Long-term tillage and crop rotation effects on microbial biomass and C and N mineralization in a Brazilian Oxisol

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Abstract

Crop rotation and tillage impact microbial C dynamics, which are important for sequestering C to offset global climate change and to promote sustainable crop production. Little information is available for these processes in tropical/subtropical agroecosystems, which cover vast areas of terrestrial ecosystems. Consequently, a study of crop rotation in combination with no tillage (NT) and conventional tillage (CT) systems was conducted on an Oxisol (Typic Haplorthox) in an experiment established in 1976 at Londrina, Brazil. Soil samples were taken at 0–50, 50–100 and 100–200 mm depths in August 1997 and 1998 and evaluated for microbial biomass carbon (MBC) and mineralizable C and N. There were few differences due to crop rotation, however there were significant differences due to tillage. No tillage systems increased total C by 45%, microbial biomass by 83% and MBC:total C ratio by 23% at 0–50 mm depth over CT. C and N mineralization increased 74% with NT compared to CT systems for the 0–200 mm depth. Under NT, the metabolic quotient (CO2 evolved per unit of MBC) decreased by 32% averaged across soil depths, which suggests CT produced a microbial pool that was more metabolically active than under NT systems. These soil microbial properties were shown to be sensitive indicators of long-term tillage management under tropical conditions.

Keywords: Basal respiration; Microbial biomass; Carbon and nitrogen mineralization; Tillage systems; Crop rotations

1. Introduction

There is worldwide interest in sequestering C in soils to offset global climate change. Agroecosystems represent a large portion of terrestrial ecosystems, are intensively managed, and provide an opportunity to stabilize atmospheric CO2 in semi-permanent soil C pools. Implementing agricultural practices that reduce soil degradation has the potential to increase agricul-...
protecting and maintaining soil organic matter (Beare et al., 1994; Gupta and Germida, 1988). Tillage disrupts soil aggregates exposing organic matter to microbial degradation. These changes in structure can affect soil water, temperature, aeration, equilibrium of reactions, and increase soil erosion. Diverse crop rotations can change soil habitat by affecting nutrient status, depth of rooting, amount and quality of residue, aggregation/microbial habitat, and can stimulate soil microbial diversity and activity.

Soil microorganisms mediate mineralization of SOM and nutrients. The microbial biomass is a small but important reservoir of nutrients (C, N, P and S) and many transformations of these nutrients occur in the biomass (Dick, 1992). Soil disturbance can cause significant modifications of soil habitat, which affects the microbial community. This has been shown in numerous examples where SOM and microbial biomass decline under agricultural or land disturbance (Sparling, 1997).

Currently, there is a strong interest in sequestration of C in soils as a means to help decrease atmospheric CO2 and to gain side benefits of improving soil quality and plant productivity (Burras et al., 2001; Sa et al., 2001). Microbial biomass measurements can detect tillage and crop rotation effects on soil earlier than total organic C or N measurements in soil (Powlson and Jenkinson, 1981; Carter, 1986; Powlson et al., 1987; Saffigna et al., 1989; Balota et al., 1998) and therefore they may be an indicator of potential C sequestration (Sa et al., 2001). In this context, microbial biomass can be a valuable tool for understanding changes in soil properties and in the degree of soil degradation or soil quality (Smith and Paul, 1990; Doran and Parkin, 1994; Brookes, 1995; Sparling, 1997).

The objective of this study was to evaluate the effect of long-term crop rotations and tillage systems on microbial biomass C and N mineralization in a tropical soil from Brazil.

