Influence of Land Use on Carbon Sequestration and Erosion in Mexico and Central America*

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Abstract

In the past centuries man incorporated many fragile natural resources into production in Mexico and Central America and exploited them under low intensity slash-and-burn system preserving their integrity for long periods. However, in more recent times, such agroecosystems have been subjected to over exploitation and intensive use, in terms of time and space, without consideration for their lack of resilience, due to population growth and the demands to generate profits, as established by the prevailing economic model. The standing practices have resulted in severe human induced land degradation, particularly in tropical areas. Land degradation in desert areas is more a natural type of degradation than an anthropogenic one. A series of alternative technologies to reduce the impact of human activities have been proposed in recent years. Among them, different types of alternative agriculture oriented either to regenerate some of the properties of the systems or to reach its stability. Conservation tillage is an example. Other, is intercropping staple crops and fruit trees (MIAF) techniques developed for hillside agriculture (20 to 60 % slopes) in Mexico. Conservation tillage and MIAF are intimately related to carbon sequestration (soils and above-ground) and to preventing soil erosion. It has been shown in Mexico that the rate of carbon entrance to these systems exceeds the rate of carbon exit. The root residues left in the soil contribute after decomposition to the soil carbon reservoirs, however, the quantity of carbon remaining in the soil after a time is dependent on and controlled by the own system. In contrast, above-ground residues, which are also controlled by the system, may or may not become part of the carbon reserve of the soil because man as an external agent decides the final destination of this carbon. The identification and understanding the structure of the system, and its components, as well as, the role that each of these components plays, is fundamental to intervene in the system and decide on the most appropriate direction. Efforts have been made lately in Mexico and Central America to benefit from international agreements that have created an emerging market for the sequestered carbon. The conservation tillage is one of the agronomic practices linked to preserving soil carbon and even to increasing it, however, a limited surface is maintained under this system in Mexico and Central America, as compared to Argentina and Brazil. A scarce availability of technology for the mostly tropical and hillside agriculture conditions in these regions of the world is often blamed for such situation. However, on-going-research efforts to better understand and to practice conservation agriculture leading to decrease soil erosion and increase carbon sequestration are rather limited.

Key words : Mexico, Central America, Land Use, Erosion, Carbon sequestration

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Introduction

Human population in Central America (including Mexico) has reached approximately 135 million inhabitants. According to demographic projections, population will reach 250 millions by the year 2025. This increasing human conglomerate shares a common territory of almost 265 million hectares. However, farming land is only a fraction of that total (approximately 41 millions ha, and 50% correspond to Mexico) (WRI, 1998).

Mexico's Situation

Mexico by its owns has a surface of nearly 200 million hectares, of which only 21 million hectares are available farmland; 1.6 million hectares are totally eroded and about 2.5 million hectares are classified as highly erodable land. Accelerated soil erosion affects 80 % of Mexico's land (Maass and García-Oliva,1990) and nearly 535 million tons of soil are lost annually (SEMARNAP, 1997). More soil has been lost during the last 40 years than in the past four centuries (Maas and García-Oliva, 1990). Concurrent surface and gully erosion from deforestation and inappropriate cultivation of drylands have been identified on 65 to 85% of the land (Bocco and García-Oliva 1992).

The available farmland in Mexico must support an increasing population that grew from almost 20 to 100 million inhabitants in the last half-century, exerting great pressure on natural resources, particularly soil, water, and forest. The situation is aggravated by the topographic conditions of the country, which presents extreme variations in altitude (sea level to more than 5000 m) where plateau, hillsides, mountains and plains are found. Climate conditions ranges from desert to tropical humid forest (< 200 mm to >2,000 mm rainfall). A very similar situation is found in Central America, as far as population growth and soil degradation.

In the first of these regions, four ecological macro-regions could be recognized (Claverán, 2000): an arid and semiarid region (<500 mm annual rainfall) covering approximately one-half of the national territory, a dry tropical region (900 to 1,200 mm, with seasonal rainfall) that occupies one-fourth of the surface and the remainder area (13 and 8 %) is covered by the temperate hilly areas (600 to 900 mm) and the humid tropics (>1,200 mm) respectively.

Agriculture is practiced in all four mentioned regions existing in Mexico. Unfortunately only 16% the arable land is as prime farm land suitable for high-input agriculture. The rest of the land is mostly either located on steep-slope terrain or in marginal semiarid conditions (INEGI 1998; Tiscareño *et al.*, 2000) inhabited by little over 3 millions farmers. Shortage of armland has resulted in increasing aggression to native forest and in a constant increment of steep slopes being cultivated. As a consequence, Mexico's temperate and tropical forests have been reduced by 30 and 75 per cent since 1960, respectively. According to the World Resources Institute (1994), Mexico ranks among countries having the highest annual rates of diminishing native forests.

Hillside agriculture is located along the sierras that crisscross the country, but mainly in the southern part where rainfall is abundant. Irrigated land, an area of more than 6 million hectares, is found in central and northern parts of Mexico. Water is one of the most serious limiting factors for present and future agriculture functioning in this part of the country. Land degradation and erosion are common features in most of the agricultural land in this country. The main types of land degradation and the fraction of territory affected by them are presented in Table 1. Almost 85% of the country's territory is affected by water erosion and 85% by biological erosion (organic matter losses) according to a methodology recommended by FAO (FAO-UNEP-UNESCO, 1980). Figure 1 shows different intensities of soil water erosion in Mexico which range from less than 10 Mg ha^{-1} up to 200 Mg ha^{-1}. Soil erosion reduces productivity. It is estimated that the average soil loss in Mexico is approximately 2.8 Mg ha^{-1} (Figueroa and Ventura, 1990). Water erosion is closely associated to slopes higher than 10% and management practices tending to maintain the soil without protection when the rainy season starts. On the opposite hand, eolic erosion is more important under arid and semi-arid conditions. Losses of approximately 140 Mg ha^{-1} of soil have been reported for that type of conditions (Amante, 1989; Osuna, 1991). This figure contrasts with losses of 40 8 Mg ha^{-1} caused by water erosion.

Table 1: Land Degradation in the Mexican Territory (CONAZA, 1994).

Type of Land Degradation	Fraction of the Territory Affected %
Water erosion	85
Wind erosion	60
Lixviation of bases	15
Physical degradation	20
Biological degradation	80
Salinity	20
Sodification	15

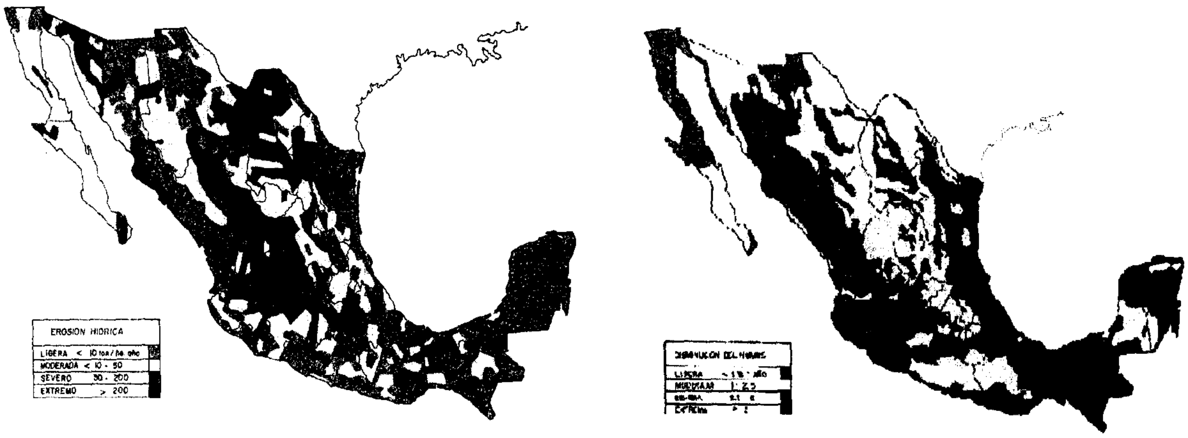

Figure 1. Water and biological erosion in Mexico (CONAZA, 1994).

Biological degradation in soils of Mexico is shown in Figure 2. It is considered the second largest process of soil degradation after water erosion in the country and it represents the rate of organic matter mineralization, according to the FAO proposed methodology (FAO-UNEP-UNESCO, 1980).

Approximately 80% of the territory is affected by biological degradation which is a function of climate. Organic matter degradation is more probable to occur in areas closer to coastlines and less probable in the semiarid and arid zones. Biological degradation is also caused by the reduction of the top soil and excessive cropping. Water and biological degradation can be reduced and even reverted by proper management, as conservation tillage.

Conservation tillage

Zero tillage farming is a pre-hispanic practice probably dating back to 5000 to 9000 years ago, associated to squash and maize cropping practices. Seeds were deposited in a hole (the soil was not inverted or moved) made with a hand operated instrument, usually after slashing and burning the native vegetation. Periods in between slash-and-burn cycles were long enough to allow the secondary vegetation to regrowth to near its original state (Figueroa and Morales, 1972). Soil erosion was rather negligible during that period. A primitive plow (Egyptian plow) introduced to America by the Europeans (Claverán et al., 2001) along the oxen and horses is blamed to be the beginning of today extensive erosion. Today farmers could make an average of 10, but as many as 23 passes of machines over their fields in the traditional mechanized system (Anonymous, 2002). FIRA (2000) estimates that in the year 2000 there were 850 thousand hectares under conservation tillage in Mexico, *i. e* approximately 4% of the cultivated surface, mostly in the central states of Michoacán, Jalisco and Guanajuato.. This surface is small when compared with figures given for other Latin America countries, for instance, Brazil and Argentina.

A strong interest on conservation tillage has been shown by multilateral organisms as the World Bank and by private institutes as the Harvard Institute for International Development. Numerous papers on the subject, mainly oriented to the economics of the practice and the improvement of environmental services, have been published . Most recently Pieri (2000) produced a general document pointing out some strategies for international cooperation, showing examples of multilateral and bilateral donors and producers getting together to increase awareness, and develop knowledge and skills in the implementation of approaches to sustainable agriculture. Pieri et al. (2002a y 2002b) recently published two papers "A road map from conventional to no-till farming" and "No-till farming for sustainable development". These documents are intended to inform and sensitize rural development stakeholders about the potential contribution and need to invest in no-tillage farming as an approach to sustainable rural development.

