NO-TILL AND RESIDUE REMOVAL EFFECTS ON SOIL CARBON CONTENT

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INTERPRETIVE SUMMARY

Soil organic carbon, an indicator of soil quality, generally increases with a conversion from inversion tillage to no-till management practices. However this assumes that the crop residue is left on the soil surface with no-till. In Mexico, crop residues are often utilized as animal fodder, even with no-till management practices. We conducted a study to determine the effect of removing different amounts of corn residue on soil organic carbon content with no-till. No-till practices with all the residue removed usually maintained organic carbon levels about that which occurred with moldboard plowing. Leaving residue generally increased soil organic carbon content. With higher mean annual temperatures, leaving residues on the surface were less effective in increasing soil carbon content than with lower mean annual temperatures. Higher rainfall usually increased soil carbon content with larger amounts of residue remaining on the surface. Leaving crop residues in the field with no-till management can increase soil carbon contents, but with some climatic conditions the residue may be better used as animal fodder.

ABSTRACT

No-till crop management often results in increased soil organic carbon contents. However, the effect of residue removal with no-till on soil carbon contents is not well understood. We conducted a multiyear study at six locations in central Mexico, with a wide range of soil and climatic conditions to determine the effect of varying rates of residue removal and no-till management on soil carbon contents. Treatments consisted of annual moldboard plowing and no-till management practices with 100%, 67%, 33% and none of the corn (Zea mays) crop residue remaining on the no-till soil surface. No-till practices maintained carbon levels above that of moldboard plowing at five of the six locations even when all crop residues were removed. Leaving crop residues on the soil surface increased soil carbon content, but at a much faster rate in cool conditions than in tropical conditions. Carbon content was greater with higher amounts of rainfall than in the drier regions. No-till will increase soil carbon contents, but climatic conditions should be considered to determine if crop residue would be more effectively utilized as animal fodder.

INTRODUCTION

Three hundred major watersheds in Mexico, with total annual water yield of about 40 billion cubic meters, are degrading due to reduction of vegetative cover, soil erosion, nutrient losses agrochemical pollution and lake eutrophication (Albert, 1996). Concurrent hillslope and gully erosion have been identified on 65 to 85% of the land (Bocco and Garcia-Oliva, 1992). Soil organic carbon (SOC) content has long been recognized as one indicator of soil quality that is susceptible to degradation with inversion tillage often practiced in Mexico. In the United States, soil organic carbon was reduced as much as 40% with the use of inversion tillage (Allmaras et al., 2000). Soil organic carbon reductions were likely to have been as great in Mexico because of the frequent use of inversion tillage practices.

While tillage usually results in a large decrease in SOC, less intensive tillage with residue management practiced for extended periods of time has been shown to increase SOC concentrations near the surface (Dick, 1983; Eghball et al., 1994). Several authors have related the change in SOC to type of tillage and the amount of biomass produced by the crop (Havlin et al., 1990; Reicosky et al., 1995; Robinson et al., 1996). Rates of carbon accumulation in soils under no-till or conservation till reported in the literature have varied widely, ranging from below zero to 1300 kg ha^{-1} yr^{-1} (Reicosky et al., 1995). The greatest increases in SOC have been reported in the colder, northern regions of the United States. Several authors have reported that SOC concentrations were increased near the surface with no-till management in the warmer southwest environment (Unger, 1991; Potter and Chichester, 1993; Christensen et al., 1994).

No-till as normally conducted in the United States involves leaving the crop residue on the soil surface. This is often not the case in Mexico, where crop residues are often harvested for livestock feed. The purpose of this study is to determine the effect of no-till management practices on soil organic carbon content with different amounts of crop residue remaining on the surface.

MATERIALS AND METHODS

Six locations were selected for study in the states of Michogan and Jalisco in central Mexico (Figure 1). The sites are locations where long-term studies of management effects on continuous corn (*Zea mays* L.) yield and soil erosion is being conducted. The management systems chosen for this study are conventional moldboard plowing and no-till with varying amounts of corn residues remaining on the soil surface. Residue treatments consisted of leaving 100%, 67%, 33%, or none of the crop residue on the soil surface. Bulk surface samples were collected and soil characterization tests performed to determine soil texture, predominant mineralogy, and organic carbon content.