2. Materials and methods

A study was established in 1976 at the Experimental Station of Agronomic Institute of Paraná (IAPAR), district of Londrina, State of Paraná, in the southern region of Brazil (23°40' S, 50°52' W and 576 m altitude) on an Oxisol ( Typic Haplorthox) with 85% clay, 12% silt, 3% sand, pH 4.6 and 12 g organic C kg⁻¹ soil. Long-term means (1976–2002) of temperature at the site ranged from 23.6 to 25.5 °C in January and from 16.0 to 24.3 °C in June, while the mean annual precipitation was 1984 and 2005 mm in 1997 and 1998, respectively (IAPAR—Instituto Agronômico do Paraná, unpublished results). The design was a split plot (three replications) with tillage as the main plot (65 m × 25 m) and crop rotation as the subplot (8 m × 25 m), which were separated by a 2 m buffer. Tillage treatments were NT planting into undisturbed soil by opening a narrow trench and CT with one disc plowing at 200 mm depth and two light harrowing for seedbed preparation. Crop rotations were soybean ( Glycine max L.)/wheat ( Triticum aestivum L.) (S/W), maize ( Zea mays L.)/wheat (M/W), and cotton ( Gossypium hirsutum L. r. latifolium Hutch)/wheat (C/W). Crop stubbles were retained on the surface in the NT system or they were tilled conventionally (plowed to 200 mm depth) following harvest, in both fall and spring operations each year. Fertilizers were added according to soil analysis before each cropping period, averaging, 95 kg of N, 55 kg of P and 42 kg of K per hectare per year for the last 20 years. N fertilizer was never applied to the soybean crop. Five sub-samples were taken with a core (55 mm diameter) randomly within each replicate (0-50, 50-100 and 100-200 mm depths) in August 1997 and in 1998 (at the end of the winter crop). The fresh soil samples were sieved through a 4 mm screen with large plant material removed and stored at 4 °C until analysis. All determinations were made in triplicate and expressed on a dry weight basis. Data were averaged across the two sampling years and were analyzed using the SAS statistical package (SAS, 1998).

2.1. Analytical procedures

Total organic C concentration in soil was measured by the Walkley-Black potassium dichromate sulfuric acid oxidation procedure (Nelson and Sommers, 1982). Soil microbial biomass C (MBC) was determined by fumigation-incubation (Jenkinson and Powlson, 1976) on a 20 g (fresh weight) sample using NaOH to trap CO2 followed by Flow Injection Analysis for electric conductivity. Soil MBC was calculated using CO2-C evolved from the fumigated samples only as suggested by Franzluebbers et al. (1999a), and
a correction factor \(k_c\) of 0.45 (Jenkinson and Ladd, 1981). Basal respiration was obtained from the measurement of CO\(_2\) released from the non-fumigated control. Metabolic quotient \(q_{\text{CO}_2}\) was obtained by dividing the basal respiration by the microbial biomass C (mg CO\(_2\)-C g\(^{-1}\) MBC per day). Mineralization of C was from incubation of 30 g moist soil in a 350 ml sealed jar in the presence of a NaOH trap and water in a separate vessel to maintain high humidity for 3, 6, 10, 17 and 24 days at 50 \(^{\circ}\)C in a dark chamber. At each sampling period, NaOH was collected and replaced. The concentration of CO\(_2\) released was measured by Flow Injection Analysis. Controls were run on six flasks that had no soil for the determination of CO\(_2\). Nitrogen mineralization was from 24-day incubation at 30 \(^{\circ}\)C of 3 g of moist soil that was extracted with 20 ml of K\(_2\)SO\(_4\) solution (0.25 M) by shaking for 50 min at 220 rpm, and then centrifuging and filtering. The concentration of NO\(_3^-\) was determined by the procedure described by Miyazawa et al. (1985), which consisted of measuring NO\(_3^-\) in soil extracts without chemical reduction by ultraviolet spectrophotometry at 210 nm (NO\(_3^-\) plus dissolved organics) and at a longer wavelength (239 nm) where the ultraviolet light absorption due to NO\(_3^-\) is negligible and that due to interfering ions is similar to that measured at 210 nm (with chemical reduction). The difference between absorbance values obtained at 239 nm (NO\(_3^-\) plus dissolved organics) and 210 nm (dissolved organics) gave nitrate concentration. The N mineralized was calculated from the difference between nitrate concentration after and before the incubation.

3. Results and discussion

No tillage practices increased total C concentrations over CT by 45, 34 and 14%, in the 0–50, 50–100 and 100–200 mm depths, respectively. There was a trend for a decrease in total C with soil depth in NT, while in CT the total C remained almost constant with depth (Table 1). There was no effect of crop rotation on total C concentrations in the soil under either tillage system.