To cope with such an intensive rate of degradation a research program on conservation tillage was initiated at the National Institute of Forestry, Agricultural, and Animal Production Research (INIFAP) during the 50's, establishing a small number of no-tillage experiments, however, these activities were soon abandoned due to lack of success (Claverán, 2000). The International Center for Maize and Wheat Improvement (CIMMYT) promoted the most recent cycle of interest on conservation tillage which started at the end of the 70's. Conservation tillage related activities were conducted jointly with FIRA (a government credit and development institution serving the agricultural sector) and INIFAP. Initial study trips and training courses gave way to demonstration plots and promotion of conservation tillage by FIRA, as well as to limited research by INIFAP (Claverán, 2000). In 1996 INIFAP created the National Research Center for Sustainable Production (CENAPROS), a program responsible for coordinating research consrvation tillage and related subjects. A first reports of activities were published by this Center in 1997 (Claverán et al., 1997; Velásquez et al., 1997) and just recently the second document has been made available (Claverán and Rulfo, 2001). In the meantime a RELACO (Red Latinoamericana de Agricultura Conservacionista, 1997) meeting was hosted by CENAPROS and FIRA in Mexico, and an international symposium on conservation tillage was held in 2000 (INIFAP, 2000).

A great portion of the experience on conservation agriculture in Latin America, including the Mexican and Central American ones, has been documented in the RELACO meeting reports (RELACO, 1993, 1995, 1997, and 1999). Some of these documents published in the proceedings of these meetings can be consulted at SIDALC (Sistema de Inf. y Doc. Agropecuario de América) on the web (http://sidalc.sidalcus.net) or in the RELACO page (http://www.iica.org.mx/investiga.htm).

Some time ago, FIRA established in central Mexico a training center (Villa Diego) mostly devoted to the validation and transfer of sustainable agriculture, and particularly of conservation tillage (http://www.fira.gob.mx). In this unit technical personnel is trained mostly on practical aspects of the conservation tillage, like machinery use. No deep research issues are in the agenda of the center, although the Villa Diego center has accomplished an important role in transferring certain aspects of the conservation tillage technology to technical personnel and farmers.

CIMMYT has been one of the most active institutions in conducting research on conservation tillage in Mexico and Central America, however, the emphasis has been on the agronomic and economic aspects of this technology. Agricultural research in Mexico has been largely driven by the concept of crop productivity, as a means to achieve business profitability and a better standard of living for farmers. The extensive literature produced by this international center on the topic makes little reference to carbon sequestration and soil erosion losses (Scopel, 1997a, b, and c Buckles and Erenstein,1996; Erestein, 1997; Erenstein and Cadena, 1997; Erenstein, 1999a; Scopel et al., 2001). CIMMYT has worked mainly in tropical regions for more than 10 years: La Fraylesca and Motozintla, Chiapas (Van Nieuwkoop et al., 1994), and Los Tuxtlas, Veracruz (Erenstein and Cadena, 1997; Buckles and Erenstein, 1996; Soule, 1997) and Ciudad Guzman, Jalisco (Scopel, 1997 a) and in irrigated districts of the northern part and the rainfed central platteau of Mexico (Sayre, 2000; Sayre et al., 2001).

In addition to INIFAP, FIRA and CIMMYt, other institutions have also developed research and conservation technology transfer programs The Colegio de Postgraduados has been one of the most active educational and research institution in this field by itself or in collaboration with the Ministry of Agriculture (SAGARPA). A number of Master of Science and Ph. D.theses (Román, 1993; Muñoz, 1993; Vidal, 1994; García, 1994; Pérez,1996; Uribe, 1997, Sandoval, 1997; Navarro 1998; Tapia, 1999; Magallanes, 1999) have been produced on conservation agriculture in recent years. The emphasis of most of these works is on soil characteristics and their relationships. Figueroa and Morales (1972) and.Navarro (2000) have published more applied technical documents addressed to producers interested in adopting the conservation tillage technology.

A few non governmental organization (NGO) are participating in the transfer process of technology generated by research experts to field conditions. An example is a network financed and consolidated by the Rockefeller Foundation that operates mainly in tropical regions (Claverán, 2000)..

Research conducted so far in Mexico has addressed crucial aspects of conservation tillage. The most important questions answered were: Is minimum, zero or ridge tillage the best option?, What is the amount of residue to be left on the soil?, What is the most appropriate sowing machinery for conservation tillage; Are conservation tillage technologies designed for irrigated agriculture adequate for rainfed conditions?.

Experimental results showed the significant advantages of zero tillage over either conventional or minimum tillage. Over a 100 experiments conducted during a 5-year period showed that zero tillage reduced the erosion rate by nearly 80% in maize crops, and by nearly 95% in wheat crops with respect to conventional tillage. Along time, the use of zero tillage tends to increase even more than soil protection (Osuna, 1997; Velasquez, 1997).Under moderate slope conditions (8%) there was a considerable reduction of soil erosion in Andosols with zero tillage (90 to 60% reduction) as compared to conventional tillage (Tiscareño *et al.*, 1997). In cultivated lands on steeper slopes in southern Veracruz, Uribe (1998) determined that 27 kg of soil were lost per each kilogram of maize produced under conventional tillage; under zero tillage the loss was reduced to less than 1 kg of soil as a mean for 4 years.

It was found in Mexico and other countries that if the third part of prior crop residue is left on the soil, protection against erosion is good enough in temperate climate environments (Velasquez, *et al.*, 1997). In tropical climates this is not enough since a larger quantity of residues is required due to the high decomposition rate of organic matter (Van Nieuwkoop *et al.*, 1994; Erenstein, 1999b). Along years, the research program has acquired enough experience on the most important crop residues, maize stubble and wheat straw.

One of the factors which has limited the adoption of conservation tillage in Mexico (and many Central American countries) is the need to use crop residues for cattle feeding, even when the farmer realizes the importance of crop residues for reducing erosion losses and restoring soil fertility. An investigation in Chiapas found that 49% of 443 farmers interviewed, who cultivated maize and maize-beans in lands of more than 40% slope, knew about the importance of using residues. Nevertheless, 87% of those interviewed had to feed at least one livestock unit (Anonymous, 2002). Other barriers have also hindered the extensive adoption of conservation tillage among Mexican farmers (Claverán, 2000): a social attitude that makes it difficult to implement any change from conventional systems; producers use stubble to feed animals; some farmers sell crop residues or burn them to "clean" the land; a deficit of technical personnel appropriately prepared; previous failures with conservation tillage, and high investments in machinery to switch from conventional to conservation tillage could be added.

Soil Erosion

Most information on soil erosion losses have been obtained from measurements conducted in small run-off plots. However large watershed and models have been also studied. Variables studied in small run-off plots ranges from different crops to the effect of soil management systems. Plots have been installed in rainfed regions as well as on irrigated areas. Three contrasting conditions are shown in the present paper. dryland agriculture, volcanic soils and hillside.

Soil erosion under rainfed-semiarid conditions. The Aguascalientes study case (Osuna 1997).

Table 2 shows the soil lost under various planted crops in a region with marked differences in seasonal precipitation (Osuna 1997).. Average rainfall was 587 mm yr^{-1} and had a high erosive potential. Eighty one percent of the events were classified as erosive in this site. Maize and beans are crops that require frequent weeding and showed higher soil losses than wheat, a crop that protects the surface because of its higher plant population. The effect of soil losses when maize was managed under different management practices is shown in Table 3. The results presented in the previous table show that under certain very specific conditions soil losses can be reduced by using an appropriate type of plow and that zero tillage was not the best option. Maintaining an adequate soil cover appears to be as important as not removing the soil. In another series of experiments conducted under similar conditions of restricted rainfall no advantages of the zero tillage over conventional tillage were observed (Jasso, 1997).

Table 2 Soil losses under different crops in a rainfed region. A 4-year-period average (El Llano, Aguascalientes, Mexico) (Osuna, 1997).

Crop	Soil loss Mg ha-1	Relative loss
Maize	12.7	0.39
Beans	8.9	0.28
Wheat	1.5	0.05
Screen	203	0.07
Check (permanent fallow)	32.3	

Table 3. Soil losses under different management systems of maize in a rainfed region. A 4-year-period average (El Llano, Aguascalientes, Mexico) (Osuna, 1997)

Soil management	Soil loss Mg ha-1	C coefficient	Maize yield Mg ha-1
Disc plow, no weeding	5.0	.08	1.70
Grade, no weeding	64.9	0.93	1.41
Chissel, no weeding	33.1	0.55	1.63
Zero tillage	26.3	0.44	1.10

Soil erosion in volcanic landscapes. The Pátzcuaro Basin study case (Tiscareño et al., 2000).

The Pátzcuaro Watershed is located in La Meseta Tarasca, Michoacán, Mexico (average annual temperature and rainfall =14.5°C and 1,002 mm, mostly from June to October, respectively; 2,100 masl). The dominant soils are sandy loam textured Andisols, easily erodible under dry or wet conditions due to its poor structure (Cabrera, 1988). The Pátzcuaro Watershed is representative of many hectares of volcanic lands in Mexico, Central America and the Andean countries, where the small landholders grow annual crops under steep-terrain conditions. Soil erosion and nutrient losses are common features in this area. According to Tiscareño *et al.* (2000) conservation tillage seemed to be an appropriate technology to solve the above-mentioned problems (Figure 2). After 4 years of research these authors concluded that Andisols were soils highly susceptible to tillage intensity. According to these authors cropping systems, which use plow and disk-based tillage implements, resulted in highly erodible conditions for the poorly structured soils of this watershed. Soil losses averaged 3.2 Mg/ha/yr for conventional tillage and 2.6 Mg/ha/yr for minimum-tillage on an 8% slope.

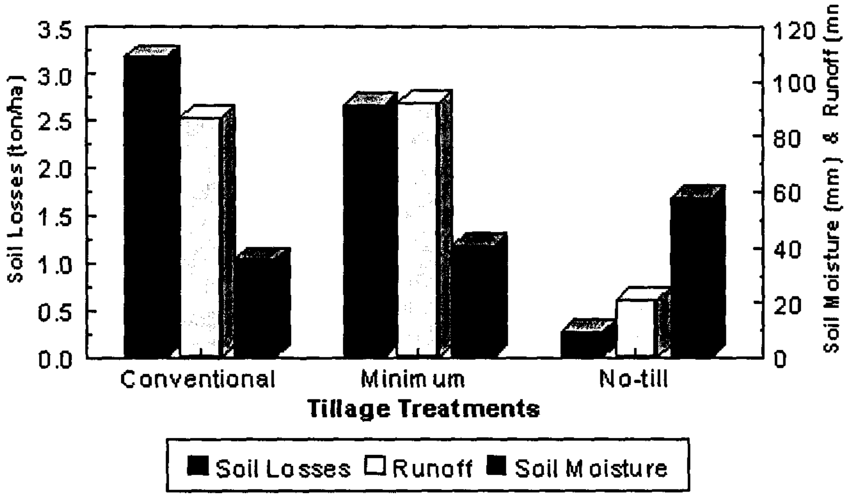

Figure 2. Soil losses, runoff and 150-mm layer soil moisture for three tillage treatments. Residual soil moisture after harvest (Tiscareño *et al.*, 2000)No-tillage was able to reduce soil losses to less than 0.3 Mg/ha/yr (Figure 3). Minimization of storm water runoff with mulched no-till systems becomes a key factor to prevent sediment yield and promote infiltration and deep-water percolation for lake recharge in this closed watershed. Compared with conventional tillage, no-tillage reduced runoff by 76% (21.2 mm vs. 88 mm of runoff) and increased soil water retention to 53% in the first 150-mm soil layer during the dry season (February to April). .

