MID-TERM EFFECTS OF TILLAGE ON MICROBIAL BIOMASS AND NUTRIENT DISTRIBUTION IN VERTISOLS AND ANDISOLS UNDER RAIN-FED CORN PRODUCTION

Efecto a Mediano Plazo de Labranza en la Distribución de la Biomasa Microbiana y Nutrimentos en Vertisoles y Andosoles bajo Producción de Maíz de Temporal

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SUMMARY

Quantifying how tillage systems affect soil microbial biomass and nutrient distribution by manipulating crop residue placement is important for understanding how production systems can be managed to sustain soil productivity. The objectives were to characterize soil microbial biomass, N mineralization and nutrient distribution in soils (Vertisols and Andisols) under rain-fed corn production for six years with three tillage management systems in Michoacán, Mexico. Treatments include three tillage systems: conventional tillage (CT), minimum tillage (MT) and no tillage (NT). Soil samples were collected at the three locations, at depths of 0 to 50, 50 to 100, and 100 to 200 mm one week before corn planting. Conservation tillage treatments (minimum, and no tillage) significantly increased crop residue accumulation on the soil surface. Soil organic C, microbial biomass C and N, N mineralization, total N, and extractable P were higher for all treatments at the 0 to 50 mm depth. These parameters were highest in the surface layer of no tillage and decreased with depth. Soil organic C, microbial biomass C and N, total N and extractable P of plowed soil were generally more evenly distributed over the 0 to 200 mm depth. Nitrogen mineralization was closely associated with microbial biomass and organic C. Higher levels of soil organic C, microbial biomass C and N, N mineralization, total N, extractable P were directly related to surface accumulation of crop residues promoted by conservation tillage management. No tillage corn grain yield was higher or equal to CT. The sustainability of the soils under rain-fed corn production appeared to be enhanced with conservation tillage management.

Index words: Mid-term tillage, surface crop residues, soil organic carbon, microbial biomass C and N, total and inorganic N.

RESUMEN

Cuantificar el efecto de los sistemas de labranza en la distribución de la biomasa microbiana y los nutrimentos, al manipular los residuos de cosecha, es importante para el entendimiento de cómo los sistemas de producción pueden ser manejados para lograr la sostenibilidad de la producción del suelo. Los objetivos de esta investigación fueron: caracterizar la biomasa microbiana, la mineralización de N y la distribución de nutrimentos en suelos (Vertisoles y Andosoles) con producción de maíz de temporal en tres experimentos a mediano plazo (seis años) en Michoacán, México. Los tratamientos incluyeron tres sistemas de labranza: labranza convencional (CT), labranza mínima (MT) y labranza cero (NT). Se tomaron muestras de suelo en las tres localidades una semana antes de la siembra, a profundidades de 0 a 50, 50 a 100 y 100 a 200 mm. Los tratamientos de labranza de conservación (mínima y cero) incrementaron significativamente la acumulación de residuos de cosecha sobre la superficie del suelo. El contenido de carbono orgánico, carbono y nitrógeno de biomasa microbiana, la mineralización de nitrógeno, el nitrógeno total, y el fósforo asimilable fueron mayores en todos los

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tratamientos en la profundidad de 0 a 50 mm. Estos parámetros fueron los más altos en la capa superficial del suelo en el tratamiento de labranza cero y decrecieron al aumentar la profundidad. El contenido de carbono orgánico, carbono y nitrógeno de biomasa microbiana, nitrógeno total y fósforo asimilable en los suelos barbechados se distribuyó uniformemente en la capa arable de 0 a 200 mm. La mineralización de nitrógeno se asoció estrechamente con el contenido de biomasa microbiana y de carbono orgánico. Los mayores niveles de carbono orgánico, de carbono y nitrógeno de biomasa microbiana, la mineralización de nitrógeno, el nitrógeno total y el fósforo asimilable se relacionaron directamente con la acumulación de residuos de cosecha promovido por el manejo de labranza de conservación. El rendimiento de grano de maíz con cero labranza fue superior o igual al de labranza convencional. La labranza de conservación puede ayudar a incrementar la sostenibilidad de estos suelos para la producción de maíz de temporal.

**Palabras clave:** Labranza a mediano plazo, residuos de cosecha, carbono orgánico, C y N de biomasa microbiana, nitrógeno total e inorgánico.