### 3.1. Microbial biomass carbon

Microbial biomass C varied from 163 to 209 \(\mu\)g g\(^{-1}\) in the soil under CT and from 204 to 367 \(\mu\)g g\(^{-1}\) under NT (Table 1). No tillage resulted in a significant increase in MBC in all crop rotations (from 11 to 98%) averaged across all depths compared to CT. The greatest differences between NT and CT occurred in the surface layer (0–50 mm) where the MBC in NT was increased by 140–198% compared to CT.
was on average 83% higher than CT plots. Soil samples from NT plots also were 55 and 28% greater in MBC than CT at 50–100 and at 100–200 mm depth, respectively. The M/W crop rotation increased MBC over other crop rotations at 50–100 mm depth under CT and 100–200 mm depth under NT. The values of MBC were similar to those observed under a range of ecosystems from temperate and tropical regions (Prasad et al., 1994; Alvarez et al., 1995; Miller and Dick, 1995; Franzluebbers et al., 1995; Balota et al., 1998; Mendes et al., 1999). Alvarez et al. (1995), studying soils of the Argentinian pampas cultivated under different tillage regimes for 12 years, observed that NT resulted in 50% greater organic C and 181% greater MBC than CT.

The increase of MBC under NT over CT could be attributed to several factors. An important factor for tropical soils may be the effect of the surface litter in an NT system lowering soil temperature, and increasing water content, soil aggregation and C content over CT systems. The microbial biomass in the surface soil under NT represents either a sink or source for plant-available nutrients, depending on cropping and climatic changes in the soil environment. The accumulation of crop residues at the surface provides substrates for soil microorganisms, which accounts for the higher MBC at the surface under NT. Increased MBC under NT is consistent with the results of Ferreira et al. (2000), who observed greater bradyrhizobia diversity at the same experimental site.

### 3.2. Metabolic quotient

The values of metabolic quotient, soil respiration per unit of microbial C ($\frac{q_{\text{CO}_2}}{\text{MBC}}$) varied from 3.6 to 5.5 under CT and from 2.16 to 3.60 mg CO$_2$-C g$^{-1}$ MBC per day under NT (Table 1). Averaged across crop rotations and depths, $\frac{q_{\text{CO}_2}}{\text{MBC}}$ in soil under NT was 32% lower than under CT. At 0–50 mm depth $\frac{q_{\text{CO}_2}}{\text{MBC}}$ values under NT were from 20 to 57% lower than under CT with all crop rotations. At 50–100 mm depth, $\frac{q_{\text{CO}_2}}{\text{MBC}}$ for NT was 19–35% lower than CT, while at 100–200 mm values under NT were from 27 to 43% lower. Crop rotation effects on $\frac{q_{\text{CO}_2}}{\text{MBC}}$ were not found at any soil depth. The inverse relationship between MBC and $\frac{q_{\text{CO}_2}}{\text{MBC}}$ was similar to the results of Prasad et al. (1994), who observed an increase in MBC of 106% and decrease of 39% in $\frac{q_{\text{CO}_2}}{\text{MBC}}$ in different ecosystems of India. On the other hand, Alvarez et al. (1995) observed that under NT there was an increase of 60% in $\frac{q_{\text{CO}_2}}{\text{MBC}}$ in the first 50 mm depth while at 50–150 mm depth, it was reversed with NT having $\frac{q_{\text{CO}_2}}{\text{MBC}}$ value 21% less than CT. Generally, it is viewed that $\frac{q_{\text{CO}_2}}{\text{MBC}}$ decreases in more stable systems (Insam and Domsch, 1988), while the incorporation of residues to soil increases $\frac{q_{\text{CO}_2}}{\text{MBC}}$ (Octio and Brookes, 1990).

According to Saffigna et al. (1989), soils under CT provide less organic matter and MBC, but a larger metabolic quotient than NT. These differences may be due to differences of accessibility to C substrates by microorganisms, changes in the metabolic rates and changes in microbial community composition (Alvarez et al., 1995). No tillage also may have a greater amount of larger aggregates, which protects microorganisms from adverse conditions. This has important implications for agriculture, because if less C is evolved from the soil, more C can be stored in soil organic matter. An increase of MBC combined with a decrease of $\frac{q_{\text{CO}_2}}{\text{MBC}}$ suggests that the soil ecosystem under NT was becoming more stable (Sparling, 1997).