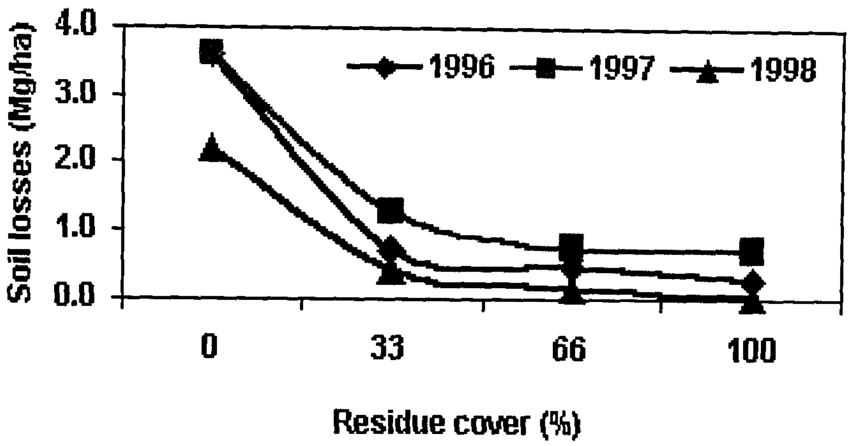

Figure 3. Reduction of sediment yield in no-tillage treatments by the effect of residue cover (Tiscareño *et al.*, 2000)

The impact of residue cover on soil losses when using no-tillage was tested with a range of residue surface cover of 0, 33, 66 and 100 per cent, consisting of chopped corn stalks from a previous harvest. Figure 3 illustrates that soil losses are reduced by 80 per cent (0.72 Mg/ha) by leaving 33 per cent of crop residue with no-till in comparison with zero surface cover in no-till (3.62 Mg/ha).

It is important to consider that farmers need crop residues to feed their animals. Because of the difficulty in making good residue cover measurements by the peasants, a practical recommendation is given in terms of straw rows. For example, "*as minimum, leave over the field one of three rows of straw to get a protective soil cover.*" It is estimated, however, that full soil coverage with crop residues is reached after six consecutive years of leaving all crop residues. Water infiltration and soil water content during the dry season (February - April) have been found to be proportional to residue cover with direct effects on crop yield (Table 4).

Table 4. Runoff, soil water and crop yield responses by tillage treatment.

	No-Tillage / Residue Cover				**Tillage**	
	0%	**33%**	**66%**	**100%**	**Minimum**	**Conventional**
Runoff (mm)	92.0	24.0	21.2	19.6	92.3	86.9
N in Runoff (kg/ha)*	3.62	2.67	1.94	0.87	9.32	7.05
Soil Moisture (mm)**	48.3	50.4	52.0	57.9	42.0	37.8
Corn Canopy Cover (%)†	7.0	8.0	12.0	12.0	4.0	6.0
Grain Yield (ton/ha)	2.63	3.06	3.18	3.52	3.00	2.84
Straw Yield (ton/ha)	6.14	7.75	6.99	6.84	9.02	8.46

* *$N\text{-}NO_3$ and $N\text{-}NH_4$*

** *In March (dry season) at the first 150-mm soil layer.*

† *30 days after planting (second week of June).*

In addition, crop yield responses have improved when applying no-tillage and crop residues as mulch. No-tillage with 100 per cent residue cover improved grain yield by 0.7 Mg/ha with respect to maize under conventional tillage. This is largely attributed to reductions in runoff and nitrogen losses and improvement of soil water retention. Recalling that the regional average maize yield is 1.5 Mg/ha, this increment of crop yield is perhaps the most attractive technological response in adopting conservation tillage (Tiscareño *et al.*, 2000).

Soil erosion in hillside slopes. The PMSL(Oaxaca) study case (Martínez, 2002)

Soil and carbon losses were monitored in selected experimental watersheds in the Northern Sierra of Oaxaca, Mexico. High population pressure in this area has lead to an extensive land clearing in the past centuries. Slash-and-burn is still a widely used practice.

The influence of different soil management systems on water run-off, soil erosion and carbon losses is being studied by Martínez (2002) in three experimental watersheds in the above mentioned region. Standard run-off plots (25m x 2 m) equipped with sediment collectors and weather stations are installed in all three watersheds in selected management systems (a total of 18).

Tables 5, 6, and 7 show the average annual run-off, soil erosion and related parameters corresponding to various soil management systems in the three experimental watersheds.

Table 5. Water run-off, run-off coefficient and soil erosion in the Mazateca Watershed (Martínez, 2002)

Treatment	**Rainfall mm**	**Run-off l**	**Run-off coeff.**	**Conc $g\ l^{-1}$**	**Erosion $g\ lote^{-1}$**	**Erosion $kg\ ha^{-1}$**
Coffee	2 215	305 (6.1)[1]	0.0028	0.0392	12.0	2.39
Maize- Traditional (L)	2 282	373 (7.5)	0.0033	0.0301	11.3	2.25
Maize+peach intercrop. (L)	2 245	162 (3.3)	0.0014	0.0446	7.3	1.45
Slash-and-Burn	2 353	446 (8.9)	0.0038	0.0700	31.2	6.25
Pasture	2 349	1,878 (37.6)	0.0160	0.2261	443.5	88.71
"Acahual"	2 365	244 (4.9)	0.0021	0.0282	6.9	1.38
Maize- Traditional (H)	2 020	618 (12.1)	0.0061	0.0931	57.6	11.51
Maize+peach intercrop. (H)	2 024	205 (4.10)	0.0020	0.0279	5.7	1.14

H and L refers to high and low locations within the watershed

[1] **( ) Runn-off values in mm**

Table 6. Water run-off, run-off coefficient and soil erosion in the Cuicateca watershed (Martínez, 2002)

Treatment	**Rainfall mm**	**Run-off l**	**Run-off coeff.**	**Conc $g\ l^{-1}$**	**Erosion $g\ lote^{-1}$**	**Erosion $kg\ ha^{-1}$**
Maize- Traditional	792	324 (6.5[1])	0.0082	17.6	5 284	1,090
Maize+peach intercrop. (H)	765	90 (1.8[1])	0.0024	15.1	1 362	272
Maize+peach intercrop.	777	644 (12.9[1])	0.0166	14.6	8 004	1,600
Quercus	721	53 (0.6[1])	0.0015	0.3	18	4
Maize+peach intercrop. (L)	712	70 (1.4[1])	0.0020	37.1	1 702	340
Pasture	702	250 (5.0[1])	0.0071	7.5	1 870	374

H and L refers to high and low locations within the watershed

[1] **( ) Runn-off values in mm**

Table 7 Water run-off, run-off coefficient and soil erosion in Mixe watershed (Martínez, 2002).

Treatment	**Rainfall mm**	**Run-off l**	**Run-off coeff.**	**Conc $g\ l^{-1}$**	**Erosion $g\ lote^{-1}$**	**Erosion $kg\ ha^{-1}$**
Coffee	1 109	706 (14.1)[1]	0.0127	0.38	202	40.
Maize+Coffee	1 121	855 (17.1)	0.0153	0.13	95	20
Slash-and-burn	1 111	780 (15.6)	0.0141	0.07	45	9
"Acahual"	1 032	487 (9.8)	0.0094	0.19	74	14

[1] ( ) Runn-off values in mm.

The extremely atypical results from the PMSL experimental plots are extensively discussed by Martínez (2002). A brief summary of his own conclusions are presented here: run-off in most conditions were very low in spite of high precipitation recorded (1000 to 2000mm) and slopes ranging from 20 to near 50%. The values of the run-off coefficient (the relation between rainfall and run-off) allows to conclude that most of the water infiltrates and does not run-off. The treatments with the lowest run-off were the maize and fruit trees intercropping. Sediments concentration in run-off was very low. Soil erosion was very low not withstanding the slope conditions and the management systems.

Soil carbon and carbon sequestration

The pool of soil organic carbon plays a key role in the global carbon cycle; it influences the atmospheric pool of CO_2. The levels of soil organic carbon can be managed to increase the terrestrial carbon pool and provide a sink for atmospheric CO_2. The potential of different ecoregions in the world to sequester carbon varies climate, soil type and depth, landuse, management. Crop and soil management practices are of particular significance to the soil organic carbon pool. A higher production of biomass and tillage methods which do not invert the soil , like no-tillage tillage, can increase soil organic carbon pool (Lal, 1984; Lal, 1989). Conversely, soil management practices leading to soil inversion and siturbance may result in a decrease of the soil organic carbon content. Tillage techniques were viewed and studied in the past mainly as soil erosion mitigation processes. However, today is understood that they can be used to increase carbon sequestration.

In addition to the above mentioned benefits of the reduced tillage practices on soil carbon content, this CO_2 is an important contributor to soil quality. Recently, soil carbon has come under increased attention as a possible method to store carbon and reduce future increases in atmospheric CO_2 concentration (Kern and Johnson, 1993) Carbon content in soils increases with no-till management practices compared to soils with annual tillage (Potter, 2002). Limited information has been published in Mexico on the effect of conservation tillage on soil carbon (Baez, 2001; Etchevers et al., 2001; Salinas et al., 2001; Sandoval, 1997; Velásquez et al., 2001). A brief summary of some relevant case studies recently published will be presented.

Soil carbon and soil management. Mega-environment 2 case study (Sandoval, 1997).

Table 8 shows the effect of conventional and zero tillage and previous crop residues management on soil organic matter, soil organic and soluble Carbon, Kjeldahl nitrogen and C/N after 5 years the initiation of the treatments in a Phaeozem representative on Mega-Environment 2 (Highlands Valleys of Mexico, Kenya, Ethiopia) (Sandoval, 1997, Etchevers, 2001). The results presented are the average value of eight different rotations including maize, wheat, and Vicia. Zero tillage influenced organic and soluble carbon, as well as Kjeldahl nitrogen, up to a 20 to 40 cm depth increment.. Largest effects of tillage systems were observed on carbon percentage and on a soluble carbon indicator in the

0 to 5 cm depth increment. Zero tillage treatments accumulated significative more carbon than conventional tillage after 5 years and more soluble carbon was measured under the former condition. Conventional tillage allowed more carbon to be accumulated in the 10 to 20 cm depth increment due to the surface soil inversion caused by plowing. Surface soil contains more root and plant residues than the underlying soil. When this is plowed down it increases the carbon content in the lower layer. Carbon located in deeper layers could be retained for a longer time than carbon in residues left on the soil surface.

Tillage system also affected some soil physical properties as shown on Table 9. Soil physical conditions were also affected by tillage and residues management system. Conventional tillage resulted in a lower bulk density, resistance to penetration, and volumetric soil moisture in the upper layers than zero tillage.