Soil cores, 1.5 inches in diameter, were obtained from each site/surface condition using a hand-driven sampler with a plastic liner to limit soil compaction. If compaction was observed, the core was discarded and another core taken. Soils were sampled to a depth of 12 inches. Cores were segmented to obtain depth increments of 0-0.8, 0.8-1.6, 1.6-2.75, 2.75-3.9, 3.9-5.9, 5.9-7.9, 7.9-11.8 inches. Soil segment wet weight was determined. The soil core was then split lengthways. Half the soil core segment was weighed, oven dried at 221 °F for 48 hours and the dry weight recorded. The soil water content was determined and used to correct the segment weight for calculating soil bulk density. The other half of the soil core was air dried until it easily crumbled and easily identified organic matter such as roots, stems, leaves, and plant crowns was removed. The remaining soil was crushed to pass through a 0.078-inch sieve. A subsample of the cleaned sample was ground in a rolling grinder (Kelley, 1994) in preparation of carbon analysis. The ground sample was oven dried for 3 hours at 150 $^{\circ}$F before burning.

Soil organic carbon was determined using a CR12 Carbon Determinator on samples weighing about one gram (Chichester and Chaison, 1991). Soil samples were burned at 1067 $^{\circ}$F and CO_2 concentration in the airflow determined with a solid state infrared detector. The combustion temperature was such that organic carbon was oxidized but inorganic carbon (i.e. CO_3) was not (Chichester and Chaison, 1991; Rabenhorst, 1988; Merry and Spouncer, 1988). The CO_2 concentration was integrated over the duration of the burn to determine the sample C concentration. Soil bulk density and water content were determined (Table 2). Soil organic carbon content was calculated based upon the equivalent soil mass as described by Ellert and Bettany (1995).

A regression analysis was used to determine statistical differences among soils and between conventional and no-till management practices within locations.

RESULTS

Sites locations are shown in Figure 1 and selected soil parameters are presented in Table 1. Length of time of continuous management, mean annual temperature and average rainfall amounts are presented in Table 2. Length of time of continuous management varied from four to nine years. Continuous management is an important factor as soil organic carbon differences among treatments can take several years to develop.

Soil organic carbon concentrations in the surface horizons are presented in Figure 2. No-till management with more than 67% residue retention increased soil organic carbon concentration in the surface ten cm of the soil profile compared to the conventional management practice. In most cases the conventional management practices resulted in soil carbon concentrations similar to the no-till with 0% residue retention. The exception was at Patzcuaro where no-till 0% residue had a lower carbon content than the conventional tillage treatment.

Organic carbon content in the surface 12 inches of the no-till soils is presented in Figure 3. Carbon content was related to residue retention by regression analysis. The soils varied a great deal in the amount of carbon present, generally depending on the amount of carbon present at the start of the experiment. For example, the carbon content at the Casas Blancas site was much greater than the rest of the experimental sites. Response to the amount of residue left on the soil surface varied among locations (Figure 3). While leaving residue on the surface increased soil carbon content, the response varied depending in part upon the length of time the management practices had been in place. The increase in soil carbon, as indicated by the slope of the regression between soil carbon and residue remaining, was corrected for length of time in management by dividing the slope by the number of years in continuous management. The normalized slope was then related to climatic factors such as the mean annual temperature and annual rainfall.

Change in carbon content varied in a nonlinear manner with mean annual temperature (Figure 3). At relatively low annual temperatures, leaving residue on the soil surface increased soil carbon content. At high mean annual temperatures, leaving crop residues on the soil surface had relatively little effect on the soil carbon content.

The amount of residue remaining on the soil surface tended to increase soil carbon contents in a linear manner across a rainfall gradient (Figure 4). At higher rainfall levels, leaving residue on the surface had a greater effect on soil carbon content than occurred at lower amounts of annual rainfall.

SUMMARY

In conclusion, no-till management practices generally increased soil organic carbon content above that occurring with conventional tillage if some residue was left on the soil surface. Leaving residue on the soil surface, while common in no-till management practices in the United States, does not always occur in Mexico were crop residues are often used for animal fodder. Leaving crop residues was most effective in increasing soil carbon content in the cooler regions of Mexico. Where mean annual temperatures were greater than 81 ºF, leaving crop residues on the soil had little effect on the soil carbon content.