### 3.3. Ratio microbial biomass C:total C

The values of microbial biomass C:total C varied from 11.6 to 14.8 mg g$^{-1}$ under CT and from 11.8 to 16.8 mg g$^{-1}$ under NT (Table 1). No significant change in ratio of MBC to total C was observed due to tillage. Crop rotation did not affect proportion of MBC as total C under either CT or NT at any soil depth. The trend of increasing percentage of total C as MBC due to NT followed the results of Carter (1986) where increasing tillage intensity decreased both MBC and percentage of total C as MBC. Variations in percentage of total C as MBC have been related to monoculturing and crop rotation. The percentages of total C as MBC were lower than other reports with values of 1.8 and 2.3% (Insam et al., 1989) and of 2.3 and 2.9% (Anderson and Domsch, 1989) for monoculturing and crop rotations, respectively. However, other studies on different soils and management systems showed a wide range for the percentage of total C as MBC (e.g. 0.6–3.7% by Insam, 1990; 0.3–5.4% by Anderson and Domsch, 1989). The wide ranges for this relationship suggest it is sensitive to soil management, time of sampling, and analytical methods.
Table 2

<table>
<thead>
<tr>
<th>Crop rotations</th>
<th>BR (µg CO₂-C g⁻¹ per day)</th>
<th>C mineralization (µg g⁻¹ per day)</th>
<th>N mineralization (µg g⁻¹ per day)</th>
<th>C:N mineralization ratio (g g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>NT</td>
<td>CT</td>
<td>NT</td>
</tr>
<tr>
<td>Depth: 0–50 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/W</td>
<td>9.0</td>
<td>7.6</td>
<td>3.30 bA</td>
<td>4.00 aA</td>
</tr>
<tr>
<td>M/W</td>
<td>6.9</td>
<td>10.9</td>
<td>3.00 aAB</td>
<td>2.90 aB</td>
</tr>
<tr>
<td>C/W</td>
<td>7.8</td>
<td>9.3</td>
<td>2.00 aB</td>
<td>2.00 aC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth: 50–100 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/W</td>
<td>7.3 aB</td>
<td>9.1 a</td>
<td>1.50 bB</td>
<td>4.00 aA</td>
</tr>
<tr>
<td>M/W</td>
<td>10.3 aA</td>
<td>10.2 a</td>
<td>3.30 aA</td>
<td>4.10 aA</td>
</tr>
<tr>
<td>C/W</td>
<td>5.1 bB</td>
<td>8.7 a</td>
<td>3.20 aA</td>
<td>3.60 aB</td>
</tr>
<tr>
<td></td>
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<tr>
<td>Depth: 100–200 mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/W</td>
<td>9.5 aA</td>
<td>6.4 bB</td>
<td>2.30 bB</td>
<td>7.10 aA</td>
</tr>
<tr>
<td>M/W</td>
<td>10.2 aA</td>
<td>8.6 aA</td>
<td>3.40 aA</td>
<td>4.30 aB</td>
</tr>
<tr>
<td>C/W</td>
<td>5.8 aB</td>
<td>5.5 aB</td>
<td>3.30 aA</td>
<td>3.70 aC</td>
</tr>
</tbody>
</table>

Means within a row followed by a different lower case letter are significantly different at \( P \leq 0.05 \). Means within a column of the same depth followed by a different upper case letter are significantly different at \( P \leq 0.05 \).

a Values are means of three replications.

b Only NO₃.

c S: soybean; W: wheat; M: maize; C: cotton.