Table 8 . Effect of soil tillage and residues management on soil organic matter, soil organic and soluble Carbon, Kjeldahl Nitrogen and C/N after 5 years of treatment (Sandoval, 1997).

Main treatments	Indicator†				
	OM	C	Csol	Nkj	C/N
	%	%	Abs	%	
			0-5 cm depth		
Zero tillage	2.3a	1.32a	0.309a	1.12a	11a
Conventional tillage	1.8b	1.05b	0.250b	0.10b	11a
With residues	2.1a	1.23a	0.311a	0.12a	11a
Without residues	2.0a	1.15b	0.256b	0.11a	11a
			5-10 cm depth		
Zero tillage	1.9a	1.09a	0.233a	0.10a	0.11a
Conventional tillage	1.8a	1.07a	0.247a	0.10a	0.11a
With residues	2.0a	1.14a	0.265a	0.10a	0.11a
Without residues	1.8a	1.04a	0.222b	0.10a	0.11a
			10-20 cm depth		
Zero tillage	1.6b	0.95b	0.218a	0.09b	11a
Conventional tillage	1.9a	1.09a	0.226a	0.10a	11a
With residues	1.8a	1.06a	0.234a	0.10a	11a
Without residues	1.7a	1.00a	0.213a	0.09b	11a
			20-40 cm depth		
Zero tillage	1.5a	0.88a			
Conventional tillage	1.6a	0.93a			
With residues	1.7a	0.96a			
Without residues	1.5a	0.86b			
			40-60 cm depth		
Zero tillage	1.4a	0.87a			
Conventional tillage	1.4a	0.80a			
With residues	1.5a	0.84a			
Without residues	1.4a	0.82a			

† Different letters after the number indicates significant differences. Comparison must be made between zero and conventional tillage,and between with and without residues.

Residues left on the surface affected only resistence to penetration at the 210 to 360 mm depth increment. Zero tillage resulted in more water being retained in the upper 5 cm of the soil profile.

Table 9. Effect of soil tillage and residues management on some phsyical soil quality indicators after 5 years of treatment (Sandoval, 1997).

Treatment	Bd 0 a 50 mm g cm^{-3}	Volumetric[4] soil moisture 0 a 50 mm cm^{3}cm^{-3}	Resistence to penetration 150 a 210 mm KPa	Resistence to penetration 210 a 360 mm KPa
Zero tillage with residues	1.5a[1]	13.9	1985a[1]	1615b
Zero tillage without residues	1.3a	9.9	2037a	1848a
Conv. tillage with residues	0.9b	7.0	1147b	1673b
Conv. tillage without residues	0.9b	6.8	1206b	1815a
DMS[2]	0.3		138	
Cv[3]	17.5		5.7	

Carbon in different land use systems in hillside conditions in Mexico (Etchevers et al., 2002; Martínez, 2002).

Carbon content in the above ground, root and the soil components found under different landuse systems in three experimental watersheds located in The Northern Sierra of Oaxaca are presented in Table 10 (Etchevers et al., 2002).

The highest stock of organic C (above-ground+roots+soil) was determined in the Mixe watershed (306 Mg ha^{-1}) and the lowest in the Cuicateca (84 Mg ha^{-1}). C stocks associated to different laduses (secondary native forest, permanent agricultural crops, annual and mixed annual+fruit trees crops) did not differed much within watersheds. That is agricultural system can accumulated as much C as secondary native forest systems. C stored in the soil was higher than in the above-ground portion. In the the agricultural systems more than 90% of the C was found in the soil, but less than 90% in the forestry systems. Secondary native forest in the Mazateca and Cuicateca watersheds showed slightly higher stocks of C than the annual agricultural systems. In the Mixe region only "acahuales" (2 to 10 years old) were measured. These acahuales contained less C than the agricultural systems. A clear increment of the C stocks in the above-ground portion of the secondary forestry vegetation (forest and "acahuales") was observed as they grew older.

In contrast, C stocked in the soil depends more on the quality of residues, moisture conditions than on the age of vegetal system. Annual increments of C in the system including fruit trees were approximately 1 to 2 Mg ha-1 year-1.

The analysis of the vertical distribution of carbon in the soil showed that carbon percentage diminished with depth. . Approximately 60% of carbon was concentrated on the first 50 cm of the soil profile (Acosta *et al.,* 2001; Acosta *et al.,* 2002). Also the spatial variability of the soil organic matter in the experimental and observation plots was studied, where a great variability was found within small distances (Vergara *et al.*, 2002).

Table 10. Organic carbon in the above-ground, root and soil (0 to 105 cm) components in landuse systems prevailing in three regions of Northern Sierra, Oaxaca, Mexico (Etchevers, 2002).

	Natural Systems	**Agricultural systems**		
Component		Perman.	----Mixed-	-------Annual-------

						Mg ha^{-1}					
						Mazateca					
	LF	AF 15	AF 10	CA	PA	Plw^{1}	Plw^{2}	CT^{1}	CT^{2}	TT^{1}	TT^{2}
Aerial part	99.5	46.3	31.0	34.5	5.4	6.1	3.5	6.1	3.5	3.2	1.8
humus	5.9	8.4	12.6	9.1	0	0	0	0	0	0	0
weed.+bush	0.5	1.0	3.0	0.7	5.4	1.3	1.6	0.6	1.2	1.0	1.4
trees	93.1	36.9	15.4	24.7	0	1.3	*	0	0	0	0
straw	0	0	0	0	0	3.5	1.9	5.4	2.3	2.3	0.5
Root	3.3	2.3	4.1	4.8	1.4	1.5	2.9	2.3	4.3	2.0	5.5
Soil	152	156	240	148	174	158	128	266	273	235	195
Total	255	205	275	187	181	166	135	274	281	240	202
						Cuicateca					
	QF			PR		Plw	Plw‘	CT‘	CT‘	TT‘	TT‘
Aerial part	37.6			2.2		4.3	3.4	4.2	3.8	3.3	2.7
humus	7.6			0		0	0	0	0	0	0
weed+bush.	0			2.2		0.2	0.5	0.6	0.6	0.3	0.4
trees	30.0			0		0.7	0	0	0	0	0
straw	0			0		3.4	2.8	3.5	3.1	3.0	2.2
Root	14.4			6.1		0.7	1.0	1.9	1.2	0.6	0.6
Soil	45			91		63	113	66	49	57	65
Total	97			99		68	117	72	54	61	68
						Mixe					
	AC10	AC7	AC2	CA		**Clw**		CT	TT		
Aerial part	25.0	24.1	9.9	11.2		5.6		3.1	4.8		
humus	7.3	6.7	3.3	2.0		0		0	0		
weed+bush.	4.3	1.9	6.6	0.3		0.9		1.0	1.0		
trees	13.4	15.5	0	8.9		0.2		0	0		
straw	0	0	0	0		4.5		2.1	3.8		
Root	7.8	5.1	3.8	4.0		1.9		2.8	2.9		
Soil	120	169	119	160		266		278	298		
Total	153	199	133	175		273		284	306		

LF = Liquidambar forest; AF10 and AF15 = Alnus forest of 10 and 15 years old; PA =Pasture, Plw = Peach living walls: CT and TT = Conservation Tillage and Traditional Tillage; QF = Quercus Forest; AC2, AC7, AC10= Acahuales of 2, 7 and 10 years old; CA = Café; Clw = Coffee living walls; ^{1}>30; ^{2}<30= slope percentage

Table 11 shows the amount of carbon captured in weeds, stubble, and peach and coffee trees of living walls and barrier systems (PLW<30), conservation tillage (CT) and traditional tillage (TT), in the three experimental microbasins (Mazateca, Cuicateca and Mixe).

Tables 12, 13, and 14 show the amount of carbon lost in soil sediments and water run-off from experimental plots located in high slopes in the Northern Sierra of Oaxaca, Mexico (Martínez, 2002.

Table 11. Carbon captured annually in selected systems of the three regions (Etchevers, 2002)

Plot	Weed C		Stubble C			Peach trees C			
	2001	2002	2000	2001	2002	2000	2001	2002	Inc/year
					Mazateca				
Plw[1]	1.3	1.6	2.2	4.3	4.3	1.2		3.5	1.9
CT[1]	0.6	1.3	2.7	3.2	3.2				
TT[1]	1.0	1.1	2.3	3.3	1.9				
Plw[2]	1.6	2.1	1.6	2.3	2.3	0		1.0	0.9
CT[2]	1.2	2.5	1.7	2.2	2.2				
TT[2]	1.4	1.4	1.0	1.8	1.9				
					Cuicateca				
Plw	0.5	N/I[3]	2.6	N/I	N/I		0	0.1	0.1
CT	0.6	0.4	3.2	N/I	N/I				
TT	0.4	N/I	2.2	N/I	N/I				
Plw	0.2	0.4	3.3	1.8	1.5		0.7	1.0	0.3
CT	0.6	0.4	2.1	N/I	N/I				
TT	0.3	N/I	3.0	2.1	2.2				
					Mixe				
Clw	0.9	2.4	4.2	2.8	2.8		0.4	1.6	1.3
CT	1.0	1.6	1.9	3.4	3.4				
TT	0.7	1.9	0.8	2.9	2.9				

Plw = Peach living walls; Clw= Coffee living walls; CT and TT = Conservation tillage and Traditional tillage; [1] >30; [2] <30=slope percentage, [3] N/I=No information.

Table 12. Soil carbon losses in surface run-off in Mazateca Watershed (Martínez, 2002)

Land use	Rainfall mm	Run-off l	Erosión kg ha^{-1}	Carbon (ppm)	
				Soil	Water
Coffee	2 215	305	2.4	19.9	67.3
Maize- Traditional (L)	2 282	373	2.3	11.5	12.5
Maize+peach intercrop. (L)	2 245	162	1.5	27.1	5.3
Slash-and-Burn	2 353	446	6.3	15.2	6.1
Pasture	2 349	1 878	88.7	10.9	3.7
"Acahual"	2 365	244	1.4	39.4	9.3
Maize- Traditional (H)	2 020	618	11.5	12.1	10.2
Maize+peach intercrop. (H)	2 024	205	1.1	13.6	4.1

H and L refers to high and low locations within the watershed

Table 13. Soil carbon losses in surface run-off in the Cuicateca Watershed (Martínez, 2002).

Treatment	Rainfall mm	Run-off l	Erosión kg ha^{-1}	Carbon (ppm)	
				Soil	Water
Maize- Traditional	792	324	1 090	2.3	7.2
Maize+peach intercrop. (H)	765	90	272	10.2	34.9
Maize+peach intercrop.	777	644	1 600	2.4	7.4
Quercus	721	53	3	37.1	26.1
Maize+peach intercrop. (L)	712	70	340	1.8	6.4
Pasture	702	250	374	3.8	88.8

H and L refers to high and low locations within the watershed

Table 14. Soil carbon losses in surface run-off in the Mixe Watershed (Martínez, 2002).

