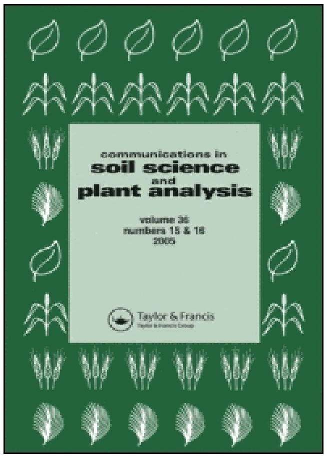

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Conservation Tillage, Rotations, and Cover Crop Affecting Soil Quality in the Tennessee Valley: Particulate Organic Matter, Organic Matter, and Microbial Biomass

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Conservation Tillage, Rotations, and Cover Crop Affecting Soil Quality in the Tennessee Valley: Particulate Organic Matter, Organic Matter, and Microbial Biomass

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Abstract: The impact of conservation tillage, crop rotation, and cover cropping on soil-quality indicators was evaluated in a long-term experiment for cotton. Compared to conventional-tillage cotton, other treatments had 3.4 to 7.7 Mg ha^{-1} more carbon (C) over all soil depths. The particulate organic matter C (POMc) accounts for 29 to 48 and 16 to 22% of soil organic C (SOC) for the 0- to 3- and 3- to 6-cm depths, respectively. Tillage had a strength influence on POMc within the 0- to 3-cm depth, but cropping intensity and cover crop did not affect POMc. A large stratification for microbial biomass was observed varing from 221 to 434 and 63 to 110 mg kg^{-1} within depth of 0–3 and 12–24 cm respectively. The microbial biomass is a more sensitive indicator (compared to SOC) of management impacts, showing clear effect of tillage, rotation, and cropping intensity. The no-tillage cotton double-cropped wheat/soybean system that combined high cropping intensity and crop rotation provided the best soil quality.

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Keywords: Conservation tillage, cotton, cover crop, soil organic matter

INTRODUCTION

Until recently, cotton production in the southern United States was generally characterized by intensive tillage operations and monoculture without use of cover crops (Reeves 1994). This system provides little carbon (C) input to soil, increases erosion, and promotes a rapid oxidation of existing soil C. The consequence of this management practice is decreased soil quality and productivity.

Reduction in soil tillage, utilization of cover crops and crop rotation, and increased cropping intensity have been shown to reverse the process of soil degradation and improve soil quality. As a key indicator of soil quality, soil organic matter (SOM) is positively affected by decreased soil disturbance (Follett and Peterson 1988; Edwards et al. 1992; Ismail, Blevins, and Frye 1994; Hussain, Olson, and Ebelhar 1999), crop rotation (Havlin et al. 1990; Edwards et al. 1992), cover crops (McVay, Radcliffe, and Hargrove 1989; Reeves and Wood 1994), and cropping intensity (Wood, Westfall, and Peterson 1991; Franzluebbers, Hons, and Zuberer 1994; Campbell et al. 1997).

Conservation tillage can lead to greater storage of C; the soil acts as a sink for C from the atmosphere, which benefits the environment (Allmaras et al. 2000). Some fractions of SOM, for example, particulate organic matter (POMc), are more responsive to changes in management systems and can be used as early indicators of improved soil quality (Cambardella and Elliott 1992; Franzluebbers and Arshad 1997; Six, Elliott, and Paustian 1999).

As a result of changes in chemical properties and substrate supply, microbial biomass is strongly affected by changes in soil management (Doran 1987; Staley 1999) and thus has been used as an early indicator of soil quality (Carter 1986; Powlson and Brookes 1987; Carter 1991).

The need for crop rotation with conservation tillage is often greater than in conventional tillage, and crop rotation can improve the efficient use of soil water and nutrients, improve soil physical properties, and reduce soil erosion (Reeves 1997). Crop rotation can affect SOM content by changing C input (Lal 1976; Havlin et al. 1990; Wood et al. 1990; Wood, Westfall, and Peterson 1991; Edwards et al. 1992).

Crop rotation not only affects soil properties but also can increase cotton production. Wesley, Elmore, and Spurlock (2001) indicated that biennial rotation of cotton with grain sorghum and soybean increased cotton yield on a Tunica soil. Bordovsky, Lyle, and Keeling (1994) reported a 20–25% increase in cotton lint by combining no-tillage and crop rotation over monocropped cotton with conventional tillage.