**INTRODUCTION**

Heightened interest in the sustainability of agriculture has occurred in recent years in Mexico. Sustainable crop production requires that the soil be in good biological, physical, and chemical condition. According to the 1993 ‘Censo Agrícola y Ganadero’, crop management strategies in Mexico differ depending on environmental and socioeconomic conditions and affect the choice of crop, crop sequence, crop residue utilization, tillage systems and fertilization (INEGI, 1993). Conventional tillage (intensive tillage), crop residue removal and the continuous growing of corn, as are widely practiced in Mexico, generally increase productivity by temporarily improving soil physical conditions (soil-air-water relations) necessary for optimal plant growth. However, these management systems are known to increase the loss of soil organic matter (SOM) as a result of mixing of the soil and crop residues, disruption of aggregates, and increased aeration. The loss of SOM and the destruction of soil aggregates promote deterioration of physical, chemical, and biological conditions over the long-term. This deterioration often leads to decreased soil fertility, increased soil erosion, potential and water stress of rain-fed crops through reduced water infiltration and storage, decreased quality of surface water, and, thus, to diminished sustainability of agriculture (Blevins et al., 1977).

This situation has required the development and implementation of tillage systems that improve biological, chemical and physical properties of soil necessary to maintain sustainable crop production. Alteration of soil conditions by tillage can significantly affect productivity and sustainability through influences on depth distribution, SOM, microbial activity, and nutrient dynamics (Doran and Smith, 1987; Follett and Peterson, 1988; Mahboubi et al., 1993). Numerous reports in the past decade have found greater organic carbon and microbial activity in the soil surface layer of NT soil compared to CT soil in response to crop residue accumulation on the soil surface (Dalal et al., 1991; Bauer and Black, 1994; Franzluebbers et al., 1995a).

Crop residues retained on the soil surface by no tillage has been shown to reduce soil erosion, increase soil organic matter, and reduce requirements of labor and fuel under cereal grain and row crop culture (Claverán et al., 1997; Salinas-García et al., 1997a). However, questions emerged about the conservation tillage system that should be used to obtain these benefits. Considering these factors, a field experiment was designed to identify an appropriate conservation tillage system. The objective was to determine the effects of six years of conservation tillage on selected soil properties important to the productivity and sustainability of an Andisol and a Vertisol used for rain-fed corn production in Michoacán, Mexico.

**MATERIALS AND METHODS**

Three mid-term rain-fed field experiments with three tillage treatments were established in 1992 in Apatzingán (190 00’ N, 1020 13’ E), Casas Blancas (190 25’ N, 1010 36’ E), and Morelia (190 48’ N, 1010 03’ E), in Michoacán, Mexico. Climatic and soil characteristics of experimental sites are presented in Table 1. The crop sequence in the three sites was continuous fallow-corn. Tillage treatments included conventional tillage (CT-disking stalks after harvest, followed by disk plowing and disking, then bedding);
no tillage (NT-shredding stalks) and minimum tillage (MT-shredding stalks and disking, then bedding). Conservation tillage treatments (NT and MT) were sprayed before planting with paraquat (0.4 kg ha\(^{-1}\)) and glyphosate (0.72 kg ha\(^{-1}\)) as needed for weed control. All tillage treatments were fertilized with INIFAP recommended doses for each region: 150-90-00 for Apatzingán, 120-90-00 for Casas Blancas, and 120-60-00 for Morelia. Fertilization was applied at planting. Corn was sown in June at Apatzingán and Morelia and in April at Casas Blancas in 160-cm beds. A randomized, complete block design was used with treatments replicated three times. Tillage plots measured 3.20 by 10 m, and harvested plots measured 1.6 by 5 m. Row spacing was 80 cm.

Surface crop residue was collected one week before planting from two midrow to midrow 1 m\(^2\) areas that were representative of each tillage treatment, stored in a warm and dry environment for four days to allow them to air dry and then weighed (Steiner et al., 1994).