Treatment	Rainfall	Run-off	Erosión	Carbon (ppm)	
	mm	l	kg ha^{-1}	Soil	Water
Coffee	1 109	706	40.4	9.6	4.4
Maize+Coffee Intercrop.	1 121	855	20.6	12.2	3.2
Slash-and-burn	1 111	780	9.0	14.2	14.2
"Acahual"	1 032	487	14.8	13.9	4.9

The carbon lost in the soil sediments and water run-off in these high slopes plots is very small. They are explained by the low rate of erosion that occurs under the prevailing conditions, where water infiltration rate is high. Traditional land use systems like slash-and-burn, may not be as aggressive on soil carbon as is generally considered.

Carbon accumulation in recovered indurate volcanic materials ("Tepetates") (Báez et al , 2002).

Báez (2001) presented information (Figure 4) that shows how this indurate volcanic material, that is not a soil in its original state, and after amelioration of its physical and chemical properties begins its transformation, accumulates carbon. Carbon sequestered is a clear function of time and management.

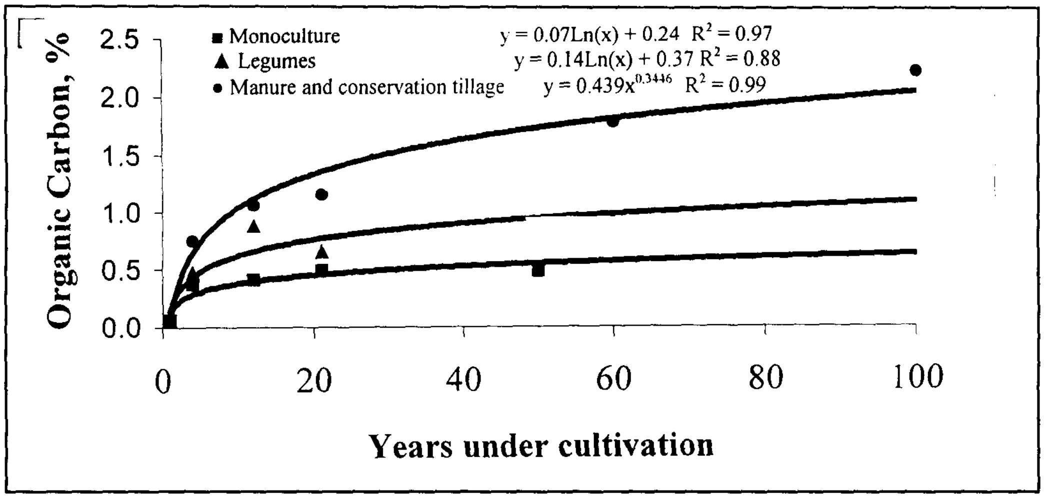

Figure 4. Organic carbon acumulation under different management systems in indurate volcanic material ("tepetate") conditioned for agriculture (Baez et al., 2002).

Effect of management system on carbon accumulation in the soil (Salinas et al., 2001: Velázquez et al., 2001).

Figure 5 and 6 show the effect of the management system on the organic carbon accumulation and distribution on the soil profile and on total carbon accumulation in the top 5 cm, respectively. Salinas et al. (2001) and Velázquez (2001) reported data obtained mainly from volcanic soils in the state of Michoacán.. In both cases it is observed that zero tillage and preserving all residues in the surface result in the highest organic carbon accumulation in the top soil. Zero tillage is a viable alternative to increase carbon sequestration by soils, however leaving the native vegetation it is not a bad alternative.

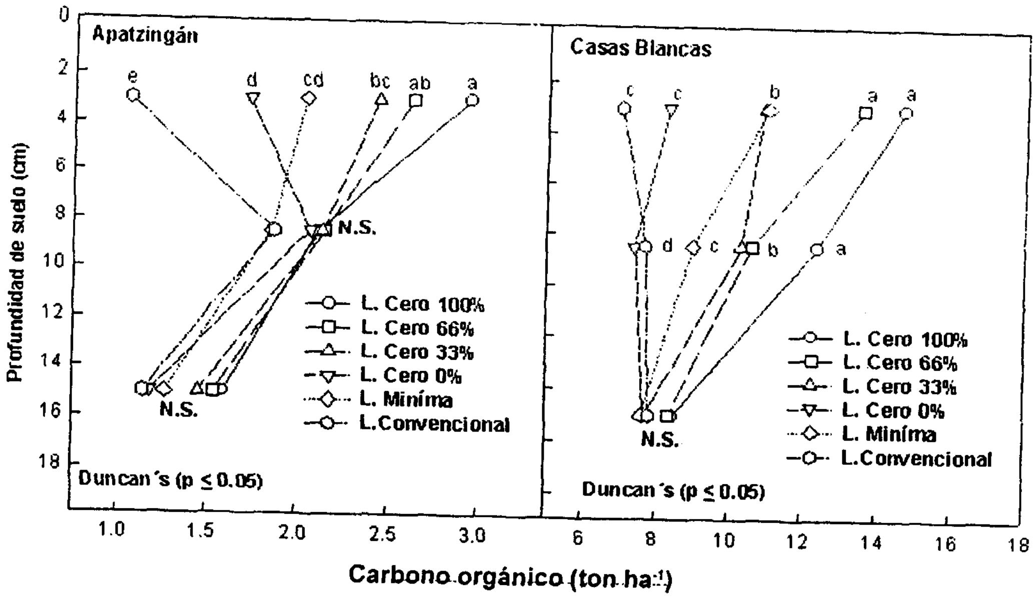

Figure 5. Effect of tillage system on organic carbon in Michoacan, Mexico (Salinas et al., 2001).

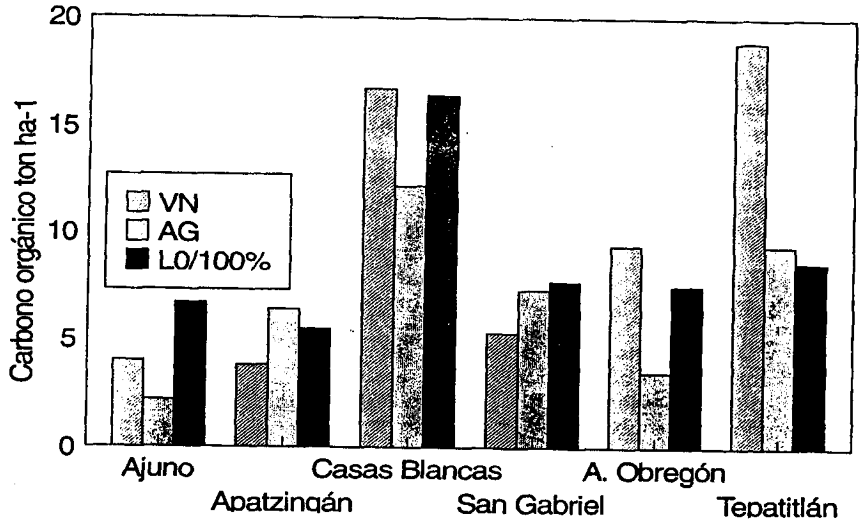

Figura 6. Organic carbon on 0 to 5 cm depth increment under native vegetation (VN), traditional system of farmer (AG) and zero tillage (LO/100%) (Velázquez et al., 2001)

Central America's Situation

Table 15 and 16 show same general information for selected countries in Central America.

Table 15. Selected general information for some Central America countries (WRI, 2001).

Variable	Units	Costa Rica	El Salvador	Guatemala	Honduras
Population	Millions	3.4	5.6	10.6	5.9
1995 GNP	Per capita	2610	1610	134	600

Table 16. Surface of arable lands, cultivated lands, irrigation lands, pasture lands, forest lands and population in Central America (World Resources, 1990-91).

Country	**Arable lands 1987**	**Cultivated lands 1987**	**Irrigation lands '85-87**	**Pasture lands 85-87**	**Forest lands '85-87**
			1000 k m^2		
Belize	23	1	0	1	10
Costa Rica	51	5	1	23	16
El Salvador	21	7	1	6	1
Guatemala	108	19	1	14	41
Honduras	112	18	1	25	36
Mexico	1909	247	52	745	446
Nicaragua	119	13	1	52	38
Panama	76	6	0	13	40
Total Central America	2419	316	57	879	628

Central America is a reduced territory of peculiar geographical conditions inhabited by near 50 millions human being, with serious economics problems and high levels of poverty.. The high population density as determined a very high level of aggression to the environment. Practically no native forest is left in this continents and erosion in the hill slopes in considerable.

Table 17 presents information on the empirical evidences of the excessive soil movements for its preparation in Central America. The mechanical tasks involved in such processes have greatly contributed to its degradation.

As it is well known, in his need for food, man has abused natural resources and soil throughout history, thus strongly contributing to their degradation and destruction. Soil has been the most affected and among the main causes of its degradation in Central America are over pasturing (28%), deforestation (41%) and the inappropriate use of tillage methods (26%) (Baumann, 2000). Forest areas are estimated to be disappearing at a rate of 388,000 hectares per year, about 44 hectares per hour (FAO, 1995).

Table 17. Empirical evidence of soil erosion in Central America and the Caribbean (Lutz *et al.*, 1994).

Country and area	**Source**	**Rainfall**	**Slope**	**Farming**	**Average annual rate erosion per hectare**	
		%	**%**	**system**	**Mg**	**mm**
El Salvador						
Metapán	Flores (1979)	1 724	---	Corn	137	9
	CTA (1956)	1 895	30	Corn and Beans	230	15
Honduras						
Tatumbla, Morazán	Welchez (1991)	2 000	45	Corn and Beans	42	3
	Sánchez (1991)	900-1 500	15-40	—	18-30	—
Nicaragua						
Cristo Rey	PCEO (1981)	1 700	30-40	Cotton	40	—

Panama						
C. del Canal	Soto (1981)	1 200	35	Rice	153	—
C. del Canal	Soto (1981)	1 200	35	Corn	137	—
C. del Canal	Soto (1981)	1 200	35	Rice	118	—
Coclé Rice	Vásquez (1991)	1 937	—	Corn	340	17
Chiriquí	Oster (1981)	1 500-2 800	—	Pasture	33	5
Chiriquí	Oster (1981)	1 500-2 800	—	Cofee	77	11
Chiriquí	Oster (1981)	1 500-2 800	—	—	183	27

Existing information on to soil conservation and land degradation in Central America and the Caribbean was summarized. by Larson and Lopez (1999), Pagiola and Dixon (1997), and Lutz et al., (1994). Based on data on degradation published at the beginning of the nineties by Oldeman et al. (1990) from ISRIC, it was concluded that conversion of native forest to agriculture and livestock (34% of degraded area), forestry activities (7.5%), grazing (25%) and agricultural production activities on existing agricultural lands (30%) are the leading causes of soil degradation in Central America. According to Pagiola and Dixon (1997), on-farm productivity effects are the most important consequences of soil erosion and the most important natural resource management problem in this world area. Land degradation is thought to pose a severe threat to the sustainability of agricultural production. Yet despite long-standing concern about this threat and dramatic claims of environmental damage, surprisingly little empirical analysis have been done on the causes and severity of land degradation in the region and how to tackle them (Lutz et al., 1994).. Scarce availability of good information makes it difficult to document the impact of soil erosion and land degradation on agricultural productivity (Larson and Lopez,1999). Until recently most of the information on erosion had been based either on the Universal Soil Loss (USLE) equation or on sediments being delivered to watersheds. USLE was developed from test plot data in the U. S. Midwest and may not estimate soil loss correctly in different situations. Erosion estimates based on sediment delivery require a delivery ratio for watershed. Since such ratios may vary between 45% of eroded soil in small watersheds to only 5% in large watershed the estimation of an average erosion per hectare can vary substantially. In one watershed in Honduras (Crosson, 1983), it was estimated that 45% of all soil delivery in the water outlet came from 2% of land areas in roads and trails.

