, USDA series (table 2, Appendix 1).


PER CAPITA MAIZE CONSUMPTION (kg yr⁻¹)
200
160
120
80
1900
1920
1940
1960
1980
YEAR
DGEA
USDA

To the best of this author's knowledge, no such phenomenon has been reported in the Mexican literature. This literature simply mentions damage to production caused by the revolution (1910-1917) and the subsequent years of reorganization, and production rehabilitation after President Cardenas' government (1934-1940). This reduction in maize consumption was not a mere shift from one type of food to another. Wheat, for example, was not a substitute for maize during the first forty years of this century (Hewitt de Alcantara, 1980).

One would expect, however, that a reduction by half of the per capita consumption of the most important foodstuff of a country would precipitate tremendous social and political consequences. Either the people went hungry in the 1930's or the available data are incorrect.

Two data series of per capita consumption of maize in Mexico were available for the period 1960-1981 (see Fig.2.3). Variability in these data is high, but it would appear that per capita maize consumption levelled off after 1965. One estimate for 1981 is far off the mark; this coincides with the high production reported by DGEA in 1980. The combined average of both series for the period 1965-1980 is 175 kg $person^{-1}$ $year^{-1}$. This seems a reasonable figure and it is commonly reported in the literature (SPP, 1981, Table IV). When transformed into a figure for daily intake, 480 g day^{-1} $person^{-1}$, this matches the statement of the introduction to the effect that Mexicans eat about half a kilo of maize every day. This is, by international standards, a very high intake indeed.

II.1.3.1. Effective demand

It has been estimated that some 38 per cent of the maize produced in Mexico never enters the market (Aburto, 1979, Table XXXIX; CDIA, 1980, Table 28). This maize is consumed by the producer and his family. Another 34 per cent of the harvest, and all imports, are marketed through the National Company of Popular Subsistence (CONASUPO). This Board sets maximum prices and controls distribution through a chain of national storehouses.

Only 28 per cent of the Mexican maize is apparently exchanged on the free market. Obviously, such a percentage of the transactions cannot have a significant effect on the price of maize in Mexico. It is, however, still interesting to see the patterns of expenditure by different strata of the population.

In the 1960's two surveys were conducted to determine how Mexicans spent their income (Banco de Mexico, 1963, 1974). The results for food expenditure showed that different income groups spent different proportions of their income on maize: the wealthier the person, the smaller the proportion. Moreover, wealthier persons purchased less maize than poorer ones. These observations suggest a negative income elasticity in demand for maize.

The surveys comprised both urban and rural segments of the population and separate estimates of these income elasticities were produced. For instance, in 1968 the rural elasticity was -0.096 and the urban was -0.148. The same calculations for expenditures on wheat show positive elasticities: 0.621 and

0.278 for the rural and urban sections respectively. These results for the urban and rural sections would support the previous suggestion that people in the countryside rely on their own maize for consumption. As wheat is not a popular crop in Mexico, the rural consumers must purchase it.

Aburto (1979) and Lamartine Yates (1981) questioned the reliability of these data, but they agreed that the direction, if not the absolute value, of the coefficients of income elasticity is probably correct. The significance of these estimates is that for any increase in real salary there is a proportional decrease in the purchase of maize and a similar increase in the purchase of wheat. If wages were to improve in Mexico, it could be anticipated that maize consumption would shift to wheat consumption.

What about the price elasticity of demand for maize? In other words, how do people's expenditures change with changes in the price of maize? There are no specific studies on this subject in Mexico to date (Lamartine Yates, 1981). Perhaps the lack of this type of information is significant in itself. It is known, however, that the wholesale consumer price of maize has lagged behind the general food price index from 1955 until 1981. This would imply that the relative price of maize, in real terms, has either declined or remained constant. But during those years, per capita consumption of maize increased only slightly (Fig.2.3). It is reasonable to suggest that relatively low prices of maize will prompt increases in per capita consumption, but scanty data do not allow verification of this hypothesis.

Given the imperfect knowledge of the economic determinants of maize demand in Mexico, existing projections for maize consumption are mainly based on population trends. In 1977, for instance, it was estimated that national consumption of maize would increase by 2.4 per cent per year; projected 1982 total Mexican consumption was 11.5 million tonnes (Garcia Mata et al, 1977, p. 14). But the two published estimates of total consumption for 1982 (Table 3, Appendix 1) indicate that the projections for 1982, made in 1977, were between 1 and 3.8 million tonnes short of the observed value (i.e., the latter was 10 to 35 per cent greater than expected). Had the predicted rate of increase in consumption better approximated the rate of increase of population for those years (i.e., around 3.2 per cent per year), the predicted and observed values would have been much closer.

II.1.4. Foreign trade

The preceeding pages have shown great changes in the total production and consumption of maize in Mexico. These changes have not always compensated for each other, and foreign trade has been relied on to relieve the pressures arising from shortages and surpluses.

The longest series of data on imports and exports goes back to 1925. Table 3, Appendix 1, shows a majority of deficient years, i.e., with net imports, and only brief periods of surplus, i.e., years with net exports. Exports were conspicuous only in the mid and late 1960's, when they represented some 11.5 per cent of the national harvest; this occurred right after the big upswing in national production that began in the 1940's, and continued until the mid 1960's. Production went up so much that it consistently exceeded total consumption from 1965 to 1972.

For most of this century, however, Mexico has relied on foreign sources of maize to balance national needs. Generally speaking, imports were 3 per cent of the national harvest until 1965. Starting in 1972, greater and more consistent imports were needed. From 1973 until 1982, maize imports were, on the average, 19 per cent of Mexican maize production. The year 1982 was only an exception to this latest trend, due to the also exceptionally large 1981 harvest; yet, Mexican government officials claimed that self-sufficiency in maize was finally achieved in 1981 (Anon., 1982b).

As noted in section II.1.3, per capita consumption of maize started to level off in 1965. Until economic forces are better understood, national consumption may be assumed to be a linear positive function of population. This means that, for Mexico to be self-sufficient in maize, a consistent 3 per cent annual rate of production increase must be sustained.

II.2. Production in the Maize Field

All of the thirty-two Mexican states produce maize, some more than others. Jalisco, for instance, contributes 13 per cent of the national harvest; Baja California Sur a mere 0.01 per cent. Veracruz, the state in which this study will focus, is the second ranking state with 9 per cent of the total. During the last decade a group of twelve states, comprising some 78 per cent of Mexico's maize land, have been producing more than 80 per cent of the crop (CDIA, 1980, Table 19). Most studies and surveys of maize production in Mexico focus on these leading states.

Galvan Lopez and Delgado Hernandez (1977) described the main agroecologic conditions in these main maize producing regions in Mexico. Table II.2 summarizes their findings. The mean altitude of these maize regions reflects the split between highland and lowland production. The observation that, on the average, these maize producing areas lie on rolling terrain is important to this thesis. As water erosion is partly a function of the slope of the land, the cultivation of maize in a predominantly rolling landscape suggests high risks of soil loss.

Table II.2 also indicates temperatures, rainfall, and other climatic events during the growing season for maize. That these vary is well illustrated by the great range of values observed in all the parameters studied. Maize is grown from the tropical (tierra caliente) lowlands having short growing seasons,

Table II.2. Some Agroecological characteristics of the Mexican maize fields

Parameters	Range	Mean[1]
Altitude(m)	25-2440	1113
Topography[2]	1.3-4.5	3
Growing Season :		
a)length(days)	140-224	171
b)mean Temp(C)	16.2-28.7	21.9
c)mean Precip.(mm)	251-1811	870
d)Thermal Units	1846-4496	3470
e)Probability		
Late frost(%)	0-7.9	1.5
early frost(%)	0-16	3.5
hail(%)	0-3.5	0.5

[1] Weights correspond to the area of each region.
[2] Classes are: 1=flat; 2=gentle; 3=rolling; 4=hilly; 5=mountainous.
Source: adapted from Galvan Lopez and Delgado Hernandez(1977)

abundant water and heat, to the temperate (<u>tierra fria</u>) highlands with longer growing seasons, scanty rainfall, less heat, and risk of frosts.

Given these climatic variations, one would expect the soils of Mexico to be diverse as well. There are Xerosols in the North, Andosols in the central Volcanic Range, Rendzinas in the Yucatan Peninsula, Luvisols and Ferralsols in the lowlands, and a plethora of other soils throughout the remainder of the country. Maize can be found growing in all these soils. Unfortunately, there are no estimates of the proportion of maize that is grown in each group of soils. Actually the only complete soil map of Mexico (SARH, 1972) is on such a small scale (i.e., 1:2,000,000), that the task of calculating the areas of different soils occupied by relatively small maize fields would be next to impossible.

Maize cultivation has been intimately associated with Mexico's natural vegetation. In the tropical regions, shifting cultivation has been the traditional system of agriculture (Watters, 1971; Sanchez, 1977, Ch.3). This nomadic cultivation of maize is known as milpa agriculture. In this system, a field is cropped for two to three years, abandoned to the fast growing bush, and cropped again some seven to fifteen years later. The natural, or more properly, second growth vegetation helps in many ways to replenish the field. Nutrients and moisture are restored to the surface horizons. Soil physical properties are improved, and erosion controlled. Aggressive weeds which otherwise take over crops are also suppressed. This system will be discussed further when soil fertility depletion is considered in chapter III.

Inside the maize field there is also biological diversity. More than fifty races of maize are known to exist in Mexico (Wellhausen et al, 1952). Hybrids and improved seeds are used in only 20 to 25 per cent of the fields (Table II.4, and Appendix 1,Table 4). Intercropping is common in 10 to 15 per cent of the fields (Appendix 1, Table 4). Beans, squashes, and chiles dominate this complex of associated crops, but they are by no means the only ones: anything from vegetables to fruit trees can be found growing together with maize.

II.2.1 Maize fields management

Management combines available resources to achieve a production goal. The basic resources of the maize field are energy, land, water, seed, and agrochemicals. CECODES (1982) has described ten management systems in Mexico based on the use of the first three, i.e., energy, land, and water.

Table II.3 summarizes these systems. The sources of energy can be totally human, supplemented with animal traction, or combined with fuel-driven tractors. The land can be cropped continuously (one, two, or even three crops per year) or only two or three times every ten years or so. Water may be entirely provided by rainfall or mostly derived from irrigation.

What proportion of these maize fields have irrigation, employ tractors or fertilizers in cultivation? The following three paragraphs explore this question.

The agricultural censuses of 1960-1970 (see Appendix I, Table 4) reported that approximately 10 per cent of the area harvested to maize was irrigated. Continuous records of the DGEA show that between 1960 and 1978, only some 4.5 to 7 per cent of this area was irrigated (CDIA, 1980, Table 14). Yet the DGEA field surveys of 1976-79 indicate that some 13 to 14 per cent of the area is fully irrigated, while an additional 7 per cent receive auxiliary irrigation (see Table II.4). It could well be that the previous two sources have only reported irrigated maize in the irrigation districts. Auxiliary irrigation is usually obtained through small, privately-owned water reservoirs, or

Table II.3. Land, water, and energy management in Mexican maize fields

Management System	Scale (Ha)	Land Use[1] intensity	Water sources	Energy[2] sources
2-crops	1-5	2-3/1	Rain-Sum Irr.-Win	Animal Fuel
Chinampa	<1	1-2/1	Irr.	Human
Irr. District	1-30	1/1	Irr.	Animal Fuel
Dryland	2-100	1/1	Rain (erratic)	Fuel Animal
Rainfed	1-20	1/1	Rain (reliable)	Animal Fuel
1/2 Rainfed	1-20	1/1	Rain+ Irr.	Fuel Animal
Year-after	1-5	1/2	Rain	Animal
Tonalmil	1-5	2/3-2/8	Rain	Animal
Tlalcol	1-3	1/3-1/5	Rain	Human
Milpa	1-3	1/>5	Rain	Human

[1] #crops/calendar year.
[2] Dominant forms; @ harvest all systems use labor.
Source: adapted from CECODES (1982).

through individual water pumps. It is also understood that auxiliary irrigation only serves a field at critical times. There is, therefore, some ambiguity in the data. The percentage of irrigated maize fields may be anywhere from five to twenty. However, the censuses' figure of 10 per cent seems to be the more reasonable one.

Only a handful of combines are known to harvest maize in Mexico (Carlos Montañez, CECODES, pers. comm.). Tractors are the only conspicuous piece of machinery found in the maize fields. Table II.5 shows that about 50 per cent of these fields have used tractors for some operations in the period 1976-79.

Chemical fertilizers are relatively less expensive inputs of production. Their use in the maize fields is modest, however. Table II.4 shows that a little more than half the fields used fertilizers at all. Overall, the average annual rates of application of nitrogen and phosporus are 40 and 15 kg ha^{-1}, respectively. In the case of nitrogen, this is about one third of the rate employed in the U.S. corn belt in 1970 (see Fig.2.4).

II.2.2 Maize fields productivity

Land productivity depends on the ecological and technological factors described above. This section examines the effects of several management inputs on maize yields. It also discusses the variability of existing estimates of maize yields.

II.2.2.1. Effects of management inputs on productivity

Table II.4 shows the effects of fertilizers, irrigation, and improved seeds on the productivity of maize fields. When all three factors are used, maize yields are three times higher than when none is used. When only two are used, yields double. The use of fertilizers alone is associated with a fifty per cent

Table II.4 Effect of irrigation, fertilizers, and improved seeds on maize fields productivity

	Combinations of seeds, fertilizers, irrigation.	#Fields (%)	Mean Size (ha)	Yield (t ha^{-1} yr^{-1})
1)	Creole No-Fertilizer No-Irrigation	32	3.2	0.8
2)	Creole Fertilizer No-Irrigation	32	3.8	1.2
3)	Improved Fertilizer No Irrigation	12	7.7	1.7
4)	Creole Fertilizer Irrigation	6	2.9	1.7
5)	Improved Fertilizer Irrigation	6	6.0	2.4
	Sum	88		

% total sample with irrigation= 19
% total sample with fertilizers= 57
% total sample with improved seeds= 24

Source:DGEA-surveys: 1976-79, see Appendix I.

increase in maize yields. This is particularly important because fertilizers are the most widely used of all three inputs (see percentages at the bottom of Table II.4).

These figures indicate average responses of maize yields to average treatments with fertilizers, irrigation and improved seeds in the Mexican maize field. Under apparently ideal conditions of soil, water, and plant management, Goldsworthy *et* al (1974), and Goldsworthy and Colegrove (1974) have shown that improved maize varieties can yield 6.3 and 7.2 t ha^{-1} yr^{-1} in the tropical and temperate regions of Mexico, respectively. These yields are almost three times greater than the best yields presented in Table II.4.; and could well indicate future trends in the productivity of the maize fields. For the moment, however, the picture is less optimistic: only six per cent of the maize fields produce more than 2 t ha^{-1} yr^{-1} of maize.

Table II.5 shows how the use of tractors, farm credit, insurance, and technical assistance affect maize yields. Yields are almost sixty per cent higher when tractors are used than when they are not. The addition of credit, insurance, and technical assistance does not seem to make much difference.

II.2.2.2. Variability on land productivity estimates

Maize yields can be calculated on the basis of the harvested lands alone, or on the basis of all the cultivated lands. Equations 2.1 and 2.2 below clearly define these two estimates.

$$\text{Yield(C)} = \text{PROD/CL} \qquad (2.1)$$

$$\text{Yield(H)} = \text{PROD/HL} \qquad (2.2)$$

where:
Yield(C) = yield based on cultivated area (t ha^{-1} yr^{-1})
Yield(H) = yield based on harvested area (t ha^{-1} yr^{-1})

Table II.5 Effect of tractor, credit, insurance, and technical assistance on maize fields productivity

inputs used	# Fields (%)	Mean size (ha)	Yield (t ha^{-1} yr^{-1})
None	39	2.9	0.95
Tractor	29	4.4	1.50
Tractor+ Credit+ Insurance+ Tech.Assis.	12	7.9	1.55
Sum	80		

% of total that use tractor= 49
% of total that use credit= 25

Source: DGEA Surveys 1976-79, see Appendix I.

PROD = tonnes of maize harvested
CL = area sown with maize (ha)
HL = area harvested (ha)

Equation 2.1 provides the best estimate of the productivity of the land because it takes into account the hazards of production (e.g., losses of crop to droughts, pests, etc.) that are characteristic of any land type. Equation 2.2, in turn, overestimates land productivity because it removes from the calculation the areas which were sown and lost. The greater the risks of production, the more these yield estimates will differ.

Table II.6 Harvested and cultivated maize yields in Mexico

Year	(1) Yield(C) (t ha^{-1} yr^{-1})	(2) Yield(H) (t ha^{-1} yr^{-1})	(3) Ratio 1/2
1976	1.108	1.282	0.86
1977	1.021	1.247	0.82
1978	1.144	1.320	0.87
1979	0.723	1.207	0.60
Averages	0.999	1.264	0.79

Source: DGEA Surveys, see Appendix I.

Table II.6 presents estimates calculated with both equations for the years 1976-1979, when the DGEA surveys of maize fields were conducted. As expected, maize yields according to Equation 2.1 are always smaller than those corresponding to Equation 2.2.

The ratio between these two yield estimates varies from year to year. In 1979, a year of drought, this ratio was only 0.6. In normal years (i.e., 1976-1978), the average maize field yielded only 85 per cent of what was reported for the harvested lands. On average this ratio is 0.79.

Governments report yields at harvest only because it is simpler to estimate. Nothing is wrong with using yields based on harvested lands if it is known: a) how different these yields may be from the ones based on all cultivated areas, and b) if these differences are small or consistent throughout the years. The second qualification does not seem to apply to the Mexican maize fields; the differences between the two methods of yield estimation are significant and varying.

This is an important indication of the risks of producing maize in Mexico. If, on the average, twenty per cent of the area sown to maize is lost every year, this must have a significant impact on producers. A farmer that faces such odds could well disregard the prospects of better yield through a new seed or fertilizer. This is probably why irrigation in Mexico has been so important in raising crop productivity, for once drought areas were irrigated, fertilizers and improved seeds could be profitably used (see Wellhausen, 1976; Florescano Mayet et al, 1980).

Another point worth exploring is the correspondence between the maize yields estimated through the 1976-79 DGEA surveys and those continuously reported by the same DGEA and by the USDA. DGEA survey data correspond to the spring-summer maize crop only. The other two sources include winter crops as well. However, this discrepancy can be corrected with existing reports on the yields and areas of the spring-summer and fall-winter crops between 1972 and 1977 (CDIA, 1980; Table 18). During these years maize yielded 1.591 t ha^{-1} yr^{-1} and 1.128 t ha^{-1} yr^{-1} in the winter and summer cycles, respectively. Since the maize winter crop represents 7.4 per cent of the total annual area harvested, the weighted average of the yields in the two cycles is 1.162 t ha^{-1} yr^{-1}. This is only three per cent higher than the average yield of the summer cycle alone, which provides an standard for comparison. An exception to this simple rule would occur if the area of the winter crop were to increase significantly, something that apparently did not happen between 1976 and 1979 (SARH-DGEA,1980, p.25).

Table II.7 Different maize yield estimates for Mexico.

Year	Yields ($t\ ha^{-1}\ yr^{-1}$)			Ratios		
	(1) DGEA-Sur	(2) DGEA-C	(3) USDA-C	2/1	3/1	3/2
1976	1.282	1.182	1.220	0.93	0.95	1.03
1977	1.247	1.357	1.220	1.09	0.98	0.90
1978	1.320	1.519	1.280	1.16	0.97	0.84
1979	1.207	1.517	1.210	1.26	1.00	0.80
Averages	1.264 (0.028) [1]	1.394	1.233	1.10	0.98	0.88

[1] 95 % confidence limits,
Source: see Appendix I.

Table II.7 includes the three available estimates of maize yields in Mexico for the years 1976-1979. In all cases yields correspond to the harvested areas (Equation 2.2). According to the correction made before, the two series of continuous yield estimates (Col. 2 and 3, Table II.4) should theoretically be 1.03 times greater than the DGEA survey in all years. As the ratios indicate, the survey yields are overestimated in all but one year by the continuous records of the DGEA, and consistently underestimated by the continuous records of the USDA. From 1977 on, the overestimation by DGEA becomes progressively worse.

The DGEA survey data should be considered the yardstick because they are, after all, a sample. The other two series of maize yields are based on informed judgement, and as such are subject to an unknown degree of error. The differences in yield estimates shown in Table II.7 are not, as yet, alarming. Perhaps a simple error could explain them. However, in the period 1980-1982 the average yields reported by the USDA were only 75 per cent of the average yields reported by the DGEA (i.e., 1.35 t ha^{-1} yr^{-1} vs. 1.80 t ha^{-1} yr^{-1}; see Appendix 1, Table 1). These are considerable differences, which should worry some officials in these agencies. If only more field data were available, as in 1976-79, the matter could rapidly be settled. But the DGEA surveys were discontinued in 1980, and the whole question of how much maize yields have been improved in the last four years remains unresolved.

II.3. A Test of Productivity Trajectories

Extensive research by the Soil Conservation Service of the U.S. during the 1930's and 1940's concluded that topsoil loss significantly reduced crop yields (Murray *et al*, 1939; Uhland, 1949; Odell, 1950; Stallings, 1950). On the basis of this data, it has been estimated that for each centimeter of topsoil lost, maize yields were reduced by approximately 100 kg ha^{-1} (Lyles, 1975; Pimentel *et al*, 1976). Assuming that the average annual rate of erosion on the U.S. cropland is 2.5 mm yr^{-1} (Pimentel *et al*, 1976), and that the base maize yields of the uneroded soils was 4 t yr^{-1}, the annual decrease in maize yields due to erosion will represent little more than 0.6 per cent of the base yield. Since the afforementioned studies were conducted, maize yields in the U.S. have continuously increased to today's average of about 6.5 t yr^{-1} (average 1979-1981, FAO, 1981).

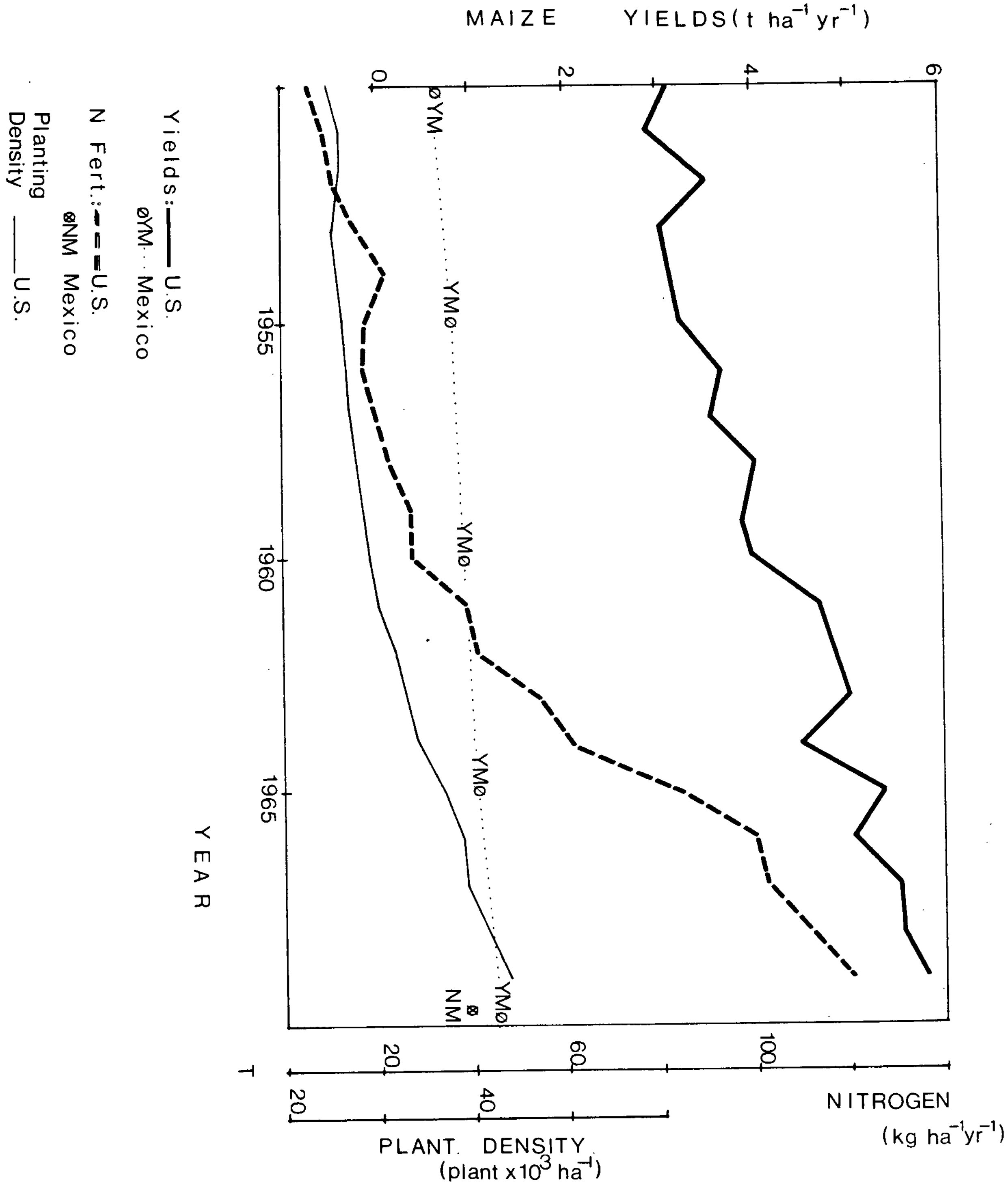
This contradiction needs explanation. That an expected decline in land productivity has been overcome in excess over the last 30 years is not surprising when due account is taken of other significant changes occurring in the same period.

Jugenheimer (1976) has shown how maize yields increased in the U.S. from 1930 to 1970. Figure 2.4 reproduces his analysis of the maize yield trends which, in the U.S., was accompanied by similar increases in maize planting densities and ever increasing nitrogen fertilization. This graph strongly suggests that maize yield improvements in the U.S. have been a byproduct of denser maize stands supported by increasing rates of nitrogen fertilization. All this has happened in one of the best, if not the best, maize growing areas of the world.

Figure 2.4 also includes Mexican maize yields for the same period and current nitrogen fertilization rates. Note how the same rate of nitrogen fertilization (i.e., approximately 40 kg ha^{-1}) was associated with quite different responses of maize yields (i.e., 4.5 vs 1.2 t ha^{-1} yr^{-1}) in the early 1960's in the U.S. and in the late 1970's in Mexico.

Obviously, these two countries must have completely different systems of production, but that big a difference in fertilizer's efficiency must be also related to different qualities of maize

Figure 2.4. Maize yields, maize planting densities and N fertilization rates in the U.S. and Mexico. Sources: U.S. data, Jugenheimer (1976). Mexican maize yields are five year averages from table 1, Appendix 1 and average Mexican N rate from 1976-1979 DGEA surveys. Mexican planting densities not available.


MAIZE YIELDS(t ha⁻¹ yr⁻¹)
0
2
4
6
ØYM
YMØ
⊗NM
1955
1960
1965
YEAR
20
60
100
NITROGEN
(kg ha⁻¹yr⁻¹)
20
40
PLANT DENSITY
(plant x10³ ha⁻¹)
Yields: U.S.
ØYM Mexico
N Fert.: U.S.
⊗NM Mexico
Planting Density U.S.

lands in the U.S. and in Mexico.

If land degradation is an old and continuing phenomenon in the Mexican maize field, this should show in the long-term statistics on maize yields discussed in this chapter.

Section II.1.2 has shown that these yields have increased continuously during the last thirty years. But this has also been associated with simultaneous increases in the use of irrigation, fertilizers, improved seeds and farm machinery. In a valid comparison of land productivity, the data should be corrected for concomitant changes in the inputs of production. The DGEA survey data presented in Table II.4 provide an appropriate sample for 1976-79. Yield data for the more distant past can be obtained only in aggregated form.

Hewitt de Alcantara (1980, Tables 6 & 12) has shown that the modern management inputs to production became popular only in the 1950's. Maize production before those years must have been predominantly unfertilized, unirrigated, and without improved seed varieties. Maize yield data from before 1930 might not be appropiate because agriculture in Mexico was then experiencing the aftershocks of the agrarian revolution.