Use of cover crops can compensate for lack of crop residue and C input from cotton monoculture (Reeves 1994) and increase cotton yield under long-term conditions as shown in the century-old rotation experiment

(Mitchell et al. 1996). Recent studies conducted in the Tennessee Valley showed that use of a winter cover crop with conservation tillage increased cotton yield (Burmester, Patterson, and Reeves 1993; Raper, Reeves, and Burt 1998; Schwab et al. 2002). The isolated influence of tillage, crop rotation, and cover crops on cotton production has been researched. However, there has been little research with cotton that integrates tillage, rotation, and cover cropping, especially long term.

MATERIALS AND METHODS

Site Characterization and History

The long-term experiment was located at the Alabama Agriculture Experiment Station Tennessee Valley Research and Extension Center on a Decatur silt loam soil, in north Alabama (latitude: 34° 41′ 30″, longitude: 86° 53′ 25″, altitude: 156 m). The region has an annual average rainfall of 1353 mm/year, and average temperature varies from 5.6 to 30.7°C for January and July, respectively.

A long-term cotton rotation experiment was begun in 1979 to determine the effect of tillage systems, rotations, and cover cropping on cotton productivity. The study site had previously been used for decades for monoculture cotton production. The study was initiated with conventional tillage; however, in 1988, two no-tillage treatments, cotton with and without a wheat cover crop, were added to the rotation. In 1995, all treatments except the conventional-tillage controls were converted to no-tillage, and all treatments were converted to 75-cm rows from 102-cm rows (Table 1). However, the integrity of the cropping rotations was maintained, as was the appropriate conventional-tillage control.

Treatments

The experiment design was a randomized complete block with four replications. Seven treatments were evaluated:

1) continuous cotton, with winter fallow, crop managed with conventional tillage (conventional-tillage cotton);
2) continuous cotton, with winter fallow, managed with no tillage (no-tillage cotton);
3) continuous cotton, with wheat as winter cover crop, managed with conventional tillage (conventional-tillage cotton with cover crop);
4) continuous cotton, with wheat as winter cover crop, managed with no tillage (no-tillage cotton with cover crop);

Table 1. Treatments, abbreviations, period under conventional tillage, year of adoption of no-tillage, and years in use prior to initial evaluation of soil-quality indicators for a degraded Decatur silt loam soil located in northern Alabama

Treatments	Abbreviation	Conventional tillage	No-tillage adoption
Conventional-tillage cotton with winter fallow	CTcot	1979–2001	—
Conventional-tillage cotton with wheat cover crop	CTcot-cov	1979–2001	—
No-tillage cotton with winter fallow	NTcot	1979–1988	1988
No-tillage cotton with wheat cover crop	NTcot-cov	1979–1988	1988
No-tillage cotton double-cropped wheat/soybean	NTcot-wht/soy	1979–1995	1995
No-tillage cotton rotated with soybean	NTcot-soy	1979–1995	1995
No-tillage cotton rotated with corn	NTcot-crn	1979–1995	1995

5) cotton–soybean rotation, with winter fallow, managed with no-tillage (no-tillage cotton–soybean);
6) cotton–soybean/wheat double-cropped rotation managed with no tillage with winter fallow in one of two years (no-tillage cotton–wheat/soybean);
7) cotton–corn rotation, with winter fallow, crop managed under no tillage (no-tillage cotton–corn).

Conventional-tillage cotton with winter fallow was disked and chisel plowed during fall and disked and field cultivated in spring. Conventional-tillage cotton with wheat as winter cover crop was disked and chisel plowed during the fall, and field cultivated in spring. The no-tillage without cover crop consisted of winter fallow and planting in previous cotton stubble. The wheat cover crop was sowed during fall and killed in early spring before cotton planting, using glyphosate.