Some efforts to introduce no-tillage system and cover crops has been underway for some years. Nevertheless, in countries where no-till systems have not yet been developed, the first step toward no tillage adoption would be to sensitize stakeholders to land issues and no-tillage opportunities, so as to create awareness and willingness to change. Thereafter, certain activities should initiate the changing processs, like to identify the pathways of change, pilot no.tillage farming, establish support for knowledge and information systems, and build capacity of local institutions and producer organizations (Pieri et al., 2002a).

In the past, much agricultural knowledge and information came through pre-determined technology packages provided by technical experts working for public agencies. Much of the information was not used because it did n'o meet the site-specific needs of the local growers. Today, many public agencies in agriculture are in the process of reform, encouraging local empowering by producer groups to provide demand-driven extension and advisory services, with direct interaction with researchers to design experiments that meet their specific needs. This emerging trend should provide a conducive environment for moving from conventional to no-tillage farming (Pieri et al., 2002)

Soil erosion and conservation tillage in Central America

Good data on soil erosion, degradation and productivity in Central America is scarce. Lutz et al (1994) reported only eight site-specific studies completed during 1956-1991 in Central America (3 in Panama, 1 in Nicaragua, 2 in El Salvador, and 2 in Honduras) and Pagiola and Dixon (1997) extrapolated to the entire El Salvador the results obtained in one plot during 1 year. In spite of such shortage of data empirical attempts have been made to evaluate the on-site costs of soil erosion. Solorzano et al. (1991) estimated an average erosion of 7= Mg ha^{-1} over the 1970-1989 period and that the soil erosion cost was nearly 7% of agricultural GDP. Their estimation was based on the cost of replacing the lost nutrients with commercial fertilizers. The and Lopez (1999) study concluded that there is no evidence of a direct relation between yield trends and the actual cost of soil erosion in Central America. However, most of the information used to estimate soil erosion levels and yield declines in this part of the globe are based on educated guess which makes the conclusions less credible. Alfsen et al. (1996) calculated that the annual productivity declines for major crops in six regions of Nicaragua were about 2% per year for beans, 1-2% for maize and sorghum, 1% for coffee, 1-3% for pasture, and less than 1% for sugar, tobacco and vegetables.

According to Lutz et al (1999), the links between soil erosion, soil attributes, soil degradation and productivity are poorly understood, in spite of having suspected that soil erosion has a negative effect on agricultural productivity. Just few reports based on solid science related to the effect of Hurricane Mitch on soil erosion and land degradation, as well as the generation of new technology to reduce future soil losses were available. Its is known that forest is disappearing at a rate of nearly 400 000 ha per year (44 ha per hour) and that soil loss is the norm due to the lack of planning, mining and dams construction (Knight, 1998).

Table 18 and 19 show the main types of soil degradation and the surface with physical or chemical limitations for agricultural use in Central America.

The future scenario for Central America is not very encouraging as the erosion problems of tropical and subtropical soils are much worse than those of areas with temperate climate, as the former are more fragile and strongly degraded because of weather conditions (heavy rains) and excessive land tillage. Also the low availability of soils adequate to be used for agriculture must be considered, as well as the need to set up crops in steep slopes, a very common practice in Central America.

Table 18. Main types of soil degradation in Central America.

Region	Total surf.	Degr. surf.	Degr. surf.	Hydric erosion	Eolic erosion	Chemical degrad.	Physical degrad
	Mill. km^2	Mill. km^2	%	in % of column 3			
Central America	17.86	2.43	13	51	17	29	3
Total land surface	130.31	19.65	15	56	28	12	4

Table 18. Surface with physical or chemical limitations for agricultural use (World Resources, 1990-91).

Total arable lands	Limitation							
	Steep slope	Thin soil	Poor drainage	Tillage problems	Al toxicity	P fixation	Soluble salts excess	Na excess
				1,000 km2				
2622	688	441	154	187	~242	~151	~4	19

The main crop used in regions of Central America, especially in tropical and subtropical zones, is corn with a low productivity level, from 1.0 t/ha up to 1.9 t/ha (Soza *et al*, 1998). Therefore, local farmers strive to increase total production per unit of area, demanding even more from the land and extending the cultivation area, even to hillside zones with strong erosion possibilities.

In this respect, because of soil degradation, strong declines of productivity have occurred over the last decades. In a recent research over the extension of the degradation caused by man, the International Soil References and Information Centre (ISRIC) estimated that 56% of the land in Central America has undergone moderate degradation, which implies productivity reduction, and that 41% of it has experienced strong degradation, which means that it cannot be used for agricultural purposes (Oldeman et al., 1990).

To reduce soil erosion and increase the efficiency of water use, high cost technologies have been implemented, like terraces, but unfortunately these technologies have been not sufficient to solve the problem. Moreover some of them may produce heavy losses at the beginning of the implementation while others require large movement of soil volume (Soza, 1994). The traditional agricultural system in Central America is the slash-and-burn. With this technology all the residues of previous crop or the secondary vegetation developed during the resting period are burnt. Residues burning in Central America amount to 10% (0.2 Gt yr^{-1}) of the world estimate (2.02 Gt yr^{-1})(Andreae, 1991). Some farmers use only hoe and machete as the sole instruments for soil preparation, without burning th residues. Seeding is done leaving the seed in the mulch layer, as was traditional perform by mayans.

An alternative to slash-and burn- is the conservation, and particularly the zero tillage which maintains soil productivity, in addition to other benefits. (Lal, 1984), however there is not enough technology available for wide transference programs. Recent work on cover crops may lead to more extensive use of zero tillage (Anderson et al., 2001; Buckles et al, 1998; Triomphe, 1996).

Unfortunately there is little documentation over the capability of tropical zones to use the conservation tillage system, and its relation to the reduction of erosion and the retention of carbon in the soil.

Costa Rica

In 1950, 35% of the country's arable lands were under pastures and in 1991, this percentage climbed to 54% (Ploey et al, 1991), .The case of Costa Rica is unique and merits to be mentioned. Although the country has an extremely small surface under conservation tillage (less than 1000 hectares), it has consciously structured and approved an extremely advanced legislation on conservation tillage to integrate it to its agriculture, which has just begun (Law 7779 "The use, management and conservation of soils", Dercksen, 1999). Different conservation tillage practices are being evaluated in the Cartago area (Benitez, 1997) where the intensive production of vegetables in the past and dominant slopes of the land, approximately 10%, have produced a large soil deterioration. Other experiences are: in the Huetar region where 60% of the beans of that country are produced (Xatruch, 1998) and the Proyecto Conservacionista MAG/FAO (Azofeifa *et al.* 1997) which includes soil conservation practices in hillside pastures (Bot and Kroes, 1997)

El Salvador

According to a study, 77% of the lands in this country are under an accelerated erosion process, mainly in the northern mountains where there are some lunar landscapes.. The entire arable surface is being cultivated and farmers are beginning to use steep slopes for agriculture, where due to erosion, after one or two years of being cultivated, lands must not be tilled. (Eckholm, 1976). Most of the erosion occurs in small areas with a 7 to 25% slope (Wiggins, 1981)

However, El Salvador, despite problems caused by the internal war that ended a few years ago, is one of the conservation tillage pioneers in Latin America, and demonstrated that conservation and productivity might be successfully associated within a productive system. A program was implemented in 1970 to incorporate conservation tillage to the traditional maize-sorghum association, which was manually sown in the Guaymango region with a nearly 5,000 hectare surface with very steep (40 to 90 percent) slopes. Small producers keep working manually mainly, and using a little animal traction. Before adopting conservation tillage they had already adopted hybrid seeds and chemical nitrogen and phosphorous fertilizers. They had stopped burning crop residues to leave part of them on the soil. During the following 16 years maize production increased from 0.7 to 3.23 ton/ha and that of sorghum from 0.6 to 2.1 ton/ha, and regional producers obtained also the rest of soil conservation and improvement benefits (Sain and Barreto, 1996; Erenstein, 1999). Unfortunately, conservation tillage has not extended as much as expected. There is only a 2,000 hectare surface under conservation tillage in the country.

Nicaragua

Obando y Peralta (1981) compared the traditional maize planting system to the mechanized system in southern Nicaragua. The economic analysis of 5 years of experiments showed no benefits for machinery assisted plantations as compared to the traditional system.

Guatemala

The erosion estimated through the USLE empirical formula is above 3000 Mg ha^{-1} . Pérez *et al.* (1981) evaluated the effect zero tillage on corn production and concluded that this technology was ideal when glifosate was used to kill the weeds.

Honduras

Some farmers of the Lempira region in Honduras switched from the traditional "slash and burn" to a system, locally named "Quesungual" a conservation system with a forestry component. This system allows to farmers to have availability of burning wood a usually scarce good in these tropical degraded areas, in addition to fruit, fiber, and grains for self consumption and surplus production for the market (Hellín, 1988)

References

Acosta, M., J. D. Etchevers, C. Monreal, K. Quednow y C. Hidalgo. 2001. Un método para la medición del carbono en los compartimientos subterráneos (raíces y suelo) de sistemas forestales y agrícolas en terrenos de ladera en México. *In*: Memoria del Simposio Internacional sobre "Medición de la Captura de Carbono en Ecosistemas Forestales. Nov. 2001. Univ. Austral de Chile, Valdivia, Chile (CD ROM)

Acosta, M.. and J. D. Etchevers. 2002. Distribución de carbono orgánico en el perfil del suelo, en diferentes sistemas de bosques de la Sierra Norte de Oaxaca. *In*: Congreso Nacional de la Ciencia del Suelo. Sociedad Mexicana de la Ciencia del Suelo, Torreón,Coahuila, México (CD-ROM)

Amante O., A. 1989. Variabilidad espacial y temporal de la erosión hídrica. Estudio de caso. Tesis de Maestría. Col. Postgraduados, Cent. Edafología, Montecillo, México. 150p.