The comparison of maize yields thus proposed is between averages of four years during the late 1940's and the four years 1976-1979; the more recent data are from fields that did not use irrigation, fertilizers, or improved seeds; data from the forties are from all Mexican maize fields, which most probably did not use these management inputs. The comparison spans thirty years, enough time for land degradation, if serious, to show its effects.

According to the DGEA and USDA series of data (see Appendix 1, Table 1), average maize yields for 1946-1949 were 0.71 t ha^{-1} yr^{-1}. In 1976-79 the yields of the unfertilized, unirrigated, and creole seeded maize fields were 0.8 t ha^{-1} yr^{-1} (see Table II.4). Evidently, maize field productivity has not declined during the last thirty years. Indeed, in this comparison, maize yields show a slight increase, even after the most important technological changes of the intervening years are taken into account.

Before dismissing the possibility of land degradation in the Mexican maize field, we should ponder the data itself. Figure 2.1b clearly shows that between 1940 and 1970 the land cultivated with maize doubled in Mexico. How might such a substantial increase in the land base affect maize productivity data? Either the new lands were marginal, in which case average productivity per hectare would decrease, or the new lands were of good quality, in which case average productivity per hectare would increase. Which of these was the case in Mexico, we cannot now say. But in either case, an increase of land could also increase average land productivity by continuously bringing into production lands that were not cultivated before. In other words, the sustained addition of land to maize production could well have had the effect of a continuous rejuvenation of the maize land base.

II.4. Summary

This critical review of what is known about maize production in Mexico has included historical, economic, demographic, geographical, and agricultural data. It was necessary to use such a broad range of data because maize is paramount among food resources in Mexico.

The history of maize production in this century shows marked changes in volume, area, and yields for this crop. During the 1940's, maize production started to grow exponentially. This coincided with the well known demographic explosion of Mexico.

Indeed, maize per capita consumption had fallen to record low levels just before production began to climb in the 1940's. This increase in production apparently brought relief to millions of Mexicans until the early 1970's, by which time, population growth had outstripped the previous gains in production. Maize had to be imported and this has continued ever since, constituting a serious drain on foreign currency reserves, which has political as well as economic implications.

Maize is produced in Mexico in millions of maize fields. Small, diverse, with low use of irrigation, of fossil energy, of fertilizers, and of improved seeds, these fields have low productivity by modern standards. As Mexico has little good quality agricultural land to spare, there is a need to improve the productivity of these fields. Irrigation and farm machinery could raise productivity, but these are too expensive for many of the small producers. The easiest way to increase maize productivity seems to lie with fertilization, both because it is effective and cheap.

Maize field productivity data are scanty. There is no doubt that average yields are low: 1.2 or 1.8 t ha^{-1} yr^{-1} makes no difference by international standards. The variability of maize yield records during the last few years is another thing. Some of these maize productivity data show impressive improvements, others show just normal gains, while the only field data suggest more modest growth.

The question of maize yields is here important because such data reflect land productivity. In the long run, land degradation should result in lower land productivity, other things being equal. A preliminary test of this contention was made on the assumption that modern management inputs were not important in the maize fields of Mexico until the late forties. Recent yields for fields that did not use those modern inputs are only slightly greater than yields in the late forties. Thus, no decline in maize yields could be observed between 1946-49 and 1976-79. During that period, however, the maize growing area in Mexico doubled. It was not possible to check whether these lands were new, previously abandoned, or of poor or good quality.

All in all, land productivity in the Mexican maize field may not yet be declining but is not growing rapidly either.

CHAPTER III. SOIL EROSION, FERTILITY DEPLETION, AND PRODUCTIVITY: A REVIEW OF THE LITERATURE

III.1. Introduction

In reviewing the effects that soil erosion and soil depletion have on land productivity, the chapter that follows defines the key elements in land degradation considered in this thesis: soil erosion and soil fertility depletion. The process of soil erosion, and its various components, will be reviewed first. Evidence on the magnitude of soil erosion in maize fields is then presented. Next, the chapter reviews evidence on the impact of soil erosion on land productivity. Finally, soil fertility depletion is examined through a number of studies that have dealt with the long-term effects of shifting cultivation on land productivity.

III.2. Soil Erosion

Soil erosion is a naturally occurring process which slowly but persistently transforms the surface of the land. It does so by removing soil particles from one site and transporting them to another. Erosion occurs in most landscapes and at all times, but it varies greatly in degree and intensity.

Water is the principal agent of soil erosion in the humid tropics (Hudson, 1971, pp. 27-31; El-Swaify *et al*, 1982). Extremely intense rainfall can result in landslides and gullying, but these catastrophic events are localized and are almost beyond human control once they have started. On the contrary, sheet and rill erosion is a pervading and continuous form of erosion that can have serious effects on soil properties and functions, but which can be controlled by sound management.

Young (1969), and Schum and Harvey (1982) have estimated that soils covered with natural vegetation lose from between 0.02 and 1 mm of soil per year. Because these soils are also being formed at rates which vary from 0.01 to 0.5 mm per year (Hall et al, 1982), soil erosion under natural vegetation may have no significant effect on soil properties and functions.

A problem arises when people remove the natural vegetation for agricultural or other uses. Under these conditions, soil erosion rates can accelerate dramatically. Soil losses as high as 45 mm $year^{-1}$ have been reported in the literature (Throeh et al, 1980, p.87). These losses are clearly beyond the normal range of soil formation rates.

Good land management can maintain a balance between soil loss and soil formation. Indeed, soil formation rates in properly cultivated lands may even be as high as 0.83 mm yr^{-1} (Hudson, 1971; but see also Pimentel et al, 1976; and Hudson, 1981). Furthermore, soil erosion can be checked through types of crops, crop rotations, plant residue management, plowing techniques, and erosion control practices.

The ultimate goal of soil conservation is to secure a steady state between soil losses and soil additions. Maximum allowable soil losses have been recommended to achieve this goal. For instance, the U.S. Soil Conservation Service established soil tolerance values which range from 0.4 to 1.1 mm yr^{-1} depending on soil type (Wischmeier and Smith, 1978). However, erosion on U.S. cropland has been recently found to exceed, even more than before, these "tolerable" soil losses (McCormack and Young, 1980).

The following pages describe the principal factors which determine sheet and rill erosion on cultivated lands.

III.2.1. Determinants of soil erosion

Rainfall and land relief give erosion its momentum; vegetative cover and soils offer resistance. Land management may well change whatever balance there is. These forces do not act separately. They all interact in any given situation (Quansah, 1981). For instance, for rainfall to have an independent effect at all, the soil surface must be bare, the soil itself must be a pile of non-aggregated earth, and the land must have no relief, conditions which are all trivial. In reality, soil erosion is a complex process, but one which, for analytical purposes, has been separated into a number of factors.

III.2.1.1. Rainfall and runoff

Rainfall plays two roles in soil erosion: it detaches surface soil particles and it transports them downslope. Rainfall hitting the ground is a powerful force which splashes particles according to its intensity and amount. Splash erosion has been defined as a function of mean raindrop size, storm kinetic energy, and rainfall intensity (Hudson, 1971, Ch. 3).

How much it rains and at what velocity are important questions in determining the erosivity of rainfall. For instance, rainfall quantities are almost the same, approximately 1.4 m yr^{-1}, in Vancouver, British Columbia, as in Xalapa, Veracruz. Autumn rains in both places fall as drizzles or light rains. In spring and summer, Vancouver gets a few rainstorms while Xalapa gets torrential rains. Because of these differences in rainfall distribution, rainfall erosivity in the two areas is bound to differ.

Runoff or overland flow can occur only when the soil water storage capacity is filled, or when the intensity of rain exceeds the rate of water infiltration into the soil. A layer of water forms on top of the soil and moves with a force which depends on the mass of the excess water and the steepness of the terrain. As runoff continues, it detaches new soil particles, further compounding the eroding effects of rainfall (splash erosion).

The other source of erosive energy comes from the slope of the land. The steeper or longer a slope is, the faster runoff proceeds, and the greater the water's power to abrade the soil underneath. It has been postulated that soil erosion is a second order polynomial function of the sine of the angle of the slope, modified by the length of the slope and its shape (Wischmeier and Smith, 1978, pp. 15-16). Put simply, the slope factor should affect erosion exponentially.

Several indexes of rainfall erosivity have been proposed to deal with both the splash and runoff components of this process (Wischmeier and Smith, 1978; Hudson, 1971). They are all empirical and need calibration to specific conditions.

III.2.1.2. Soil erodibility

It has already been mentioned that the infiltration of rainfall into the soil precludes runoff and consequently reduces soil erosion. The permeability of the soil affects the rate at which water infiltrates. Obviously there are limits to the amount of water that soils can absorb. It could well happen that runoff would start even before a soil becomes completely saturated, as water might not penetrate the soil fast enough.

In this respect, soil structure is important. A massively compacted soil has few pores in which to accomodate water. Conversely, a soft, well tilled topsoil allows water to soak into it rapidly. Moreover, soil structure produces aggregation of soil particles, which prevents these particles from splashing away upon rainfall impact.

Soil particle distribution is also responsible for the net effect of splash erosion. Silty soils are more easily eroded than either sands or clays (Wischmeier and Mannering, 1969). Because organic matter contributes to the aggregation of a soil as well as to its infiltrability, it is too considered an important factor in controlling erosion (Neal, 1939; Wischmeier and Mannering, 1965).

Recent research on tropical soils has brought attention to a number of other soil properties that might affect erodibility. For instance, the amount of sesquioxides (Roth et al, 1974), and the stability of soil aggregates (El-Swaify and Dangler, 1976), have been shown to have a significant negative effect on soil erodibility.

Given the number of soil properties that might have an effect on erodibility, as well as the many possible interactions, it is difficult to have a clear picture of the factors on which erodibility is specifically dependent (Rorke, 1968). Early attempts at simplifying this relationship identified soil particle-size distribution, organic matter, and soil permeability and structure as the key variables to take into account (Wischmeier et al, 1971).

III.2.1.3. Vegetative cover

Vegetation intercepts rainfall and diminishes its velocity. Vegetation also redirects the entry of water into the soil through stemflow and canopy drip. Furthermore, a soil with vegetation offers obstacles to the overland flow of water. These are the basic roles of vegetation in reducing the impact of erosion.

It actually does not matter what type of vegetation covers a soil, provided that it is thick at the ground level. Annual crops can produce enough plant cover by the end of the growing season to be effective against erosion. Maize takes between two and five months to fully develop a complete canopy on the field. The effectiveness of this plant cover depends on the seasonal distribution of erosive rains. Therefore, in any discussion of the beneficial effect of plant cover, the cycle of the vegetation should be compared with that of rainfall (Elwell and Stocking, 1976).

For instance, a tropical dry forest loses most of its leaves during the dry season. When the rain season sets in, there is little effective cover and early rains can produce significant erosion, if the soil can not soak up excess water. On the other hand, mulch spread over the seedbed of a maize crop can resist erosion as well as a luxuriant forest (Roose, 1973; Lal, 1976).

Plowing has the double effect of increasing soil infiltration and altering soil structure (Greenland, 1977). Much controversy is recently going on in the U.S. about the advantages and disadvantages of zero-tillage and minimum tillage as a means of preventing erosion (see, for instance, the 1983 May-June special issue of the Journal of Soil and Water Conservation). Plowing certainly has other important functions in agriculture, such as weed control, soil aeration, and seedbed preparation. Therefore, the negative effects of plowing on erosion should be weighed against the known beneficial effects of plowing, if the worth of this old agricultural practice is to be properly assessed.

III.2.1.4. Soil erosion control

Rainfall erosivity, soil erodibility, topography and vegetative cover are the key factors to any discussion of soil erosion control. All have an important bearing on the magnitude and rate of erosion and are extremely variable, which makes it practically impossible to foresee them all.

Agriculture is an ancient human activity which has been faced with the loss of soil many times and has survived. Terracing has been the most conspicuous form of controlling erosion. There are many kinds and styles of terraces, but their basic role is to break the slopes and to prevent runoff. Contour planting is a common modern practice which also cuts a field across the slopes, although it is confined to gentle slopes.

Crop rotations and intercropping with legumes are means of restoring soil fertility, but also contribute to controlling erosion by increasing vegetative cover. Hudson (1971, pp.195-99) has found that high density stands of maize, with high levels of production, reduced erosion more than ten times. Crop residue management helps to protect the soil during the off-season. This can provide an adequate cover, particularly when yields are high and when residues are properly handled in post-harvest operations.

Perhaps the more crucial factor in controlling erosion in croplands is timing. Farm operations can be effectively adjusted to offer the minimal soil exposure to the erosivity of rainfall. Farmers should know this well. Rainfed agriculture is particularly tied to the cycle of rainfall. A good crop depends strongly on the right time for planting. In areas with seasonal rains, farmers have to time planting to coincide with the onset of rains. Fields should be plowed in advance for the first rains to moisten the soil and create good seedbed conditions. But what is good for the crop may not be so good for the soil at this particular time; bare and loosened, the soil might be hard hit by heavy rains and erode. Therefore, trade-offs can be made between the likelihood of a good crop and the prospects of soil erosion, which also depend on soil type, rainfall, and crop development patterns.

III.2.2. Evidence of soil erosion in maize fields

Soil erosion research is painstaking. It requires expensive and time-consuming experimentation. The number and variability of factors affecting erosion makes difficult the generalization of results.

The leading agricultural nation in the world, the U.S., is also the leader in soil conservation research. Although that country has experienced massive erosion events (i.e., the dust bowl of the 1930's), and more recently an oil crisis that threatened a model of agricultural development based on the substitution of fossil fuels for soil resources (Pimentel *et al*, 1976), it is widely believed that the magnitude of soil erosion in the U.S. is minimal when compared with erosion in the tropical, developing world (see FAO, 1977; Greenland and Lal, 1977; Stocking, 1980; El-Swaify *et al*, 1982).

In order to assess the magnitude of soil erosion in the

Mexican maize fields, three types of sources will be reviewed here: a) general surveys; b) detailed field studies of maize fields throughout the world, particularly in the tropics and c) preliminary studies of erosion in Mexican maize fields.

III.2.2.1. Surveys

During the early 1950's, the Food and Agriculture Organization of the United Nations carried out a survey of soil erosion trends in Latin America, including Mexico (FAO, 1954). A paragraph described the erosion problem in Mexico as follows:

> "In the more humid forested and mountainous lands of Mexico soil erosion is chiefly due to the cultivation of corn (maize). In many places corn is grown under primitive conditions of shifting agriculture, but regardless of the method of cultivation, corn grown on slopes always leads to a certain degree of erosion. Any detailed assessment of such damage must be based on a thorough study of soil characteristics but, as a general rule, the deep soils formed from young volcanic ash are least subject to damage and are most readily restored because of their inherent erosion-resistant physical properties and their high level of mineral fertility. Subject to the most severe and permanent damage are the shallow sloping soils that are underlaid by infertile parent rock materials or by hard impervious layers, such as the <u>tepetate</u> (caliche) so widespread in parts of Mexico"[1]

This study used aerial photographs to map at the scale 1:10,000,000 areas with different degrees of erosion. On this

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[1] FAO, 1954, p.162. Italics and notes in brackets are FAO's.

basis, Samario Pineda (1965) calculated the extent of each erosion class in Mexico. Pockets of severe erosion (4 per cent of the country) were noticed in the arid lands of the north and in the mountainous tropical lands of the south. Some 33 per cent of the land in the north and west of the country was moderately to severely eroded. Central and south-eastern Mexico contained 30 per cent of moderately to slightly eroded soils. Finally, the remaining 32 per cent of the land in the tropical lowlands and the forested mountains was found to be slightly eroded or not eroded at all.

These estimates are tentative at best, because they were based on photointerpretation of the amount of vegetative cover at a particular time, and had little fieldwork to support it. More recently, the Soil Conservation Service of Mexico has been updating these estimates with satellite images and field work (A. Benitez Omaña, Dto. Areas Erosionadas, SARH, México, 1981, pers. comm.). Unfortunately, these results have not yet been made available.

III.2.2.2. Erosion rates in tropical maize fields

As maize is cultivated today in most of the tropical world, it is worth reviewing soil erosion measurements for these conditions.

Lal (1976a) found that, on two years of observations, a Nigerian Alfisol on 15 per cent slopes lost an average of 28 t ha^{-1} yr^{-1} when cultivated continuously to maize. On a 5 per cent slope, the same cropping system resulted in 7.1 t ha^{-1}

yr^{-1}, or roughly 1/4 of the losses of the steeper slope. The study also showed that straw mulch applied on these fields reduced erosion to insignificant levels, even on the steep slopes.

Hudson (1971; table II.1) reported two years of data on his earlier work in Zimbabwe. Soil erosion in a gently sloping maize field was reduced from an average 12.3 t ha^{-1} yr^{-1} to an average 0.7 t ha^{-1} yr^{-1} when plant density, fertilization, and plant residues additions were increased. According to Temple (1972) these studies also showed that soil erosion is dependent on soil type. In soil capability classes for agriculture II to IV, soil losses ranged from 1.8 to 21.9 t ha^{-1} yr^{-1}, respectively, with poor management, and from 1.2 to 10.6 t ha^{-1} yr^{-1}, respectively, with good management. Temple (1972) also reported three years of measured soil erosion rates for a volcanic soil in Tanzania. Continous maize on a 40 per cent slope was associated with average soil losses of 12 t ha^{-1} yr^{-1}. The same treatment with the addition of stover and trash bunds resulted in average soil losses of 1 t ha^{-1} yr^{-1}.

Roose (1967) studied soil erosion of an almost level soil in Senegal with several cropping systems. Continuous cropping of maize resulted in the greatest soil losses, a 10 year average of more than 10 t ha^{-1} yr^{-1}.

Quintiliano et al (1961) reported ten years of soil erosion measurements for several soils in southern Brazil. These authors found that continuous cropping of maize on slopes from 8 to 12 per cent resulted in soil losses ranging from 8 to 30 t

ha^{-1} yr^{-1}.

This review suggests that measured soil losses in tropical maize fields range from 1 to 30 t ha^{-1} yr^{-1}, with a more common range of 10 to 20 t ha^{-1} yr^{-1}. The latter roughly corresponds to soil depth losses of between 1 and 2 mm per year. Steep slopes and good management can dramatically change this picture, for better or worse.

By way of comparison, average annual soil loss rates in the U.S. corn belt were recently estimated at slightly more than 10 t ha^{-1} yr^{-1} (Larson, 1981; Larson et al, 1983).

III.2.2.3. Erosion rates in Mexican maize fields

Only a few studies have actually measured soil erosion in Mexican maize fields. Terraza Gonzalez (1977) tested for one year the effects of different crop management practices on soil erosion. The study, near Mexico City, examined three soils on 3.5 per cent slopes. When maize was intercropped with beans, soil losses varied from 2.3 to 6.2 t ha^{-1} yr^{-1}. When maize was cultivated alone, losses varied among soils from between 3.1 and 5.5 t ha^{-1} yr^{-1}. Zero-tillage and additions of manure and plant residues reduced soil erosion by between twenty and forty per cent.

Figueroa Sandoval (1975) also studied soil erosion in the vicinity of Mexico City. Soils and vegetation were the main variables of the study. Two maize fields, located on 2 per cent slopes, experienced annual soil losses of 1.6 and 3.1 t ha^{-1} yr^{-1} during the year of the study. These rates were exceeded only by a poorly grassed Tepetate (hardpan soil) which lost 16.1 t ha^{-1} yr^{-1}. Unfortunately, no details of the cropping system were given in the report of this study, but apparently one of the maize fields studied had been in rotation with other crops.

Trueba C. et al, (1979) studied four conservation practices in 0.7 ha plots cultivated with maize. Little information was provided on the soils, location, and topography of the study sites, although it could be assumed that these soils are also in the vicinity of Mexico City. Average soil losses (2 years) under traditional maize cultivation were a mere 0.5 t ha^{-1} yr^{-1}, while all conservation works (i.e., contour planting and different types of terraces) reduced these losses by up to 80 per cent.

Finally, Wegener (1979) reported preliminary data from erosion plots in the highlands of Puebla. Maize was used as the principal crop in half the plots, while the other half was kept bare. Slopes ranged from 4-11 per cent and observations were made during only one growing season. Only graphs depicting soil losses from single storm events were provided. This report concluded, however, that soil losses ranged from medium to very high, depending on soil type.

The general impression left after reviewing these studies is one of inadequacy. At best, only a couple of years of measurements are reported. They were all concentrated in the Mexican highlands--implying that the probably most erosive lands in Mexico, the tropics, have not been studied at all--and included only gentle slopes in their treatments. An interesting feature of all these studies is that they reported low rates of soil erosion. The information provided by the authors about methods and procedures suggests that these were pilot studies, and that more and better planned studies are about to come.

III.3. Soil Erosion and Productivity

This section first describes the effects of soil erosion on the soil properties that control land productivity. A review of the literature containing evidence of land productivity decline associated with soil erosion will follow.

III.3.1 Soil erosion effects on soil properties

Soil is the product of long-term soil forming processes involving climate, living organisms, relief, rocks and vegetation acting on soil parent materials over time. Soil depth is an important feature of soils because it defines the volume and rooting depth of a soil. Soil depth can be measured from the surface to the contact with underlying rocks or the unaltered soil parent materials. The depth of a soil provides the starting capital for land use activities.

Soil erosion can significantly reduce the depth of a soil. A net soil loss of 40 t ha^{-1} yr^{-1} (i.e., approximately 4 mm yr^{-1}) could reduce the depth of a shallow (i.e. 40 cm) soil by 20 per cent in 20 years. On the other hand, a deep (i.e. 100 cm), moderately eroding soil (i.e. 5 t ha^{-1} yr^{-1}) will only suffer a 1.0 per cent reduction during a similar period of time. These values are representative and illustrate the range of impact that soil erosion can have on soil resources.

Soil is a heterogeneous assortment of particles of various sizes. Gravel and stones are less easily eroded than finer particles. Erosion of coarse-textured soils will increase the relative proportion of coarse fragments in the profile, and reduce even further the effective rooting volume of the soil.

The fine particles of a soil are organized in relatively stable physical aggregates. To a great extent, these aggregates control the movement of air, water, and nutrients in the soil. The splashing of rainfall and the abrasion of runoff, which precede soil erosion, compact soil aggregates and seal the surface of the soil. A compacted soil structure results in poor tilth and in problems for plant germination and growth.

Organic matter is the product of soil-plant interactions over time, and naturally accumulates on the topmost portion of the soil. Organic matter is responsible for a number of important functions of the soil: a) it supplies most of the nitrogen and phosphorus; b) it enhances the cation exchange capacity, particularly in acid soils; c) it retains otherwise fixable or leachable nutrients in a form available to plants; d) it improves soil aggregation and structure; and e) it generally enhances soil water retention capacity (Sanchez, 1976).

Erosion reduces soil volume, affects soil structure, and impairs the levels of soil organic matter, all of which are indirect determinants of the soil water balance. Further, and foremost, erosion leads to reduced water infiltrability and increased runoff which directly reduce the water available for crop production. This may not be important in humid climates, but in all those lands where rainfall is scarce, any loss of water can be crucial for the success of a crop.

Nutrients are also lost with the eroding soil. As with organic matter, these nutrients are more readily available in the topsoil. Different nutrients have different water solubilities and this could lead to differential losses of nutrients with water erosion.

The foregoing discussion indicates that there is a wide range of effects of soil erosion on soil properties. The properties just discussed are all important factors determining the productivity of the land.

One would expect that serious impairment of these soil properties would result in a loss of productivity. Indeed, if the properties of topsoil and subsoils are markedly different, it could be anticipated that the loss of productivity would be proportionally greater than the rate of erosion. The following section checks this proposition against literature evidence.

III.3.2. Soil erosion impact on productivity

Odell (1950) surveyed maize production in two prairie soils (Tama silt loam and Swygert silt loam) for two years. Approximately 250 data sets were obtained with information on soil depth, phosphorus and lime applications, crop rotation, and maize yields. Regression analysis of the data yielded several interesting conclusions. Tama soil produced more maize (4.5 t ha^{-1} yr^{-1}) than Swygert soil (3.3 t ha^{-1} yr^{-1}), because it had a more friable and permeable subsoil. For each centimeter of Tama soil missing, about 30 kg ha^{-1} yr^{-1} less maize was harvested. In Swygert each cm of soil loss resulted in a loss of 67 kg ha^{-1} of grain. There were no significantly consistent effects of fertilization upon this general relationship. On the other hand, topsoil depth had a relatively smaller effect on yields during the dry year, when yields were only 71 per cent those of the moist year. However, this effect was only important in Swygert soil (25 kg ha^{-1} yr^{-1} less grain per cm of topsoil loss).

Engelstad et al (1961) laid out fertilizer trials on differentially eroded sites of two Mollisols, Marshal and Monona silt loams (minimal Brunizens, permeable, derived from loess) cultivated with maize. The authors found it difficult to measure topsoil depth visually and used the content of organic carbon (C) as a surrogate of soil thickness. Two years of data were analysed through multiple regression techniques. A dry spell in one year produced contrasting results. During the normal year, N applications of 112 kg ha^{-1} yr^{-1} completely overrode differences in maize yields over the full range of C contents of the topsoil. Lack of N fertilization, however, showed that yields in soils with low C contents were only 82 per cent of topsoils with high C contents. During the dry year, both fertilized and non-fertilized plots with low C contents yielded approximately 8.7 per cent of the plots with high C contents.

These results did show the restorative potential of fertilizers on eroded soils, but they also highlighted the differential responses that can be expected during climatically adverse years. It should also be pointed out that the levels of maize yields in these experiments were high, i.e., between 6 and 8 t ha^{-1} yr^{-1}.

More recently, two similar studies have been conducted on soils of the southeast region of the U.S.. Langdale et al (1979) studied a watershed containing principally Cecil sandy loam (a Typic Hapludult). Sites with topsoil depths ranging from 10 to 60 cm were cultivated for three years with maize at constant rates of NPK (140/24/125 kg ha^{-1} yr^{-1}). Average maize yields for the whole experiment increased asymptotically with topsoil depth from 1.0 t ha^{-1} yr^{-1} at 10 cm depth to 6 t ha^{-1} yr^{-1} at 60 cm. This generally non-linear relationship, however, is almost linear for soil depth between 10 and 40 cm, which the authors considered to be the maximum natural topsoil depth without deposition. Within this range, the average reduction in maize yield per cm of topsoil loss was 150 kg ha^{-1} yr^{-1}/cm. In the dry year, the same ratio was 172 kg ha^{-1} yr^{-1}/cm. Abundant fertilization did not compensate for yield losses due to erosion.

Frye et al (1982) reported on another study in the U.S. Southeast where two Alfisols (Typic Paleudalfs) were tested. These authors classified plots as eroded, moderately eroded and uneroded on the basis of the clay content of the topmost 7.5 cm of these soils. Various rates of N fertilizers and several winter plant cover treatments were tried in one soil. Different fertilizers, to obtain laboratory predicted yields of 9.4 t ha^{-1} yr^{-1}, were used in eroded and uneroded plots of the other soil. Three years average yields in the latter experiment showed that, regardless of the sophisticated fertilization scheme used, yields in eroded plots were 21 per cent lower than in uneroded plots (7.9 t ha^{-1} yr^{-1}). Average yields for eroded and uneroded plots in the former experiment were significantly different, and only twelve per cent lower in the eroded sites. The N fertilization never fully compensated moderate past erosion; differences between eroded and uneroded plots were reduced from thirteen per cent to three per cent when 100 kg ha^{-1} of N were supplied together with winter stalk residue, but in the other four winter management options, differences remained or even increased after N fertilization. Unfortunately, the amount of soil loss was not precisely measured in this otherwise very complete study.

As said before, only a few studies could be located in this search which included actual measurement of soil loss and crop yields. Lamb <u>et al</u> (1950) studied erosion plots located on four soils in the Northeastern U.S.. Some plots were in fallow soil, some on soil with small grain crops for a period of 5-10 years. After enough differential erosion was produced, maize was cultivated for a couple of years. Manure, and/or NPK was uniformily provided to all plots. Honeoye gravelly silt loam yielded an average of 4.1 t ha^{-1} yr^{-1} of grain in the slightly eroded (i.e., 5 cm) plots. This is a decrease of 186 kg ha^{-1}

yr^{-1} of grain per cm of soil loss.

