Residue removal and climatic effects on soil carbon content of no-till soils

K.N. Potter, J. Velazquez-Garcia, E. Scopel, and H.A. Torbert

Abstract: While no-till management practices usually result in increased soil organic carbon (SOC) contents, the effect of residue removal with no-till is not well understood, especially in warmer climates. A multi-year study was conducted at six locations having a wide range of climatic conditions in central Mexico to determine the effect of varying rates of residue removal with no-till on SOC. Mean annual temperatures ranged from 16°C to 27°C (61°F to 81°F). Mean annual rainfall ranged from 618 to 1099 mm yr^{-1} (24 to 43 in yr^{-1}). Treatments consisted of annual moldboard plowing under residue and no-till with 100%, 66%, 33%, and no corn (*Zea mays* L.) residue retained on the no-till surface. At five of the six locations, no-till with all surface residues removed maintained SOC levels above that of moldboard plowing which incorporated all residues. Retaining 100% of the crop residues with no-till always increased or maintained the SOC content. SOC increased in cooler climates, but as mean annual temperature increased, more retained crop residues were needed to increase the SOC. In tropical (mean annual temperature > 20°C) conditions, 100% corn residue retention with no-till only maintained SOC levels. Mean annual temperature had a greater impact on SOC than did annual rainfall. It appears that, in warmer climates, residue in excess of that needed for erosion control may be used for animal fodder or energy production. At the higher temperatures, most of the residue will decompose if left on the soil surface without improving soil carbon contents.

Key words: no-till—residue harvest—soil organic carbon—temperature

Crop residue harvesting has been considered as a method to obtain additional benefits when growing a high residue crop such as corn (*Zea mays* L.) (Karlen et al. 1984). The residues are useful as animal fodder or as a biofuel source. Larson (1979), discussing the role of crop residue from an agronomic viewpoint, pointed out the benefits of crop residue remaining on the soil surface. He stated that residue provides erosion protection, serves as a source of plant nutrients to following crops, and reduces the amount of rainfall runoff. This assessment was supported by subsequent research which indicated increased residue removal levels increased water runoff and erosion rates as well as nutrient removal that exceeded standard fertilization practices (Lindstrom 1986). Recent literature reviews have examined residue harvest from the viewpoint of providing biofuels for energy production (Wilhelm et al. 2004; Mann et al. 2002). Both reviews pointed out that, in addition to the considerations discussed by Larson (1979), residue harvest impacts on soil organic carbon (SOC) should be considered. One rationale for this includes the potential for sequestering carbon in the soil to reduce atmospheric carbon dioxide, a greenhouse gas.

SOC content is recognized as a soil quality indicator that is susceptible to degradation with tillage. SOC was reduced as much as 40% with the long term use of inversion tillage (Allmaras et al. 2000). In contrast, less intensive tillage with residue management practices over extended periods of time have increased SOC concentrations near the surface (Dick 1983; Eghball et al. 1994). Several authors have related the change in SOC to the 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} (1160 lb ac^{-1} yr^{-1}) (Reicosky et al. 1995). Most studies reporting increases in SOC with no-till were conducted in the colder, northern climates of the United States and Canada (Mann et al. 2002). A few authors have reported that SOC concentrations were increased near the surface with no-till management in the warmer climate in the southwestern United States (Unger 1991; Potter and Chichester 1993; Christensen et al. 1994: Potter et al. 1998). Comparisons among the southwestern studies are difficult, however, because of differences in crops and management practices. Inferences regarding residue harvest in the Southwest are also complicated because nearly all the research regarding soil carbon and no-till has involved retaining the entire residue on the soil surface.

A uniform experiment with six locations was conducted in central Mexico comparing no-till management with conventional management using the moldboard plow for primary tillage for corn production. A primary factor in this study was the removal of selected rates of corn residue from the no-till plots. The six locations encompassed a broad range of soil and climatic conditions. Temperature and rainfall ranges included that of the southern Corn Belt in the lower range, but also included conditions found in subtropical regions. The purpose of this report is to document the effect of no-till management practices on SOC content where different amounts of crop residue remained on the surface across a range of rainfall amounts and temperatures.