Soil samples were collected prior to the 1998 corn growing season one week before planting. Soil samples from each plot for chemical and biological analysis consisted of two composite sub-samples that were taken with a narrow spade and divided into segments of 0 to 50, 50 to 100, and 100 to 200 mm, placed on plastic bags and brought to laboratory for analysis. The soil samples were air-dried during a 2-day period and sieved to pass a 2 mm screen (Franzluebbers et al., 1995b; Franzluebbers, 1999). A 7 g portion was extracted in 28 mL of 2 M KCl for 30 min on a reciprocating shaker. The soil extract was analyzed for NH\(_4\)+-N using spectrophotometer techniques (Plenecassangne et al., 1997). Soil microbial biomass N (SMBN) was determined using the following equation:

\[ \text{SMBN} = \frac{[\text{mg NH}_4^+\text{-N kg}^{-1}\text{ soil } 10 \text{ days}^{-1}]_{\text{fumigated}} - [\text{mg NH}_4^+\text{-N kg}^{-1}\text{ soil } 10 \text{ days}^{-1}]_{\text{unfumigated}}}{K_N} \]  

Where \(K_N = 0.41\) (Carter and Rennie, 1982).

Unfumigated and fumigated soils were incubated during 10 d, dried at 60 °C for 24 h and sieved to pass a 2 mm screen (Franzluebbers et al., 1995b; Franzluebbers, 1999). A 7 g portion was extracted in 28 mL of 2 M KCl for 30 min on a reciprocating shaker. The soil extract was analyzed for NH\(_4\)+-N using spectrophotometer techniques (Plenecassangne et al., 1997). Soil microbial biomass C (SMBC) was determined using the following equation:

\[ \text{SMBC} = \frac{[\text{mg CO}_2\text{-C kg}^{-1}\text{ soil } 10 \text{ days}^{-1}]_{\text{fumigated}} - [\text{mg CO}_2\text{-C kg}^{-1}\text{ soil } 10 \text{ days}^{-1}]_{\text{unfumigated}}}{K_C} \]  

Where \(K_C = 0.41\) (Voroney and Paul, 1984).

Potential nitrogen mineralization was estimated from the quantities of NH\(_4\)+-N and NO\(_3\)-N that were mineralized from unfumigated samples (incubated for 0, 5, 10, and 15 days at 25 °C and a soil water potential of –0.03 MPa) (Campbell et al., 1991) using spectrophotometer techniques with indophenol blue method (Plenecassangne et al., 1997) and Cd

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Casas Blancas</th>
<th>Morelia</th>
<th>Apatzingán</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude (m)</td>
<td>2400</td>
<td>1822</td>
<td>330</td>
</tr>
<tr>
<td>Climate</td>
<td>Subhumid temperate</td>
<td>Temperate</td>
<td>Dry tropical</td>
</tr>
<tr>
<td>Annual precipitation (mm)</td>
<td>1100</td>
<td>698</td>
<td>650</td>
</tr>
<tr>
<td>Annual temperature (°C)</td>
<td>15</td>
<td>17</td>
<td>27</td>
</tr>
<tr>
<td>Soil type</td>
<td>Andisol</td>
<td>Vertisol</td>
<td>Vertisol</td>
</tr>
<tr>
<td>Particle distribution (%)</td>
<td>13 - 42 - 45</td>
<td>15 - 29 - 56</td>
<td>20 - 30 - 50</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>5.8</td>
<td>2.3</td>
<td>1.2</td>
</tr>
<tr>
<td>CEC (cmol kg(^{-1}) soil)</td>
<td>7.1</td>
<td>19.8</td>
<td>53</td>
</tr>
<tr>
<td>pH (1:2)</td>
<td>6.1</td>
<td>7.4</td>
<td>8.2</td>
</tr>
</tbody>
</table>

† Silt, sand, and clay.
reduction method (Mulvaney, 1996), respectively. Day 0 represents the in situ inorganic soil N concentration.

Another portion of soil was used for chemical analyses, it was grounded to pass a 0.5-mm sieve. Total Kjeldahl N (TKN) was determined by digestion in H₂SO₄ (Nelson and Sommers, 1980), followed by analysis of NH₄⁺-N using a spectrophotometer (Plenecassagne et al., 1997). Total soil organic C was determined by the Walkley-Black method (Nelson and Sommers, 1982). Extractable P was removed with 0.5 M NaHCO₃, pH 8.5 and determined using a colorimetric molybdate blue method (Olsen et al., 1954) for alkaline and neutral soils. While for acid soil, extractable P was removed with 0.025 N HCl in 0.03 N NH₄F and determined using a colorimetric ascorbic acid method (Bray and Kurtz, 1945). Soil bulk density was calculated from dry weight (105 °C, 48 h) and the volume of samples taken with a hammer-driven core sampler (132.88 cm³) and was used to convert soil chemical and biological properties from a mass to a volume basis (Blake, 1965). Corn was harvested by hand and threshed by machine from 16 m² area. Grain weights were determined and the resulting weights were adjusted to 14% moisture basis, then converted to kg ha⁻¹.