A deep Lordstrom laggy silt loam lost from almost nothing up to 2.6 cm of soil depth and yielded between 4.9 and 1.6 t ha^{-1} yr^{-1}, respectively, with a decline in maize yield of 1.27 t ha^{-1} yr^{-1} per cm of soil loss! A plot that had supported unfertilized continuous maize for ten years lost approximately 0.9 cm, while another in a ten years rotation of maize-oat-clover lost 0.15 cm of soil depth. Average maize yields for the next 2 years of cultivation with fertilizers were 1.6 and 2.5 t ha^{-1} yr^{-1}, respectively, or, again, approximately 1.2 t ha^{-1} yr^{-1} decline in maize yield per cm of topsoil loss.

In the same study, Ontario sandy loam under fallow for ten years lost 3.8 cm of topsoil and yielded 3.2 t ha^{-1} yr^{-1} of maize. When sodded, Ontario sandy loam lost almost nothing in those 10 years and yielded 6.1 t ha^{-1} yr^{-1}. This is a maize yield decline of 600 kg ha^{-1} yr^{-1} per cm of topsoil loss.

Finally, Durham silty clay loam lost 0.6 cm of topsoil in 10 years of a rotation with vegetables and later yielded 5.2 t ha^{-1} yr^{-1} of maize. Under fallow, previous soil losses amounted to 6.6 cm and yields of maize were 3.4 t ha^{-1} yr^{-1}, or 300 kg ha^{-1} yr^{-1} less per cm of soil loss.

Lamb et al (1950) offered little additional discussion for such a gigantic experimental enterprise. It is clear, however, that the ratios of productivity decline caused by soil loss are impressive and varying with soil type. Although no data on the interaction between soils and fertilizer was provided, it seems also clear that reasonable amounts of fertilizers did not compensate for the losses due to erosion.

A similar long range study still going on in Canada seems to refute all the previous findings (Ketcheson and Webber, 1978). Erosion plots on Guelph loam (Typic Hapludalf) have been monitored from 1953 to present, under a variety of crop rotation and soil conservation practices. Between 1953 and 1962 (i.e., Ketcheson and Webber, 1978, table 1) plots which lost a total of 1.25 cm of topsoil yielded 4.1 t ha^{-1} yr^{-1} of maize. Plots which lost a total of 0.12 cm of topsoil yielded 4.5 t ha^{-1} yr^{-1} of maize. This is equivalent to a 355 kg ha^{-1} yr^{-1} decline in maize yield per cm of topsoil loss.

Between 1971 and 1976 (i.e., Ketcheson and Webber, 1978, table 2), a variety of manures, plant residues, and tillage practices were tried. All plots received 168 kg ha^{-1} yr^{-1} of N, and P and K according to their needs. A control plot (unplowed, unmanured, with residues removed) lost a total of 1.2 cm of topsoil and yielded an average of 2.8 t ha^{-1} yr^{-1} of maize. Manured plots lost 1.4 cm and yielded 3.6 t ha^{-1} yr^{-1}. Manured and plowed plots lost 2.2 cm and yielded 4.8 t ha^{-1} yr^{-1}. Plowed plots with manure and plant residues lost 1.4 cm and yielded 4.6 t ha^{-1} yr^{-1}. Finally, unplowed plots with manure and abundant plant residue lost only 0.06 cm and yielded 4.4 t ha^{-1} yr^{-1}. Obviously, the effects of erosion on productivity were overcome through careful soil management, for the most eroded plot had the better yield.

Just recently, Ketcheson and Stonehouse (1983) reported that maize yields in 1981-1982 stood at a flat 6 t ha^{-1} yr^{-1} over a range of 4.1 cm of topsoil loss, which was obtained through twenty-seven years of experimentation.

Three brief observations can be made about this study: a) the rates of measured erosion are probably normal in Guelph, but they are low when compared with other studies reviewed here; b) Guelph loam must be an extremely good soil; and c) soil, plant, and fertility management, although not reported in detail, appears to have been extremely sophisticated.

Fayette silt loam is apparently a good soil also. Hays et al (1948) tried a similar experiment on this soil. Six years of erosion measurements revealed a loss of 16 cm of topsoil under fallow and continous maize, and 2.5 cm with a rotation of small grain crops. Manure was applied uniformly to all plots, but lime, P, and K were supplied according to plot needs (although the authors suggested that applications to the more eroded plots were on the average twelve per cent greater). Consequently, maize was cultivated in rotation and nine years of maize yield data were obtained. The average yield for the severe and moderately eroded plots was 4.9 t ha^{-1} yr^{-1}, which works to 67 kg ha^{-1} yr^{-1} of maize yield decline per cm of topsoil loss. However, the authors pointed out that by the end of the experiment, the yields of both plots were much alike, implying that the soils could be reclaimed through careful management.

Another method employed to study the effects of erosion on land productivity is to simulate erosion by cuts, i.e., by physically removing chunks of topsoil. This method has helped to speed up research in this area because it is simple, and because it allows experimental control of the amount of erosion.

Recently, Langdale and Shrader (1982) summarized most of these studies for the U.S.. Table III.1 includes these authors' compilation of data plus some others here found for tropical soils. All experiments reported in table III.1 included fertilization to remove potential deficiencies from the erosion treatment. A rough classification of these data into "good" i.e., deep, temperate soils and "poor", i.e., shallow and/or tropical soils shows an interesting contrast in the responses of maize yields to erosion. Topsoil removal in the "good" soils resulted in maize yield reductions from between 10 and 30 per cent. Topsoil removal in the "poor" soils resulted in greater maize yields reductions, from 30 to 70 per cent.

The evidence reviewed in this section indicates that the impact of soil erosion on maize productivity is a function of the quality of soil and land management practices: the poorer the soil, the greater the impact; the better the management, the less maize yields will suffer from erosion.

III.4. Soil Fertility Depletion through Continuous Cultivation

Section II.2 stated that milpa agriculture has been the traditional system of maize cultivation in the tropics of Mexico. It has been long recognized that a critical factor for the survival of this shifting cultivation system is the availability of land to rotate fields with second growth vegetation (Cook, 1921). Figure 2.1b showed that the area

Table III.1 Estimated maize yield reduction in topsoil removal experiments

Soil Type (Classification)	% Yield Decrease	Original Reference
Deep, Medium, Temperate Soils		
Memphis silt loam, (Typic Hapludalf)	9	(Buntley & Bell 1976)
Marshal silt loam, (Typic Hapludoll)	13-17	(Engelstad et al. 1961)
Beadle silt clay loam, (Typic Argiustoll)	17	(Olson, 1977)
Gardena sandy loam, (Pachic Udic Haploboroll)	19	(Carlson et al. 1961)
Ida silt loam, (Typic Udorthent)	8-30	(Spomer et al. 1973)
Grenada silt loam, (Glossic Fragiudalf)	26	(Buntley & Bell 1976)
Shallow, Medium to Coarse, Tropical Soils		
Durian Malaysia, (Alluvium)	27	(Siew and Fatt, 1976)
Groseclose clay loam, (Typic Hapludult)	36	(Batchelder & Jones, 1972)
Cecil sandy clay, (Typic Hapludult)	40	(Langdale et al. 1979)
Egbeda silt clay loam, (Typic Paleustalf)	41	(Lal, 1976)
Brandon silt loam, (Typic Hapludult)	44	(Buntley et al. 1976)
Sedang Malaysia (Colluvium)	70	(Huat, 1974)

Source: adapted from Langdale and Shrader (1982)

dedicated to maize in Mexico has not grown during the last twenty years. This suggests that milpa agriculture must be giving place to a more continuous form of maize cultivation.

Watters (1971) dedicated a chapter to shifting cultivation in Mexico and included a special section on milpa agriculture in Veracruz. This author reported that the young volcanic soils near San Andres Tuxtla might not need fallowing if plowing and/or fertilizers are used from time to time. Maize yields declined only after long periods of continuous cropping. However, nearby Latosols had more problems in sustaining continuous cultivation with maize.

The latter soils were cultivated with maize for about four to five years and then abandoned for two to three years. Declining soil fertility, i.e., "the soil was tired", was the common explanation provided by local peasants as the reason for abandoning their fields. As proof, Watters (1971) cited results from fertilizer trials which indicated that nitrogen and phosphorus had a significant effect in raising the productivity of the maize fields.

A significant response of maize to nitrogen and phosphorus has been more recently confirmed for the state of Veracruz as a whole (Ceballos Piedra, 1980), as well as for the Xalapa region in particular (Marten and Sancholuz, 1981; Aguilar Acuña, 1981).

Describing milpa agriculture in the peninsula of Yucatan, Watters (1971) referred to the Rendzina soils characteristic of that region of Mexico. He stated that these calcareous soils might have a higher fertility level than previously believed, but also that yields of maize declined with time of cultivation unless the fields were fallowed and burnt, or applications of nitrogen and potassium were made.

Sanchez (1977, Ch.3) reviewed a number of studies on forest-soil nutrient cycles in Central America and the Caribbean. Second growth forests accumulated nutrients and biomass at a faster rate than crops in the same soil. Most nutrients were retained within the living parts of the forest, and only small fractions of these nutrients were stored in the soil. Although litter production and decomposition was high, the nutrients released through this mechanism were rapidly taken up by the roots of the fast growing vegetation. The burning of these forests during shifting cultivation practices produced several effects on soil properties. A high amount of bases was released from the ashes. These bases raised the soil pH and this contributed to neutralizing the soils' reaction which is typically acidic. While organic matter and nitrogen were easily volatilized during burning, losses were conspicuous only on the topmost surface of the soil. Phosphorus concentrations have been shown to increase in the soil after burning.

Stark (1978) considered that the crucial factor in tropical shifting cultivation is the management of fire. If fires are carefully planned, an equilibrium between nutrient losses and nutrient additions can be obtained. This wise use of fire, the author concluded, could lead to good crop production and sound land use. But local people should know about this, for they have used fire for a very long time.

The question remains: What if there is not enough land to keep this otherwise efficient milpa system alive? Answers to this question are not simple, but a number of experts have provided some responses.

Agboola and Fayemi (1972) and Arnason et al (1982) proposed careful selection of crop rotations and plant species to rebuild soil fertility in continuously cultivated fields. They recommended the study of legumes and P-concentrating species which could supply tropical soils with badly needed nitrogen and phosphorus.

In a rather different vein, Blevins et al (1977) and Aina (1979) recomended minimum tillage practices, not only to protect the soil's physical properties but also to build up the organic matter, and thus the nutrient supplying capacity of tropical soils.

Finally, Sanchez et al (1982) proposed the intensification of agriculture in the best soils of the tropics to release pressure from the marginal lands. They reached this conclusion from successful experiments that significantly raised crop productivity. These experiments included high dosages of fertilizer and lime, improved crop varieties planted in different rotations, good rainfall or irrigation, and flat, deep, and well aggregated tropical soils. The authors properly cautioned their readers that to achieve similar results elsewhere, not only must the biophysical constraints be removed, but a proper economic and institutional environment needs to be created to promote the adoption of these agricultural innovations among small farmers.

III.5. Summary

Land degradation has been defined as the result of soil erosion and soil fertility depletion. The mechanics of both these processes have been reviewed. Continuously cultivated tropical soils are subjected to high risks of soil erosion and to soil fertility stresses.

Literature data suggest that soil losses on maize fields in the tropics could range from 10 to 20 t ha^{-1} yr^{-1}. In Mexico, a few studies conducted on gently sloping sites in the cool-temperate climatic zone measured much smaller soil losses.

The effects of erosion on maize productivity have been studied mainly in the U.S.. Topsoil removal experiments in deep temperate soils indicate that yields could decline from 9 to 30 per cent. Topsoil removal in shallow tropical soils produced maize yield declines from between 30 and 70 per cent. A few complete studies conducted under excellent soil and management conditions suggest that careful soil fertility management can compensate for the decline in maize yield brought about by erosion.

Soil fertility depletion is a pervasive factor in the tropics. Few studies have documented the magnitude of the crop losses incurred through continuous cultivation, but it is generally accepted that tropical soils cannot sustain crop productivity indefinitely, unless intensive land management practices are adopted, or the land is reverted to fallow from time to time.

CHAPTER IV: ENVIRONMENTAL FRAMEWORK FOR A CASE STUDY IN CENTRAL VERACRUZ

IV.1. Introduction

Chapter II examined the agricultural production system under study: the Mexican maize field. Chapter III surveyed the key question of this thesis: how serious is the threat of land degradation in those fields? It is the task of the present chapter to show which experimental conditions were chosen for field tests and how.

The possible combinations of ecological and managerial factors of maize production in Mexico are so numerous that only a case study could tackle the problem in a reasonable and productive way. The Xalapa region, in the center of the State of Veracruz, is a small ecological model of Mexico. This region includes examples of most of the climatic, vegetational and edaphic conditions of the country. Maize is no exception and it grows there from the coast to the mountains in a 4000 m altitude range that starts in the tropical lowlands and culminates in the arid highlands. Familiarity with this area and its maize fields made this author think that there he could find the range of biophysical conditions required to test the contentions of this study.

The next step was to further select, within the Xalapa region, a subset of conditions on which field experiments could be run. Throughout this area, maize is grown for subsistence purposes using traditional techniques and tools. Therefore, management was considered to be uniform.

Climate, particularly rainfall, is crucial in determining land productivity. Maize production in the region has been shown to be extremely sensitive to water stress (Marten and Sancholuz, 1981). Rainfall is characteristically unpredictable. Therefore it could not be anticipated when planning the field experiments. However, sites with different average rainfall and maize growing seasons are considered in the selection described below.

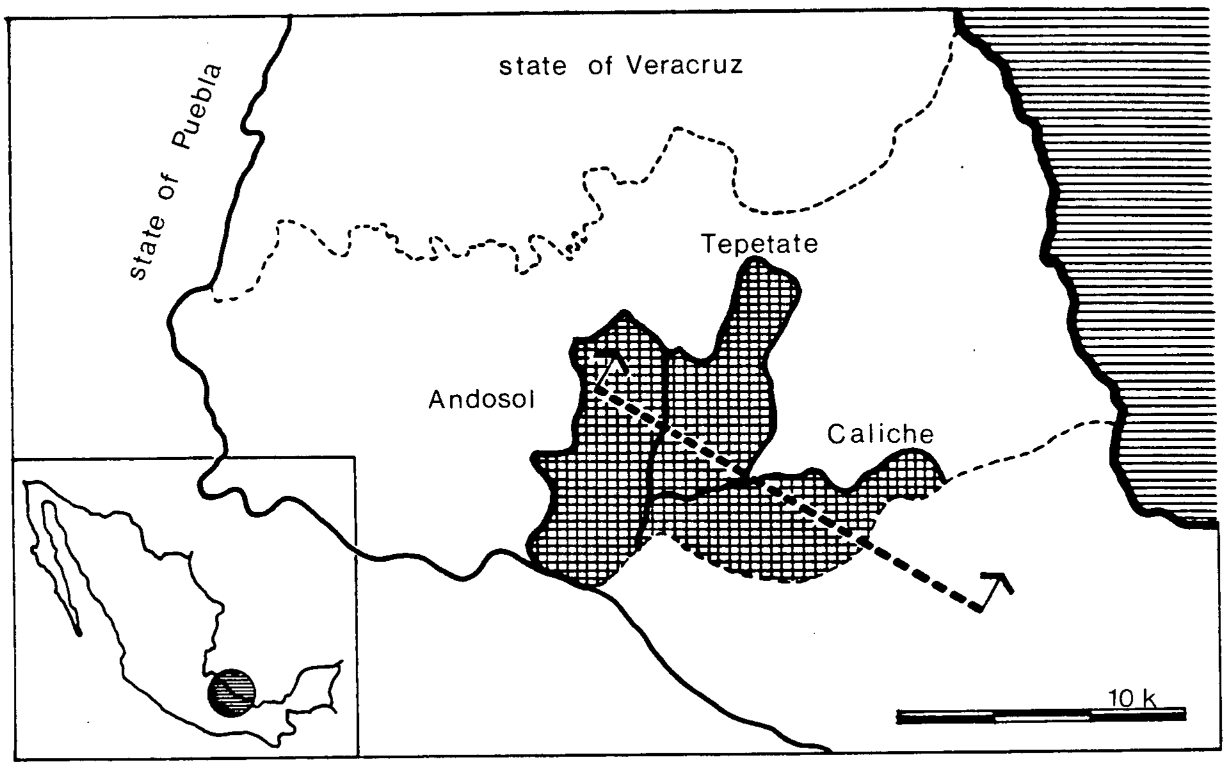
Having set aside management and climate as experimental parameters, logically the variable to study was soils. Soil depth is a primary factor in determining the volume of soil that is available for plant growth. Deep soils store proportionally greater amounts of nutrients and water. Moreover, deep soils allow better rooting and easier cultivation than shallow soils. Therefore, three soils, covering a range of deep, medium, and shallow profiles, were chosen to include a range of inherent land productivities.

IV.2. Geographical Location

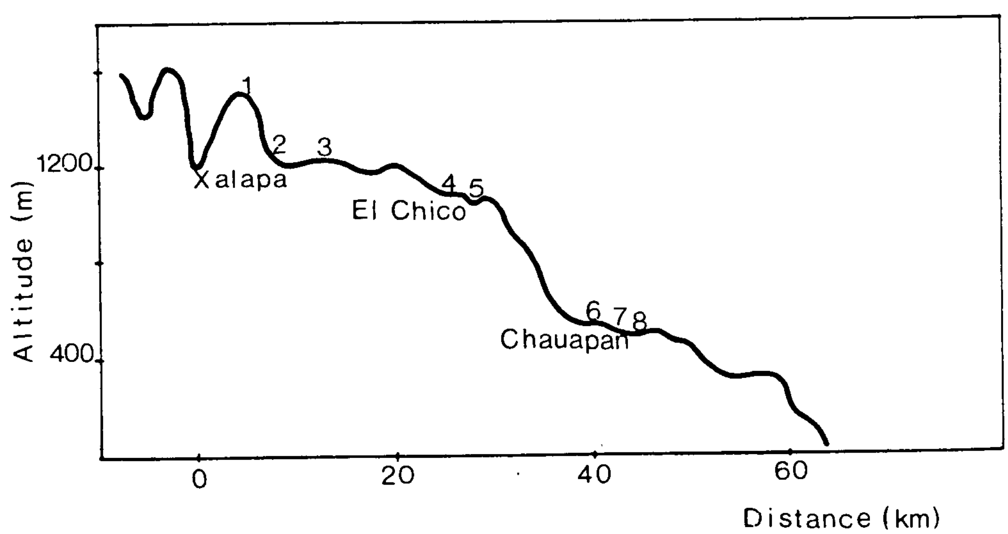
The State of Veracruz lies between the oriental mountain range (Sierra Madre Oriental) and the Gulf of Mexico (see fig.4.1a). It extends from 17° to 22° latitude North. Among the mountains to the west of the State is the highest peak in Mexico (Citlaltepetl, 5747 m). On the eastern side of this longitudinally elongated state lie, almost uninterrupted, the

Figure 4.1. Location of the study areas. 4.1a, map with the Xalapa region in central Veracruz; 4.1b, idealized profile correspond to arrows in fig. 4.1a. Curves numbers are sites of Appendix 2.

(a)


state of Veracruz
state of Puebla
Tepetate
Andosol
Caliche
10 k

(b)


1
2
3
1200
Xalapa
4
5
El Chico
6
7
8
Chauapan
400
Altitude (m)
0
20
40
60
Distance (km)

tropical lowlands of Mexico.

Because of these great latitudinal and altitudinal variations, the state of Veracruz is probably the most ecologically diverse of all the Mexican states. Garcia (1970) has identified more than 12 different climatic types in the Koppen classification system. Mean annual temperatures range from more than 26 °C to less than 2°C; rainfall from less than 800 mm to more than 4000 mm. The soils of the state of Veracruz, although poorly studied, include the following orders of the FAO-UNESCO system: Latosols, Vertisols, Andosols, Planosols, Mollisols, and Luvisols (SARH,1972). There are twenty-two great types of vegetation, from tropical rain forests, in the southern lowlands, to tundra-like grasslands, in the highest mountain peaks (Gomez Pompa, 1973).

Agriculture is also diverse. More than seventy plant crops, as varied as wheat and mangoes, compete for the use of the land with cattle and forestry operations (Marten and Sancholuz,1977). Maize, however, is the most common crop in Veracruz, and, as shown in Chapter II, this state occupies second place in the total national production of maize.

Figure 4.1a shows the location of this study. A land use survey of central Veracruz found there most of the agricultural, vegetational, edaphic, and climatic variants of the state of Veracruz (Marten and Sancholuz, 1982). Fifty-six land use systems and thirty three land types were described on the basis of climate, soils and land forms. During 1977, the same study surveyed more than 300 maize fields (Marten and Sancholuz, 1981). These studies, in central Veracruz, provided a framework from which to select more detailed sites for the present study.

IV.3. Soils

The soils to be discussed here were chosen as contrasting examples of the variety of soils in the center of Veracruz. They include: a) deep loam Andosols in the hills surrounding the city of Xalapa; b) shallow sandy loam Tepetates (a common name in Mexico meaning soils with an underlying hardpan) in the rolling landscape of El Chico-Miradores; and c) medium depth stoney, clayey Caliches (rendzinas) on the gently undulating old marine terraces around Carrizal and Chauapan.

The spatial variation of soils is a well known process, particularly when relief and climate vary abruptly. All the three soils of this study can be found within 40 km, but almost 1000 m of altitude separates the Andosols from the Caliches. Within this 40 km, the climate ranges from humid warm temperate to subhumid tropical.

Given the environmental variation of this rather small area, it was decided to study a total of eight soil profiles, to include not only the main soil types but the principal variants as well.

Figure 4.1b shows the relative position of the eight soil sites in the regional landscape. Sites 2, 4 and 7 are the modal sites for the Andosol, Tepetate and Caliche respectively. Sites 1,5,6, and 8 are topographical variants within these soils, while site 3 represents a climatic transition between the

Andosols and the Tepetates.

Soil profiles of all eight sites were described in the field. Detailed laboratory analyses were conducted on samples of the modal sites and fewer analyses were performed on samples from the variants (sites 1,3,5,6, and 8). The methods of analysis and the tabulated results are included in Appendix 2.

The following pages discuss the principal physical and chemical properties of the three soil types. The non-specialist reader will find in these pages sufficient information about the soils of this study.

IV.3.1. Andosols

The hills around the city of Xalapa have characteristically deep brown soils with red-yellow subsoils. They sit on huge deposits of volcanic ash and cinders of contrasting white color, which are geologically recent (Pleistocene). This underlying white material is actually sand which, as evidenced by a number of active quarries in the area, is used for construction purposes. Looking at the exposures of these excavations, one can see, from top to bottom, a brown layer 20-80 cm deep, followed by 1.5 to 2 m of yellow-red earth, and 30 to 50 m of white sand.

The topmost 2 m of this mega-profile are the Andosols discussed in this thesis. Abundant rain, warm temperatures, luxurious vegetation, and the soft white rock have combined to produce a considerable amount of soil in a relatively short period of time.

The landscape is made of hills and volcanoes. The landforms on which the Andosols are formed include hill slopes, hill tops and hill bottoms and cover about 20 per cent of the land area in central Veracruz (Table IV.1). Topography is rough: an average slope measures close to 30 per cent inclination.

Table IV.1. Extension, altitude, and slopes of the soils in this study.

Soil Type	Area (ha)	Altitude (m)	Weighed Avge. slope (%)
Andosols	88800	1250-1600	29.9
Tepetates	21200	800-1200	8.7
Caliches	25200	300-600	3.8

Total area Xalapa region (central Veracruz) =475,000ha.
Source: Marten & Sancholuz (1981, table IV).

The profiles of the Andosols characteristically include a topmost dark brown organic layer. This varies in depth according to topography and past land use, but ranges from 30 to 80 cm. Sites 1 and 2 (see Appendix 2, profile descriptions) show these extremes quite well. Below this rich humus layer, the soil turns to a yellow-red color. This layer is much more structured, compacted, and less inhabited by roots and fauna alike. There are minute oxide concretions, but no stones or gravel. This second layer can go as deep as 2.0 m , but as it goes further down it becomes much more compacted and there are no signs of plant roots reaching these depths. There is a distinct boundary between the weathered material and the parent material which, being white, sharply contrasts with the subsoils above it.

Another common characteristic of these soils is the almost complete absence of coarse fragments throughout the profile. Surface textures are invariable coarser than those of the subsoils. Local peasants call the eroded sites "barro" (mud), and the uneroded ones "tierra de grano" (granular earth). Particle size analysis of these soils may be difficult to interpret (Sanchez, 1976). Standard textural determinations without previous removal of $Fe2O3$ yield considerably higher sand contents and much less clay than determinations made after the removal of oxides. As noted on the profile descriptions of the soils, iron oxides concretions are a common feature and they could account for the coarser textures occurring when they are present.

As shown in Appendix 2, these soils have very low bulk densities (0.7-0.9 g cm^{-3}) throughout the profile. Most probably, this is due to the presence of allophane, which is known to give volcanic soils a characteristic lightness. The high organic matter content in the topsoils certainly adds to this lightness, but alone it cannot explain the consistently low bulk densities of the subsoils, where organic matter is much decreased. On a weight basis, water contents at 1/3 bar pressure are high, and while they are, as expected, lower at 15 bar, the difference is not great.

The Andosols are definitely acidic soils. The pH ranges from 5 to 5.7 throughout the profile and across sites. Organic matter varies from 10 per cent in the surface to 1 per cent at 1m depth. Phosphorus is in short supply, and this is so regardless of the method of extraction. Acidity may be responsible for the fixation of phosphorus in these soils, but the high concentrations of iron and aluminium oxide could also be closely linked to this notorious deficiency. Total nitrogen content is relatively high and follows a decreasing pattern with depth as shown by organic matter. Base saturation is about 20 per cent, which indicates a low cation exchange capacity and probable nutritional deficiencies in these soils.

IV.3.2. Tepetates

A few kilometers east of Xalapa, the hilly landscape becomes gentler. Altitude drops slowly but steadily, and the moist and warm weather changes into a drier and hotter one. It is a rolling landscape, dissected only by deep canyons carrying the excess water from the mountains into the sea. The mesas between the canyons have characteristic soils, the Tepetates.

These soils are much shallower (40-70cm) and paler in color than the Andosols. The underlying rocks are still of volcanic origin, but instead of forming piles of ashes they have hardened into thick layers of impermeable rocks (Tepetates, proper). Curiously, another use has been found for this material, as witnessed by a number of artificial lagoons resulting from the excavations of nearby brick factories.

The natural vegetation is also indicative of changes: it is scrub dominated by species of oak and interrupted by patches of grassland. Less water, warmer temperatures, and a sparse vegetation are responsible for the meagerness of the Tepetate soils.

In this rolling landscape, ravines are steep (10-25 per cent inclination), but the soils there benefit from alluvial deposits which make them deeper and richer in nutrients. It is worth noting that mainly coffee is grown in the ravines, while grasslands and maize fields are found on the crests. Patches of bare rock on these crests are an outstanding feature of the landscape. Local people recall having parts of their fields washed away by heavy rainstorms. This will be discussed later, but it takes little imagination to see that a shallow soil, sitting on hard rock, can easily become saturated with water and slide down the slope, even on gentle slopes.

The profiles of the Tepetate soils include a thin brown organic layer. This ranges from 5 to 25 cm in depth and it is well represented by sites 4 and 5 (Appendix 2). The organic matter content of this horizon is 3-4 per cent. Below the relatively dark topsoil there is either a red-yellow or a pale brown horizon with less organic matter and finer textures. It is not unusual to find gray mottles and iron concretions. Somewhere between 30 to 40 cm, the soil becomes much harder and compacted, and it gives little indication of life in the form of roots or fauna. Finally, at 40-50cm the soil has become a soft rock which hardens further down the profile to become the Tepetate.

The topsoils of the Tepetates are sandier and lighter than the subsoils. Bulk densities increase with depth and so does the clay content. Moisture retention tests show very little water between 1/3 and 15 bar pressures. Infiltration is definitely impeded at the bottom of the soil as shown by the abundant mottling; it practically stops at the duripan and eventually forms a perched water table when rains are abundant. Given these physical properties, the Tepetates are not good agricultural soils.