The wheat cover crop received 34 kg N ha^{-1} as ammonium nitrate in February each year, whereas wheat for grain received a total of 110 kg N ha^{-1}, with 22 kg N ha^{-1} applied in fall and 88 kg N ha^{-1} in spring. A sidedressed N application of 80 kg N ha^{-1} was used for cotton each year. Corn received 157 kg N ha^{-1} per year after planting. Appropriate fertilization for P and K for each crop was applied based on soil testing and Auburn University Extension recommendations (Cope, Evans, and Williams 1981). Insecticides, defoliants, and herbicides were applied following Auburn University Extension recommendations.

Soil Sampling and Handling

All soil samples, with exception of aggregate stability, were collected using a portable soil coring system described by Prior and Rogers (1992). The molychrome steel soil corer measured 5.1 mm in diameter by 600 mm long and was designed to hold a 600-mm clear plastic liner tube. The steel corer with plastic liner tube was pushed 30 cm deep into the soil using a pneumatic hammer, then pulled from the soil, and the plastic tube was pushed out. To avoid soil-core disturbance and moisture loss, a foam circle was pushed into the butyrate liner tube until it contacted the soil core, and the tube was capped. The tubes were stored at 4°C until processing.

Microbial Biomass Determination

Soil samples for microbial biomass were collected in October 2000. A total of 10 soil cores were collected from each plot from the interrow position. When crop residue was present on the soil surface, only identifiable pieces were removed to do the soil sampling.

In the laboratory, soil cores were removed from liner tubes and separated into depths of 0–3, 3–6, 6–12, and 12–24 cm. The 10 cores from each plot were combined by depth, and samples were gently passed through a 4-mm sieve under field moisture condition. After sieving, samples were kept for less than a week under controlled temperature (4°C) before evaluation of microbial biomass. Duplicate soil samples were used to determine microbial biomass by fumigation incubation analysis as described by Jorgensen (1995). Soil microbial biomass C was calculated as follows (Voroney and Paul 1984; Franzluebbers, Haney, and Hons 1999):

$$\text{Soil microbial biomass C} = \frac{(\text{mg CO}_2 - \text{C kg}^{-1}\,10\text{d}^{-1})\ \text{fumigated}}{K_c}$$

where K_c is the fraction (0.41) of the microbial biomass C mineralized to carbon dioxide (CO_2) during a 10-day incubation at 25°C.

Soil Organic Matter and Particulate Organic Matter

Soil samples for chemical analyses were collected in March 2000, using the same soil-sampling procedure as for microbial biomass. A portion of 4-mm-sieved soil was air dried and sieved again to 2 mm.

Using the same sampling technique and sample numbers, soil particulate organic matter was determined from a soil sample collected in April 2001, following methodology described by Cambardella and Elliott (1992). The total C from each fraction was determined by dry combustion using a nitrogen/carbon analyzer (Fisons Instruments, Beverly, MA 01915). Total C is equivalent to SOC for these soils, which contain no carbonate C.

Statistical Analyses

Data were subject to analyses of variance (Littell, Freud, and Spector 1991). Sampling depths were analyzed as a split in the design. Coefficient correlation, R^2 selection method, and stepwise regression were used to analyze relationships among chemical variables of soil quality. Preplanned single-degree-of-freedom contrasts (Table 2) and Fisher's protected least significant difference (LSD) were used for mean comparisons. A significance level of $P \leq 0.05$ was established a priori.

RESULTS AND DISCUSSION

SOC and C Sequestration

A tillage by depth interaction was observed for SOC data, and treatment effects are discussed by depth. A sharp reduction in SOC with depth in no-tillage systems (Table 3) was noted. No-tillage systems increased SOC in the top 3 cm compared to conventional-tillage systems. These results agree with findings of increased SOC within the first few centimeters of soil

Table 2. Preplanned single-degree-of-freedom contrasts used for mean comparisons

Contrast	Treatments
Tillage system effect for cotton monoculture with winter fallow	Conventional-tillage cotton with winter fallow vs. no-tillage cotton with winter fallow
Tillage system effect for cotton monoculture with winter cover crop	Conventional-tillage cotton with wheat cover crop vs. no-tillage cotton with wheat cover crop
Cover crop effect for conventional tillage cotton monoculture	Conventional-tillage cotton with winter fallow vs. conventional-tillage cotton with wheat cover crop
Cover crop effect for no-tillage cotton monoculture	No-tillage cotton with winter fallow vs. no-tillage cotton with wheat cover crop
Cropping intensity effect under no tillage	No-tillage cotton double-cropped with wheat/soybean vs. no-tillage cotton rotated with corn and with soybean
Combined effect of tillage and rotation	Conventional-tillage cotton vs. no-tillage cotton rotated with corn, with soybean, and double-cropped with wheat/soybean

surface with reduced soil tillage (Blevins et al. 1983; Edwards et al. 1992; Motta, Reeves, and Touchton 2002).