Methods and Materials

The six locations selected for study were in the states of Michoacan and Jalisco in central Mexico (figure 1) where long-term studies of management effects on continuous corn (*Zea mays* L.) yield and soil erosion were being conducted. The management systems chosen for this study were conventional moldboard plowing and no-till with varying amounts of corn residues remaining on the soil surface. Residue treatments consisted

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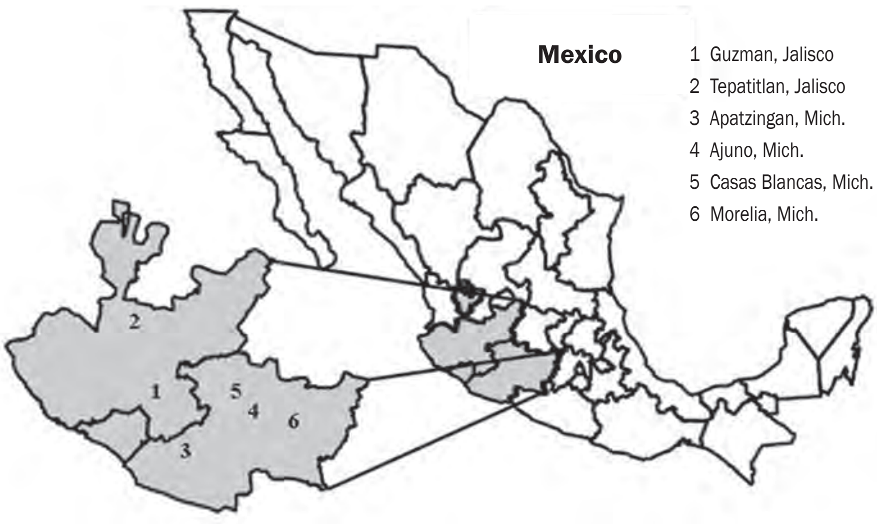
Figure 1
Location of the study sites.



of leaving 100%, 66%, 33%, or none of the crop residue on the soil surface. The study was designed as a randomized complete block with two replications per location. Plot size was 9.2 m by 30 m (30 ft by 98 ft) for all locations except Ajuno which was 4 m by 15 m (13 ft by 49 ft). For analysis, the residue mass was assumed to be equivalent to grain yield from the plot. Such assumptions are commonly used in agricultural simulation models to estimate grain and yield ratios (Williams et al. 1984). Bulk surface samples were collected and soil characterization tests were performed to determine soil texture by the pipette method (National Soil Survey Center 1995).

Two soil cores, 38.1 mm (1.5 in) in diameter, were obtained from each site/residue combination using a hand-driven sampler with a plastic liner to limit soil compaction. If compaction was observed, the core was discarded and another was collected. Soils were sampled to a depth of 0.3 m (12 in). Cores were segmented to obtain depth increments of 0 to 0.02, 0.02 to 0.04, 0.04 to 0.07, 0.07 to 0.1, 0.1 to 0.15, 0.15 to 0.2, 0.2 to 0.3 m (0 to 0.8, 0.8 to 1.6, 1.6 to 2.75, 2.75 to 3.9, 3.9 to 5.9, 5.9 to 7.9, 7.9 to 11.8 in). The wet weight of each soil segment was determined. The soil core segment was then split lengthways. Half the soil core segment was weighed, oven dried at 105°C (221°F) for 48 hours and then dry weight recorded. The soil water content was determined and used to correct the segment weight for calculating soil bulk density. Bulk density was calculated based upon the entire mass of the soil segment. The other half of the soil core was air dried until it reached a friable state, and then easily identified organic matter such as roots, stems, leaves, and plant crowns were removed. The remaining soil was crushed to pass through a 2 mm (0.078 in) sieve. A subsample of the cleaned sample was finely ground and oven dried for three hours at 65°C (150°F) before combustion in a Leco CR12 Carbon Determinator. Soil samples were combusted at 575°C (1,067°F), a temperature at which organic carbon was oxidized but inorganic carbon (i.e., CO_3) was not oxidized (Chichester and Chaison 1991). SOC content was calculated based on the equivalent soil mass as described by Ellert and Bettany (1995).