Differences in soil chemical and biological parameters attributed to tillage treatments were analyzed by ANOVA (SAS Institute Inc., 1985). Duncan’s multiple-range test was used to separate significant differences in response parameters due to tillage (Steel and Torrie, 1980). Unless otherwise indicated, significance is indicated at p ≤ 0.05.

RESULTS AND DISCUSSION

Surface Crop Residue

Surface crop residue was significantly affected by tillage at Casas Blancas, Morelia, and Apatzingán (Figure 1). Surface crop residue was highest from soils under no tillage at the three sites, while soils receiving disk plowing exhibited the least residue. Quantity of residue from MT treatment was intermediate to those two extremes. The use of NT and MT resulted in increases in surface crop residues of 97, 94, and 90% at Casas Blancas, Morelia, and Apatzingán, respectively, compared to CT. Accretion of surface crop residues can be expected with tillage systems (i.e., NT and MT) which do not completely incorporate crop residues. Holland and Coleman

![Figure 1. Crop residue on the soil surface as affected by tillage at three locations in Michoacán. Means within tillage treatments followed by the same letter are not significantly different (Duncan’s P ≤ 0.05).](image-url)
Figure 2. Depth distribution of soil organic carbon as affected by tillage at three locations in Michoacán. Means within depth followed by the same letter are not significantly different (Duncan’s P ≤ 0.05). NS indicates non-significant.

(1987) reported higher crop residue over the soil surface with no tillage compared with plowing because buried residue generally decomposes faster than crop residues left on the surface. Increased surface residues may be especially important in decreasing soil water loss by evaporation in the dry tropical region of Apatzingán, and reducing erosion on the steep-slop Andisols of the subhumid temperate region of Casas Blancas (Tiscareño-López et al., 1999).

Soil Organic Carbon (SOC)

Soil organic C was significantly affected by tillage and generally decreased with soil depth at all locations (Figure 2). In the surface layer (0 to 50 mm), SOC average content was 10.8, 4.1, and 2.1 t ha⁻¹ at Casas Blancas, Morelia, and Apatzingán respectively; this difference is attributed to the higher initial organic matter content of Casas Blancas and Morelia, than Apatzingán. In the surface, SOC was 46, 36, and 57% greater with conservation tillage treatments (NT and MT) than with conventional tillage, at Casas Blancas, Morelia and Apatzingán, respectively. Those results occurred because tillage mixes crop residue throughout the tillage zone, whereas residues are concentrated on the soil surface with NT. Reduced contact between soil microorganisms and crop residues resulting in slower organic matter decomposition is probably the main reason for SOC accumulation in NT. Brown and Dickery (1970) showed that percentage dry matter loss from wheat straw remaining on the soil surface or exposed above the soil during an 18-month period ranged from 22 to 40%. Losses of 93 to 98%, however, were observed for wheat straw incorporated into the soil. Below the surface at the three locations, SOC decreased with NT and MT, but tended to remain constant or actually increased in CT. Incorporation of crop residues with disk plow may account for this effect.

Soil microbial biomass C and N were significantly affected by tillage, only at the soil surface 0 to 50 mm, and followed a pattern similar to SOC with depth at Casas Blancas, Morelia, and Apatzingán
Figure 3. Depth distribution of soil microbial biomass carbon as affected by tillage at three locations in Michoacán. Means within depth followed by the same letter are not significantly different (Duncan's $P \leq 0.05$). NS indicates non-significant.