The Tepetates exhibit chemical limitations as well. Acid conditions are still prevalent. Organic carbon is at the limit of adequacy. Nitrogen also seems to be in short supply. Phosphorus probably gets fixed by the high contents of iron oxides and the acidic medium. Base saturation is not too bad, possibly because the bases cannot be leached into the hardpan. However, cation exchange capacities are the lowest for the three groups of soils studied. Again, the storage of nutrients and the capacity to transfer them are limiting factors in the Tepetates.

IV.3.3. Caliches

Continuing the descent to the seashore from Xalapa, one passes from the hills to a landscape characterized by a series of relatively flat marine deposits. The rocks are limestones dating back to the Pliocene age. The climate shows marked seasonal changes, with rainfall concentrated into 5-6 months of the year. Temperatures are always high.

The natural vegetation is a low deciduous tropical forest. The soils have changed dramatically. They are now black, clayey, and spotted with white fragments of the limestone underneath.

The landscape is gently undulating. The relatively higher places in the toposequence are clearly distinguished by the surface stoniness; these sites are called Caliches proper. The lower sites have deeper soils, less stones, and are locally differentiated from the former as "barros" (mud). Slopes are gentle, with a 3-10 per cent inclination. Maize fields are found everywhere but land is also used for grasslands and papaya.

The profiles of these Caliche soils have a characteristic color sequence with depth: black; gray; white. The strong black color of the topsoils partially responds to organic matter concentrations, but it is also known that calcareous materials combined with organic carbon enhance the darkness of these soils. The gray color and the mottling of the subsoils are indicative of poor internal drainage.

These soils are definitely fine textured and stick when wet. When carbonates are removed for soil particle analysis (see Appendix 2, Site 7), the amount of clay is 60 to 70 per cent of the fine earth fraction. This actually corresponds to a heavy clay textural class. However, organic matter and coarse particles help in creating a better tilth in the surface horizons.

Gravel and stones are common throughout the profile, particularly in the most eroded sites. Total soil depth ranges from 35 to 60 cm, which could be clearly distinguished by the sharp color change on contact with the limestone. Soil structure is strong in blocks and prisms. Also characteristic are vertical cracks which disappear when the soil is moist. Bulk densities are relatively low (0.8 to 1.0 g/cm^3) given the fine texture of these soils.

Water retention is the highest among the 3 groups of soils studied here. At field capacity these Caliches can accumulate between 60 and 70 per cent of their weight in water. Water content at the permanent wilting point is still a considerable 40 per cent of fine earth weight. Thus, the amount of water available to plants is quite high in these soils, a fact that is of great importance in a subhumid environment.

The Caliches have alkaline reaction; pH ranges from 7.5 to 8.0. Calcium dominates the other cations in the exchange complex. The exchange capacity is high and base saturation is close to 100 per cent. There should be no fertility problems, other than a slight P fixation and N deficiencies in the shallower sites. On average, total N is intermediate between the Andosols and the Tepetates previously discussed.

IV.4. Climate

Some characteristics of the climate of the study area have been mentioned when discussing soils. There is an intimate correlation between soil types and climate in this study, but, this section will further discuss those climatic parameters which affect maize growth: growing seasons, rainfall patterns, and temperature regimes.

IV.4.1. Growing season

The growing season for maize in Mexico is either controlled by low temperatures or by the pattern of rainfall throughout the year (Galvan Lopez and Delgado Hernandez, 1977). Early and late frosts, and/or the quantity of thermal units, are determinant factors in controlling maize development in the temperate zones of Mexico. Conversely, maize in the tropical and subtropical lands of Mexico is affected by the distribution of rain. The study area includes both types of climatic controls of maize growth.

In the vicinity of Xalapa (humid warm temperate), temperature rather than rainfall is the critical factor in determining the calendar for maize. Table IV.2 shows that these humid-warm-temperate zones experience frosts at the rate of 20 days a year, mostly in February. Lower mean annual temperatures and evaporation would indicate that there is less radiant energy available for crops to use. Accordingly, local varieties of maize take 7 to 9 month to fully mature, from February-March to

Table IV.2. Climatic parameters of study area

Climate Type	Mean Temperature (°C)	Mean Annual Rainfall (mm)	Rainfall variability (CV%)	Tank Evaporation (mm)	Frost (#days /year)
Humid Warm[1] Temperate	18.7	1638	13.8	1146	22.5
Subhumid[2] Subtropical	20.7	1082	21.4	1313	?
Subhumid[3] Tropical	24.6	872	17.4	1736	0

Source: 15 year averages from nearby meteorological stations: [1] Xalapa-Coatepec, [2] Rancho Viejo-Miradores, [3] Carrizal-Rinconada.

September-October.

In the next climatic zone to be considered, the subhumid subtropical shown in Table IV.2, the climate is warmer and drier. Although records of frosts were not available for this zone, they are locally known to be less important--and also immaterial because little rain falls there until May, when frosts are rare. Higher temperatures and evaporation rates indicate higher levels of radiant energy which are correlated with a shorter growing season. Typically, maize in this climate matures within 5-6 months, from April-May to September.

Finally, the subhumid tropical zone has no frosts on record whatsoever (Table IV.2). High temperatures will allow year round cultivation of maize in this zone, but rainfall is much scarcer which seriously limits maize growth to 4-5 months, from

May-June to September. If irrigation were available, this zone could accomodate two crops a year and even 3 with fast growing hybrids (Marten and Sancholuz, 1982).

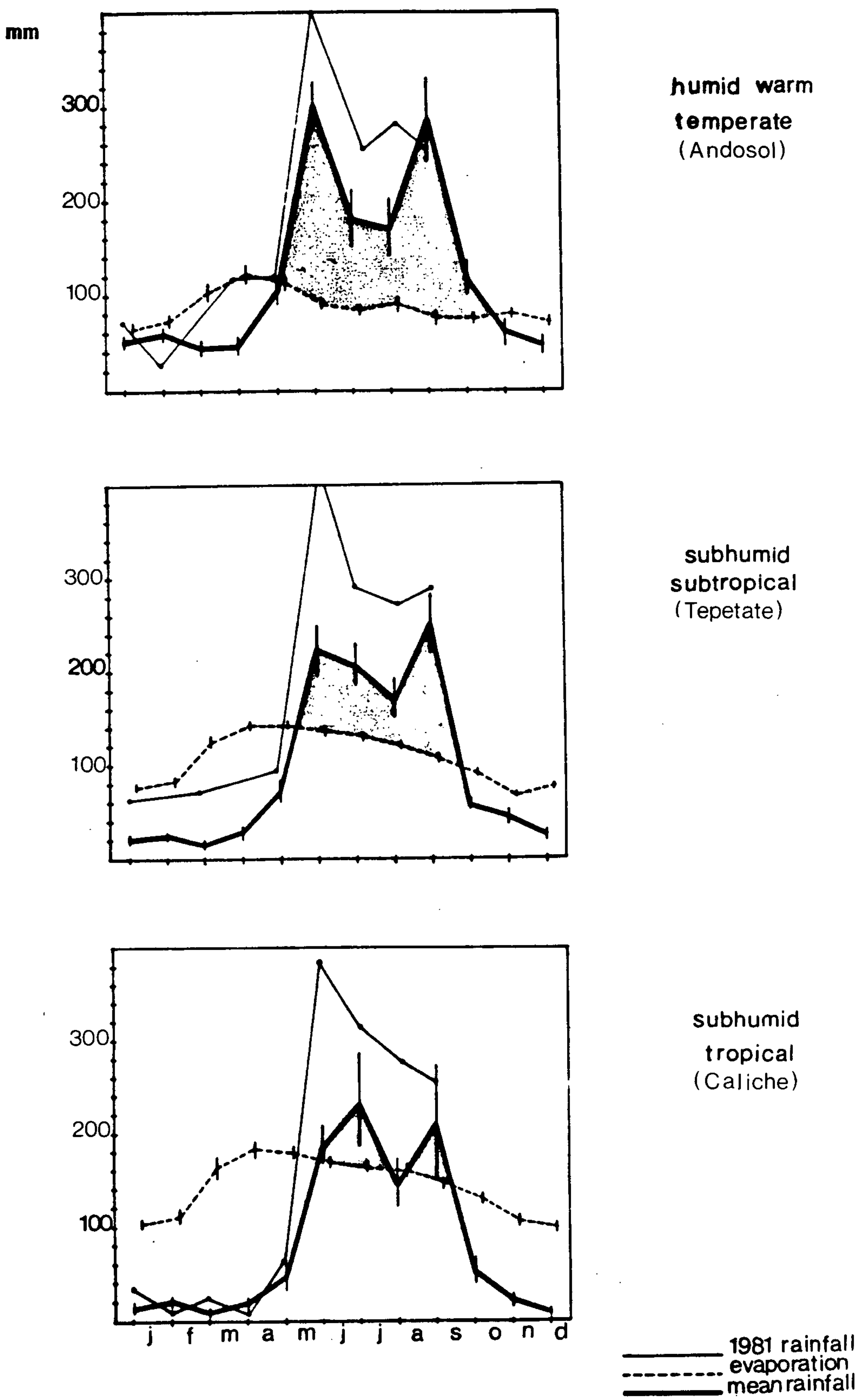
IV.4.2. Rainfall patterns

The three climatic zones under discussion correspond with the three soil types described before (Section IV.3). Figure 4.3 includes typical climodiagrams for these three soil-climate zones. The annual patterns of rainfall and evaporation further clarify the differences in growing season for these zones. In all cases there is a clear rainy season during the summer. However, when rainfall is compared with evaporation rates the differences among the three zones are much clearer.

Roughly speaking, the monthly difference between rainfall precipitation and evaporation is the amount of water that can be stored in the soils for later use by plants. The shaded areas of Fig.4.2a-c indicate this atmospheric surplus water. Clearly, both the number of months with water surpluses and their magnitude change from zone to zone. On the average, for the temperate, subtropical, and tropical zones, there are 5 months with a total of 60 cm of surplus water, 4 months with 35 cm of surplus water, and 3 months with 12 cm of surplus water, respectively.

Year to year variations, particularly of rainfall, is another important consideration for estimating water supply in these zones; this seems to be inversely correlated with the amount of rainfall (see bars in fig.4.2). Thus, it is not only a question

Figure 4.2. Climodiagrams for the three soil-climate zones. Meteorological Stations: 4.1a Andosol: Xalapa; 4.1b Tepetate: Rancho Viejo; 4.1c Caliche: Carrizal. Data are 20 year averages. Bars are Standard errors. Shaded areas indicate atmospheric surplus of water.


mm
300
200
100
humid warm
temperate
(Andosol)
300
200
100
subhumid
subtropical
(Tepetate)
300
200
100
subhumid
tropical
(Caliche)
j f m a m j j a s o n d
1981 rainfall
evaporation
mean rainfall

of how much it rains in these zones, but also of how reliable these rains are. When both factors are combined it will appear that the subhumid subtropical zone is a worse environment for maize production than the humid warm temperate zone. However, it must not be forgotten that the varieties of maize change from zone to zone, that they develop much faster in warmer climates, and that real water balances must include not only the atmospheric supply but the soil's capacities to store water as well.

IV.5. Maize Field Management

This section describes the management of maize fields that is characteristic of the area of study. In the previous section, mention was made of the differences in maize growing seasons of the three soil-climate zones selected for this study. These differences do affect the choice of seeds and the number of cultivations that the fields receive in these zones. Otherwise, the tools, the methods, and the handling of the crops are the same. What follows is a simplified model of maize field management, common to all zones, but with notations of the slight differences among them.

IV.5.1. Cultivation

Machetes, hoes, planting sticks, Egyptian plows, and oxen are the basic tools used in the maize fields. One rarely sees tractors, electric pumps, or trucks. Cropping energy is mostly human and animal. Obviously, a peasant using these methods can only cultivate small areas. Typically, the fields range from less than a hectare to 15 or 20 ha, while average field size is about 2 ha.

Table IV.3 Calendar of cropping activities

Activity	Andosol (Xalapa)	Tepetate (El Chico)	Caliche (Chauapan)
Cleaning the field	January	Early April	April
Plowing	February	Early April	May
Rows and seeding + Fertilization	Late Feb./ Early March	Late April/ May	Late May
First Cultivation + Fertilization	Mid April	June	June
Second Cultivation (Fertilization)	Mid May	July	July
Doubling and Cleaning	September	August	August
Harvesting	October	September	September

Table IV.3 gives the calendar of activities for each site. The land is prepared for cultivation with hoes or plows, depending on the availability of oxen as traction for the latter. This operation takes place after harvest, or 1 to 3 months before planting. The soil is then plowed 10 to 20 cm deep, depending on the hardness and stoniness of the soil. If plows are used these open rows just before planting the field. Planting is almost always achieved with the help of a planting stick which makes holes 5 to 10 cm deep in the soil. Two to four seeds are dropped in each hole, approximately 90 cm apart, in each row. Row spacing is variable between 70 and 90 cm. Fertilizers, if used, are buried in a circle around the seeds.

The fields are cultivated two or three times during the growing season, depending on the length of the season. Fields of the warm temperate zone usually get three weedings, while the subtropical and tropical fields get only two. The first cultivation can be performed with plows, but even this is rare. In general, cultivation with hoes is the norm. This operation affects the soil very superficially, usually the topmost 2 to 4 cm are softened to remove weeds. It is also spatially concentrated to the immediate surroundings of the maize hills--machetes chop weeds in the inter-row areas of the field. It is also typical to create earth mounds around the hills during the last cultivation (atierra), the purpose being to prevent lodging of the plants.

When the earcones are fully developed, usually a month before harvesting, the plants are folded over the node just below the earcone (doblada). In this way, maize dries out in the field and is ready for storage after harvesting, while predation by birds as well as rusting are prevented by the inversion of the earcone tip. At the time of doblada, the undergrowing vegetation is chopped with machetes to facilitate harvesting. Forage from leaves and plant tips is also collected at this point for domestic animals to feed upon.

IV.5.2. Plant breeds

Maize seeds are predominantly local varieties known as creole maize (*Zea mays* L. var. Cónico and Tuxpeño; Wellhausen *et al*, 1952). Only the subhumid tropics are known to have adopted hybrid and improved maize varieties (Tuxpeñito, H503, H507). However, these improved seeds are risky given the unreliability of rains and the patchiness of fertility in rainfed fields. Only when these seeds are provided almost free of charge do the peasants utilize them in their fields. For instance, in 1981, Tuxpeñito varieties were distributed among peasants in Chauapan. Curiously, about a third of the fields were sown to this little known variety. That year it rained extensively in Chauapan. Tuxpeñito did well only in those fields whose fertility status was high (i.e., the bottoms of the landscape), or that were well fertilized. Creole varieties did much better on the tops of hills (the crests or stoney sites).

Seed selection is mostly a craftsmanlike activity carried on by the peasants every year. They select their best earcones from each harvest and save the seeds for the next year. Seeds can also be obtained in the local storehouses which carry a surplus of seeds from year to year.

Other plant species are usually intercropped with maize. Black beans (*Phaseolus vulgaris*, *Phaseolus spp*) are the most common. These vines are sown alternatively with the maize in the hills at low densities. They grow under the maize canopy until the doblada of the maize plants; after that the beans flourish and mature rapidly. Usually yields of beans range from between 200 and 700 kg/ha, depending on seeding densities, fertility and care. Squash are also commonly found in the floor of the maize field; these yield only domestic rations, but help to balance the diet of the peasant family. It is not either uncommon to see fruit trees intercropped in a maize field: oranges, bananas, avocadoes, mangoes are the most important of these.

IV.5.3. Harvest

The harvest of maize is done by hand. It is a highly social task which involves, for a few days, to most members of the community. Stalks and plant residues are left behind until plowing opens a new cultivating season in the following spring. But, weeds, tender residues, and grasses are commonly consumed by domestic animals in the fall.

IV.5.4. Maize yields

Maize yields range from less than 1 t ha^{-1} yr^{-1} to more than 4 t ha^{-1} yr^{-1}, the latter being specially high. Overall, mean yields are known to be about 1.5 t ha^{-1} yr^{-1} (SARH,1979).

Mean maize yields for the three sites of this study were assessed with two different and indirect sources of data, as

Table IV.4 Maize yield estimates (t ha^{-1} yr^{-1}) for the soils of this study

Soil type	Source of data	
	COTECOCA[1]	Field survey[2]
Andosol	2.05	1.87
Tepetate	1.20	1.15
Caliche	1.76	1.55

[1] Mean grassland productivity, COTECOCA (1979);
[2] Projected average grain yield, Marten and Sancholuz (1981)

Table IV.4 indicates. One of these sources (COTECOCA, 1979) provides estimates of grassland productivity for the study area. Phytosociological analysis and extensive surveying of producers in the field have been used to assess forage production and consequently livestock carrying capacity. Annual grass biomass production data are provided for different site qualities and grassland management options.

The other source in Table IV.4 is the previously mentioned survey of maize fields in the Xalapa region (Marten and Sancholuz, 1981). Mean maize yields for the three soil types under consideration are extrapolations from 1977 data. Because maize productivity and potential evapotranspiration are strongly correlated, yield predictions for an average year are possible.

Table IV.4 shows that, on the average, the Andosols should yield better than the Caliches, and these even better than the Tepetates. The two estimates differ from one another, but not by much; although both are coarse, they are the only regional estimates of mean maize productivity for the three soils under study.

IV.6. An Evaluation of Soil Erosion Risks for the Test Sites

What are the risks of erosion for the three soil types included in this study?

The following assesment is based on the Universal Soil Loss Equation (USLE) of the USDA (Wischmeier and Smith, 1978). The USLE is an emprically derived formula which predicts average annual soil losses ($t\ ha^{-1}\ yr^{-1}$) from a field. It is based on a number of biophysical factors which are known to affect the rate of erosion. These factors are: R, rainfall erosivity; LS, angle and length of the slope; K, soil erodibility; C, crop management; and P, conservation or erosion control practices.

The following four subsections discuss, one at a time, the calculations of these parameters for the three main soils of this study. Section IV.6.5 discusses the resulting soil loss estimates.

IV.6.1. Rainfall erosivity, R

In estimating the erosivity of rain, this study follows the method proposed for maximum 6-hour rainfall data (Wischmeier, 1974, p. 183). EI30, the standard rainfall erosivity index, and

KE>1, a variant developed for the tropics (Hudson, 1971) both rely on data on intensity and duration of rainfall, data which are not published in Mexico (CP, 1977, p. 33).

The meteorological stations of the area of study have published 24-hour rainfall data for the last twenty years. In order to use Wischmeier's 6-hour approximation, an assumption has to be made on the equivalence of 24 and 6 hour rainfall events. Marten and Sancholuz (1982) have proposed that in the Xalapa region this is a reasonable assumption, for most of the rains of a year fall during the summer in a few concentrated storms (see Fig.4.2). On this basis, Marten and Sancholuz (1982, Table I) estimated R for the climatic zones considered in this study. Expressed in metric units, these R estimates range from 471 t ha^{-1} yr^{-1} in the area of the Andosols to 850 t ha^{-1} yr^{-1} in the area of the Caliches (see Table IV.9).

IV.6.2. Soil erodibilities, K

Wischmeier and Smith (1978, pp. 8-11) proposed that four properties determine the inherent erodibilities of soils. These are: soil particle-size distribution, organic matter, soil structure, and soil permeability. Operationally, these soil properties are defined in the following manner: m, the per cent of very fine sand (0.1-.05mm) plus silt (0.05-.002mm) in the soil particle-size distribution ; a, the soil's percent organic matter; b, the soil structure class(USDA); and c, the soil permeability class(USDA). K is obtained either through a non-linear equation in which m multiplied by (100-%Clay) is raised to the 1.14 power, or through a nomograph solution.

Table IV.5 USLE-Soil erodibility parameters and K (metric) values for the topmost 30 cm of three soils of this study.

Soil Type	Parameters[1]					Erodibility
	m	%S	a	b	c	K
Andosol[2]	51	17	10	2	2	0.22
Tepetate[2]	33	29	2	4	5	0.32
Caliche[2]	9	20	3	3	4	0.14

[1] m: %Silt+VFSand; %S: % Sand; a:% OM; b: Soil structure class; c: Soil permeability class.
[2] Calculated from surface horizons of sites #2, 4, and 7, Appendix 1.

Table IV.5 reports the intermediate calculations and the final K values for the three soils to a depth of 30 cm. The estimates of these parameters are based on the data for sites 2,4, and 7 of Appendix 2.

IV.6.3. Slope effect, LS

The two key components of this topographic parameter are slope angle and slope length. Another dimension to this parameter can be provided by the shape of the slope.

To evaluate these components, a special field survey was designed. Aerial photographs covering the whole area (scale, 1:50,000) were screened for representative sequences of the landscape. Five 500 m long transects were selected to study in the field. At every 25 m on these transects, the shape and angle (measured with a pocket clinometer) were recorded. Slope lengths were later obtained as the difference between the beginning and end of each slope segment.

Table IV.6 shows the resulting data for the three soils studied. The Tepetate soils showed significantly gentler average slopes than the other two soils. The Andosols have the steeper slopes while the Caliches have slightly more tilted slopes than the Tepetates.

There does not seem to be much difference in the shape of the slopes of all three soils. The dummy averages in Table IV.6 indicate that Tepetates and Caliches tend to have convex slopes while the Andosols are quite uniform. The Tepetates showed significantly shorter slope lengths than the other two soils. The Andosol slopes are slightly shorter than the Caliche's, but this difference is insignificant.

These estimates can now be used to evaluate the LS factor in the USLE. The calculation will assume an ideal field with slope propertiers as depicted in Table IV.6. For practical reasons, the slopes of these three soils are considered uniform. The calculation is now straigthforward. Using the USLE metric nomograph (Wischmeier and Smith, 1978, fig 11), yields the LS values reported in table IV.6. As can be readily seen there, LS is to a great extent a function of slope angle for these soils.

Table IV.6. Slope characteristics of the soils of this study and USLE-LS (metric) values.

Soil Type	Slope Characteristics[1]			LS
	length(m)	angle(%)	shape[2]	
Andosol	118.8 (15.0)	22.3 (1.4)	1.99	8.8
Tepetate	72.5 (8.6)	7.5 (0.5)	2.11	1.4
Caliche	138.6 (16.0)	4.5 (0.5)	2.31	0.9

[1] Figures in brackets are Standard Errors.
[2] Values coded as: 1=concave, 2=uniform, 3=convex.

The difference in LS between the Andosol and the other two soils is much greater than the differences in slopes because LS is an exponential function of the angle of the slope.

IV.6.4. Crop management, C

Several aspects of the vegetative cover of the land affect soil erosion. These can be grouped into inter and intra-annual variation of plant cover. From year to year, crops and natural vegetation can replace one another in a field. For long-term predictions, this succession of crops matters because each crop or vegetation produces a different canopy which, in turn, differently protects the soil from the impacting rainfall and the abrading runoff. To assess these effects the rotation of crops of a field has to be known, and properly defined.

The rotations of the maize fields for this study were

Table IV.7. History of land use in the maize fields of the 3 soils of this study

	Years with	
Soil	Maize	Agriculture
Andosol	13.6 (1.7)	20.3 (2.2) [1]
Tepetate	8.3 (1.9)	11.3 (2.1)
Caliche	8.0 (2.1)	38.8 (6.1)

[1] Figures in brackets are Standard Errors.

estimated from interviews with local cultivators conducted in 1977 (Marten and Sancholuz, 1981). Table IV.7 contains a summary of this data. These reveal that, on the average, the maize fields have been continuously cultivated with maize for between 8 and 13 years. It is interesting to note that, on the average, Tepetates are the less frequently used of all three soils (i.e., for only 11 years) which would suggest that these soils may be less sustaining than the other two.

The number of years in any other agricultural use varied from 11 to 39. Prior to that, most fields had been resting in second growth vegetation (Acahual). No information could be obtained on the sequence of crops for the years preceding the last cycle of continuous maize. However, with the exception of the Caliches, which are known to support papayas for two to four years in a row, most of these fields turn to another crop only for one or two years. In conclusion, most of these fields are cultivated continuously to maize, with brief periods of alternate crops or Acahual.

Another effect of vegetative cover on erosion arises from the seasonal variation of plant cover. As the crop matures, more and more plant cover develops. The crop development schedule must be related to the seasonal distribution of the erosive rains, for it is the coincidence, or lack of it, between periods of erosive rains and poor plant cover, which matters the most.

To estimate the seasonal effects of a crop on soil erosion, first the monthly distribution of 24-hour rainfall was obtained for each climatological stations depicted in Fig. 4.2. Next the six cropstage periods called for in the USLE procedure (Wischmeier and Smith, 1978, pp 17-18) were defined as to field operations and plant cover development. Table IV.8 contains the percentage of R in each period for each soil together with the calculated C values.

The crop management factor also takes into account the method of cultivating the land. Tillage and plant residue management have a significant effect on the amount of erosion that a field would experience. The level of production of a field is also important because the more plant cover a field produces the less erosion it should undergo, provided these residues are returned to the soil. For the C-value calculations, local conditions appproached the following conditions described by Wischmeier and Smith (1978, table 5, line 12): moldboard plowing, plant residue removal or burrying, and low productivity. C-values among soil types do not differ very much, even though late planting in both

Table IV.8. USLE-cropstage periods and Crop-Management Factor (C) for the three soils of this study

Soil	%R in Cropstage period[1] F	P1	10%	50%	75%	H	C
Andosol	11	12	7	45	17	7	0.54
Tepetate	32	13	3	27	17	8	0.59
Caliche	42	6	3	27	18	4	0.58

[1] F: period in fallow; P1:Just plowed; 10-75: % plant cover development; H: Harvest.

the Tepetates and Caliches makes the fallow period very susceptible to erosion.

IV.6.5. Soil conservation practices, P

Marten and Sancholuz (1982) found no evidence of terracing or contour plowing in the maize fields of central Veracruz. Since soil conservation practices are not being used in this area, the P factor of the USLE will be assumed to be equal to 1.

IV.6.6. Soil loss estimates, A

Table IV.9 summarizes the values of all USLE-factors with the estimated annual soil losses for the three soils of this study; the latter vary between 62 and 492 t ha^{-1} yr^{-1}. These values are high in all cases, even when compared to the highest measured soil losses reported in Section III.2.2.

Table IV.9. USLE-factor values and estimated soil loss values under continuous maize cultivation for the 3 soils of this study

	USLE-Factors[1]				Annual Soil Loss	
Soil	R	LS	K	C	(t ha^{-1})	cm^2
Andosol	471	8.8	0.22	0.54	492	6.3
Tepetate	645	1.4	0.32	0.59	170	1.3
Caliche	850	0.9	0.14	0.58	62	0.7

[1] Factor P = 1 in all soils
[2] Adjusted with bulk densities, Appendix 2

One problem in these calculations is rainfall erosivity. R values reported in Table IV.9 are an approximation using maximum 24-hours rainfall data. However, the R values as such are similar to the ones reported from other tropical and subtropical zones, such as southeastern U.S. and Hawaii (Wischmeier and Smith, 1978).

Another limitation of these estimates is the K-values for the three soils. The Tepetate owes its relatively high K-factor value to low permeabilities and low organic matter content. In contrast, the Andosol has excellent physical properties and is high in organic matter content, but its high silt and very fine sand contents explain the intermediate K value reported in Table IV.9. The Caliche soil shows the lowest K value because this is a heavy-clay-textured soil with medium organic matter contents.

The values of the slope-length, LS, and the crop management factors for the soils of this study seem in line with other values reported for similar conditions (El-Swaify et al, 1982). The range of LS values across soils is of the same order of magnitude that the range of estimated soil losses, i.e., almost one order of magnitude in both cases (see table IV.9).