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Table 1. Selected properties for six soils.

Site	Clay (%<2µ)	Sand (0.05>%<2mm)	Textural Classification	Predominate Clay Mineralogy †	pH ±
Guzman	12.3	63.2	Sandy Loam	FD3	5.5
Patzcuaro	12.2	48.7	Loam	KK1	5.5
Casas Blancas	16.1	25.5	Silt Loam	NX6	5.3
Tipititlan	47.1	13.1	Clay	KK2, HE2	5.6
Apatzingan	58.9	21.7	Clay	MT4	7.8
Morelia	77.4	0.6	Clay	CR2, MT2	6.7

† MT = montorillonite, FD = feldspar, CR = cristobalite, NX = non-crystaline, KK = kaolinite, HE = hematite. The number refers to relative peak size: 1 = very small, 2 = small, 3 = medium, 4 = Large, 6 = no peak.
± pH is 1:1 H_2O paste.

Table 2. Climatic factors and length of continuous management.

Location	Temperature °F	Rainfall inches	Continuous Management Years
Cd. Guzman	68	30.9	7
Tepatitlan	64	32.6	8
Apatzingan	81	25.6	7
Patzcuaro	63	43.3	5
Casas Blancas	61	39.3	7
Morelia	68	31.5	4

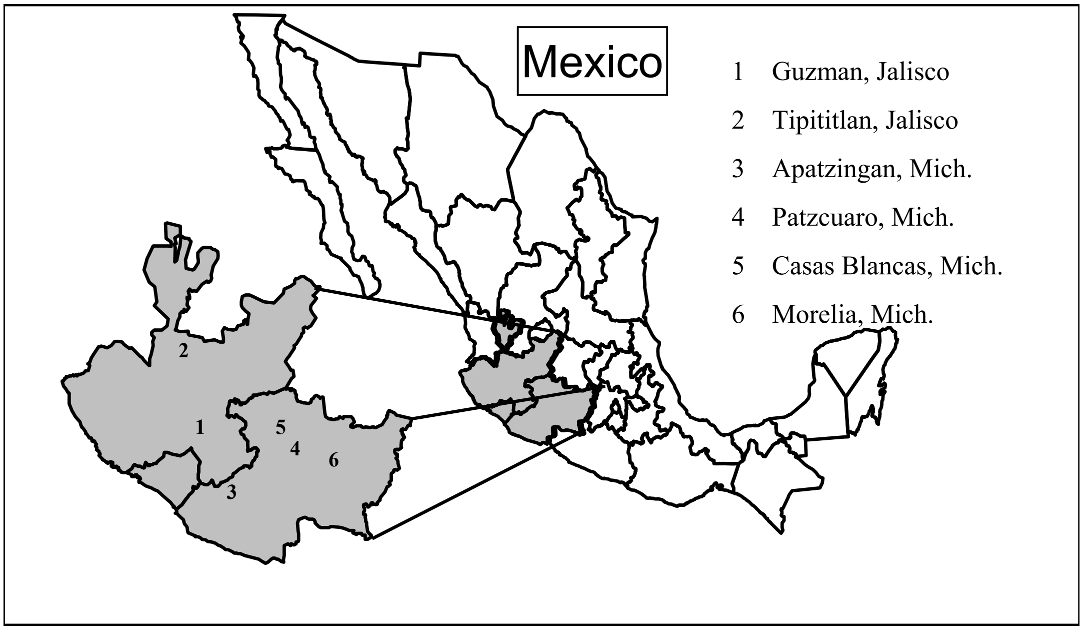

Figure 1. Location of the study sites.