Figure 4. Depth distribution of soil microbial biomass nitrogen as affected by tillage at three locations in Michoacán. Means within depth followed by the same letter are not significantly different (Duncan's $P \leq 0.05$). NS indicates non-significant.
(Figures 3 and 4). In the surface layer (0 to 50 mm) of Morelia and Apatzingán Vertisols, soil microbial biomass C and N fluctuated from 360 to 968 kg ha$^{-1}$ and from 24 to 53 kg ha$^{-1}$, respectively. While in Casas Blancas Andisols soil microbial biomass C and N fluctuated from 311 to 707 kg ha$^{-1}$ and from 42 to 73 kg ha$^{-1}$, respectively, with the different tillage treatments. Soil microbial biomass C and N in the surface layer were 25 to 50% greater with the NT and MT treatments than with CT. At higher depths, soil microbial biomass C and N were generally not significantly different and decreased in all tillage treatments. However, this decrease was least evident in plowed soils and it probably resulted from the incorporation and mixing of crop residues. In contrast, higher soil microbial biomass concentrations with NT and MT may be due to accumulation of crop residues at soil surface. Doran (1987) evaluated long-term tillage effects on soils at several sites in the USA and found that microbial biomass in surface layer of NT soils averaged 54% higher than plowed soils. He also reported that microbial biomass was closely associated with distributions of SOC and moisture content as influenced by tillage. The lower soil microbial biomass C and N observed with plowing indicates that this tillage system may not be sustainable, especially in soils with low initial concentrations of soil organic matter. The observed decrease in microbial biomass with plowing is similar to that reported by Follett and Schimel (1989) who found that microbial biomass decreased in the order of sod>NT>stubble mulch>plow.

**Potential Nitrogen Mineralization**

Potential N mineralization one week before planting was significantly affected by tillage, and followed closely the pattern observed for soil microbial biomass C and N at Casas Blancas, Morelia, and Apatzingán (Figure 5). In plowing layer (0 to 200 mm) of Morelia and Apatzingán Vertisols potential nitrogen mineralization fluctuated from 4.1 to 17.7 kg ha d$^{-1}$. While in Casas Blancas Andisol potential nitrogen mineralization N fluctuated from 2.7 to 6.2 kg ha d$^{-1}$, respectively, with the different tillage treatments. No tillage showed the highest average nitrogen mineralization rate (10.3 kg ha d$^{-1}$), and MT showed intermediate mineralization rate (7.6 kg ha d$^{-1}$), while CT showed the lowest mineralization rate (6.1 kg ha d$^{-1}$) at the three locations. Potential nitrogen mineralization increased as crop residues accumulated with NT treatments. Franzluebbers et al. (1994) reported an increase in potential nitrogen mineralization with tillage systems, which do not

![Figure 5. Potential nitrogen mineralization to a depth of 200 mm as affected by tillage at three locations in Michoacán. Means within tillage treatments followed by the same letter are not significantly different (Duncan’s P ≤ 0.05).](image-url)
incorporate crop residues. Higher N mineralization rates in no-till soils than in plowed soils have also been detected in other laboratory incubations (Follett and Schimel, 1989). The lower N mineralization rates observed one week before planting in plowed soils indicates that incorporation of crop residues with disk plow speeds organic matter mineralization during the fallow period and planting of the next crop. Differences in organic matter decomposition and N mineralization are related to crop residue distribution within the plowing layer (Douglas et al., 1980; Salinas-García et al., 1997b).

Total Kjeldahl Soil Nitrogen

Total soil N followed a pattern similar to SOC and was significantly affected by tillage only in the upper 0 to 50-mm soil layer at all locations (Figure 6). In the surface layer (0 to 50 mm) of the Morelia and Apatzingán Vertisols total N fluctuated from 312.9 to 736.0 kg ha\(^{-1}\), while in Casas Blancas Andisol total nitrogen fluctuated from 691.3 to 1090.5 kg ha\(^{-1}\), with the different tillage treatments. NT showed the highest average total nitrogen concentration (834.4 kg ha\(^{-1}\)), and MT showed intermediate concentration (498.9 kg ha\(^{-1}\)), while disk plowing showed the lowest concentration (444.4 kg ha\(^{-1}\)) at the three locations. Total N at higher depths decreased in all tillage treatments, especially with NT. This tendency was less evident with plowing. Increased total N apparently resulted from the increased accumulation of crop residues near the soil surface with conservation tillage systems (NT and MT). Total nitrogen is known to be enhanced by increasing soil organic matter content (Blevins et al., 1977; Elliott et al., 1987). Greater total N near the soil surface with conservation tillage systems is consistent with results reported by other researchers at various locations (Blevins et al., 1977; Hooker and Schepers, 1984; Follett and Peterson, 1988; Unger, 1991). These authors also indicated that total N in NT soils sharply declined below 50 mm from the soil surface. The decline was closely associated with decreasing organic matter content with soil depth.