A regression analysis was used to identify response of SOC to conventional and no-till management practices and residue amount within locations. Normalized SOC responses (slope of SOC/residue divided by the number of years in a management system) were regressed against mean annual temperature and precipitation (Steel and Torrie 1960). Separate regressions were conducted relating soil carbon with mean annual temperature, one regression excluded the high temperature Apatzingan site and the second regression excluded all sites with a mean annual temperature less than 18°C (64°F).

Results and Discussion

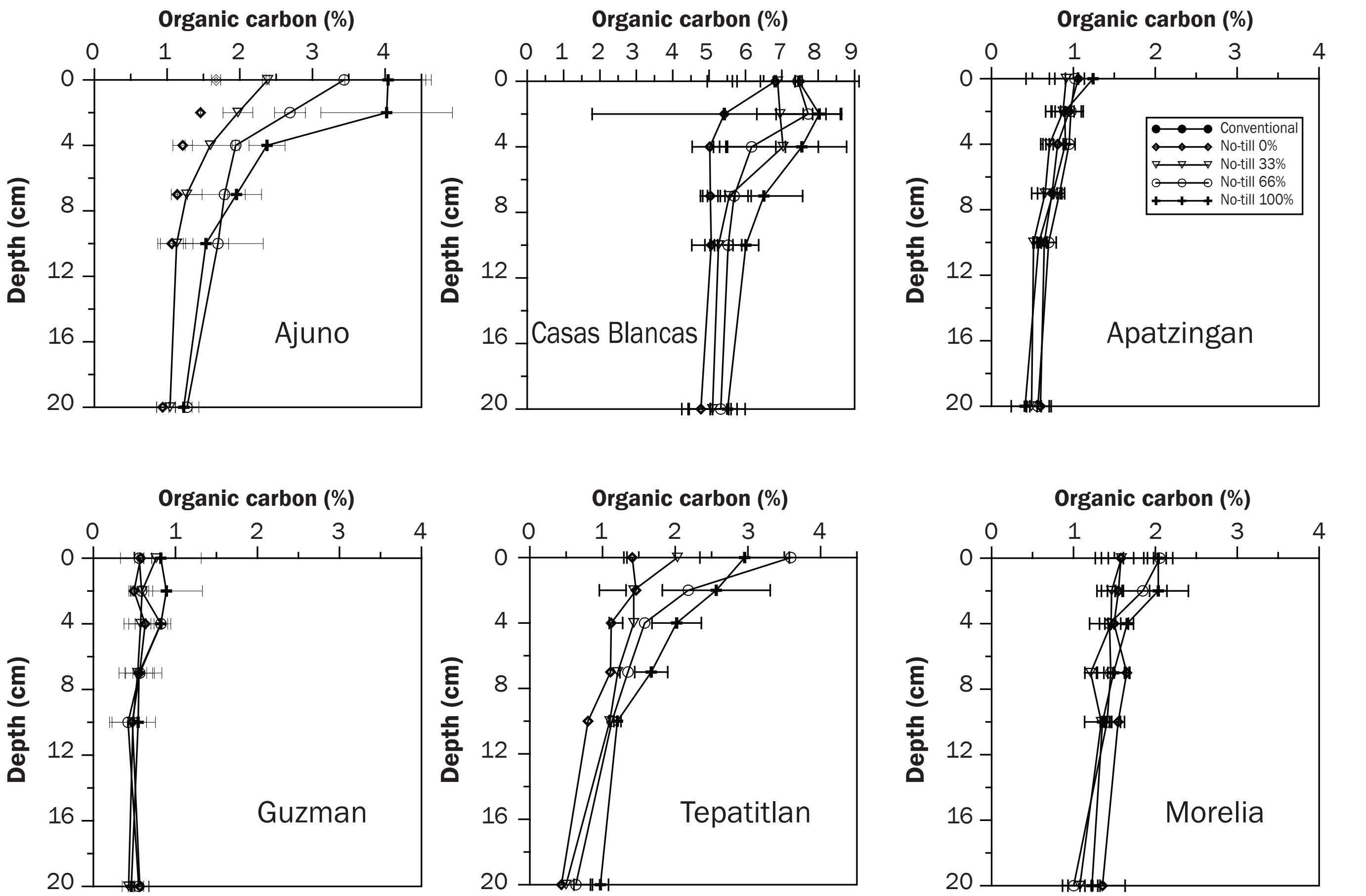
Site locations are shown in figure 1. Length of time of continuous management, mean annual temperature and average rainfall amounts are presented in table 1. Mean annual temperatures ranged from 16°C to 27°C (61°F to 81°F). Mean annual rainfall ranged from 618 to 1099 mm yr^{-1} (24 to 43 in yr^{-1}). Length of time of continuous management varied among locations from four to eight years. Continuous management is an important factor, as it can take several years to develop measurable differences in SOC among treatments (Rhoton 2000).