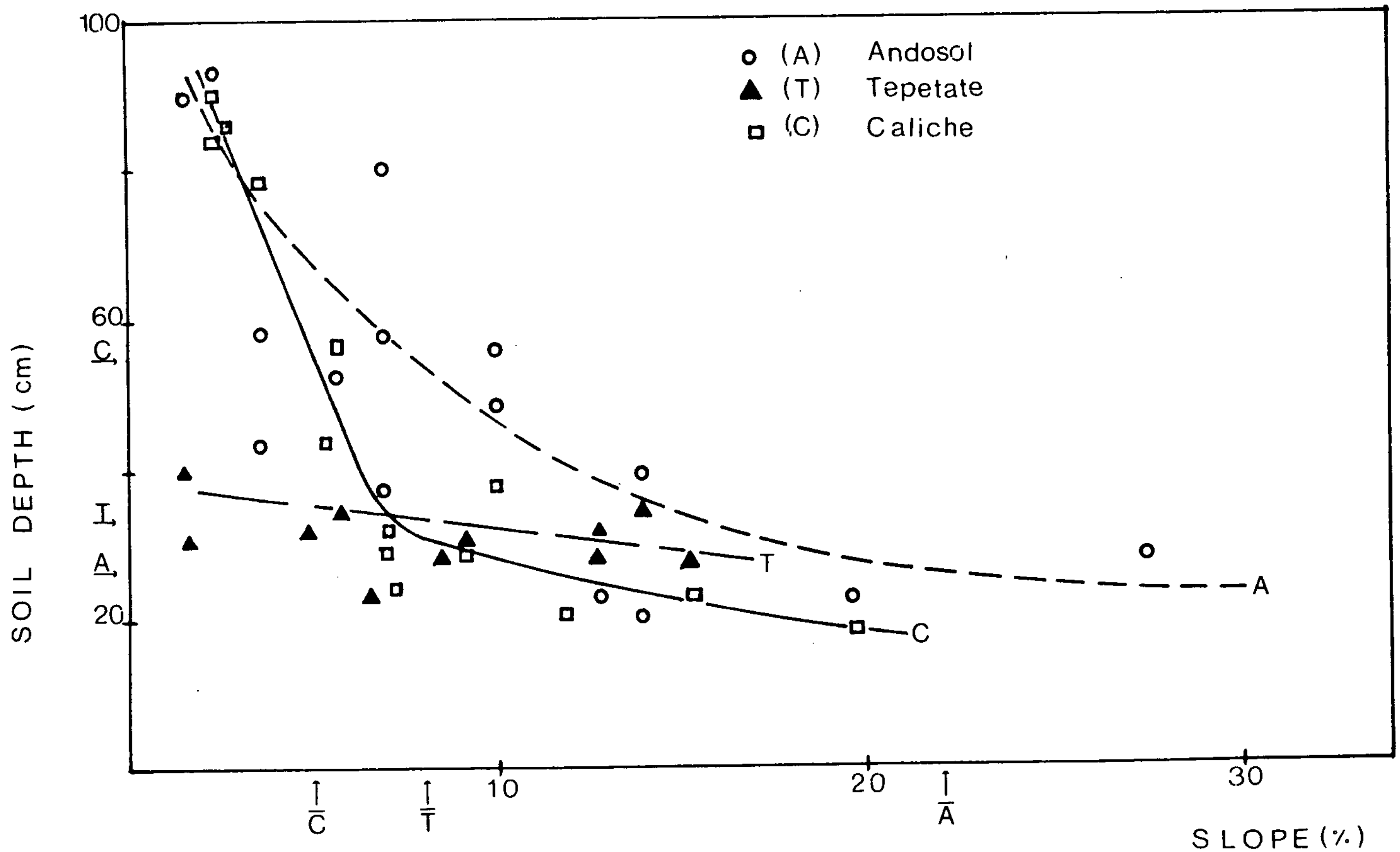
IV.7. A Field Test on Soil Losses

Is there a simple way of checking the accuracy of the preceeding soil loss estimates?

Figure 4.3 shows slope and topsoil depth data collected from more than ten maize fields in each of the three soils of this study. The deepest soil, the Andosol, showed the greatest range of values. Conversely, the Tepetate varied the least in topsoil depth and slope inclination. Depths in the Tepetate and the Caliche represent total soil depth because it was difficult to recognize soil horizons from auger samples of these soils.

It is tempting to attach meaning to these data. As a sample of maize fields in the area they could indicate past land use management, the natural variation of soil depth within each soil type, or else a strong inverse relationship between soil depth and slope angle. If only the latter proposition were true, we would have strong evidence of the long term effects of soil erosion on soil depth in the maize fields under study. Soil

Figure 4.3. Topsoil depth and slopes in the three soils of the study. Topsoil defined as: AB horizon in Andosols; duripan in Tepetates; and Limestone in Caliches. Each data point is an average of 3 measurements of slope (clinometer) and soil depth (auger) in maize fields. Curves are eye fitted .



SOIL DEPTH (cm)
100
60
20
C
T
A
o (A) Andosol
▲ (T) Tepetate
□ (C) Caliche
T
A
C
10
20
30
C
T
A
SLOPE (%)

depth follows a dramatic exponential decline with increasing slopes, both in the Andosol and the Caliche. In the Tepetate, the change in soil depth with slope is minor, only because there is not too much of a range in values.

Table IV.7 showed the number of years these soils have been in agriculture, in general, and cultivated to maize, in particular. It could be inferred from these data that both the Tepetate and the Andosol are cropped to maize 7 out of every 10 years. The Caliches seem to be less frequently cropped to maize, but, since other annual crops are used in these soils, it could be considered that, on the average, these soils are cultivated to annual crops 5 out of every 10 years. For those years in which the fields are resting as Acahual the C-USLE factor would approach 0.1 (see Wischmeier and Smith, 1978, Table 10).

Calculating a weighted average C value for the total number of years in agriculture for every soil results in the following: Andosol, 0.39; Tepetate, 0.46; Caliche, 0.34. Substituting these values for each soil in table IV.9 and multiplying for the total number of years under agriculture (i.e., from Table IV.7) gives the expected total soil losses for the average maize fields (see table IV.10).

The slope-depth curves for each soil in Fig.4.3 can be used to calculate observed soil depth losses. The difference in soil depth between sites with mean slopes and sites with the lowest slopes in each soil (see arrows in Fig.4.3) is an approximation of the observed average losses naturally experimented under average maize field management during the period described.

Table IV.10. Expected and observed soil losses for the three soils of this study.

Soil	Soil losses (cm) Expected[1]	Observed[2]	Difference[3] %
Andosol	91	68	+34
Tepetate	11	6	+83
Caliche	16	29	-45

[1] From table IV.9 for a full rotation as in table IV.7.
[2] From figure 4.3, Soil depth differences are between mean and minimum slope in each soil.
[3] Calculated as: 100x(E-O)/O.

Table IV.10 compares predicted and observed soil losses for the three soils of this study. Differences range from 34 to 83%. Expected soil losses for the Andosol and the Tepetate are greater than the observed soil losses. The contrary happens in the Caliche.

Something must be wrong, but where? There are too many built-in assumptions in the estimates presented in table IV.10 to attempt an explanation of the discrepancies. In relative terms, however, the observed values fall within the same order of magnitude of the expected values across soils. The steep slopes of the Andosol should explain the high losses, both expected and observed. The shorter rotation exemplified in the Tepetate probably explains the difference with the Caliche, which otherwise should be less erodible (i.e., see table IV.9).

Finally, it should be remembered that the soils studied here have different average soil depths. Under average management conditions, the Tepetates are the most shallow of all, and also the least erodible. The Andosols are the deepest of all, and also the most erodible. Thus, the impact of erosion on these soils must not only be a function of the rate of erosion, but of the initial depth of the soils as well.

IV.8. Summary

This chapter described the environmental setting for field tests. Soils, climate, and management parameters have been discussed. Three soil-based sites of study were chosen. They include a deep volcanic soil, a shallow hardpan soil, and a medium black clay. Maize in the area is cultivated almost continuously, and with traditional management techniques.

An application of the Universal Soil Loss Equation predicts high risks of erosion in these maize fields. These predictions are discussed with regard to literature and field data. While literature data would suggest that these rates are too high, field evidence on topsoil depths across the range of slopes of these soils indicates that the magnitude of the predicted soil losses is correct. Under average management conditions, soil losses will be much greater in the Andosol than in the other two soils, mostly because of its steep slopes.

CHAPTER V: AN EXPERIMENTAL APPROACH

V.1.Introduction

Crops, soils, climate and management, these all have an effect on land productivity. To assess the independent effect of soil erosion on land productivity may not be a simple task. Research in so complicated a problem must proceed cautiously: only a few factors can be varied at a time if experimental results are to be properly interpreted.

A brief analysis of the key variables for research will make that point clear. It has already been shown (Section 3.3) that soil erosion is a slow process which takes great care and effort to measure. An ideal experiment on soil erosion and land productivity should allow two plots in the same soil to erode differentially. After this is achieved, a crop can be tested to assess productivity in the two soils. With enough experimental facilities, perhaps several crops and/or managerial practices can be alternated to explore single effects and interaction terms. Only a handful of studies have followed this tedious but sound approach (i.e., recall Lamb et al, 1950; Ketcheson and Webber, 1978). These studies required between ten and twenty years to generate results for a few crops on a single soil.

Two alternative research strategies that have been more commonly used are: a) to survey sites with already different erosional histories and setting experiments or making observation on them; and b) to simulate erosion by mechanical means. Both these alternatives resolve the problem of waiting for the soil to erode by either a) a measurement of soil depth, or b) a cut to a standard depth. Still a choice has to be made about the crop-management-soil type combination to use, but the same treatment of erosion can be applied repeatedly.

For an indication of the potential number of experimental cells in one of these experiments (let alone replications), consider the following: 3 soil types x 2 crops x 3 levels of N fertilization x 3 levels of erosion = 56 treatments. When several soils have been included in one such experiment, pot experiments in the greenhouse have been used because of the obviously greater possibilities for increasing the number of experimental units.

Accordingly, in this Chapter two series of experiments are presented for the soils described in chapter IV. These experiments explore the simultaneous response of maize yields to soil erosion and fertilization. One series was run in the greenhouse; there, soils, levels of erosion and fertilization, and water regimes were studied. The other series was run in the field; there, only erosion and fertilization were studied on three soils. Section V.2 describes the greenhouse experiments and discusses the results. Section V.3 describes the field experiments and discusses the results. Section V.4 compares this experimental evidence with that reviewed in Chapter III.

V.2. Erosion and Productivity in the Greenhouse

The greenhouse experiments represent a compromise between accuracy and precision, statistically speaking. They attempt to mimic the real world and at the same time to gain insight into the various processes under study. Pots are seen here as miniature farms in which erosion, fertilization, and water management are all simulated to match the real world described in Chapter IV. With the selection of crop and cultivation practices, a model maize field is defined for study in the greenhouse.

Greenhouse experiments allow fine tuning of environmental parameters and rapid checks of experimental problems. They also permit the selection of many treatments and numerous replications, all of which enhance the scope of research and the precision of results. Two pot experiments were designed to test four hypotheses:

i) Maize yields are different for the different soils included in this study.

ii) Maize yields decrease with erosion, regardless of soil type.

iii) Fertilization tends to compensate the reduction of yields produced by erosion.

iv) Water stress reduces even more the yields in i, ii, and iii.

V.2.1. Materials and methods

Statistically speaking, the greenhouse experiments are compounded factorials in a completely randomized design (Hicks, 1973; Ch 8). The experiments are compounded because--using a basic lay-out--two sets of treatments were included: 1) a set with erosion and eight soils; 2) a set with erosion, fertilizers, water, and 3 soil types.

Experiment 1 can be modeled as follows:

$$Yijk = U + Si + ERj + SERij + Ek(ij) \quad (5.1)$$

where:

Y = biomass yield of maize (g/pot);
U = population mean;
Si = soil type, i=1,8;
ERj = erosion, j=1,3;
Ek = error, k=1,5.

This experiment is an 8 (soils) x 3 (erosion levels) completely randomized factorial with five replications per cell. Neither fertilizers nor water treatments were included in experiment 1. Equation 5.1 shows that this experiment contains only one first order interaction, i.e., soil type x erosion.

Experiment 2 includes soils, erosion, fertilization, and water regimes. The statistical model for experiment 2 can be written as follows:

$$Yijklm = U + Si + ERj + SERij + Fk + SFik + ERFjk + SERFijk + Wl + SWil + DWjl + FWkl + SERWijl + ERFWjkl + SFWikl + SERFWijkl + En(ijkl) \quad (5.2)$$

where:

Y = biomass yield of maize (g/pot);
U = population mean;
Si = soil type, i=1,3;
ERj = erosion, j=1,3;
Fk = fertilization, k=1,3;
Wl = water regime, l=1,2;
En = replications, n=1,5.

This second experiment is a 3 (soil type) x 3 (erosion levels) x 3 (fertilization levels) x 2 (water regimes) completely randomized factorial with five replications per cell. Equation 5.2 shows 6 first order interactions, 5 of second order, and 1 of third order.

All pots were laid out in a completely randomized design. Each pot received a number and was assigned a position in a grid marked on the greenhouse floor using a table of random numbers. As replication was the only random factor in these experiments, the fixed effects, ANOVA model type I applies to the ensuing data. Data were processed at the UBC Computer Centre. All analyses were performed with the variance-covariance program MFAV (Le, 1980).

V.2.1.1. Greenhouse facilities

A 10 x 10 m temporary greenhouse was built for these experiments in the Clavijero Botanical Garden in Xalapa, Veracruz, Mexico. This site is 1380 m above sea level and has a humid warm temperate climate (see Section IV.2). The greenhouse had a transparent plastic roof on a tilted, wooden structure. The four sides of the greenhouse were kept open to prevent overheating during hot summer days (Ritchey, 1973). The floor was covered with one inch of volcanic gravel. Pots were positioned on this gravel in a grid containing 345 points, each separated by 50 cm intervals.

Unlined clay pots were used in the experiments. The pots were obtained from a manufacturer of garden supplies in Xalapa, and had truncated cone shapes which measured: height, 18.4 cm; diameter at the top, 25.6 cm; diameter at the base, 15.5 cm; full volume, 6468 cm^3. Slight variations in pot weights were observed (i.e., 7.3 per cent variation around a mean weight of 3.08 kg), but since none of the other dimensions varied much, it was concluded that the difference was caused by pots' wall thicknesses. As pot weight was an important datum for monitoring watering and potting, all pots were weighed before the experiments began. Pot drainage was provided by a single hole (2.5 cm in diameter) at the center bottom of each pot.

V.2.1.2. Soils

All soils reported in Appendix 2 were represented in these experiments. Figure 4.1b shows the sampling sites for these soils. The Andosol has two variants, the Tepetate has one, and the Caliche two. One additional variant is transitional between the Andosols and the Tepetates. Variants were selected so as to include depositional and erosional phases of the three main soil types. As Tepetates were already so shallow, only one variant could be recognized.

The aim of these experiments was to study the impact of soil erosion on the pot maize yields of up to eight different soils. It was thus necessary to standardize the levels of the erosion treatment. For all soils, the topmost 30 cm of the profile were defined as controls or uneroded, the following 15-45 cm were defined as eroded, and the lower 30-60 cm of the profile were defined as severely eroded. Thus, erosion was produced by successively removing 15 cm-thick layers of soil.

These three levels of erosion were generated through a special sampling program. In each of the eight soil sites, a pit 1 m deep and 50 cm wide was opened. The topmost slice of soil (0-30 cm) was dug out first. The 15-45 cm layer was removed from the exposed wall left by the removal of the 0-30 cm slice, after the topmost 15 cm had been scraped away. The final slice, 30-60 cm, was shoveled from the pedestal left by the other two samples, i.e., from the bottom of the 0-30 cm cut. Care was taken to avoid contaminating these bulk samples with one another or with the spoils of the excavation. Approximately

250 kg of moist soil were needed from each layer in a soil type, and 50 kg in a variant. The material thus collected was put into properly labelled sacks and transported to the greenhouse.

Once there, the samples were spread over plastic sheets and air dried for 3 to 5 days. Final moisture contents in all sample varied between 6 and 9 %. Samples were raked for stones bigger than 2.5 cm. Soil crumbs were also crushed when larger than 2.5 cm. Big aggregates were eliminated because pot volumes were already too small, and plant roots would have been further impeded by big clasts and crumbs. Conversely, grinding beyond 0.5 cm was avoided because this would have caused too much disruption of the soils' aggregation characteristics.

When samples were dry, they were thoroughly mixed, and readied for potting. Preliminary tests showed a range of potting densities among soils. A soil volume of 5.5 l was used as the yardstick for potting. This volume left enough room in the pots for the soils to expand when wet and for water to be supplied with ease. Dry weight equivalents of this volume were worked out for every soil. This equivalent depends on the bulk density and packing density of the soil, both of which were ascertained in potting trials. Soil potting weights ranged from 4.45 kg in an Andosol to 4.87 kg in a Tepetate.

Just before potting, a 2.5 cm thick layer of fine volcanic gravel was laid on the bottom of each pot to facilitate drainage and aeration. The soils were then shaken into the pots with three strokes. When fertilizers were to be added, these were first mixed with the soil in a lidded can, and the mixture was potted afterwards. Two days before seeding, pots were placed on the greenhouse grid and saturated with water.

V.2.1.3. Fertilization

Experiment 2 tested three levels of nitrogen (N) and phosphorus (P): control, medium and high. These were designed to match, respectively, the non-existent, modest, and high fertilization levels reportedly used in the local maize fields (SARH, 1980). Lime was also supplied to the acidic soils. Pot fertilization rates were calculated on a surface basis and correspond with N/P field rates of 150/100 and 300/200 kg ha^{-1}, respectively. In fact, these rates are double those commonly used in the local maize fields, i.e., approximately 75/50 for medium and 150/100 for high. Pot rates were doubled in this experiment because it is known that fertilizers are approximately half as efficient in small pots as in the field (Terman and Mortvedt, 1978). The Andosols and the Tepetates were limed at a rate comparable to 4 t ha^{-1}.

Nitrogen sources were nitrate and ammonium sulfate. The former was supplied before planting in a formula (18-46-0) containing all the P as triple superphosphate. The ammonium sulfate was applied when plants were two weeks old. Lime was contained in a commercial mixture (Cal Agrícola, Guanomex) as hydroxide of calcium and sodium and calcium carbonate. In total, 0.531 g of N, 0.353 g of P, and 14.12 g of lime were given to each pot with low rate of fertilization. The high fertilization rate contained double the amount of N and P.

V.2.1.4. Watering procedure

The watering treatment required careful planning. A meaningful and practical water stress treatment was needed: meaningful, that is, with regard to the water holding properties of nine different soils. These, expressed as water held at field capacity (WFC), ranged from between 50 and 60 per cent in the clayey Caliches, to between 20 and 30 per cent in the sandy loam Tepetates. The highly organic Andosols fell in the middle of this range with between 30 and 50 per cent WHC. These water contents, soil by soil, correspond to the field capacity treatment. The water stress treatment was defined as 60 per cent of the water which each soil held at field capacity.

A practical water treatment was needed to assess the water levels of 345 pots during the experiment. To this end, two pots from each treatment were selected at random every other day, weighed, and their water contents assessed. The procedure worked well throughout most of the experiment. On very hot days, or when maize was growing very fast, the water contents were assessed every day, and extra water was added to those pots showing the greatest consumption. Tap water was used to irrigate the soil surface according to treatment needs. Leaking at the bottom of the pots was rarely observed. Leaking at the top did occur after some stormy winds damaged the plastic roof: dripping saturated some pots with water, which afterwards were carefully watched and adjusted to standards.

V.2.1.5. Seeds and cultivation methods

Seeds of creole maize (Zea mays L. var. conico) were used in all these experiments. These seeds were obtained from farm stores in Xalapa, Veracruz. There are no sources of certified seed in the area; these would have been preferred to reduce experimental error. Cónico variety is adapted to subtropical and warm temperate climates with particularly long growing seasons.

A test was conducted to determine the variability in germination of different selections of these seeds. Grains from the center of the earcone were sorted into groups of two different sizes, two colors, and scarification or no scarification of the embryonic apex. Results showed no significant difference among any of these groups (X^2: $P<0.05$) and, on average, 95 per cent of the seeds germinated. Consequently, the same selection procedure was followed to obtain enough seeds for the experiments.

Seeding took place on 28/7/81. Four seeds were planted 5 cm deep in the center of each pot. Germination was closely watched during the following week. By then most pots had produced at least three seedlings. The few pots in which germination failed were promptly reseeded. Two weeks after seeding, all pots were thinned to two plants each.

The height of the tallest plant in each pot was measured every week, from base to tip of up-stretched leaves.

V.2.1.6. Weed and pest control

Every week weeds were removed, although few were noticed. Pests were more problematic. Rabbits entered the greenhouse soon after maize had germinated. Seedlings in approximately 15 pots were damaged and these pots had to be subsequently reseeded. To prevent further attacks, a chicken wire fence was built around the greenhouse. During the experiment, two sprayings with Malathion were given to all pots to prevent insect attacks.

V.2.1.7. Harvesting procedures

Eight weeks after sowing date (11/9/81), all pots were harvested. The two plants of each pot were cut at the base, clipped into smaller pieces, and put into paper bags. All samples were dried on a herbarium plant dryer until they reached constant weight--about two days after harvest. The samples were then oven-dried at 80 ^{o}C, for a night. Next morning, plant weights were recorded to the nearest milligram. Therefore, in these experiments, yield means the oven dry weights of two plants of creole maize grown for six weeks in 5.5 l pots.

V.2.2. Results and discussion

Section V.2.3.1 presents the results of experiment 1, where eight soils were studied at three levels of erosion. Two hypotheses will be considered: i) yields differ among soils, and ii) yields are reduced through erosion. Section V.2.3.2

presents the results of experiment 2, where three soils, three levels of erosion, three levels of fertilization, and two water regimes were combined. The two hypotheses discussed are: iii) fertilization compensates yield losses due to erosion, and iv) water stress reduces yields in all circumstances.

V.2.2.1. Experiment 1, erosion effects on maize growth and yields

As Figure 5.1a shows, maize plant biomass is well correlated with plant heights (see also Marten and Sancholuz, 1981). It is thus possible to consider the heights plotted in Fig. 5.1b-g as surrogates of biomass production. In general, Fig.5.1 shows that maize growth rates decreased as the experiment progressed. The experiment was concluded after six weeks, because some plants in the poorest-yielding treatments were already dying off. Only maize grown on one or two soils showed typical growth curves, i.e., fig. 5.1h, and perhaps fig. 5.1b. Given the short period of time involved, this quasi-general trend of declining maize growth rates must be attributed to the limiting effects of small pot volumes. However, uneroded soils did better than the eroded ones in all cases. Differences in maize growth were greater by the end of the experiment.

Table V.1 shows the analysis of variance for this experiment. Maize yields were significantly different among soils and across erosion levels. Note also that the interaction between these two experimental factors was not significant, which means that soils' yields decreased in a similar fashion with erosion.

Figure 5.1. Maize growth patterns in experiment 1. 5.1a, correlation between maize plants heights and biomass. 5.1b-i, plant Growth patterns, plant heights are averages of 10 plants.

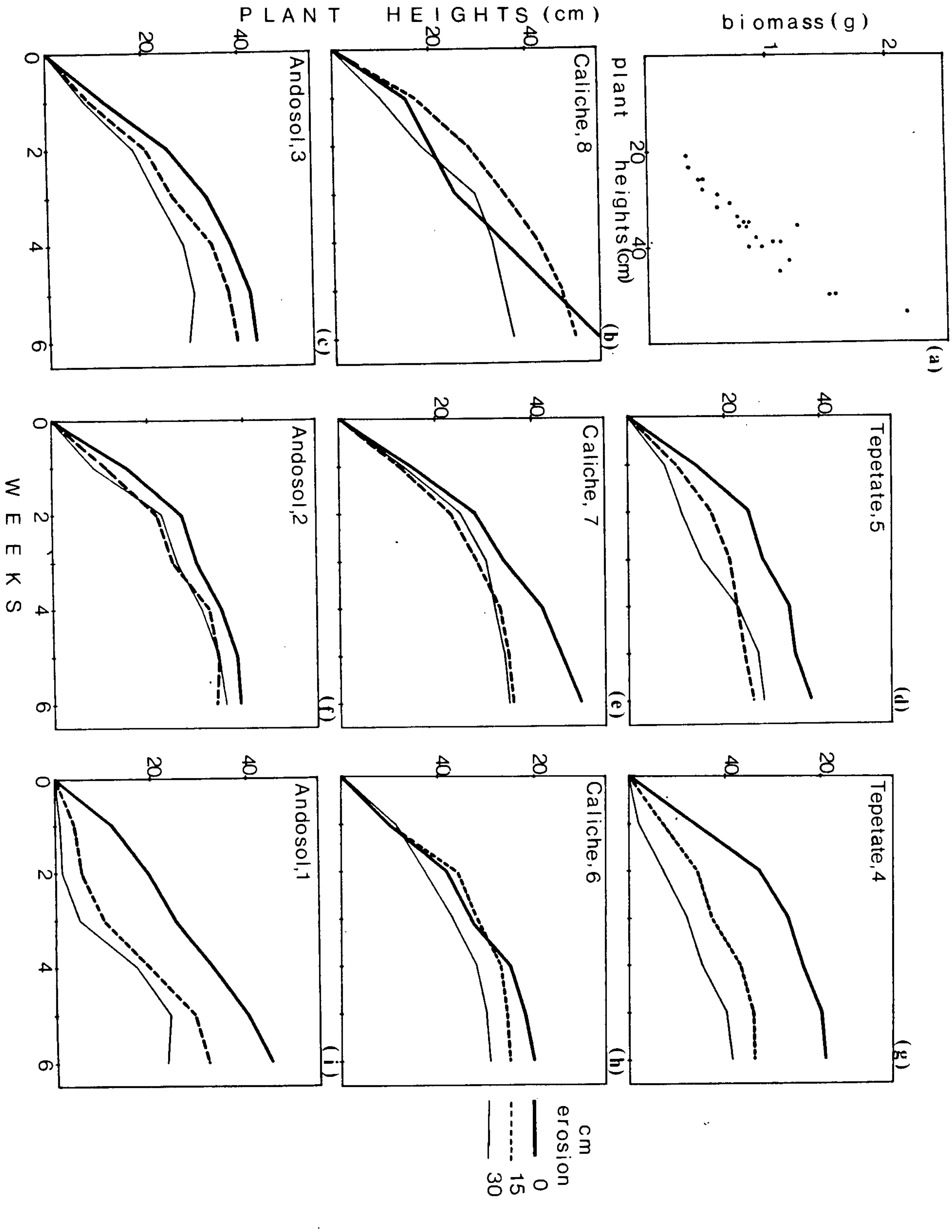

biomass (g)
plant heights (cm)
PLANT HEIGHTS (cm)
WEEKS
Tepetate, 5
Tepetate, 4
Caliche, 8
Caliche, 7
Caliche, 6
Andosol, 3
Andosol, 2
Andosol, 1
cm erosion
0
15
30
(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)

Table V.1. ANOVA for yields of experiment 1

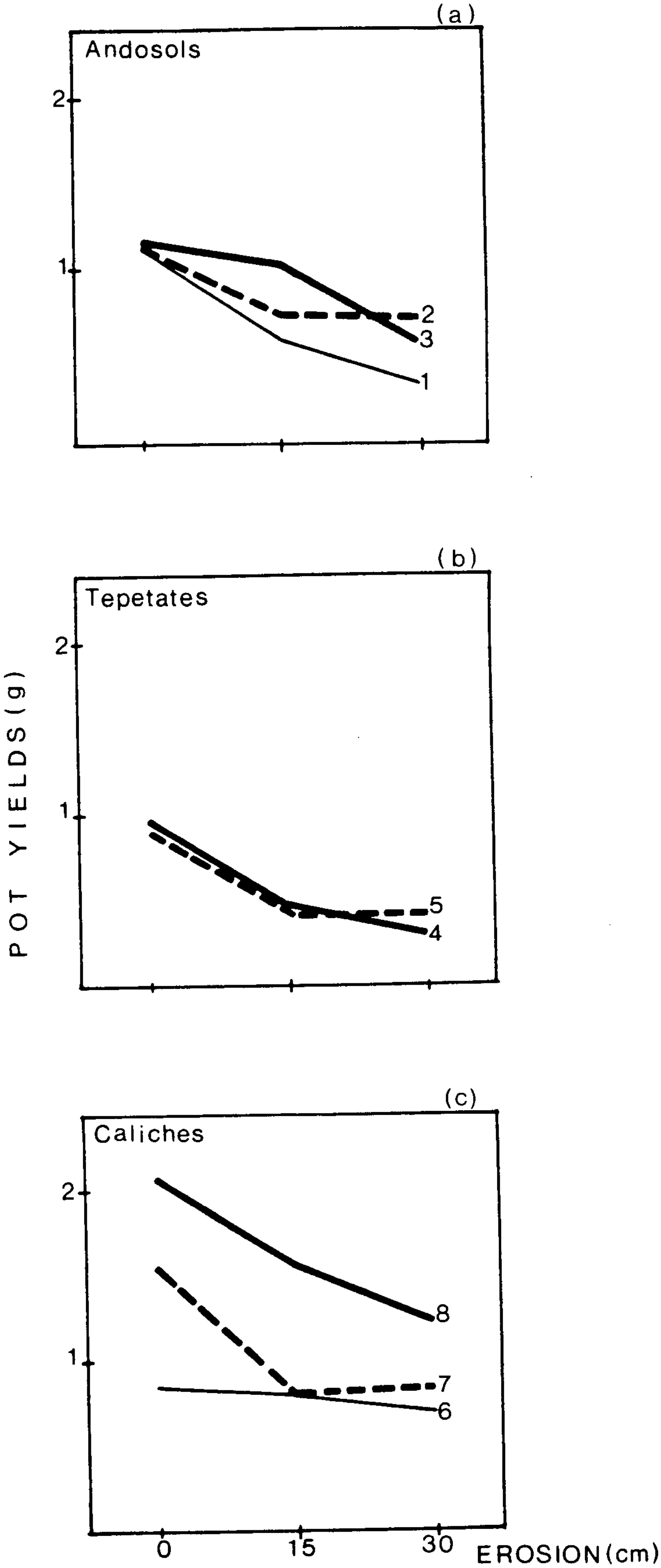
Source	DF	MS	F[1]
Soil(S)	7	1.745	15.3 **
Erosion(E)	2	3.331	29.2 **
S x E	14	0.109	1.0 ns
Error	96	0.114	

[1] ** significant ($P<0.01$); ns: non significant

Figure 5.2 plots maize yields for experiment 1. The poorest-yielding soils, as expected, were the Tepetates. While the Caliches did better than anticipated, the Andosols did relatively worse. For all soils, the erosional phase was less productive than either the normal or depositional phase. Not all individual soils showed significant differences in yields; rather, there were four distinct maize yielding groups of soils. This only partially supports hypothesis i), namely that all soils should yield differently. Alternatively, had a greater number of replicates been provided in this experiment, the chances of picking up significant differences with tests on means would have increased.