Andreae, M. O. 1991. Biomass Burning; Its History, Use, and Distribution and its Impact on Environmental Quality and Global Climate. In: Joel S. Levine, ed., Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications, MIT Press, Cambridge, MA.

Alfsen, K. H. M. A. de Franco, S. Glomsrod and T. Johnsen. 1996. The cost of soil erosion in Nicaragua. Ecological Economics 16:129-145.

Anderson, S., S. Gundel, B. Pound, and B. Triomphe. 2001. Cover crops in smallholder agriculture. Lessons from Latinamerica. IDTG Publishing, London, UK. 136 p.

Anonymous. 2002. Conserving crop land. AgJournal.com 8/9/2002 (http://www.agjournal.com).

Azofeifa, R., P.M. Dercksen, N de Kroes. 1997. Costa Rica: Agricultura conservacionista para la seguridad alimentaria. *In:* Claverán, A.R. y F.O. Rulfo V (eds). Mem. IV Reun. Bienal de la Red Latinoam. de Labranza Conservacionista. Morelia, México. CENAPROS- INIFAP-SAGAR. pp 57-79.

Báez P., A. 2001. Dinámica del carbono orgánico en tepetates cultivados. Tésis de Maestría. Col. Postgraduados, Cent. Edafología, Montecillo, México.

Báez P., A. J. D. Etchevers B., C. Hidalgo M., C. Prat, V. Ordaz C. y R. Núñez E. 2002. Organic C and Olsen-P in cultivated tepetates of Mexico. Agrociencia Vol 36, 6: 643-653.

Baumman, J. 2000. La degradación de suelos-procesos, causas y su combate. *In*: R. Quintero *et al.* (Eds.) La edafología y sus perspectivas en el siglo XXI. Tomo I. Colegio de Postgraduados, México.

Benites, J. R. 1997. Labranza de conservación y agricultura sostenible en América Latina. *In:* Claverán, A.R. y F.O. Rulfo V (eds). Mem. IV Reun. Bienal de la Red Latinoam. de Labranza Conservacionista. Morelia, México. CENAPROS- INIFAP-SAGAR

Bocco G., F. García-Oliva. 1992. Researching Gully erosion in México. JSWC 47 pp.365-367.

Bot A.J., NKY de Kroes. 1997. Labranza conservacionistas en pastizales de ladera, Costa Rica. *In:* Claverán, A.R. y F.O. Rulfo V (eds). Mem. IV Reun. Bienal de la Red Latinoam. de Labranza Conservacionista. Morelia, México. CENAPROS- INIFAP-SAGAR

Buckles, D. y O. Erenstein .1996. Intensificación de los sistemas de cultivos basados en el maíz en la sierra de Santa Martha, Veracruz. NRG 96-07 Es. México, D. F.: CIMMYT. 62 p.

Buckles, D., B. Triomphe, and G. Sain. 1998. Cover crops in hillside agriculture. Farmer innovation with Mucuna. IDRC, Ottawa, Canada. 218p.

Claverán A., R. 2000. Conservation tillage in Mexico and Latin America: An overview. *In*: Mem. Simp. Intern. de Labranza de Conservación, 24 al 27 de Enero 2000, Sinaloa, México. (CD-ROM)..

Claverán A., R., L. E. Fregoso and C. Sánchez B. 2001. La labranza de conservacionista en México. *In:* I World Congress on Conservation Agriculture. Madrid (España) 1-5 October, 2001. ECAF, Madrid, España. (http://www.ecaf.org/documents/claveran.pdf)

Claverán A., R., J. Velásquez G. J. A. Muñoz V., M. Tiscareño L., J. R. Salinas G., and M. B. Nájera R. 1997. Avances de Investigación en labranza de conservación I. Libro Técnico No. 1. INIFAP-CENAPROS, Michoacán, México. 288 p.

Claverán A., R., and F. O. Rulfo V. 2001|. Avances de Investigación en labranza de conservación II. Libro Técnico No. 2.. INIFAP-CENAPROS, Michoacán, México 293 p.

CONAZA (Comisión Nacional de Zonas Áridas). 1994. Plan de acción para combatir la desertificación en México. Com. Zonas Áridas, Secr. de Desarrollo Social. México, D. F. 160 p.

Dercksen, P.M. 1999. Panorama del desarrollo de la legislación agroconservacionista en Costa Rica. Paper presented at 5th Meeting of RELACO, Florianopolis, Brazil. 3-7 October 1999.

Eckholm, E. P. 1976. Losing Ground, Environmental Stress and World Food Prospects, W.W. Norton and Co., New York.

Erenstein, O. and P.I. Cadena 1997. La adopción de labranza de conservación en un sistema de cultivo en ladera en Motozintla, Chiapas. NRG 97-01 Es. Mexico, D.F.: CIMMYT. 54 p.

Erenstein, O. 1997. La economía d ela labranza de conservación en México. *In:* R. Claverán A *et al.*, Avances de Investigación en labranza de conservación I. Libro Técnico No. 1. INIFAP-CENAPROS, Michoacán, México. pp. 225-244.

Erenstein, O. 1999a. La conservación de residuos en los sistemas de producción de maíz en Cuidad Guzmán y San Gabriel, Jalisco. Document del NEG 99-01. CIMMYT, Mexico, D. F.

Erenstein, O. 1999.b The economics of soil conservation in developing countries. The case of crop residue mulching. Thesis. Wageningen University. 301 p.

Etchevers B., J. D., M. Acosta. C. Monreal, K. Quednow and L. Jiménez. 2001. Los *stocks* de carbono en diferentes compartimentos de la parte aérea y subterránea, en sistemas forestales y agrícolas de ladera en México. Mem. del Simp. Interna. "Medición de la Captura de Carbono en Ecosistemas Forestales. Nov. 2001. Univ. Austral de Chile, Valdivia, Chile (CD ROM)

Etchevers B., J. D. 2002. Metodología para la medición de la captura de carbono. Proyecto Manejo Sostenible de Laderas. Cuarta reunión del Comité Técnico de Coordinación y Seguimiento. Colegio de Postgraduados, Montecillo México (CD-ROM)

FAO-UNEP-UNESCO. 1980. Metodología provisional para al evaluación de la degradación de los suelos. FAO, Roma, Italia.

FAO. 1995. Forest ressources assesment 1990. Global synthesis. FAO Forestry Paper 124. FAO, Rome, Italy. pp.12-17

Figueroa S., B., and F. Morales. 1992. Manual de producción de cultivos con labranza de conservación. Colegio de Postgraduados. Secr. de Agri. y Rec. Hidráulicos. Montecillo, México.

Figueroa S., B., and E. R. Ventura. 199o. Proyecto para el efecto de la labranza en la estructura del suelo y su relación con el crecimiento, desarrollo y rendimiento de los cultivos. Serie Doc.Téc. de la Red de Conservación de Suelo y Agua. INIFAP-SARH, Salinas, San Luis Potosí, México. 62p

FIRA. 2000. Informe de actividades 2000. FIRA, Morelia, Mexico. (http://www.fira.gob.mx/Informe2000/Informe2000.pdf)

García S., R. 1994. Las propiedades físicas y químicas de un regosol del Estado de Puebla, bajo labranza mínima y convencional. Tésis de Maestría. Col. Postgraduados, Cent. Edafología, México.

Hellin, J. 1998. El sistema Quesungual: un sistema agroforestal indígena de Lampira Sur, Honduras. Versión borrador. Proyecto Lempira Sur GCP/HON/018/NET.

INEGI, 1998. Estadísticas del medio ambiente. México 1997. INEGI, SEMARNAP. 461 p.

INIFAP. 2000. Simposium Internacional de Labranza de Conservación. Sinaloa, México 24 al 27 de Enero de 2000. INIFAP-CENAPROS, Michoacán, México. (CD-ROM)

Jasso Ch., C. 1997. Efecto de la labranza en al estructura del suelo y su relación con el rendimeinto de los cultivos. *In:* R. Claverán A. Et al., Avances de Investigación en labranza de conservación I. Libro Técnico No. 1. INIFAP-CENAPROS, Michoacán, México. pp. 215-223.

Kern, J. S., and M. G. Johnson. 1993. Conservation tillage impacts on national and atmospheric carbon levels. Soils Science Society of America Journal 57:200-210.

Knight, D. 1998. Central America's environmental decline. (http:// hartford-hwp.com/archives/47/084.html).

Lal, R. 1984. Soil erosion from tropical arable lands and its contro. Advances in Agronomy 37: 187-242.

Lal, R. 1989. Conservation tilage for sustainable agriculture: tropics vs. temparate environments. *In:*R. Lal, J. Kimble. E. Levine, and B. Stewart (Eds) Soil management and greenhouse effect. Lewis Publ., Boca Raton, Florida. pp. 1-8.

Larson, B. A. and J. M. López 1999. Sustainability and agricultural externalities in Central America at the intensive margin: A critical review and synthesis on the literature. Central America Project Series: Development discussion papers. Harvard Institute for International Development, Harvard University, (http://www.cid.harvard.edu/hiid/699pdf. August, 2002)

Lutz, E., S. Pagiola, and C. Reiche. 1994. The cost and benefits of soil conservation: the farmer's viewpoint. The World Bank Research Observer 9:273-294.

Magallanes E., A. 1999. Efecto de la estabilidad de agregados y la labranza en el rendimiento y acumulación de nitratos en el sistema suelo, planta. Tésis de Doctorado. Col. Postgraduados, Inst. de Rec. Nat., Especialidad de Edafología, Montecillo, México.

Martínez M., M. 2002. Caracterización geográfica y medición de escurrimientos. Proyecto Manejo Sostenible de Laderas. Cuarta reunión del Comité Técnico de Coordinación y Seguimiento. Colegio de Postgraduados, Monrecillo México (CD-ROM).

Maass, J.M.M. y F. García-Oliva 1990. La conservación de suelos en zonas tropicales: el caso de México. Ciencia y Desarrollo 90: 21 - 36.

Muñoz R., J. de J. 1993. Efecto de la labranza y residuos de cosecha sobre las propiedades físicas del suelo y su influencia en la producción de maíz bajo condiciones de temporal en Durango. Tésis de Maestría. Col. Postgraduados, Cent. Edafología, Montecillo, México.

Navarro B., A. 1998. Sistema de labranza en la preparación de camas de siembra para la emergencia y desarrollo inicial del maíz y fríjol. Tésis de Maestria. Col. Postgraduados, Inst. de Rec. Nat., Especialidad de Edafología, Montecillo, México.

Navarro B., A. 2000. Manual Práctico de Labranza de Conservación. Secretaría de Agricultura, Ganadería y Desarrollo Rural, México, D. F.

Obando E., J. M. y Peralta V., J. R. 1981. Efectos de la labranza el suelo y aplicación de nitrógeno en el rendimiento del maíz (*Zea mays* L.) cultivado en ultisoles. *In:* Resúmenes de XXVII Reunión Anual P.C.C.M.C.A. Santo Domingo, República Dominicana.