SOC concentrations in the surface horizons are presented in figure 2. No-till management with more than 66% residue retention increased SOC concentration compared with the conventional management practice in the 0 to 4 cm (0 to 1.5 in) depths

Table 1
Long-term record climatic factors, length of continuous management, and soil texture for the study sites.

Soil number	Location	Temperature	Rainfall (mm)	Continuous management years	Percent sand	Percent clay	USDA soil textural classification
1	Guzman	20.0°C	785	7	63%	12%	Sandy loam
2	Tepatitlan	17.8°C	828	8	13%	47%	Silty clay
3	Apatzingan	27.2°C	650	7	22%	59%	Clay
4	Ajuno	17.2°C	1099	5	48%	12%	Loam
5	Casas Blancas	16.1°C	998	7	25%	16%	Silt loam
6	Morelia	20.0°C	800	4	0.6%	77%	Clay

Figure 2
Organic carbon concentration for selected treatments.



Notes: Note the scale difference in the Casas Blancas site. Error bars are plus or minus one standard deviation.

of the soil profile at Ajuno and Tepatitlan, but there is much overlap for deeper depths and the other sites have great overlap for all depths. In most cases, the no-till with 0% residue retention resulted in soil carbon concentrations similar to or greater than the conventional management practices. The exception was at Ajuno, where no-till 0% residue soil had lower carbon content than the conventional tillage treatment soil.

Organic carbon content in the surface 0.3 m (12 in) 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 at the other sites. Response to the amount of residue left on the soil surface varied among locations (figure 3). Leaving residue on the surface generally increased soil carbon content. However, the magnitude of the response varied, depending in part on 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 mass of residue remaining, was normalized for length of time in management by dividing the slope by the number of years in continuous management. This was necessary because the soil carbon content measured at a given point in time reflects the cumulative impact of multiple years of management in which varied amounts of residue are produced. Annualized residue mass retained on the soil surface with no-till management practices has been shown to strongly affect SOC content in Eastern Colorado (Sherrod et al. 2003) and Central Iowa (Robinson et al. 1996). The normalized slope was then related to climatic factors such as the mean annual temperature and annual rainfall. Change in carbon content varied depending on the mean annual temperature (figure 4). At annual temperatures less than 20°C (68°F), soil carbon content increased with larger amounts of residue on the soil surface. The rate of carbon accumulation decreased with increasing mean annual temperatures as indicated by the negative temperature parameter estimate (-0.14, $Pr > |t| = 0.013$). This implies that more crop residues should be left on the soil surface to increase or maintain the soil carbon content at higher temperatures.

At mean annual temperatures greater than 20°C (68°F), even leaving 100% of the surface residues with no-till did not significantly affect soil carbon content, as indicated by the low R^2 value for mean annual temperatures greater than 20°C (68°F) (figure 4). The lack of response with warmer temperatures is probably caused by an accelerated decomposition rate, which may be three to four times