Overall, means for the three levels of erosion (i.e., 0-30cm, 15-45cm, and 30-60 cm depth intervals) were 1.21, 0.803, and 0.653 g/pot, respectively. These are all significantly different (Duncan's multiple range test, $P<0.01$). Yields without 15 cm of topsoil are only 66 per cent of the yields of the topsoils. If 15 cm more are scraped these soils respond with a further decline of 12 per cent, to end up yielding only

Figure 5.2. Yields in pot experiment 1. a) Andosol, b) Tepetate, c) Caliche. Numbers correpond are for different sites, described in Appendix2.


(a)
Andosols
2
1
2
3
1
(b)
Tepetates
2
1
5
4
POT YIELDS (g)
(c)
Caliches
2
1
8
7
6
0
15
30
EROSION (cm)

54 per cent of what the topsoils yield. Apparently, the topmost 15 cm layer of these soils is the most productive of them all. These findings obviously support hypothesis ii) which proposed that erosion should reduce yields, regardless of soil type.

V.2.2.2. Experiment 2, erosion, fertilization, and water effects on yields

Table V.2 shows the analysis of variance of the results. The pattern of factors' effects is complicated by the number of significant interactions. Almost all terms in the model (i.e, Equation 5.2) were statistically significant. This indicates that the effects of erosion, water and fertilizer on yields are interdependent. A change in one of these factors alters the effect of another on yields.

Figure 5.3 depicts the interaction between soil, fertilizer and erosion. These yield-isocline diagrams show the simultaneous response of yields to erosion, abscissa, and fertilization, ordinate, for the three soils under study (graphs a, b and c). Extra values are computer interpolations which show a clearer picture of the interactions. The flat yield response to erosion in the Andosol (Fig.5.3a) contrasts with the more inclined response in the Tepetate (Fig.5.3b), and with the noticeably tilted response in the Caliche (Fig.5.3c). An upward tilt of these curves indicates that more fertilizers are needed to keep yields constant as erosion progresses. Hence, the effects of erosion can be more easily compensated with

Figure 5.3. Interaction between soil type, fertilizer and erosion, experiment 2. Curves are computer interpolations between data points with equal yields (g/pot). 5.3a, Andosol, 5.3b, Tepetate, 5.3c, Caliche.

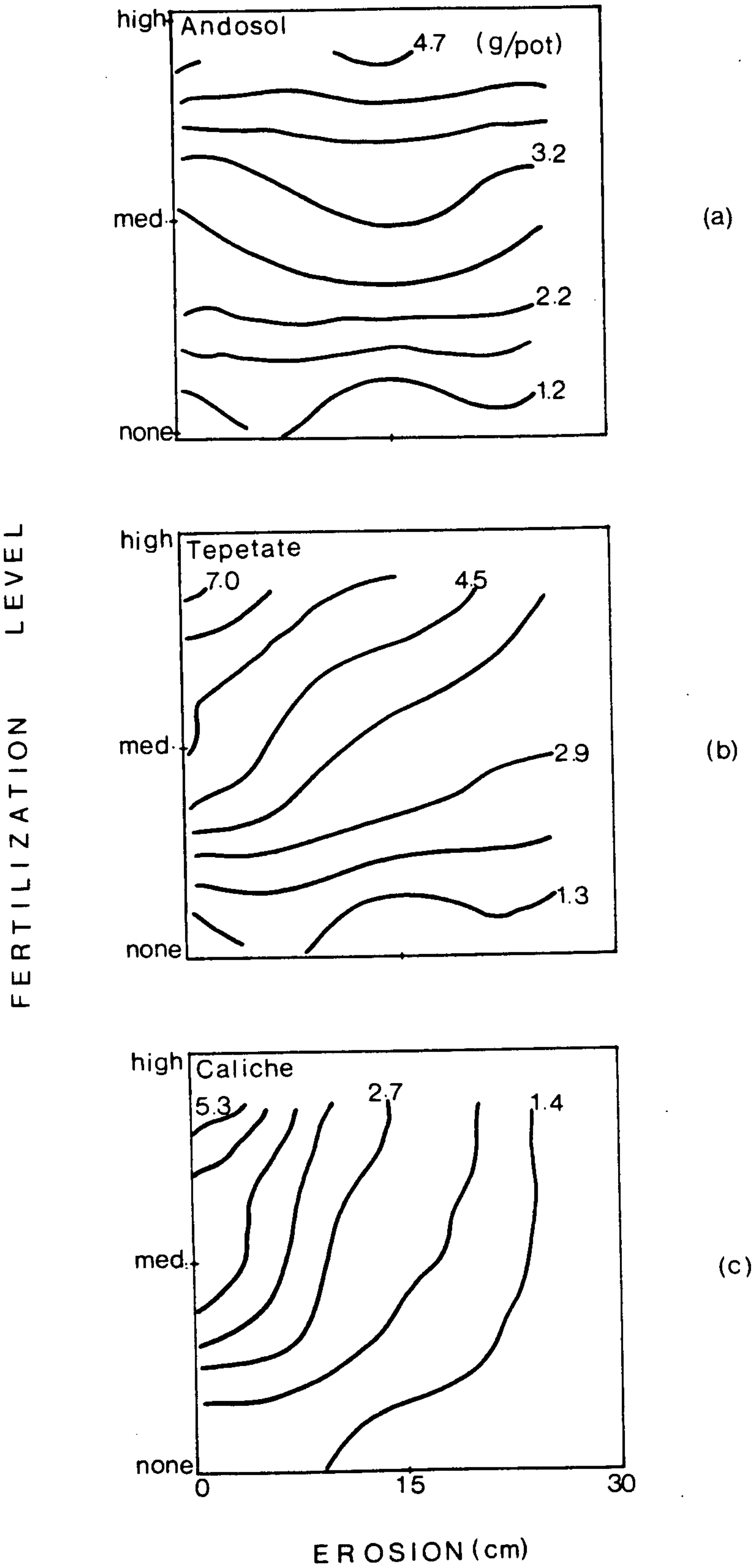

Andosol
4.7
(g/pot)
3.2
2.2
1.2
(a)
Tepetate
7.0
4.5
2.9
1.3
(b)
Caliche
5.3
2.7
1.4
(c)
high
med
none
0
15
30
FERTILIZATION LEVEL
EROSION (cm)

Table V.2. ANOVA of yields for experiment 2

Source	DF	MS	F[1]
Soil(S)	2	26.67	23.3 **
Erosion(E)	2	90.72	79.2 **
Fertilizer(F)	2	340.12	296.9 **
Water(W)	1	109.32	95.4 **
S x E	4	22.30	19.4 **
S x F	4	17.57	15.3 **
S x W	2	11.51	9.7 **
E x F	4	17.97	15.7 **
E x W	2	5.93	5.2 **
F x W	2	26.66	23.3 **
S x E x F	8	5.95	5.2 **
S x E x W	4	1.96	1.7 ns
S X F X W	4	3.39	3.0 *
E x F x W	4	1.29	1.3 ns
S x E x F x W	8	0.89	0.8 ns
Error	216	1.15	

[1] ns: non significant; * : $P<0.05$; ** : $P<0.01$

fertilizers in the Tepetate than in the Caliche; apparently, the productivity of the Andosol did not suffer from erosion.

Average yields were 4.78 g in the Tepetate, 3.92 g in the Andosol, and 2.93 g in the Caliche. The Tepetate, which when unfertilized yielded the least in the previous experiment, when fertilized became the highest yielding. This is a somewhat puzzling result, which for the moment can only be interpreted as arising from the comparatively low intrinsic fertility of the Tepetate.

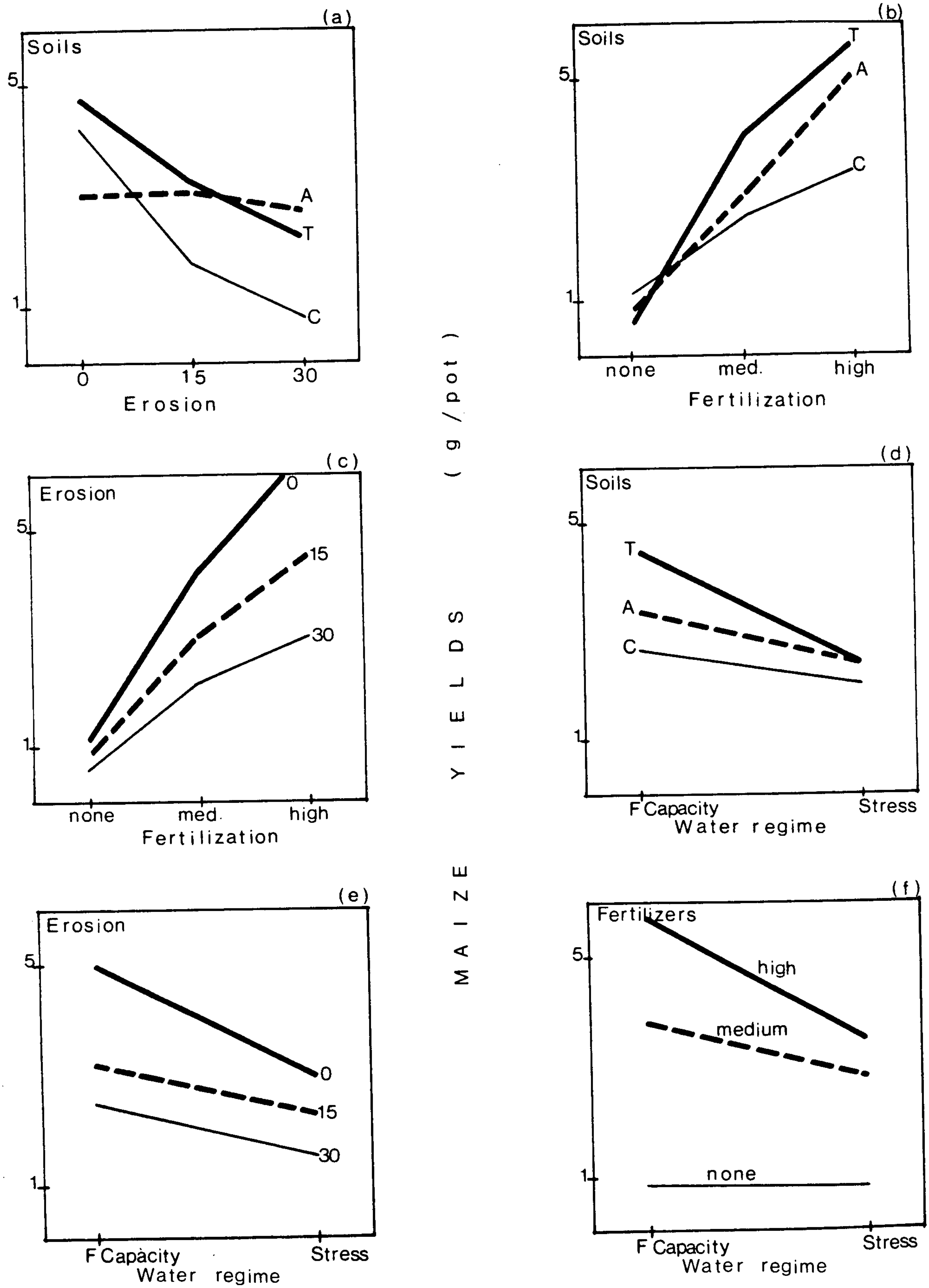
Figure 5.4 shows the six, highly significant, second order interactions. Figure 5.4a further emphasizes the almost complete lack of response of yields to erosion in the Andosol. This is also contrasted with the sharp decline in yields in the

Caliche. Figure 5.4b shows slightly different yield responses to fertilization among soils. The Caliche's poor response to the high level of fertilization is worth noticing. Figure 5.4c, on the other hand, shows that fertilizer efficiency decreased with increasing erosion. For example, it would take twice as much fertilizer to make the yields of a soil missing 15 cm equal the yields of an uneroded soil. A similar trade-off applies for the loss of an additional 15 cm of topsoil.

However, the first level of fertilization (N+P in fig 5.5c) produced a sharp yield response, regardless of erosion. For this particular case, it must be said that fertilizers amply compensated for the losses to erosion. But it should also be remembered that the N+P treatment included quite a high dosage of these nutrients, because it was initially thought that fertilizer efficiency in small pots was about half that of the field. Indeed, Terman and Mortvedt (1978) suggest this ratio for maximum pot yields. An informed reader would have by now noticed that this was not the case in these experiments: an average yield of 4g/pot is less than half the yields reported by these authors as optimal maize yields in small pots. Of course, there was no intention of attaining optimal values in these experiments, which included erosion and lack of fertilization among other treatments.

Hypotheses iii) and iv) have been already discussed. That fertilizers compensate the depressing effects of erosion on yields is in general supported by the results of Experiment 2. In this respect, the Andosol showed the greatest flexibility.

Figure 5.4. Second order interactions for experiment 2. 5.4a, Soils (Andosol, Tepetate, Caliche) vs Erosion (none, 15 cm, 30 cm). 5.4b, Soils vs Fertilization (0, NP, 2NP). 5.4c, Erosion vs Fertilization. 5.4d, Soils vs Water regime (Field capacity, 60% Field Capactity). 5.4e, Erosion vs Water regime. 5.4f, Fertilizers vs water regime.


(a)
Soils
5
1
A
T
C
0
15
30
Erosion
(b)
Soils
T
A
C
5
1
none
med.
high
Fertilization
(c)
Erosion
0
15
30
5
1
none
med.
high
Fertilization
(d)
Soils
T
A
C
5
1
F Capacity
Stress
Water regime
(e)
Erosion
0
15
30
5
1
F Capacity
Stress
Water regime
(f)
Fertilizers
high
medium
none
5
1
F Capacity
Stress
Water regime
MAIZE YIELDS (g / pot)

The Tepetate and the Caliche suffered relatively more from erosion and required more fertilizers to sustain yields. Were it not for the sharp response of yields to the first level of fertilization, a symmetrical response of yields to erosion and fertilization would have been found. The problematic symmetry is as follows: for every 15 cm of soil loss, twice as much fertilizer is required to keep yields unchanged (see Fig.5.5c). This symmetry may still be applicable. If we concede that plant nutrition in small pots is the limiting factor, then fertilizers can well offset this limitation and open ways for better production. After plant nutrition was amended with the N/P treatment, erosion still halved production, and 2(N/P) were needed to double yields again.

That water stress depresses yields even further seems plausible and well supported by the results.

Every single factor in Experiment 2, i.e., soil, erosion, fertilization, and water, had a significant effect on maize yields (see Table V.2). The extent of significance is suspect, however, because the relevant interaction terms were also significant. Under these circumstances, statisticians would recommend that the interactions--not the factors be interpreted--which is precisely what has been done so far. However, from Table V.2 it can be calculated that fertilizers, water, and erosion are significant even when tested against their respective significant interaction terms (F values > 3, have $P<0.05$). This is something that an statistician should also agree is proof of the differences among levels of each factor.

V.2.3. Preliminary conclusions: greenhouse

It was mentioned in the introduction, that these experiments were a compromise between precision and accuracy. Precision has been achieved through the relativelly great number of experimental cells and repetitions contained in these experiments. For this, the completely randomized factorial design deserves credit.

Accuracy is suspect. The tremendous response of yields to fertilization seems unreal. Fertilization alone accounts for 40 per cent of the variance reported in Table V.2. It is also true that there was a better yield response to fertilizers in the uneroded soils (see Fig.5.4c), and, on balance, there was a net yield loss for each erosion level.

Table V.3 compares the effects of varying levels of erosion on maize yields in both experiments. Columns 2 and 4 of this table, show a comparable decrease of yields in both greenhouse experiments. This suggests that, regardless of the use of fertilizers, erosion of 15 cm of topsoil reduced yields by about 68 per cent. Another 15 cm of soil lowered yields about 50 per cent more.

Column 5 in table V.3 compares the yields of both experiments. Yields without fertilizers were only 30 per cent those with fertilizers, both in the noneroded and moderately eroded soils. This percentage rose to 55 in the severely eroded

Table V.3. yields and per cent reduction[1] due to erosion in pot experiments 1, and 2

Level of erosion (cm)	Yield Exp 1 (g/pot) (1)	Reduc. Exp 1 % (2)	Yield Exp 2 (g/pot) (3)	Reduc. Exp 2 % (4)	Y1/Y2 % (5)
non-eroded (0)	1.21	--	3.93	--	31
moderate (15)	0.80	66	2.71	69	29
severe (30)	0.65	54	1.93	49	55

[1] % based on the yields of the non-eroded treatment.

soils. That is to say, the efficiency of fertilizer decreases with erosion.

Water stress reduced yields proportionaly more on fertilized than on unfertilized pots (see fig.5.4f). On the average, yields were depressed 15 per cent in unfertilized pots and almost 40 per cent in fertilized pots. This simple result could be construed to explain the reluctance of some Mexican farmers to use fertilizers in erratic rainfed areas. Although the application of fertilizers can be expected to increase yields even in drought years, the full potential of fertilizers cannot be realized without proper rainfall. High expectations die hard. If fertilizers account for a large share of production costs, and it does not rain, then fertilizers, rather than rain, will likely be blamed for the poor results.

V.3. Soil Erosion and Productivity in the Field

The following experiment was conducted under field conditions which reproduce the most common maize cultivation practices found in the maize fields of the study area. However, erosion had to be simulated to permit both comparable and significant soil losses to be studied across soil types. Erosion was simulated by removing topsoil in half the experimental plots. The other half of the plots was left untouched.

This experiment tests similar hypotheses to the ones tested in the greenhouse experiments:

i) Maize yields are different for the different soils included in this study.

ii) Maize yields decrease with erosion, regardless of soil type.

iii) Fertilization tends to compensate for the reduction of yields produced by erosion.

Only the water stress hypothesis is missing from the present experiment.

V.3.1. Materials and methods

Treatments for this experiment were: a) erosion, as artificial topsoil removal; b) N/P fertilization; c) soil type. The statistical model can be written as follows:

$$Yijkl = U + Si + ERj + SERij + Fk + SFik + ERFjk + SERFijk + El(ijk) \quad (5.3)$$

where:

Y = maize yield in t ha^{-1} of grain;
U = population mean;
Si = soil type, i=1,3;
ERj = erosion, j=1,2;
Fk = fertilization, k=1,2;
El = replications, l=1,3.

This field experiment is thus a 3 (soil type) x 2 (erosion levels) x 2 (fertilization levels), completely randomized factorial with 3 replications per cell. For analysis, the fixed effects ANOVA model I will be applied.

Twelve 8 x 5 m plots were distributed in 35 x 20 m rectangular experimental areas. After clearing the land, plots and alleys were delimited with stakes and strings. Drainage ditches were dug in the alleys around each plot. To prevent up-slope runoff from entering the experimental areas, earthen dykes were built and peripheral drains were opened. Each plot was allotted treatment and replication at random.

V.3.1.1. Soils

Sites 2, 4, and 7 from the Andosol, the Tepetate, and the Caliche, respectively, were chosen for these experiments. Figure 4.1b showed the geographical location of these sites. Section IV.3 discussed the main soil properties of these sites. Appendix 2 contains detailed soil data. Sites were located on erosional phases of each soil type: the slopes in the Andosol;

the hill-tops in the Tepetates; the gentle slopes of the Caliches. Sancholuz et al (1981) and Marten and Sancholuz (1981) have shown that maize is commonly cultivated in these places.

To simulate soil erosion, about 17 cm of topsoil was scraped from half the plots in all sites. Scraping was done by hand, with spades and hoes, as the random lay-out of the experiment precluded the use of machinery. Continuous measurements of the depth of the excavation with stakes, levels, and strings were made during this operation.

Table V.4. Average depths of excavation in experimental plots

	Topsoil Removed (cm)		
Plot #	Andosol	Tepetate	Caliche
1	17.4	17.3	14.8
2	20.4	16.4	12.4
3	21.3	10.8	12.7
4	20.2	15.3	15.8
5	23.2	16.4	18.6
6	22.7	16.9	18.1
Averages	20.9	15.6	15.4

Table V.4 shows that final depths varied within and among sites. Plots in the Andosol were scraped deeper than plots in the other two soils. Clearly, the erosion treatment could not be standardized as would have otherwise been desired.

V.3.1.2. Fertilization

The same criteria discussed in Section V.2.1.3 were used to select fertilizer contents, rates, and source of nutrients for this experiment. Similar fertilization schemes were applied to half the plots in all sites. They contained 78 kg ha^{-1} of N, and 46 kg ha^{-1} of P. Lime at 4t ha^{-1} was supplied only to the acidic Andosols and Tepetates.

One week before planting, lime was banded 5 cm deep to the prepared rows. At planting, all the P and 18 kg ha^{-1} of N were buried in a circle around each maize hill. The rest of N was buried in each hill when maize plants were in the period of fast growth.

V.3.1.3. Seeds and cultivation practices

Sites were cleared of grasses and shrubs with machetes and hoes just before tillage. Given the size and lay-out of the plots, plows could not be used to till the land before planting. Instead, soils were tilled with hoes. All plots, eroded or not, received the same intensity of tillage in their uppermost 15 cm of soil.

Seeds were drawn from creole varieties. Local cultivators were contacted and asked to provide "good stuff" for each area. Seeds, from the center part of the maize ears only, were collected, discarding those which looked defective. For the area of the Caliche soil alone there are known improved seeds (cf discussion on Tuxpeñito, Section IV.5.2). These seeds, while yet being tested for the Caliches, do not prosper in either the Andosols or the Tepetates, mainly because of climatic reasons. It was impossible then to obtain genetic homogeneity across sites.

Seeding rates were the same for in all experimental plots. Six rows with ten hills were each separated by 80 cm. Hills received four seeds each. Whenever the fourth plant emerged the seedling was removed to approximate 45000 plants ha^{-1}, the recommended planting density in the area (CDIA, 1977; SARH, 1980).

Seeds were buried 5 cm deep with the help of a planter stick. Fertilizers, if necessary, were applied 10 cm apart from the seed's hill and both covered with soil. Sowing dates were different in the three sites. The Andosol, with the longest growing season, was seeded first on 10/4/81. The Tepetate, having an intermediate growing season, was next on 12/6/81. The Caliche, with the shortest season, was last on the 27/6/81. In all cases sowing dates coincide with the onset of the rain season, which is closely watched by all cultivators in the region. Checks of soil moisture were made before seeding to guarantee germination.

Maize germination was studied during the first three weeks. Counts on plant survival were made of all plots. As poor germination was noticed in both the Tepetate and Caliche soils, these sites had to be reseeded .

Crop growth was monitored every two weeks. Plant heights, from base to tip, were measured in one randomly chosen row of each plot.

V.3.1.4. Weed and pest control

Three weedings were given to the Andosol sites and two to the Tepetates' and Caliches'. Different maize growth rates called for different intensities of weeding to maintain approximately the same levels of plant competition. The timing of these weedings was selected with the advice of local cultivators and the agricultural service's officers. Machetes and hoes were used to chop and uproot weeds growing in between rows and around maize hills.

A pervasive pest, particularly at sowing time, was the grackle (a bird: Cassidix mexicanus). Serious damage was prevented with a local tactic: crisscrossing white string over the plots which acts as a flight barrier to the bird. The Andosol site was attacked by a beetle (Macrodactylus spp) when maize was at the silking stage. Hexachlore Cicle-Hexane (3%) was sprayed on plots the day after the attack was noticed. The Tepetate site was said to be infested with a corn borer and was also treated with Hexachlore before sowing.

V.3.1.5. Weather

During the year of these experiments, it rained more than usual throughout the region. Preliminary 1981 returns from nearby meteorological stations show a greater than average precipitation (see Fig.4.3 for comparison). A drought spell set in the Xalapa site soon after sowing. It was promptly corrected by hand irrigation to each maize hill, as facilities permitted.

Drainage was more of a problem, particularly in the Tepetate and Caliche sites. Torrential rains temporarily clogged the ditches of these two sites and some accumulation of water took place, particularly in the eroded plots.

Strong winds are always a major concern in the region. Since all maize varieties are relatively tall, they also tend to lodge when winds blow hard. This nuisance is partly corrected by the support given to the plants with the mounds of earth surrounding each hill. However, the experiments were damaged by the winds, specially in the Andosol. Care was taken to raise all lodged plants and to support some with sticks.

V.3.1.6. Harvesting procedures

Harvesting was conducted at all sites before the grain was completely dried. Early harvesting was necessary because of the disparity of growth between treatments, as well as to prevent further damage by late-season winds. Harvest dates were 26/8/81 for the Andosol, 16/10/81 for the Tepetate, and 17/10/81 for the Caliche. To eliminate border effects, only the 4-center rows and the 8-center hills of each plot were harvested. Fresh biomass and grain yields were recorded at the site. Samples of these were oven dried for moisture content determinations. Yields reported in the next section correspond to 15 per cent moisture content for grain, and completely dry matter for biomass.

V.3.2. Results and discussion

Germination, growth, and yield data will be presented first. A more general discussion of the treatment effects concludes this section.

V.3.2.1. Germination and survival patterns

Table V.5. Maize germination in field experiments

Treatment	% Survival after 10 days			Means
	Andosol	Tepetate[1]	Caliche[1]	
Control	95	39	89	74
Erosion	93	16	78	62
Eros.+Fert.	92	14	78	61
Fertilizer	95	52	89	79
Means	94	30	84	69

[1] After reseeding

Table V.5 shows how germination varied among treatments. Poor maize germination was observed in the Tepetates, specially when eroded, and even after reseeding. On the the other hand, the Andosols showed excellent germination in all treatments. Maize germination in the Caliches was higher than in the Tepetates, and slightly lower than in the Andosols.

Final plant populations, at harvest, were approximately 40000 plants ha^{-1} in the Andosols, 18000 in the Caliches, and 13000 in the Tepetates. Treatments did not make much difference in the final plant densities of the Andosols and the Caliches. In the Tepetates, however, eroded plots ended up with one fourth the plants of the non-eroded plots.