The influence of a wheat cover crop differed between tillage systems, with no effect for no tillage, and an increase in SOC for conventional tillage (Table 3). In addition, enhancement of SOC with cover cropping under conventional tillage extended to the second and third soil depth layers, probably due to residue incorporation. Such a large influence of wheat cover crop was not expected because of low production of crop residue, because the cover crop was historically killed at an early stage of development.

Table 3. Effect of tillage system, rotation, and cover crop on SOC concentration (g kg^{-1})[a] for a Decatur silt loam soil located in northern Alabama

	Depth (cm)			
Parameter	0–3	3–6	6–12	12–24
Treatments				
CTcot	8.3	9.3	6.4	5.4
NTcot	18.8	10.0	6.5	5.1
CTcot-cov	10.7	11.0	8.0	5.8
NTcot-cov	18.9	10.4	7.1	6.3
NTcot-soy	12.1	9.3	6.7	5.8
NTcot-wht/soy	14.7	9.4	7.4	6.2
NTcot-crn	12.5	9.4	6.9	5.9
$LSD_{0.05}$	2.1	1.7 ns	1.2 ns	0.6 ns
Contrasts				
CTcot vs. NTcot	8.3 vs. 18.8*	9.3 vs. 10.0	6.4 vs. 6.5	5.4 vs. 6.1
CTcot-cov vs. NTcot-cov	10.7 vs. 18.9*	11.0 vs. 10.4	8.0 vs. 7.1	5.8 vs. 6.3
CTcot vs. CTcot-cov	8.3 vs. 10.7*	9.3 vs. 11.0*	6.4 vs.8.0*	5.4 vs. 5.8
NTcot vs. NTcot-cov	18.8 vs. 18.9	10.0 vs. 10.4	6.5 vs. 7.1	6.1 vs. 6.3
NTcot-wht/soy vs. NTcot-crn + NTcot-soy	14.7 vs. 13.6*	9.4 vs. 9.4	7.4 vs. 6.8	6.2 vs. 5.9
CTcot vs. NTcot-wht/soy +NTcot-crn +NTcot-soy	8.3 vs. 13.9	9.3 vs. 9.5	6.4 vs. 7.0	5.4 vs. 6.0

*Significant at $P \leq 0.05$.

[a] SOC = soil organic carbon, CTcot = conventional-tillage cotton with winter fallow, CTcot-cov = conventional-tillage cotton with wheat cover crop, NTcot = no-tillage cotton with winter fallow, NTcot-cov = no-tillage cotton with wheat cover crop, NTcot-wht/soy = no-tillage cotton double-cropped wheat/soybean, NTcot-soy = no-tillage cotton rotated with soybean, NTcot-crn = no-tillage cotton rotated with corn. $LSD_{0.05}$ = least significant difference value refers to comparison between treatments in each depth; ns = no significant at $P \leq 0.05$.

Within no tillage, cropping intensity had a significant influence on SOC with lower values noted for cotton–soybean and cotton–corn rotations compared to cotton–wheat/soybean double cropping. This result seems to reflect the amount of C returned to the soil, and it is important to note that the wheat was used as grain in the no-tillage cotton–wheat/soybean system, which provided a much larger supply of crop residue compared to wheat as a cover crop. In opposition to wheat for grain, corn, widely recognized as a high C-input crop, frequently suffered loss in productivity due to the short-term droughts and historically provided a more limited supply of crop residue.

Several studies have shown the importance of an increasing C input in the form of crop residue to maintain or increase SOC normally obtained by increasing yields or cropping intensity (Hargrove et al. 1982; Havlin et al. 1990; Wood, Westfall, and Peterson 1991; Edwards et al. 1992; Wood and Edwards 1992; Franzluebbers, Hons, and Zuberer 1994). We also speculate that the inclusion of soybean in the rotation intensifies C mineralization because of introduction of residues with a low C/N ratio.