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

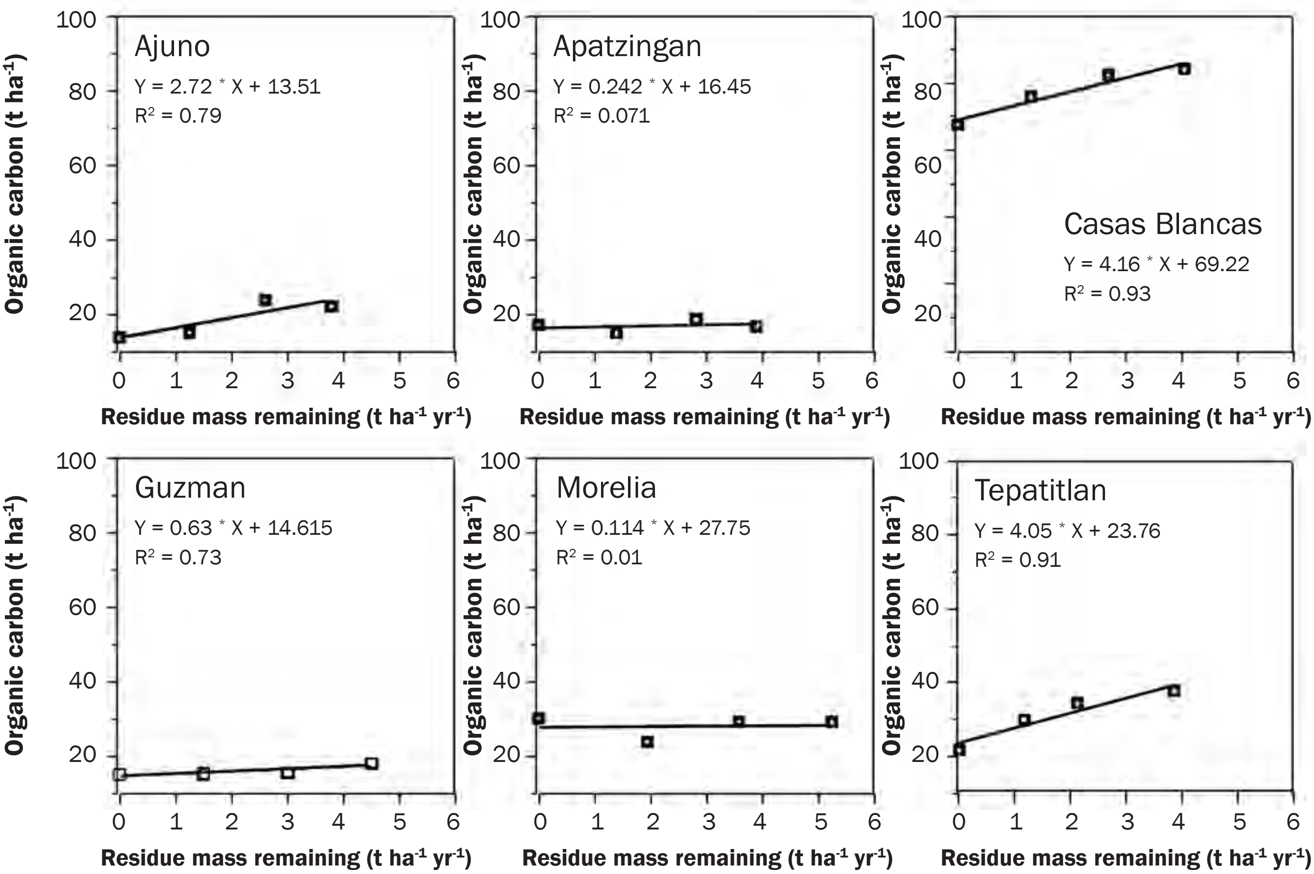
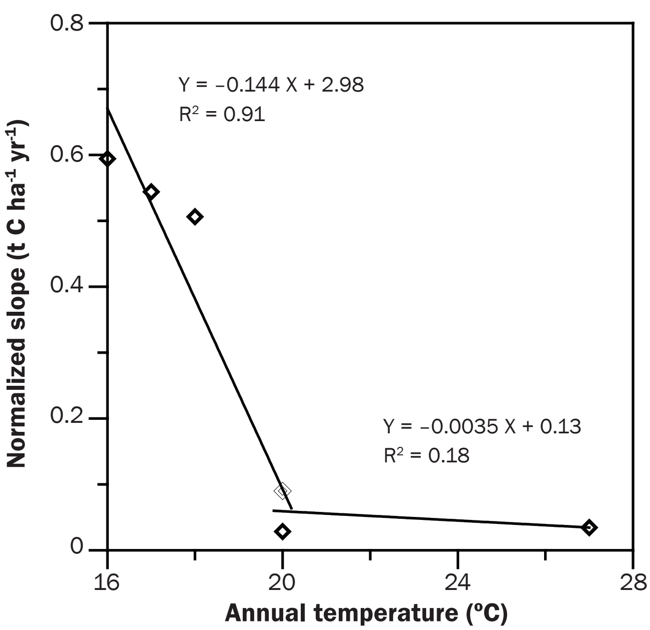