Changes in the percentage of total C as MBC may be related to organic matter formation and efficiency of conversion of recalcitrant C pools into MBC (Sparling, 1992). The percentage of total C as MBC has been suggested as an indicator of whether soil organic matter is decreasing, increasing or in a steady state (Anderson and Domsch, 1989; Insam, 1990). Jenkinson and Ladd (1981) suggested 2.2% as a threshold value for when soil is in equilibrium. All of our results were ≤ 1.7%, which was lower than this threshold. Nonetheless, there was 45% greater organic C at 0–50 mm under NT than CT. Generally, if a soil is intensively disturbed, MBC will decline faster than the organic matter, and the percentage of total C as MBC will decrease (Powlsion and Jenkinson, 1981; Sparling, 1992). Our results suggest that ratio of MBC/total C under tropical/subtropical conditions may have a different threshold as an indicator of C accumulation than in temperate regions.

3.4. Basal respiration and carbon mineralization

The values of basal respiration (BR) varied from 5 to 10 µg CO₂-C g⁻¹ per day under CT and from 5 to 10 µg CO₂-C g⁻¹ per day under NT (Table 2). There was significantly greater BR in the C/W rotation under NT compared with CT at 50–100 mm depth, but the opposite occurred in the S/W rotation at 100–200 mm depth. Crop rotation had a significant effect on BR at 50–200 mm layer. Under CT, the M/W rotation at 50–100 mm depth and S/W and M/W rotation at 100–200 mm had greater BR than other crop rotations, while under NT, BR was 40% greater in the M/W rotation at 100–200 mm depth than other rotations. On average, there was no difference in BR between NT and CT. Franzluebbers and Arshad (1996) observed a tillage effect that varied from 4 to 28 µg CO₂ g⁻¹ un-der CT and from 4 to 31 µg CO₂ g⁻¹ under NT. It is suggested that BR be regarded as an index of potential CO₂ loss or a microbial index, but should not be regarded as an indicator of C accumulation or loss from soils under field conditions. Basal respiration can indicate soil quality since soil quality is preserved with high BR and reduced with low BR.

The values of C mineralization released as CO₂ during 24-day incubation varied from 1.5 to 3.4 µg C g⁻¹ per day under CT and from 2.0 to 7.1 µg C g⁻¹ per day under NT (Table 2). No tillage resulted in a significant increase in C mineralization under the S/W rotation at all depths compared with CT. On average
the C mineralization under NT was 50% greater than CT. The C mineralized was affected by both tillage and crop rotation which is consistent with research of Franzluebbers et al. (1995) who obtained values from 8 to 11 μg C g⁻¹ per day under CT and from 8 to 10 μg C g⁻¹ per day under NT in 24-day incubations. In general, C mineralization decreases with depth, mainly due to the total C be lower in deeper layer, however we observed a slight increase of C mineralization at deeper depth even though total C was somewhat lower in this layer under NT.

Basal respiration and C mineralization values vary widely in the literature, depending on a variety of factors including soils, climates, and experimental conditions. For example, BR varied from 8 to 84 μg CO₂ g⁻¹ per day (Gupta and Germida, 1988; Insam et al., 1991; Prasad et al., 1994), while C mineralization ranged from 21 μg C g⁻¹ per day under cultivated soils to 34 μg C g⁻¹ per day under native soils during 14-day incubations (Gupta and Germida, 1988).

Although NT had greater C mineralization than did CT, the experimental manipulations would not have reflected field conditions, particularly for NT, which would have minimal disturbance under field conditions. The disturbance of sampling and processing would likely have exposed protected soil organic matter in NT soils, artificially stimulating C mineralization. Incorporated crop residues decompose 1.5 times faster with less immobilization and greater mineralization of nutrients than do surface placed residues (Holland and Colleman, 1987; Kushwaha et al., 2000).

Reicosky (1997) observed that under field conditions, tillage released 13.8 times greater release of CO₂ from soil than did NT for the first 19 days after moldboard incorporation of residues. Bayer et al. (2000) adjusted a first-order exponential model to predict total organic C based on C losses and C inputs under subtropical field conditions of Brazil. They observed that the coefficient for C loss under NT was one-half as large as the coefficient under CT, providing support for higher concentrations of total C under NT than CT.