V.3.2.2. Maize growth

Figure 5.5 shows maize growth curves for this experiment. Differences in maize plants' heights among sites (i.e., Fig.5.5a-c) mean little because maize phenotypes were quite different. Within sites, however, there was much better growth in the uneroded and fertilized plots. Growth in the uneroded unfertilized plots was comparatively good in the Andosol and the Caliche (Fig.5.5a,b). Eroded but fertilized plots did relatively well only in the Andosol (Fig.5.5a). There was very little difference among the uneroded unfertilized, the eroded fertilized, and the eroded unfertilized treatments in the Tepetate (Fig.5.5c).

V.3.2.3. Grain yields

Figure 5.6 shows average maize yield for all treatments in this experiment. This histogram compares yields for eroded and uneroded plots for each soil type and fertilization level. In all soils erosion had a tremendous impact on yields. Only the Andosol and the Caliche produced some grain when eroded (the

Figure 5.5. Growth patterns of maize plants in field experiments. 5.5a, Andosol; 5.5.b, Tepetate; 5.5c, Caliche.

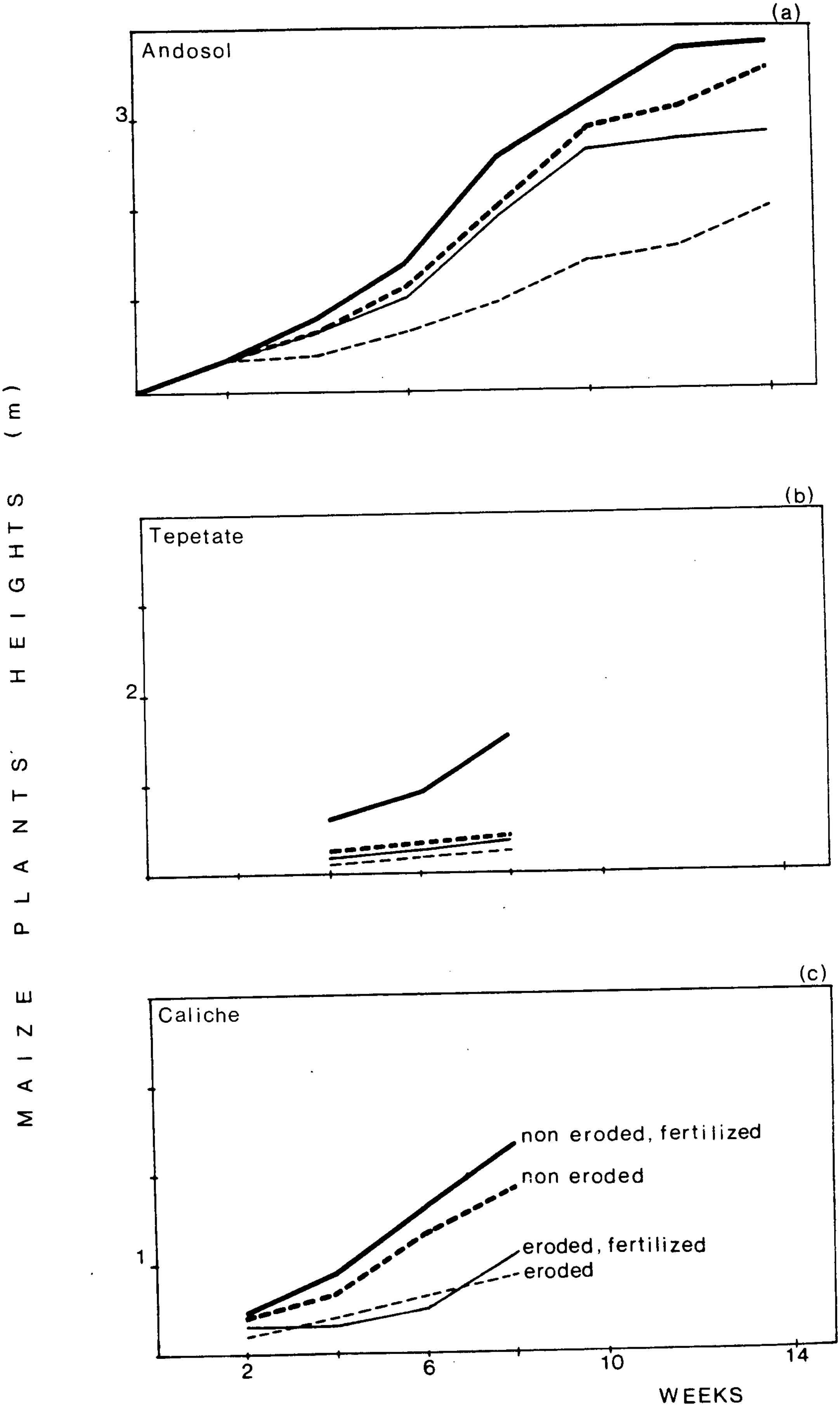
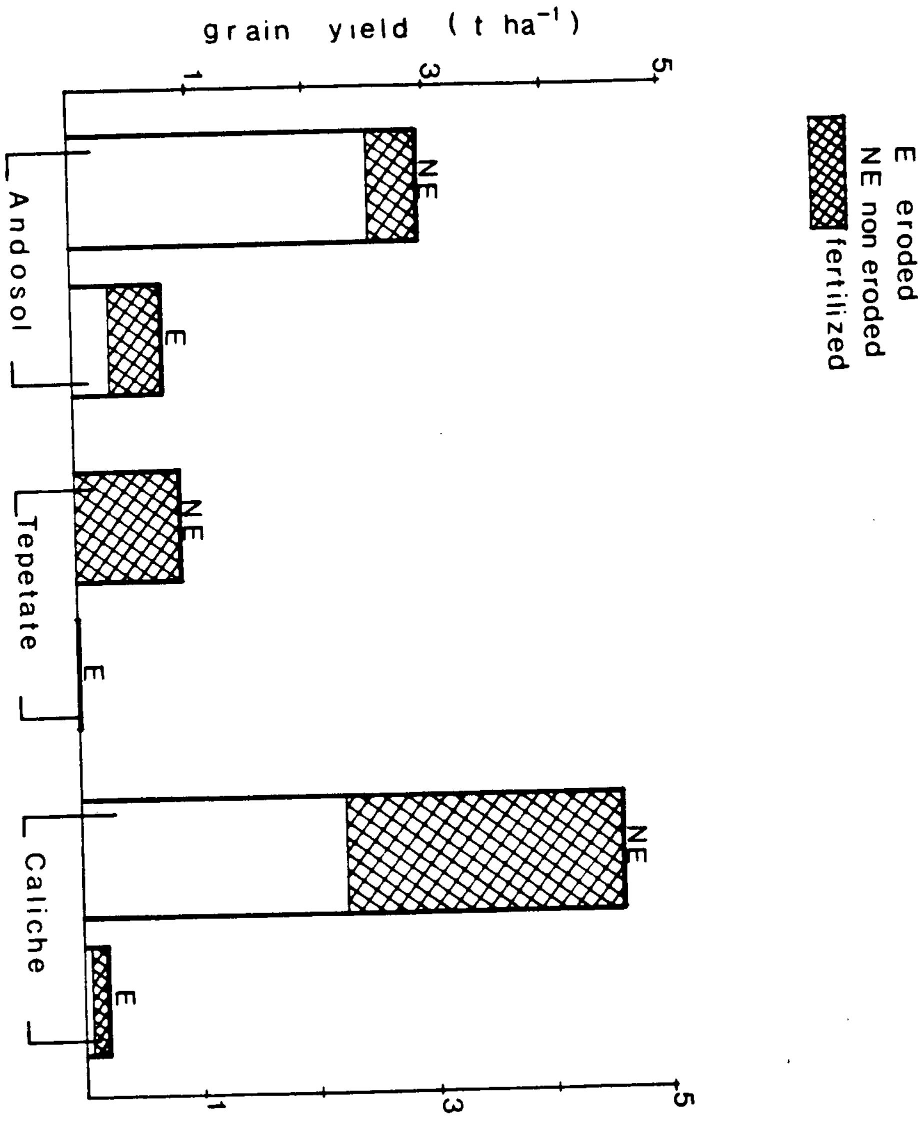

(a)
Andosol
3
(b)
Tepetate
2
(c)
Caliche
1
non eroded, fertilized
non eroded
eroded, fertilized
eroded
2
6
10
14
WEEKS
MAIZE PLANTS HEIGHTS (m)

Figure 5.6. Grain yields for different treatments in field experiment. Note that eroded Tepetates did not yield grain, with or without fertilizers.


grain yield (t ha-1)
1
3
5
NE
E
Andosol
Tepetate
Caliche
E eroded
NE non eroded
fertilized

Caliche's yield was, however, a meager 0.2 t ha^{-1} when fertilized). The Tepetate did not produce grain at all when eroded, nor did uneroded and unfertilized plots.

Fertilizers had a marked effect on yields only in the Caliche. For this soil, the average yield of the fertilized plots was twice the average yield of the unfertilized plots. In the Andosol, yields with fertilizers were almost 30 per cent greater than without them. It should be emphasized that the Tepetate without fertilizers did not yield at all; fertilizers seem mandatory in this soil.

The Caliche soil yielded slightly more than the Andosol, but differences are not great (i.e., 1.79 vs 1.65 t ha^{-1}). The Tepetate, as said before, produced grain only when fertilized and uneroded which meant that mean yields for this soil were a mere 0.22 t ha^{-1}. The grand mean of yields for the experiment is 1.22 t ha^{-1}, a datum that will be later recalled.

V.3.3. Preliminary conclusions: field experiment

Table V.6 presents the ANOVA table for this experiment. Again, as in the greenhouse experiment, most interaction terms were found to be significant. Only the soil x fertilizer interaction was not significant, which means that maize yields in all soils reacted in the same (positive) way to fertilization.

Erosion had a different impact (always negative) on the maize yields of different soils. The most marked decrease of yields

Table V.6 ANOVA for grain yields in field experiment[1]

Source	DF	MS	F[2]
Soil(S)	2	0.687	127.2 **
Erosion(E)	1	2.255	417.8 **
Fertilizer(F)	1	0.279	51.7 **
S x E	2	0.233	43.1 **
S x F	2	0.006	1.2 ns
E x F	1	0.052	9.7 **
S x E x F	2	0.063	11.7 **
Error	24	0.005	

[1] Data are log transforms to correct for heterogeneity of variances. [2] ns:non significant; *:$P<0.01$; **: $P<0.05$.

was produced in the Tepetate, which yielded nothing when eroded. Maize yields in the Caliche were also much depressed. The Andosol yielded some maize when eroded and fertilized, but it was not much. Finally, erosion and fertilizers interacted differently in all soils. The significance of this interaction term suggests that maize yields responded differently to erosion, with and without fertilizers in each soil.

Hypotheses I to iii can now be considered. Results from this experiment support hypothesis i, grain yields for the Andosol, Caliche, and Tepetate were all significantly different (i.e., $P<0.05$, log-transformed data, Duncan multiple range test). Hypothesis ii can not be rejected either: all soils suffered great reductions in yields when eroded.

Hypothesis iii, however, has to be rejected. Although fertilizers did have a significant effect on maize yields, this was not enough to compensate the losses to erosion. For instance, the yields of eroded fertilized plots never matched the yields of uneroded and unfertilized plots (see Fig.5.6).

V.4. Summary

The greenhouse and field experiments discussed in this chapter produced contradictory results. In the greenhouse, erosion depressed yields of the three main soil types but fertilizers restored these yields. On the contrary, erosion in the field had a persistent and quite important negative effect on maize yields; fertilizers could not help it.

Phillips and Kamprath (1973) found that pot maize yields of cut soil surfaces and subsoils could be raised, through fertilization, to levels similar to those shown by unaltered soil surfaces. Ritchey (1973) has also shown that careful fertilization of subsoils can restore maize yields to the same levels of the topsoils. Both these studies have dealt with problematic soils of the tropics and subtropics.

There is a problem with the interpretation of results from greenhouse studies. Fertilization in small pots may not be a good indicator of similar responses in the field. When soil volume is so limited, fertilizers may be the only significant source of nutrients for the plants. This is particularly true for maize which requires relatively more nutrients to grow than other crops.

The field experiments included real soil volumes, real plant populations, real fertilizer dosages, and real cultivation practices. Results compare well with those reported in the literature reviewed in chapter III. Table III.1 showed that similar levels of erosion in tropical soils could depress maize yields between 30 and 70 per cent. The experiments reported here show a range of yield losses from 27 to 100 per cent.

CHAPTER VI: SUMMARY AND CONCLUSIONS

Mexican maize harvests have increased in the recent past. In the last thirty years fertilizers, irrigation, and new lands have been added to increase the production of maize in Mexico. According to national statistics, even unirrigated and unfertilized maize fields today yield slightly more than thirty years ago.

This finding is contrary to predictions contained in the literature reviewed in chapter III. According to these predictions, soil erosion and soil fertility depletion should have lowered the productivity of the Mexican maize fields.

While actual rates of erosion under current management practices were not measured in this study, all the assembled evidence strongly suggests that soil losses in the maize fields are high. Traditional and continuous cultivation of maize on sensitive sites should further deplete the fertility of the soils. Maize is a highly demanding crop. Without fertilizers and/or crop rotations, it can only yield subsistence quantities of grain. Yet, the national statistics on maize production suggested otherwise. While the amount of land dedicated to maize has apparently ceased to grow, land productivity is on the increase.

This conflicting evidence had to be checked in the field. Chapter IV surveyed three contrasting Mexican soils in central Veracruz. Assessment of erosion of these soils under maize cultivation confirmed the expected high soil losses.

Accordingly, experiments in the greenhouse and in the field were designed to simulate these significant soil losses. The results, reported in Chapter V, are again conflicting. In greenhouse tests fertilizers did compensate for yield losses resulting from erosion. Field experiments, on the other hand, demonstrated that erosion has a dramatic and negative effect on maize yields. In these experiments, fertilizers did not compensate for the losses caused by erosion.

Having reviewed the main findings of this thesis, it is time to put them into perspective. Can evidence coming from field, greenhouse and national statistics be considered on an equal footing? Of what consequence is an individual maize field in the national average? Of what consequence is a six liter pot in the maize field? Both the national statistics and six liter pots are only abstractions of a more meaningful reality: the maize field itself.

The lands surveyed in the national statistics today and thirty years ago are not the same. They have been added to; doubled in fact. Is 14 per cent a significant difference in yield[1] between a series of samples (1970's) and a series of informed estimates (1940's)? No, it is not, particularly when we recall that each data set has an internal variability which exceeds the difference tested.

In a few more years, however, it will be ten years since the last comprehensive survey of maize fields was conducted in

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[1] i.e., between 0.7 and 0.8 t ha^{-1} yr^{-1}

Mexico. If this survey were to be repeated to update agricultural statistics, then a data set would be available to check trends in maize field productivity during a period in which the extent of Mexican maize land would not have changed significantly. I believe this would be a worthwhile enterprise.

What of the evidence from the pot trials? Pots provide a neat and convenient way of collecting experimental data. However, pots are small containers of soil. In such a limited environment, fertilizers are taken up by the plants immediately. Further, plants cannot be grown to maturity in this environment. Therefore, the response of maize to fertilizers is likely to be disproportionately large.

To evaluate the questions of this thesis realistically we must go to the field. That is where Mexican maize production takes place, and that is where results are depressing. Maize production will suffer from erosion, fertilizers notwithstanding. Similar findings have been reported from other field studies throughout the world, with a few exceptions which do not obtain in Mexico.

Conclusions can be drawn in two areas. One has to do with scientific investigation itself, while the second relates to Mexican agriculture.

With respect to the first, questions posed at one level of resolution cannot be answered with experimental or survey data gathered at another. The potential impact of soil erosion on maize production can only be answered with data gathered at the field level. In national statistics available here, it is suggested that confounding variables masked the effects visible in the field data. Neither did greenhouse experiments simulate field conditions well enough to produce even remotely comparable results.

Turning to the dilemma of Mexican agriculture, maize cultivation in Mexico is a popular, essential and preeminent human activity. Maize productivity is low, demand for maize is high and increasing. Many millions of people have only a small parcel of land to cultivate for their livelihood. This dilemma is compounded by the evidence on land degradation that was provided here. How do we go about finding solutions?

One radical solution would be to change current land use. At present the delicate maize fields are confined to slopes and shallow soils while cash-crop and cattle production take place on the flat and deep soils. Were this land use pattern be altered, the combined amplifying effects of slope and scarce plant cover on soil erosion would be reversed. This solution, however, is improbable for economic and political reasons. At minimum, cultivators of maize fields might be given better incentives to upgrade productivity and to adopt management practices that would keep the soil in place.

Soil conservation is not a new idea to Mexicans, nor is agricultural development, but neither is working in the maize fields. Faced with repeated warnings of the potential impact of erosion and the importance of maize, why has there been no attempt to to document the magnitude of the losses incurred? This study offers an initial evaluation. Further studies may document the dilemma more completely.

Studies of soil erosion in tropical Mexico are badly needed. An extensive but simple survey of soil depths across tropical soils will quickly document the magnitude of current soil losses. If such a survey is coupled with measurements of land productivity, the impact of these soil losses on crop production may also be determined.

Yet another alternative is provided by market minded economists. Mexico could forget about producing maize and concentrate on producing coffee, strawberries, chiles, cacao, or any other cash crop at which she excels. After all, its northern neighbor needs those goods and has plenty of corn to exchange. This could work well, and indeed it has been working for a while, for those who obtain maize through the market. But this solution does not solve the problem of those rural Mexicans living on the edge of the cash economy, striving to survive on a small maize field in the hills.

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APPENDIX 1. STATISTICS OF MAIZE PRODUCTION AND CONSUMPTION IN MEXICO

1.1. Sources of maize production and consumption data

This Section provides a description of the raw data employed in Ch.2. Two types of data will be considered: continuous or long term series, and a production survey for the years 1976-79. Tables containing serial data are includeded at the end of this appendix.

1.1.1. Production series of data

Since 1925 the Agricultural Economic Department (DGEA) of the Mexican Ministry of Agriculture and Water Resources has kept continuous records of maize production. Data are obtained from mail reports by the mayors of all counties in the country (FAO, 1975). For the period 1895-1924, this agency collected similar data from various other sources. As these were years of great political upwheal in Mexico, some data are missing and others are very doubtfull indeed. Gomez Cobo (1977) has however revised these series and suggest a new series which is used here.

Data included are: area harvested to maize, volume of production, yield per hectare (obtained from the previous two). Table 1 of this appendix reproduces these data. Production data are reported on a calendar year basis. Even though there are two crops of maize in Mexico every year, a production year includes the harvest of the last year winter crop and the harvest of this year's summer crop.

Production reports by the Food and Agriculture Organization of the United Nations (FAO), coincide with the DGEA reports. This is no surprise because FAO policy is to transcribe the official statistics of all member countries (see FAO, Production Yearbooks).

The Foreign Service Division of the United States Department of Agriculture (USDA hereinto) has two series of data on Mexican maize production. Both are compiled from all available Mexican statistics but they also include judgment by the agricultural attaches at the USA embassy, who travel in the field and consult local experts. One series starts in 1932 and is published in Agricultural Statistics, a yearly publication of USDA. This series includes area harvested and production volumes of maize (yields can be deduced). Starting in 1960 , the Foreign Agricultural Circular of the same department also publish import-export volumes and human consumption (see Table 3).

The period of reporting corresponds to the international crop year (Oct-Sept). The winter maize crop in Mexico is moved forward one year, thus making it compatible with all other reporting periods mentioned.

Mexico has taken decennial agricultural censuses, from 1930 through 1980. These contain data on production, and area harvested. There are also tabulations by cropping patterns, use of inputs, and land tenure regimes. The data are valid for the year before the census because this is usually taken on the spring and questions refer to the last production year. Table 4 contains data from the three last censuses which were available at this writting. The national agricultural censuses are the responsibility of the National Direction of Statistics which, to carry out the field work, convocates enumerators from all over the country.

1.1.2. Consumption series of data

Maize consumption is reported periodically as the difference between national production and the net balance of trade for the upcoming year. This is further adjusted for the initial stocks of the grain before the commercial year begins. Both the DGEA and the USDA-FS have produced these data: the former starting in 1940; the latter in 1960 (SARH-DGEA, 1981; USDA-FAS, 1982). Both series are reproduced in Table 3 of this appendix.

1.1.3. Surveys of production

From 1975 to 1979 the DGEA run a survey of basic crops in Mexico. Approximately 5000 maize fields were sampled each year on the 17 more productive states of the country. The survey was designed to estimate national production and thus it stratified the country into zones known to have different productive potential. Samples were latter drawn at random in a multistage sampling procedure (Lozano Lube, 1978).

In these surveys, farmers were interviewed in their fields near harvest time--which for the spring-summer crop corresponds to the months of November and December. A previously designed questionnaire was employed to code information regarding production inputs, land areas, production levels, financial and marketing channels. The great number of samples obtained each year, and the variety of data recorded makes these surveys one of the most complete and reliable sources of information on the productive structure of the Mexican maize fields. Unfortunately, the surveys were discontinued in 1980. Only 1975 results have been so far analysed and published (Gomez Cobo, 1977).

A copy of the computer tape containing the raw data for the years 1976-1979 was here obtained directly from DGEA. The data were screened, selected, transformed, and analysed using MIDAS (Fox and Gutre, 1976), a statistical package available at the Amdhl 470 V/6, model II, computing centre of UBC. Results of these analysis are presented in Ch.II.

1.2. Data

Table 1: Yields, harvested areas and total production of maize in Mexico from 1895 to 1982.

Year	Maize Yields (kg/ha)		Area Harvested (x1000ha)		Total Production (t)	
	USDA	DGEA	USDA	DGEA	USDA	DGEA
1895		585		3249		1900665
1896		570		3399		1937430
1897		577		5213		3007901
1898		575		4780		2748500
1899		577		4166		2403782
1900		572		4036		2308592
1901		580		4042		2344360
1902		569		3871		2202599
1903		568		3950		2243600
1904		570		3881		2212170
1905		584		3653		2133352
1906		573		4743		2717739
1907		584		4900		2861600
1908		590		4541		2679190
1909		570		4386		2500020
1910		584		5413		3161192
1911		588		2926		1720488
1912		560		2466		1380960
1913		560		2120		1187200
1914		560		1922		1076320
1915		540		2000		1080000
1916		560				
1917		560		2320		1299200
1918		550		2480		1364000
1919		565		2680		1514200
1920		580		2928		1698240
1921		612		2946		1802952
1922		607		2856		1733592

To Continue

Table 1. Continued

Year	Maize Yields (kg/ha) USDA	DGEA	Area Harvested (x1000ha) USDA	DGEA	Total Production (t) USDA	DGEA
1923				3209		
1924				3267		
1925		670		2936		1967120
1926		680		3137		2133160
1927		647		3181		2058107
1928		698		3112		2172176
1929		513		2865		1469745
1930		448		3075		1377600
1931		633		3378		2138274
1932	609	609	3243	3243	1974987	1974987
1933	603	601	3198	3198	1928394	1921998
1934	577	580	2970	2970	1713690	1722600
1935	565	565	2966	2966	1675790	1675790
1936	559	560	2852	2852	1594268	1597120
1937	546	545	3000	3000	1638000	1635000
1938	546	547	3091	3094	1687686	1692418
1939	605	605	3267	3267	1976535	1976535
1940	497	491	3342	3342	1660974	1640922
1941	608	608	3492	3492	2123136	2123136
1942	628	628	3748	3758	2353744	2360024
1943	562	587	3048	3083	1712976	1809721
1944	672	690	3501	3355	2352672	2314950
1945	634	634	3451	3451	2187934	2187934
1946	722	719	3313	3313	2391986	2382047
1947	716	717	3512	3512	2514592	2518104
1948	760	761	3722	3722	2828720	2832442
1949	555	757	3998	3792	2218890	2870544
1950	603	721	3998	4328	2410794	3120488
1951	747	773	4427	4427	3306969	3422071
1952	729	756	4237	4236	3088773	3202416
1953	737	766	4340	4857	3198580	3720462
1954	877	854	4399	5253	3857923	4486062

To continue

Table 1. Continued

Year	Maize Yields (kg/ha)		Area Harvested (x1000ha)		Total Production (t)	
	USDA	DGEA	USDA	DGEA	USDA	DGEA
1955	858	836	4000	5371	3432000	4490156
1956	780	803	4399	5460	3431220	4384380
1957	747	835	5500	5392	4108500	4502320
1958	898	828	5500	6372	4939000	5276016
1959	879	880	6325	6324	5559675	5565120
1960	990	975	6415	5558	6350850	5419050
1961	870	993	6391	6288	5560170	6243984
1962	850	995	6400	6372	5440000	6340140
1963	1000	987	6700	6963	6700000	6872481
1964	1040	1133	7200	7461	7488000	8453313
1965	1070	1158	7500	7718	8025000	8937444
1966	1090	1119	7500	8287	8175000	9273153
1967	1060	1130	7500	7611	7950000	8600430
1968	1120	1181	7600	7676	8512000	9065356
1969	900	1184	7250	7104	6525000	8411136
1970	1110	1194	8000	7444	8880000	8888136
1971	1140	1272	8000	7692	9120000	9784224
1972	1080	1264	7500	7292	8100000	9217088
1973	1140	1131	7900	7606	9006000	8602386
1974	1010	1168	7700	6717	7777000	7845456
1975	1170	1264	7900	6694	9243000	8461216
1976	1220	1182	7870	6783	9601400	8017506
1977	1220	1357	7920	7470	9662400	10136790
1978	1280	1519	8000	7184	10240000	10912496
1979	1210	1517	7600	5569	9196000	8448173
1980	1280	1770	8100	6955	10368000	12310350
1981	1530	1812	8150	8150	12469500	14767800
1982	1250	1829	6000	5383	7500000	9845507

<u>Data Sources:</u>

DGEA Series: 1895-1976, Gomez Cobo, 1977, pp. 36-37; 1977-1978, SARH-DGEA, 1980, pp. 112-115; 1979-1981, SARH-DGEA, 1981; 1982, SARH-DGEA, Departamento de Estimacion Agricola Nacional, Pers. Com. June 1983.

USDA Series 1932-1960, USDA,(1936-1964);

Table 2. Decenial maize production in Mexico (1900-1982). DGEA-USDA series: means and percentual change

Period	Area Harvested (ha×10³)				Yield (kg ha⁻¹)				Production (tons×10³)			
	1. DGEA		2. USDA		3. DGEA		4. USDA		5. DGEA		6. USDA	
	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%	Mean	%
1900-1909	4200				576				2420			
1910-1919	2703	-4.4			562	-0.2			1532	-4.6		
1920-1929	3044	1.1			625	1.1			1879	2.0		
1930-1939	3104	0.2	3073**		569	-0.9	576**		1771	-0.6	1774**	
1940-1949	3482	1.1	3513	1.3	659	1.5	635	1.0	2304	2.6	2235	2.3
1950-1959	5202	4.0	4713	2.9	805	2.0	785	2.1	4217	6.0	3733	5.1
1960-1969	7104	3.1	7057	4.0	1086	3.0	999	2.4	7762	6.1	7085	6.4
1970-1979	7038	-0.1	7839	1.1	1283	1.7	1158	1.5	8999	1.5	9083	2.5
1980-1990[1]	7126	0.4	7417	-1.8	1804	11.4	1353	5.2	12309	10.4	10113	3.6

* = ln (Xt+1/Xt)/t+1-t

** Include years 1932-1939.

[1] Projection based on 1980-82 data only.

(Source: Table 1, this Appendix)

Table 3. Population, consumption of maize, and maize balance of trade in Mexico.