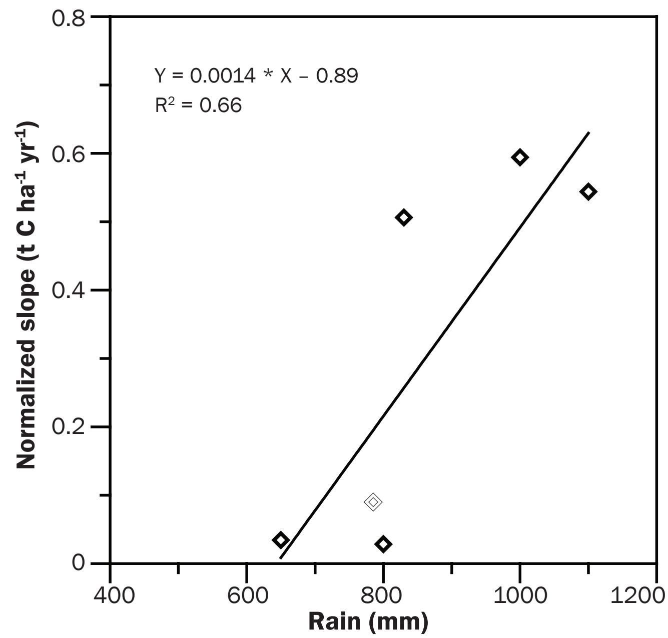
Figure 4
Change in the normalized slope with mean annual temperature.



faster in the tropics than in temperate regions (Dalal and Carter 2000). This agrees with the conclusions of Grisi et al. (1998) that the organic matter of tropical soils is more degraded than that in temperate soils. Even in temperate climates, temperature influences SOC contents as the organic carbon content of native grasslands decreases with increases in mean annual temperature (Burke et al. 1989: Sims and Nielsen 1986). In Australian natural ecosystems with warm climates, SOC concentration decreased exponentially as mean annual air temperature increased from 21°C to 31°C (70°F to 88°F) (Dalal and Carter 2000).

The rate of carbon accumulation in the surface soil increased in a linear manner across a rainfall gradient, but the regression parameter was not significant (0.0014, $Pr > |t| = 0.14$) (figure 5). With larger rainfall amounts, leaving residue on the surface had a greater effect on soil carbon content than occurred with smaller amounts of annual rainfall. The R^2 between rainfall and carbon accumulation rate was 0.66, which was not significant and much lower than the R^2 =

Figure 5
Change in carbon accumulation with mean annual rainfall.



0.91 (Pr > |t| = 0.013) between temperature and the carbon accumulation rate for temperatures less than 20°C (68°F). Multiple linear regression analysis using both temperature and rainfall amount did not explain more of the variability. Parameter estimates were not significant and the R^2 was the same in the expanded (<20°C temperature and rainfall) model compared to the temperature only model (data not shown). One reason for this may be the highly seasonal patterns of rainfall at some of the locations. Tepatitlan, for example, has an annual rainfall of 828 mm yr^{-1} (33 in yr^{-1}) but the distribution is restricted almost exclusively to the growing season. The soils are extremely dry during the fallow periods. This may increase carbon storage in the soil at Tepatitlan as residue decomposition has been reported to be a function of both temperature and water availability in regions with more uniform rainfall distribution (Steiner et al. 1999.). Other sites, such as Morelia, that had more uniform rainfall distribution throughout the year, did not increase soil carbon as much with residue retention—probably because of more rapid decomposition.

Summary and Conclusions

No-till management practices generally increased SOC content above that occurring with conventional tillage provided that some residue was left on the soil surface. Leaving crop residues was most effective in increasing soil carbon content in the cooler regions of Mexico with mean annual temperatures less than 20°C (68°F). Where mean annual temperatures were greater than 20°C (68°F), leaving crop residues on the soil had little effect on the soil carbon content. Annual rainfall amount affected SOC, but the relationship was not as strong as with annual temperature. This may have been a function of rain distribution throughout the year.

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