C mineralization rates were highest when soybean was in the rotation despite having significantly less biomass input to soil than with maize. Alvarez et al. (1995) found that maize produced 9.7 Mg ha⁻¹ per year and soybean produced 5.7 Mg ha⁻¹ per year of dry residue. At our site soybean had 42% less crop residue (straw and root) than maize (data not shown). Higher C mineralization when soybean was in the rotation may have been due to its lower C:N ratio and ready decomposibility. Furthermore, decomposition rates are regulated by other residue properties such as lignin, polyphenol, and silica content, and available evidence suggests that soybean has suitable chemical characteristics for rapid C mineralization (Aulakh et al., 1991; Tian et al., 1992).

The values of C mineralized to total C during 24 days varied from 2.7 to 5.8 g C m⁻² under CT and from 2.3 to 10.4 g C m⁻² under NT (Table 3). On average under CT, the ratio of total C mineralized to MBC was 4.7 g g⁻¹ while under NT it was 5.6 g g⁻¹ MBC during 24-day incubations. The percentage of MBC mineralized during 24 days varied from 18 to 55% under CT and from 15 to 80% under NT. On average, across crop rotations and depths, the percentage of MBC mineralized in 24 days, was approximately the same (38%) under both tillage systems.

3.5. Nitrogen mineralization

The values of N mineralization during 24 days of incubation varied from 0.05 to 0.09 μg N g⁻¹ per day under CT and from 0.07 to 0.22 μg N g⁻¹ per day under NT (Table 2). The S/W rotation under NT had significantly greater (54–364%) N mineralization at all depths than CT. On average, NT had 78% greater N mineralization than CT, while S/W had 35 and 63% greater N mineralization than M/W and C/W rotations, respectively. Greater N mineralization under NT has been observed previously, with values ranging from 8 to 13 μg N g⁻¹ per day under CT and from 10 to 22 μg N g⁻¹ per day under NT in different aggregate-size fractions during a 20-day incubation (Beare et al., 1994) and from 0.2 to 1.0 μg N g⁻¹ per day under CT and from 0.4 to 1.2 μg N g⁻¹ per day under NT in 24-day incubation (Franzluebbers et al., 1995). Gupta and Germida (1988) observed an average value of 3.1 μg N g⁻¹ per day under native soils and 1.6 μg N g⁻¹ per day under cultivated soils during 14 days of incubation. Mendes et al. (1999) found values from 0.3 to 1.9 μg N g⁻¹ per day in 16-day incubations among different aggregate-size fractions in soil collected in different seasons. The majority of these studies analyzed the amount of mineralizable N as NH₄-N plus NO₃-N, whereas Gupta and Germida...
Table 3
Ratio C mineralization (MinC) during 24 days to total C or microbial biomass C in soils under different tillage and crop rotation systems

<table>
<thead>
<tr>
<th>Crop rotations</th>
<th>MinC:total C (mg g⁻¹ per 24 days)</th>
<th>MinC:MBC (g g⁻¹ MBC per 24 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CT</td>
<td>NT</td>
</tr>
<tr>
<td><strong>Depth: 0–50 mm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/W</td>
<td>5.18 aA</td>
<td>7.57 aA</td>
</tr>
<tr>
<td>M/W</td>
<td>4.90 aA</td>
<td>3.10 bB</td>
</tr>
<tr>
<td>C/W</td>
<td>3.45 aA</td>
<td>2.35 cC</td>
</tr>
<tr>
<td><strong>Depth 50–100 mm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/W</td>
<td>2.69 bA</td>
<td>5.55 aA</td>
</tr>
<tr>
<td>M/W</td>
<td>5.17 aA</td>
<td>5.18 aA</td>
</tr>
<tr>
<td>C/W</td>
<td>5.82 aA</td>
<td>4.39 abB</td>
</tr>
<tr>
<td><strong>Depth 100–200 mm</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/W</td>
<td>3.83 bB</td>
<td>10.45 aA</td>
</tr>
<tr>
<td>M/W</td>
<td>5.23 aA</td>
<td>6.00 abB</td>
</tr>
<tr>
<td>C/W</td>
<td>5.74 aA</td>
<td>5.48 abB</td>
</tr>
</tbody>
</table>

Means within a column of the same depth followed by a different upper case letter are significantly different at $P \leq 0.05$. Means within a row followed by a different lower case letter are significantly different at $P \leq 0.05$.