Year	Population (#people)	Maize Consumption (t)		Balance of Trade (t)	
		USDA	DGEA	USDA	DGEA
1895	12632427		1900700		
1900	13607272		2403800		
1910	15160369		3161158		
1921	14334780		1803628		
1925	15208225				66235
1926	15467986		2077970		109238
1927	15737944		2163263		28421
1928	16011729		2068872		9938
1929	16295901		2180742		7897
1930	16552722		1548119		79314
1931	16875977		1395494		18731
1932	17169696		2138710		33
1933	17469782		1973586		117
1934	17776303		1852862		-71003
1935	18089633		1642481		-80996
1936	18409591		1670124		-4442
1937	18736900		1600865		3662
1938	19071181		1656792		22062
1939	19413084		1746563		53897
1940	19653552		1985002		8271
1941	20195000		1640003		316
1942	20751000		2125098		1013
1943	21323000		2363959		736
1944	21910000		1971748		163656
1945	22514000		2364772		48586
1946	23134000		2195025		8831
1947	23772000		2383221		589
1948	24427000		2517625		32
1949	25099000		2817325		-14614
1950	25791017		2871002		363
1951	26585000		3172777		50735
1952	27585000		3448942		24820
1953	28246000		3578678		376788
1954	29116000		3868549		146714
1955	30012000		4430001		-57636
1956	30935000		4608557		118477
1957	31887000		5194062		812286
1958	32868000		5310434		810436
1959	33880000		5324561		47812

To Continue

Table 3. Continued

Year	Population (#people)	Maize Consumption (t)		Balance of Trade (t)	
		USDA	DGEA	USDA	DGEA
1960	34923129		5134288		428966
1961	36253340	5381000	5453764	8000	33982
1962	37583551	5478000	6260259	17000	14073
1963	38913762	6681000	6812781	450000	457422
1964	40243973	5980000	6633886	61000	-23631
1965	41574184	6478000	7118890	-1150000	-1334156
1966	42904394	6986000	8089018	-1091000	-847363
1967	44234605	7385000	8022602	-1040000	-1248883
1968	45564816	7494000	7712172	-896000	-891107
1969	46895027	7784000	8281122	-920000	-780621
1970	48225238	7775000	9169819	729000	758925
1971	50418000	8240000	8619504	-154000	-259880
1972	52196000	8767000	9557204	-432000	-238638
1973	54021900	8754000	10337004	1204000	1116166
1974	55898700	9150000	9884993	1200000	1275861
1975	57826700	9600000	10474379	2100000	2626606
1976	59801200	10000000	9413731	1450000	955127
1977	61821800	10480000	9709606	1460000	1727426
1978	63843900	10800000	11491000	1690000	1465180
1979	65899300	11100000	11653030	630000	894005
1980	67400000	12700000	11839654	3870000	3713200
1981	68900700	11900000	15224300	3833000	2844400
1982	70402000	12500000	15245000	700000	500000

<u>Data Sources:</u>

Population Data: 1895-1970, National Population Censuses (I-IX); SPP, 1981(Table 3.1.3); 1980, Xth. National Census, reported in Comercio Exterior, English ed., <u>27</u> #1, Jan. 1981; 1971-1979, Interpolation from Garcia Mata et al., 1977, Table 3; 1981, extrapolated from 1980.

Consumption, DGEA: 1895-1921, Total Consumption=Production; 1925-1939, Hewitt de Alcantara, 1980; 1940-1972, Garcia Mata, Barraza Vazquez, and Cruz Cobo, 1977, Table 3; 1973-1978, CDIA, 1980, Table #27; 1979-1981, Consumption=Production-Net Balance of Trade for the Preceding Year.

Consumption, USDA: 1961-1975, 1976-1981, USDA-FAS, 1976, 1982.

Balance of Trade: Same Sources as for Consumption.

Table 4. Decennial censuses data on Mexican maize production (Source: CDIA, 1980, Table #16; Aburto, 1979, Table VIII.

	1950	1960	1970
Land Under Maize (hax10^6)	5.74	6.82	5.87
Production (tx10^6)	4.85	5.71	5.77
Average Yield (t/ha)	0.84	0.84	0.98
Creole Maize			
%Total Area	na[1]	80.2	79.7
Yield(t/ha)	na	0.84	0.93
Intercropped Maize			
%Total Area	na	15.2	10.7
Yield (t/ha)	na	0.64	0.71
Hybrid Maize			
%Total Area	na	4.5	8.9
Yield (t/ha)	na	1.47	1.83
Irrigation			
%Total Area	na	9.1	11.6

[1] Data not available.

APPENDIX 2. SOIL ANALYSIS

2.1. Methods of soil analysis

2.1.1. Field methods

Eigth soil profiles were described in the field. A soil description form (UBC, 1976) was used to codify field observations. Soil textures were determined by 'feel' in the field. Moist soil colors were obtained from Munsell color tables. Taxonomical classification was attempted for the FAO (FAO, 1974) and the USDA (Soil Survey Staff, 1975) soil classification systems.

Slope angles were repeatedly measured with a pocket clinometer in each site. Altitudes were estimated with an altimeter, and double-checked on topographical charts of the area (scale 1:250,000), from which latitudinal and longitudinal coordinates were also obtained. Geology of the study sites was derived from the a local geological map (Mooser and Palacios, 1977).

2.1.2. Laboratory methods

Unless specified otherwise, the following methods are described in detail elsewhere (UBC, 1981).

PH = 1:1 solution of soil and water, after shaking and resting for 1 h, was measured with glass electrode.

Bulk density = samples were drilled from the profiles with a metallic cylinder (255 cm^3 in volume), oven-dried for 12 h @ 105 C^0, and weighed to calculate dry weight/volume ratios.

Particle size distribution = Method of the hydrometer. Samples were treated with Sodium dithionite to remove free iron oxides. NaO-Acetate was used to remove carbonates from the Caliche soils (sites 6-8).

% moisture retention = Determined with porous membrane apparatus at 1/3, 1, 3, and 15 bar pressures. Only 1/3 and 15 bar readings are presented here, on a dry weight basis.

Field capacity = determined with Colman columns (Wilde, Voigt, and Iyer, 1972) . These were replicated determinations on polyethylene tubes 25 cm in diameter and 30 cm long. Soil samples were saturated with water, sampled 24 h later, and oven-dried for 12 h to calculate % water content on a dry weight basis.

Exchangeable cations = Cations were extracted with NH4-Acetate @ pH 7. Concentrations were read with spectrophotometer of atomic absorption.

% Nitrogen = Digested with Kyedahl method. Total nitrogen was read in autoanalyser.

% Organic matter = Carbon was determined with Walkley-Black method. Organic matter was calculated using 1.724 as the convertion factor.

Available phosphorus = Water soluble, soluble in 0.03N NH_4F and 0.025N HCl (Bray method), and (Olsen) extracts were read colorimetrically.

Sesquioxides = these free oxides were extracted with citrate-bicarbonate-dithionite solution (Mhera and Jackson, 1960) and read with spectrophotometer of atomic absorption.

2.2. Soil data

Andosol (site #1)

Classification: Ochric Andosol (FAO-Unesco), Oxic Dystrandept (USDA).

Location: 150 m behind Normal School, east entrance to Xalapa City. 19° 31' LN, 96° 58' LW. Altitude: 1500 m above sea level.

Physiography: Hilly, Xalapa Land System, land unit #57 (Sancholuz, Marten, and Zola, 1981).

Topography: Hill top (crest), convex slope, 9% inclination.

Drainage: Well drained.

Vegetation: Induced grasses.

Parent material: Volcanic ash and cinders of Pliocene eruptions.

Remarks: Moderately eroded phase.

Horizon description (Andosol, Site #1)

A	0-15 cm	Dark brown (10 YR 4/3) loam. Moderate coarse granular structure, friable. Abundant fine oblique pores, abundant fine vertical roots. Diffuse irregular boundary.
AB	15-30 cm	Yellowish brown (10 YR 5/6) sandy clay loam. Moderate to strong angular blocky structure (consistency 3). Plenty medium oblique pores in ex-peds. Plenty of medium and fine roots in ex-peds. Few fine oxide concretions. Wavy horizon boundary.
B2	30-90 cm	Red yellow (7.5 YR 4/8) clay. Moderate to strong coarse columnar structure (consistency 4). Few fine pores in ex-peds. Few fine roots in ex-peds. Abundant oxide concretions. Abrupt horizon boundary.
B3	90-150 cm	Red yellow (7.5 YR 5/8) clay. Strong very coarse prismatic structure (consistency 6). Very few coarse pores in ex-peds. No roots.

Analytical data (Andosol, site #1)

Horizon Depth (cm)	A 0-15	AB 15-30	B2 30-90	B3 90-150
pH	5.6	5.2	5.2	5.1
Bulk density (g/cm³)	0.8	0.81	1.0	1.1
Particles > 2mm (%dry soil)	1.0	2.0	2.0	2.0
Fine texture(%)				
Coarse sand(2-.1mm)	30.6	{46.2	{9.3	{8.2
Fine sand(.1-.05mm)	18.2			
Silt(.05-.002mm)	29.8	20.0	10.9	6.0
Clay(<.002mm)	21.4	33.8	79.8	85.8
Field Capacity(%)	32	34	35	n.a.
Total elements (ppm)				
Ca	1055	650	1500	950
K	65	33	93	90
Mg	95	176	580	128
% N	0.32	0.11	0.06	0.05
% OM	5.7	1.7	0.7	0.7
C/N	10.3	9.0	6.8	8.1
Available P (Bray)	1.21	1.61	n.a.	0.32

Andosol (site #2)

Classification:	Humic Andosol (FAO-Unesco), Typic Dystrandept (USDA)
Location:	Experimental area of Clavijero Botanical Garden, km 5, Old Road Xalapa-Coatepec, Veracruz. 19° 30' LN, 96° 56' LW. Altitude: 1300 m above sea level.
Physiography:	Hilly, Xalapa Land System, Land Unit #56 (Sancholuz, Marten and Zola, 1981).
Topography:	Lower slope, slightly concave, 15% inclination.
Drainage:	Well drained, small stream 150 m appart.
Vegetation:	Abandoned orange and coffee orchard (10 years old), has abundant grass and herbs cover.
Parent material:	Volcanic ash and cinders of Pliocene eruptions.
Remarks:	Slightly to moderately eroded phase. Next to experimental plot of this study (see Chapter V, Xalapa site).

Horizon description (Andosol, Site #2)

0	2-0 cm	Dark brown (10 YR 3/3), partially decomposed organic material, fibrous, abundant leaves and many roots. Abrupt boundary.
A1	0-10 cm	Dark brown (10 YR 4/3) loam. Weak to moderate coarse granular structure, friable (moist). Plenty medium size, randomly oriented pores. Few coarse roots but plenty of medium and fine roots. Diffuse irregular boundary.
AB	10-30 cm	Light yellowish brown (10 YR 6/4) loam. Moderate, very coarse granular structure, friable. Plenty medium sized pores. Common fine oxide concretions. Plenty of coarse and medium roots. Clear wavy horizon boundary.
B2	30-85 cm	Yellowish brown (10 YR 5/6) sandy clay loam. Moderate coarse columnar structure. Roots follow peds faces until boundary. Abundant fine oxide concretions. Abrupt boundary.
B3	85-150 cm	Reddish yellow (7.5 YR 6/8) sandy clay loam. Strong coarse prismatic structure. Few roots and pores.

Analytical data (Andosol, site #2)

Horizon Depth (cm)	A1 0-10	AB 10-30	B2 30-85	B3 85-150
pH	5.1	5.2	5.0	5.5
Bulk density (g/cm³)	0.75	0.80	0.83	0.90
Particles > 2mm (%dry soil)	1.7	0.4	0.1	3.0
Fine texture(%)				
Coarse sand(2-.1mm)	32.8	30.2	43.2	47.0
Fine sand(.1-.05mm)	16.7	14.5	9.3	10.1
Silt(.05-.002mm)	30.7	38.5	24.3	20.7
Clay(<.002mm)	19.8	16.8	23.2	22.2
% Moisture retention (dry basis)				
@ .3 bar	52.5	49.8	50.0	49.0
@ 15 bar	35.6	33.8	43.4	42.0
Field Capacity(%)	46	50	59	n.a.
Exch. cations (meq/100g)				
Ca	5.9	3.6	2.2	0.3
K	0.6	0.5	0.3	0.2
Mg	2.6	1.6	1.6	2.9
Na	0.2	0.2	0.2	1.0
Mn	0.2	0.2	0.2	1.0
H	29.6	31.3	0.1	0.02
C.E.C. (meq/100g)	39.1	37.2	30.0	20.0
% Base saturation	24	16	15	22
% N	0.52	0.42	0.18	0.06
% OM	11.4	9.2	3.5	1.0
C/N	12.6	12.6	10.9	9.7
Available P (H2O)	0.03	0.03	n.d.	n.d.
(Bray)	0.79	n.d.	0.42	0.4
CBD Extractable (%)				
Fe2O3	5.6	6.7	6.6	n.a.
Al2O3	3.4	9.0	3.5	n.a.
SiO2	0.5	0.5	0.6	n.a.

Transitional Andosol-Tepetate (site #3)

Classification:

Location: 300 m East of CONAFRUT, 4 km East of Xalapa on National Highway. 19°30'32" LN, 96°48'36" LW. Altitude: 1200 m above sea level.

Physiography: Hill crest. Transition between Xalapa and Tepetate Land Systems (Sancholuz, Marten & Zola, 1981).

Topography: Convex slope, 10% inclination.

Drainage: Poorly drained.

Vegetation: Medium, subtropical forest.

Parent material: Volcanic ash and basalts.

Horizon description (Transitional Andosol-Tepetate, Site #3)

A	0-6 cm	Dark brown (7.5 YR 4/4) clay loam. Weak to moderate medium granular structure. Plenty of medium size random and continuous pores. Abundant coarse roots in peds. Earthworm activity common. Common medium Fe concretions, reddish brown (5 YR 4/4) in color. Wavy and diffuse boundary.
AB	6-23 cm	Strong brown (7.5 YR 5/6) clay loam. Moderate medium angular blocky structure. Sticky consistency when wet, slightly plastic. Plenty medium sized, oblique pores in peds. Frequent coarse oblique roots, abundant fine roots. Common Fe concretions reddish brown (5 YR 4/4) in color. Clear wavy boundary.
B	23-60 cm	Dark yellowish brown (10 YR 4/6) gravely clay loam. Strong medium angular blocky structure. Very few coarse random pores in expeds. Few roots. Common medium greyish (7.5 YR 6/0) mottles. Abundant Fe concretions. Slow to moderate permeability. Clear boundary.
R	60-96 cm	Light brown (7.5 YR 6/4). Massive. Abundant Fe concretions. Few pores, roots. Slow permeability.

Analytical data (Transitional Andosol-Tepetate, site #3)

Horizon Depth (cm)	A 0-6	AB 6-23	B2 23-60
pH	5.1	5.3	5.3
Bulk density (g/cm^3)	0.9	0.95	1.0
Particles > 2mm (%dry soil)	n.d.	2.0	7.0
Fine texture(%)			
Coarse sand(2-.1mm)	24.5	{39.3	{31.3
Fine sand(.1-.05mm)	7.5		
Silt(.05-.002mm)	29.0	24.0	32.0
Clay(<.002mm)	39.0	36.7	36.7
Field Capacity(%)	n.a.	28	27
Total elements (ppm)			
Ca	n.a.	850	400
K	n.a.	48	15
Mg	n.a.	129	154
% N	0.13	0.30	0.08
% OM	4.72	3.96	0.98
C/N	21.1	7.7	7.1
Available P (Bray)	n.a.	1.05	n.d.

Tepetate (Site #4)

Classification:	Typic Durandept (USDA)
Location:	3 km NE from El Chico, Veracruz. Ejido plot of Emilio Martinez. 19°28'30" LN, 96°45'30" LW. Altitude: 1080 m above sea level.
Physiography:	Hill crest in Dos Rios Land System, Tepetate landscape.
Topography:	Convex slope 6.8% inclination, moderately eroded phase.
Drainage:	Poor.
Vegetation:	Pangola grass for 15 years (sugar cane before).
Parent material:	Volcanic ash and basalt.
Drainage:	slow to very slow
Remarks:	Right besides El Chico experimental plots (see Ch.V).

Horizon description (Site #4)

A	0-9 cm	Brown (10 YR 5/3) sandy clay loam. Moderate medium granular structure. Slightly hard consistency. Plenty of fine pores in pedons. Plenty fine and medium roots. Clear boundary.
B1	9-30 cm	Pale brown (10 YR 6/3) clay loam. Moderate to strong medium subangular blocky structure. Common grayish (10 YR 6/1) mottles. Plenty of fine roots. Many yellowish red (5 YR 4/8) fine Fe oxide concretions. Horizon boundary clear.
B2	30-50 cm	Light brown gray (10 YR 6/2) clay. Massive structure. Abundant fine and medium Fe oxide concretions, yellowih red in color (5 YR 4/8). Few roots. Many coarse grayish (10 YR 6/1) mottles. Poor drainage. Diffuse boundary.
R	50 + cm	Light brown (7.5 YR 6/4) clayey hardpan. Strong massive structure. No roots, few pores.

Analytical data (site #4)

Horizon Depth (cm)	A 0-13	B1 13-30	B2 30-50	C 50 +
pH	4.6	5.1	4.8	5.3
Bulk density (g/cm³)	1.21	1.43	1.44	1.57
Particles > 2mm (%dry soil)	5.2	4.2	3.6	13.1
Fine texture(%)				
Coarse sand(2-.1mm)	39.9	33.1	22.2	28.6
Fine sand(.1-.05mm)	10.7	8.9	6.8	7.4
Silt(.05-.002mm)	20.4	26.1	22.9	22.1
Clay(<.002mm)	29.0	31.9	48.1	41.9
% Moisture retention (dry basis)				
@ .3bar	31.4	25.5	26.5	25.4
@ 15bar	16.9	16.2	18.6	17.9
Field Capacity(%)	26	25	23	n.a.
Exch. cations (meq/100g)				
Ca	3.24	3.12	3.22	2.2
K	0.2	0.1	0.1	0.2
Mg	2.2	4.4	5.4	3.6
Na	0.17	0.59	0.85	0.3
Mn	0.15	0.03	0.01	0.01
H	7.6	6.2	4.1	15.6
C.E.C. (meq/100g)	13.5	14.5	13.6	21.9
% Base saturation	44.0	57.0	70.0	29.0
% N	0.15	0.06	0.02	0.02
% OM	3.2	1.3	0.22	0.34
C/N	12.7	12.3	8.7	11.1
Available P (H2O)	0.18	n.d	0.03	n.d.
(Bray)	0.5	n.d.	n.d.	n.d.
CBD Extractable (%)				
Fe2O3	n.a	10.3	3.7	5.4
Al2O3	n.a	1.2	0.5	0.4
SiO2	n.a	0.2	0.2	0.3

Tepetate (Site #5)

Classification:	Typic Durandept (USDA)
Location:	Same as Site #4.
Physiography:	Ravine in Dos Rios Land System, Tepetate landscape.
Topography:	Complex slope 25% inclination.
Drainage:	Imperfectly drained.
Vegetation:	Grass land, usually cropped with coffee.
Parent material:	Basalt and Volcanic Cinders.
Remarks:	Influenced by alluvial deposits

Horizon description (Tepetate, Site #5)

A	0-13 cm	Dark brown (7.5 YR 4/2) loam. Weak to moderate granular structure. Plenty medium sized oblique pores in matrix. Earthworm activity. Plenty medium fine roots. Common fine Fe oxide concretions. Clear wavy boundary.
AB	13-22cm	Brown (7.5 YR 5/2) clay loam. Moderate angular blocky structure. Plenty fine random pores. Common medium Fe oxide concretions. Few fine greyish mottles. Few medium oblique roots. Abrupt boundary.
B2	22-39cm	Reddish brown (5 YR 5/4) clay loam. Coarse angular block structure. Very few fine horizontal pores in ex-peds. Abundant medium Fe oxide concretions. Very few roots, expeds common medium greyish mottles.
B3	39-50cm	Reddish yellow (7.5 YR 6/6) clay. Strong medium prismatic structure. No pores or roots. Has water table at bottom. Abundant pink (7.5 YR 7/4) mottles and reddish Fe oxide concretions. Clear boundary.
R	50+ cm	Light brown (7.5 YR 6/4) clayey Hardpan. Strong massive structure.

Analytical data (Tepetate, site #5)

Horizon Depth (cm)	A 0-13	AB 13-22	B2 22-39	B3 39-60
pH	5.7	5.8	5.7	5.8
Bulk density (g/cm³)	0.91	1.0	1.1	1.3
Particles > 2mm (%dry soil)	1.0	2.0	5.0	8.0
Fine texture(%)				
Coarse sand(2-.1mm)	n.a	n.a	{45.0	{34.3
Fine sand(.1-.05mm)	n.a	n.a		
Silt(.05-.002mm)	n.a	n.a	22.3	20.0
Clay(<.002mm)	n.a	n.a	32.7	40.7
% Moisture retention (dry basis)				
@ .3bar	n.a.	31.4	25.9	26.1
@ 15bar	n.a.	16.9	17.9	17.6
Field Capacity(%)	31	30	27	27
Exch. cations (meq/100g)				
Ca	6.01	6.34	4.34	2.93
K	0.19	0.08	0.04	0.05
Mg	1.48	1.05	0.83	0.71
% N	0.24	0.25	0.09	0.05
% OM	4.04	3.79	1.10	1.00
C/N	9.76	8.79	7.09	11.60
Available P (Bray)	2.73	1.58	0.61	n.d.

Caliche (Site #6)

Classification:	Pellic Vertisol (FAO-Unesco), Typic Pellusterts (USDA)
Location:	Road Carrizal-Chauapan (km 2.5). 19°21'30" LN, 96°40'LW. 550 m above sea level.
Physiography:	Carrizal Land System, Carrizal Landscape, Crest Land Unit (Sancholuz, Marten and Zola, 1981).
Topography:	Convex slope, 7% inclination.
Drainage:	Well drained.
Vegetation:	maize field, with papaya in past rotation. Low tropical desiduous forest.
Parent material:	marine calcareous (marl) deposits.
Remarks:	Eroded phase, locally called caliche soil because of abundant gravel and stones in surface horizons.

Horizon description (Caliche, Site #6)

A	0-10cm	Black (7.5 YR 2/0) gravelly clay loam. Moderate medium angular blocky structure. Plenty medium sized, continuous pores. Abundant fine and medium roots. Moderate efervescence with HCl. Clear wavy boundary.
B	10-22cm	Dark gray (7.5 YR 4/0) gravelly clay. Moderate to strong coarse angular block structure. Plenty fine continuous pores. Plenty fine and medium roots. Moderate efervescence with HCl. Abrupt boundary.
BC	22-50cm	Gray (7.5 YR 6/0) stoney clay. Massive structure. Very few pores and roots. Strong efervescence with HCl. Gradual boundary into marl.
C	50cm +	White (10 YR 8/1) marl.

Analytical data (Caliche, site #6)

Horizon Depth (cm)	A 0-10	B 10-22	BC 22-50
pH	7.8	7.9	8.0
Bulk density (g/cm^3)	0.75	1.0	1.1
Particles > 2mm (%dry soil)	20.0	27.0	35.0
Fine texture(%)			
Coarse sand(2-.1mm)	21.9	n.a.	n.a.
Fine sand(.1-.05mm)	12.1	n.a.	n.a.
Silt(.05-.002mm)	30.7	n.a.	n.a.
Clay(<.002mm)	35.3	n.a.	n.a.
Field Capacity(%)	55	51	40
Exch. cations (meq/100g)			
Ca	64.2	n.a.	72.9
K	0.7	n.a.	0.6
Mg	3.1	n.a.	1.8
Na	0.2	n.a.	0.1
Mn	0.2	n.a.	0.1
H	1.5	n.a.	0.0
C.E.C (meq/100g)	69.8	n.a.	75.3
% Base saturation	98.0	n.a.	99.0
% N	0.25	n.a.	0.23
% OM	5.1	n.a.	4.7
C/N	11.83	n.a.	11.85
Available P (H2O)	0.43	n.a.	0.21
(Bray)	5.6	4.4	n.a.

Caliche (Site #7)

Classification:	Pellic Vertisol (FAO-Unesco), Typic Pellusters (USDA)
Location:	Chauapan, E. Zapata County. School plot in the Chauapan Ejido. 19°21'30" LN, 96°40'30"LW. 1590 m above sea level.
Physiography:	Carrizal Land System, Carrizal landscape, crest land unit (Sancholuz, Marten and Zola, 1981).
Topography:	Upper slope, near crest. 4-5% inclination.
Drainage:	Moderatly well drained.
Vegetation:	Maize fields, cultivated for 15 years.
Parent material:	Marine calcareous deposit, marl.
Remarks:	Beside Chauapan experimental plot (see Ch.5). Moderate erosion phase.

Horizon description (Caliche, Site #7)

A	0-15cm	Black (7.5 YR 2/0) fine clay, weak medium subangular block structure. Plenty fine continuous pores. Few thin clay films. Plenty fine and medium roots. Weak efervescence to HCl. Abrupt boundary.
B1	15-25cm	Very dark gray (10 YR 3/1) very fine clay. Weak to moderate coarse angular blocky structure. Abundant fine and medium roots. Common thin clay films in-ped. Weak efervescence to HCl. Abrupt wavy boundary.
B2	25-40cm	Gray (10 YR 6/1) gravelly very fine clay. Strong angular blocking structure. Few fine pores. Very few fine roots, horizontal. Common moderately thick clay films in. Moderate efervescence to HCl. Gradual boundary.
BC	40-65cm	White (10 YR 8/2) gravelly marl. Massive structure altered by gravel and cobbles. Common pale gray (10 YR 7/2) mottling. Very few pores, no roots. Continues into deep marl.

Analytical data (Caliche, site #7)

Horizon Depth (cm)	A 0-15	B1 15-25	B2 25-40	BC 40-65
pH	7.9	7.7	7.7	7.9
Bulk density (g/cm³)	0.75	1.05	1.1	1.2
Particles > 2mm (%dry soil)	10.0	20.0	35.0	40.0
Fine texture(%)				
Coarse sand(2-.1mm)	10.4	15.0	12.3	n.a.
Fine sand(.1-.05mm)	5.8	8.9	4.7	n.a.
Silt(.05-.002mm)	23.8	2.4	14.3	n.a.
Clay(<.002mm)	60.0	73.7	68.7	n.a.
% Moisture retention (dry basis)				
@ .3bar	60.2	70.2	63.5	n.a.
@ 15bar	38.3	43.4	37.8	n.a.
Field Capacity(%)	55	52	55	55
% N	0.19	0.16	0.09	0.06
% OM	4.09	2.30	1.40	1.20
C/N	12.5	8.3	9.02	11.6
Available P (Olsen) (ppm)	8.5	5.4	5.2	3.0
CBD Extractable (%)				
Fe2O3	0.26	0.14	0.11	n.a.
Al2O3	0.30	0.23	0.23	n.a.
SiO2	0.34	0.30	0.30	n.a.

Caliche (Site #8)

Classification:	Pellic Vertisol (FAO-Unesco), Typic Pellusters (USDA)
Location:	250 m west of Site #7.
Physiography:	Carrizal Land System, Carrizal Landscape, Bottom Land Unit (Sancholuz, Marten and Zola, 1981)
Topography:	Gently concave bottom, slope 1-2% inclination, accumulation site.
Drainage:	Moderatelly well drained.
Vegetation:	Maize field cultivated for 15 years.
Parent material:	Marine calcareous deposits (marl).
Remarks:	Known locally as "barro de fondo" (local mud).

Horizon description (Caliche, Site #8)

A1	0-15cm	Black (7.5 YR 2/0) clay loam. Moderate medium angular block structure. Plenty fine continuous pores. Plenty fine and medium roots. Very weak HCl efervescence. Diffuse boundary.
A2	15-30cm	Black (7.5 YR 2/0) clay loam. Moderate medium angular blocky structure. Plenty fine continuous pores. Plenty fine and medium roots. Weak HCl efervescence. Clear wavy boundary
B1	35-45cm.	Very dark gray (7.5 YR 3/0) clay. Moderate coarse angular blocky structure. Few fine pores, few medium roots. Moderate efervescence with HCl. Diffuse boundary.
B2	45-60cm	light brown-gray (10 YR 6/2) clay. Strong coarse angular block structure. Very few pores and roots. Common thick clay films. Strong HCl efervescence.
BC	55cm +	White (10 YR 8/2) gravelly clay, marl.

Analytical data (Caliche, site #8)

Horizon Depth (cm)	A1 0-15	A2 15-30	B1 30-45	B2 45-60
pH	7.9	7.7	7.7	7.5
Bulk density (g/cm³)	0.80	0.85	0.90	1.0
Particles > 2mm (%dry soil)	5.0	5.0	10.0	20.0
Field Capacity(%)	57	58	58	
% N	0.19	0.21	0.22	0.12
% OM	4.09	5.09	4.54	2.78
C/N	12.5	14.1	11.9	13.44
Available P (Olsen) (ppm)	8.2	3.8	2.8	0.8