Extractable Soil Phosphorus

Extractable soil P followed a pattern similar to SOC, and was significantly affected by tillage, at the three soil sampling depths on Casas Blancas, Morelia, and Apatzingán (Figure 7). In the surface (0 to 50 mm) of the Morelia and Apatzingán Vertisols extractable P fluctuated from 3.06 to 36.70 kg ha\(^{-1}\), while in Casas Blancas Andisol extractable P fluctuated from 0.10 to 0.32 kg ha\(^{-1}\) with the different tillage treatments. In the surface soil layer,
extractable P concentration was approximately 50% greater with NT and MT than with plowing; however, this difference decreased with soil depth especially at Morelia and Apatzingán. In the 100 to 200 mm soil depth, disk plow resulted in the highest extractable soil P at Casas Blancas. Deep incorporation of crop residues and fertilizer with mid-term plowing may account for this effect. Similar results have been previously reported (García, 2000). Increased extractable P with NT in Morelia and Apatzingán alkaline soils apparently resulted from the increased concentration of organic residues near the soil surface and the slight decrease in soil pH associated with this treatment. Phosphorus solubility is known to be enhanced by increasing soil organic matter and decreasing pH in alkaline soils (El-Baruni and Olsen, 1979). Organic matter accumulation in surface layer of NT soils has also been shown to influence P distribution (Follett and Peterson, 1988). Unger (1991) reported that for a wheat-sorghum-fallow system, extractable P was greater in the upper 200 mm of NT soil than in stubble-mulch and plowed soil, and declined below this depth. The decline was closely associated with decreasing organic matter with depth.

Corn Grain Yield

Distribution of precipitation during growing season in 1998 was favorable for rain-fed corn production and grain yields were high. Corn grain yield was significantly affected by tillage at Casas Blancas, Morelia, and Apatzingán (Table 2). Corn grain yield was significantly higher under no tillage at Casas Blancas, while at Morelia and Apatzingán no significant difference was observed as compared to conventional tillage. Minimum tillage resulted in the lowest grain yield at the three sites. The apparent reason was an adequate plant stand and good biological and chemical soil conditions in NT. This may indicate that NT systems, as used in this study,

Table 2. Mid-term tillage effects on rain-fed corn yields, 1998.

<table>
<thead>
<tr>
<th>Tillage treatments</th>
<th>Casas Blancas</th>
<th>Morelia</th>
<th>Apatzingán</th>
</tr>
</thead>
<tbody>
<tr>
<td>No tillage</td>
<td>6232.0 a †</td>
<td>9175.0 a</td>
<td>4975.8 a</td>
</tr>
<tr>
<td>Minimum tillage</td>
<td>3994.8 b</td>
<td>7766.0 b</td>
<td>4093.0 b</td>
</tr>
<tr>
<td>Conventional</td>
<td>4398.1 b</td>
<td>9398.0 a</td>
<td>5182.0 a</td>
</tr>
<tr>
<td>C.V.</td>
<td>18.72</td>
<td>14.31</td>
<td>18.86</td>
</tr>
</tbody>
</table>

† Means within a column followed by same letter are not significantly different.
can produce higher or equal corn yields to conventional tillage systems. Minimum tillage appears not to be well adapted to the conditions of those regions. Vyn and Raimbaut (1993) indicated that when plant population was adequate and weeds were controlled, NT corn yields were higher or similar to yields of plowed tillage systems. No tillage yields were depressed during the early years of the experiment, but after some years, yields reached levels close to those with plowing.

CONCLUSIONS

The results of this study indicate that conservation tillage management alters the depth distribution and concentration of crop residue, organic C, microbial biomass C and N, potential nitrogen mineralization, total N, and extractable P. Surface crop residues are highest in soils under conservation tillage (NT and MT), while soils with disk plow tillage exhibit the lowest values. Conservation tillage systems (NT and MT) promoted accumulation of crop residues and offered the best opportunity to increase C sequestration, soil microbial biomass, and nutrient cycling. Higher levels of soil organic C, microbial biomass C and N, total N, and extractable P are directly related to surface accumulation of crop residues which is promoted by conservation tillage management. Organic matter enhancement, with all its beneficial effects, is probably the most important change in those soils with conservation tillage. Regardless soil type (Vertisol or Andisol) or tillage system (NT, MT or CT) organic matter content decreased with increasing annual temperature. The long-term quality and productivity of the Casas Blancas, Morelia, and Apatzingán soils can be maintained or improved with the use of conservation tillage.

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