* S: soybean; W: wheat; M: maize; C: cotton. All values are mean of data obtained from soil samples collected in 1997 and 1998.

The C:N mineralization ratio showed few effects due to tillage or crop rotations. Nonetheless, there was a wider C:N mineralization ratio under C/W and M/W rotations, which may have been due to microbial populations using organic matter that was less labile with wide C:N ratios. A lower soil mineralizable C:N ratio can suggest that the flow of C and N through the mineralizable fraction has become less stable, which may decrease conservation of C and N in the long term (Franzluebbers and Arshad, 1996). All the C:N mineralization ratios were greater than 25, which according to Franzluebbers and Arshad (1996) indicate that the crop residues and resulting soil organic matter fractions were low in concentrations of N.

There was also an interactive effect of tillage, crop rotation, and soil depth on the C:N ratio mineralized (Table 2). Crop rotation using C/W under CT resulted in a higher C:N mineralization ratio than under NT at 0–50 and 100–200 mm depth, while a greater ratio was found under NT with the S/W rotation in the 50–100 mm depth (Table 2). There was a crop rotation effect only at 50–100 mm depth where C/W rotation under CT and M/W rotation under NT showed a higher ratio than other crop rotation.

Our results of greater N mineralization under NT are in agreement with previous research (Beare et al., 1994; Franzluebbers et al., 1995; Franzluebbers and Arshad, 1996). However, nitrification can be inhibited in NT soils under field conditions, because of accumulation of organic matter and nutrients, such as N, at or near the soil surface that may restrict N-mineralization (Kushwaha et al., 2000).

Although the samples were collected at wheat harvest time (winter crop), nearly 3 months after tillage, there was a crop rotation effect on N mineralization. Again, as with C mineralization, the high N mineralization rates with soybean may have been due to its narrow C:N ratio and other favorable chemical characteristics for rapid release of N.

4. Perspectives

One explanation for the effect of NT on microbial biomass and nutrient mineralization is that NT systems provide a more favorable habitat for microorganisms. Previous studies at the same experimental site showed that NT systems compared with CT increased size of macroaggregates (Castro Filho et al., 2002). Macroaggregates probably provided an improved microhabitat for microorganisms, since macroaggregates have been reported with greater enzyme activities, respiration and MBC than in microaggregates (Gupta and Germida, 1988; Dick, 1992; Miller and Dick, 1988). Mendes et al. (1999) and our study measured only NO₃-N.

The C:N mineralization ratio showed few effects due to tillage or crop rotations. Nonetheless, there was a wider C:N mineralization ratio under CT and M/W rotations, which may have been due to microbial populations using organic matter that was less labile with wide C:N ratios. A lower soil mineralizable C:N ratio can suggest that the flow of C and N through the mineralizable fraction has become less stable, which may decrease conservation of C and N in the long term (Franzluebbers and Arshad, 1996). All the C:N mineralization ratios were greater than 25, which according to Franzluebbers and Arshad (1996) indicate that the crop residues and resulting soil organic matter fractions were low in concentrations of N.
Crop rotation within a tillage regime had small effects on total C. However, inclusion of maize increased MBC (50–100 mm depth) and increased C mineralization for both the 50–100 and 100–200 mm depths over other rotations. It was surprising that inclusion of maize in the crop rotation had little effect on MBC in the surface layer since it had substantially higher biomass inputs. It is likely that in a tropical setting with year-round warm soils there is rapid decomposition and high losses regardless of crop inputs. However, the significant effect of maize in the lower depths suggests there is either leaching or root-derived input of organic compounds to support high microbial biomass. Conversely, inclusion of soybean stimulated C and N mineralization in the surface depth, which likely reflects its higher quality and narrow C:N ratio to increase microbial activity.

The results indicate that for this subtropical site in southern Brazil, tillage is the critical factor in seques-tering C and microbial activities. Disturbance had a greater impact than the type of C inputs from crop rotations for maintaining or improving soil microbial biomass and activity.

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