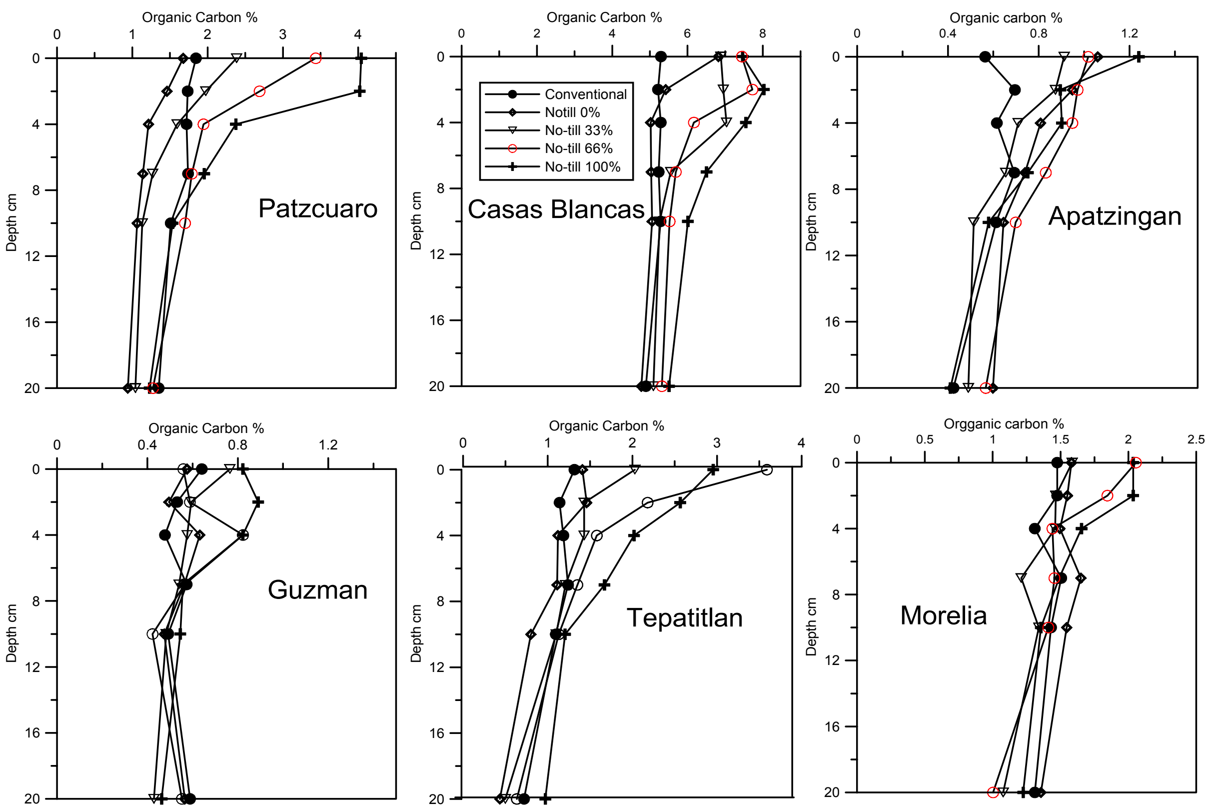

Figure 2. Organic carbon distribution in the surface 30 cm.