Oldeman, L.R., T.A., Hakkeling, W.G. Sombroek, 1990.. Global Assessment of Soil Degradation. ISRIC/UNEP, Wageningen, The Netherlands.

Osuna C., E. S. 1991. Efecto de la cobertura vegetal en el proceso erosivo. Mem. Sem. "Conservación de Agua y Suelo (Manejo integral de cuencas)". SARH-CNA-IMTA, México, D. F. pp 148-166.

Osuna C., E. S. 1997. Investigación sobre erosión y labranza de conservación en al región Norte-Centro de México. *In:* R. Claverán A. *et al.*, Avances de Investigación en labranza de conservación I. Libro Técnico No. 1. INIFAP-CENAPROS, Michoacán, México. pp. 199-214.

Pérez, C., M. A. Dardon,. y H. Cordova, 1981. Efecto de interacción cero labranza-fertilización sobre el rendimiento del maíz (*Zea mays* L.) En: Resumen de XXVII Reunión Anual PCCMCA. Santo Domingo, República Dominicana.

Piagola, S. and J. Dixon. 1997. Land degradation problems in El Salvador. El Salvador Rural Development Study. Report 16253-ES.

Pieri, C. 2001. Strategies for international cooperation. *In: In:* I World Congress on Conservation Agriculture. Madrid (España) 1-5 October, 2001. ECAF, Madrid, España.

Píeri, C., G. Evers, J. Landers, P. O'Connell, and E. Terry. 2002a. A road map from coventional to No-Till Farming. The International Bank for Reconstruction and Development. Washington, D. C. 20p.

Pieri , C., G. Evers, J. Landers, P. O'Connell, and E. Terry. 2002b. No-till farming for sustainable development. The International Bank for Reconstruction and Development. Washington, D. C. 65p.

Pérez N., J. 1996. Efectos de la erosión y sistemas de labranza sobre la productividad y rentabilidad de dos suelos de Oaxaca. Tésis de Doctorado. Col. Postgraduados, Inst. de Rec. Nat., México.

Ploey, J., A. Imeson, and L.R. Oldeman, 1991. Soil erosion, soil degradation, and climatic change. In F.M. Brouwer, A.J. Thomas, and M.J. Chadwick (eds.), Land Use Changes in Europe. Kluwer Academic Publishers, London. Ch.12. pp.275-92.

RELACO (Red Latinoamericana de Labranza de Labranza Conservacionista). 1993. Memoria I Reunión Bienal la Red Latinoamericana de Labranza de Conservación. I. Pla Sentís and F. Ovalles (Eds.). Maracay, Venezuela. 386p.

RELACO. 1995. Memoria IV Reunión Bienal de la Red Latinoamericana de Labranza de Conservación. F. Bertsch y C. Monreal (Eds.). San José, Costa Rica.

RELACO. 1997. Memoria IV Reunión Bienal Red Latinoamericana de Agricultura de Conservacionista. R. Claverán A y F. O. Rulfo V. (Eds.). Morelia, Michoacán, México. 361p.

RELACO. 1999. Memoria V Reunión Bienal Red Latinoamericana de Agricultura de Conservacionista. Brasil. (CD-ROM).

Román C., S. S. 1993. Respuesta agronómica y dinámica del nitrógeno del suelo en trigo, maíz, veza y medicago, bajo distintos manejos de la labranza, residuos de cosecha y fertilización nitrogenada. Tésis de Maestría. Col. Postgraduados, Inst. de Rec. Nat., Especialidad de Edafología, México.

Sain E.G. and H.J. Barreto 1996 The adoption of soil conservation technology in El Salvador: Linking productivity and conservation. J. Soil and Water Cons. 51: 313-321.

Salinas G., J. R. M. Gallardo V.,a nd F. Caballero H. 2001. Efecto de al labarnza de conservación en la distribución de carbono y nutrimentos. *In:* R. Claverán A. y F. O. Rulfo V. (eds.) Avances de Investigación en Agricultura Sotenible II. CENAPROS-INIFAP, Morelia, Micoacán, México.

Sandoval E., M. A. 1997. Indicadores de calidad de suelos con diversos manejos Tésis de Maestría. Col. Postgraduados, Inst. de Rec. Nat., Especialidad de Edafología, Montecillo, México.

Sayre, K. D. 2000. Effects of tillage, crop residue retention and nitrogen management on the performance of bed-planted, furrow irrigated spring wheat in northern Mexico. *In:* 15th Conference of the International Soil Tillage Research, July 2-7, Forth Worth, Texas.

Sayre, K. D., M. Mezzalama,a nd M. Martínez. 2001. Tillage, crop rotation and crop residue management effects on maize and wheat production for rainfed conditions in the altiplano of central Mexico. *In:* I world Congrees on Conservation Agriculture, October 1-5, Madrid, Spain.

Scopel, E. 1997a Labranza de conservación para maíz de temporal. *In:* R. Claverán A. *et al.*, Avances de Investigación en labranza de conservación I. Libro Técnico n°1. INIFAP-CENAPROS, Michoacán, México. pp. 77-90.

Scopel, E. and E. Chávez G. 1997b. Efectos de la labranza de conservación sobre el balance hídrico del cultivo del maíz de temporal. *In*: R. Claverán A. *et al.*,Avances de Investigación en labranza de conservación I. Libro Técnico N° 1. INIFAP-CENAPROS, Michoacán, México. pp. 91-106.

Scopel, E. (Ed.) 1997c. Memoria del taller de transferencia de labranza de conservación para maíz de temporal en el Estado de Jalisco. México, D.F.: CIMMYT, INIFAP, CIRAD, SDR. 83 p.

Scopel, E., F. Tardieu, G. O. Edmeades, and M. Sebillote. 2001. Effects of conservation tillage on water supply and rainfed maize production in semiarid zones of West-Central Mexico. NRG Paper 01-01. CIMMYT, Mexico, D. F.

SEMARNAP, 1997. http://www.semarnap.gob.mx

Soule, M.J. 1997. Farmer assesment of velvetbean as a green manure in Veracruz, Mexico: Experimentation and expected profits. NRG paper 97-02. Mexico, D.F.: CIMMYT 21 p.

Soza, R.F., K.O. Adu-Tutu, K. Boa-Amposem, E.K. Lampoh and W. Haag. 1994. Progress in Soil Conservation Through No-Tillage in Ghana. Ghana/CIDA Grains Development Project (GGDP). ASA Meeting, St. Louis.

Tapia V., L. M. 1999. Escurrimientos y producción de sedimentos en sistemas de manejo agrícola en la cuenca del Lago de Pátzcuaro. Tésis de Doctorado. Col. Postgraduados, Inst. de Rec. Nat., Especialidad de Edafología, Montecillo, México.

Tiscareño L. M. Gallardo y M. Velásquez. 1997. Impacto de los sistemas de labranza en las laderas. Avances de Investigación en labranza de Conservación I. INIFAP-CENAPROS. pp. 107-122.

Tiscareño, M., M. Gallardo y M. Velásquez. 1997. Impacto de los sistemas de labranza en la agricultura de ladera. *In:* A. Claverán R. *et al.*, (Eds.) Avances de Investigación en labranza de conservación I. Libro Técnico No. 1. INIFAP-CENAPROS, Michoacán, México. 288 p.

Tiscareño-López, M., A. D. Báez-González, M. Velázquez-Valle, R. Claverán-Alonso, K. N. Potter, and J. J. Stone. 2000. Case Study: Conservation Tillage to Save Patzcuaro Lake Watershed. *In:* Mem. Simp. Inter. de Labranza de Conservación, 24 al 27 /01/2000, Sinaloa, México. (CD-ROM).

Triomphe, B. L. 1996. Seasonal nitrogen dynamics and long-term changes in soil properties under the mucuna/maize cropping system on the hillside of Northern Honduras. ph-D, Cornell Univ., N-Y. 217 p.

Uribe G., S. 1997. Manejo pro-sustentable de laderas con terrazas de muro vivo en el trópico sub-húmedo. Tésis de Doctorado. Col. Postgraduados, Inst. de Rec. Nat., Edafología, Montecillo, México.

Uribe S. 1998. Tecnologías prosostenibles de manejo de suelos tropicales en el sur de Veracruz. Mem. de la XII Reunión Científica y Tecnológica, Forestal y Agropecuaria INIFAP-CIRGOC. pp. 93-100.

Van Nieuwkoop, M., W.B. Walter, A. M. Zamarripa, R.C. de la Piedra, F.U.C. Cruz, R.G. Camas, J.L. Martínez 1994. La adopción de tecnologías de labranza de conservación. La Fraylesca, Chiapas. CIMMYT-INIFAP. 93 p.

Velásquez V., M., M. Tiscareño, R. Claverán y M.. Gallardo. 1997. Erosión y productividad bajo labranza de conservación I. Avances de investigación en suelos de ando de Michoacán. INIFAP-CENAPROS. Folleto Técnico N° 1. 34 p.

Velásquez, G. and J. P. Pérez. 2001. Interacción labranza-fertilización-residuos en maíz de temporal en la región centro de México. *In:* R. Claverán, and F. O. Rulfo V. 2001. Avances de Investigación en labranza de conservación II. Libro Técnico No. 2. INIFAP-CENAPROS, Michoacán, México 293 p.

Vergara, M. A., J. D. Etchevers B, and M. Vargas H. 2002. Variabilidad del carbono orgánico en suelos de ladera del sureste de México. Agrociencia (in process)

Vidal P., I. R. 1994. Estimación *in situ* de la mineralización de nitrógeno en trigo bajo diversas rotaciones y sistemas de labranza. Tésis de Doctorado. Col. Postgraduados, Cent. Edafología, México.

Wiggins, S.L.1981. The economics of soil conservation in the Acelhuate River basin, El Salvador. *In:* R.P.C. Morgan (ed.) Soil Conservation: Problems and Prospects, J. Wiley and Sons, N-Y, pp. 399-417

World Resources Institute. 1990. World Resources. 1990-91. Oxford U. Press, New York, 383 pp.

World Resource Institute. 2002. World resources 1998-1999. Regions at glance. Central America. (http://www.wri.org, August, 2002).

Xatruch C., C. 1998. Validación de equipos para labranza mínima con tracción animal en el cultivo del frijol. *In:* Claverán, A.R. y F.O. Rulfo V (eds). Mem. IV Reunión Bienal de la Red Latinoamericana de Labranza Conservacionista. Morelia, México. CENAPROS-INIFAP-SAGAR. pp. 57-79.

Etchevers, J. D.; Prat, C.; Balbontin, C.; Bravo, M.; Martinez, M.; Ortiz, C. - Influence of land use on carbon sequestration and erosion in Mexico and central America, pp. 284-310, Bulletin du RESEAU EROSION n° 23, 2004.