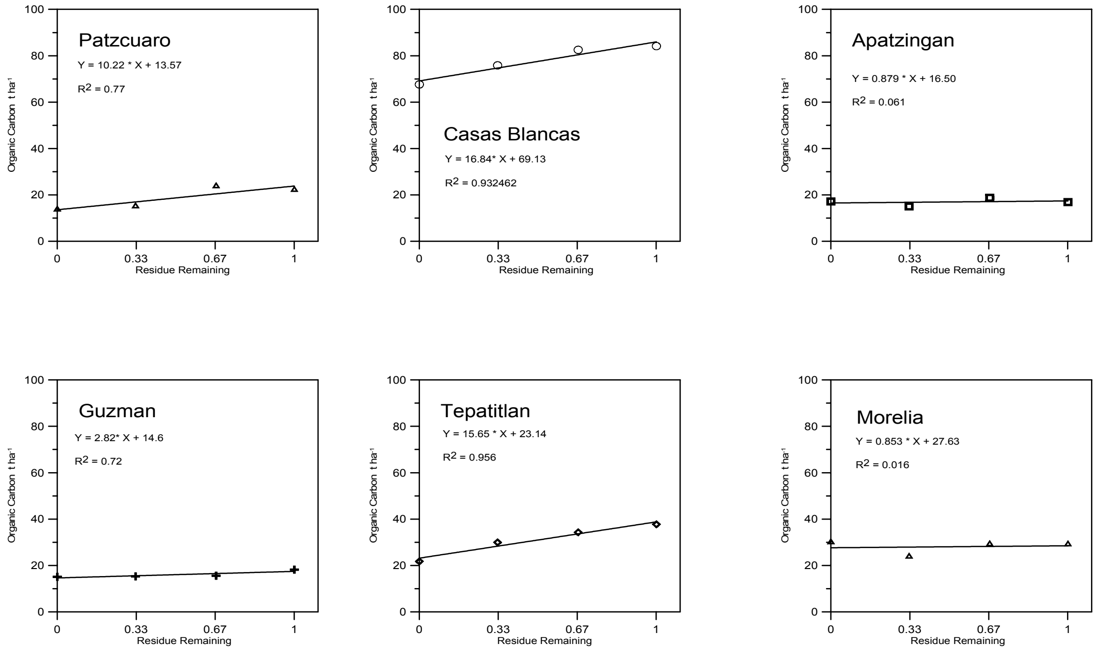

Figure 3. Regression analysis of change in soil carbon with the amount of residue left on the soil surface.

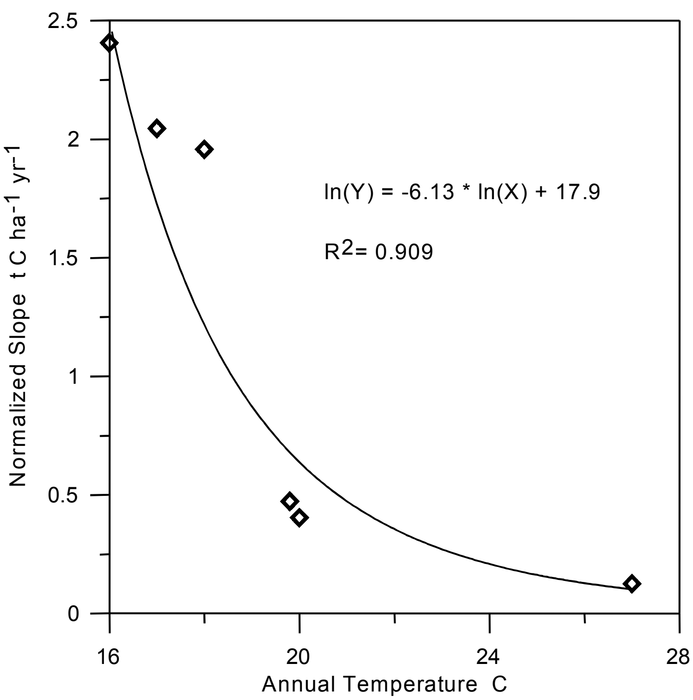

Figure 4. Change in the normalized slope with mean annual temperature.

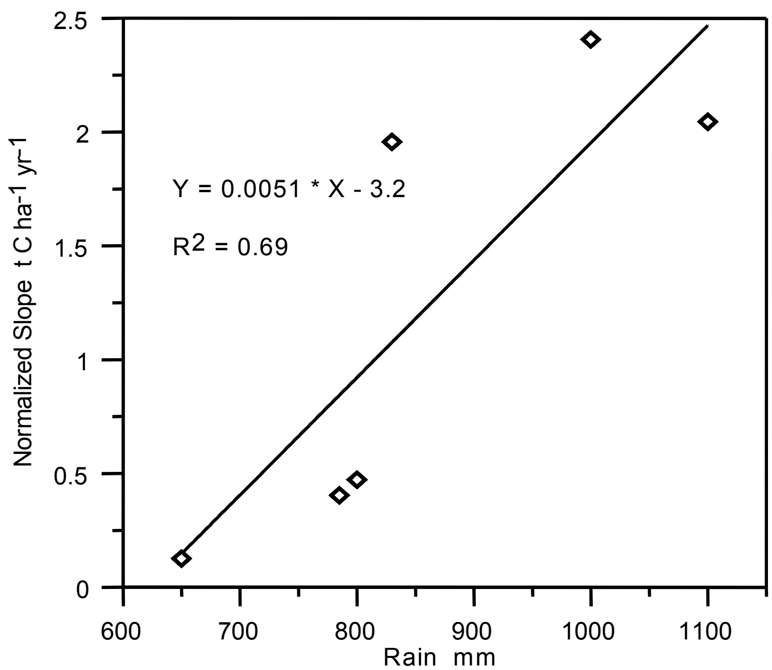

Figure 5. Change in the normalized slope with mean annual rainfall.