Surprisingly, continuous cotton with no tillage, regardless of cover cropping, had higher numeric values of SOC than no-tillage cotton–soybean and no-tillage cotton–corn, even though each was fallow in the winter and they probably have small differences in C input. We believe this is related to the longer period of implementation, because no-tillage cotton (with or without a wheat cover crop) and no-tillage cotton–soybean and cotton–corn had 12, 6, and 6 years in tillage-rotation management schemes, respectively, at the time of sampling (Table 3).

Adoption of cover cropping or no tillage, and cropping intensity, resulted in between 3.4 and 7.7 Mg ha^{-1} more C stored in the soil (0 to 24 cm deep) compared to conventional tillage (about 23 Mg ha^{-1} for 0 to 24 cm deep) (Table 4). Similar values were reported by Six, Elliott, and Paustian (1999), who noted that no tillage maintained a higher level of C (2.2 to 6.2 Mg ha^{-1} more C for 0 to 20 cm deep) than conventional tillage in all of four sites studied, a Haplustoll, a Fragiudalf, a Hapludalf, and a Paleudalf soil located in Nebraska, Ohio, Michigan, and Kentucky, respectively.

Cover cropping increased soil C storage with conventional tillage. Long-term (21 years) addition of small amounts of cover-crop residue maintained more C in the soil for conventional tillage with cover crop than without covercrop. This was not observed with no-tillage systems. It seems that the improvement in C storage with no tillage overshadowed the effect of cover cropping after 12 years of implementation. Despite the benefit of increased cropping intensity with the wheat/soybean system for SOC concentration in the soil surface, there was no increase in the amount of C stored in to 0- to 24-cm depth range compared to other no-tillage systems with soybean or corn rotations after 6 years of implementation. This could be associated with a lower bulk density observed for no-tillage cotton–wheat/soybean compared to no-tillage cotton–corn and cotton–soybean.

Table 4. Effect of tillage system, rotation, and cover crop on POMc and C storage for a Decatur silt loam soil located in northern Alabama

	POMc (%)		C mass (Mg ha^{-1})
Parameter	0–3 cm deep	3–6 cm deep	0–24 cm deep
Treatments			
CTcot[a]	28.7	20.1	23.0
NTcot	48.3	16.7	29.3
CTcot-cov	28.6	21.5	26.4
NTcot-cov	45.0	19.3	30.7
NTcot-soy	32.3	17.7	26.3
NTcot-wht/soy	36.5	16.1	27.3
NTcot-crn	35.9	18.7	27.2
$LSD_{0.05}$	9.7	3.3	2.9
Contrasts			
CTcot vs. NTcot	28.7 vs. 48.3*	20.1 vs. 16.7*	23.0 vs. 29.3*
CTcot-cov vs. NTcot-cov	28.6 vs. 45.0*	21.5 vs. 19.3	26.5 vs. 30.7*
CTcot vs. CTcot-cov	28.7 vs. 28.6	20.1 vs. 21.5	23.0 vs. 26.5*
NTcot vs. NTcot-cov	48.3 vs. 45.0	16.7 vs. 19.3	29.3 vs. 30.7
NTcot-wht/soy vs. NTcot-crn + NTcot-soy	36.5 vs. 34.1	16.1 vs. 18.2	27.3 vs. 26.8
CTcot vs. NTcot-wht/soy + NTcot-crn + NTcot-soy	28.7 vs. 34.9	20.1 vs. 17.8*	23.0 vs. 27.2*

*Significant at $P \leq 0.05$.

[a] CTcot = conventional-tillage cotton with winter fallow, CTcot-cov = conventional-tillage cotton with wheat cover crop, NTcot = no-tillage cotton with winter fallow, NTcot-cov = no-tillage cotton with wheat cover crop, NTcot-wht/soy = no-tillage cotton double-cropped wheat/soybean, NTcot-soy = no-tillage cotton rotated with soybean, NTcot-crn = no-tillage cotton rotated with corn. $LSD_{0.05}$ = least significant difference value refers to comparison between treatments in each depth.

No-tillage systems all increased soil C compared to conventional-tillage monocropped cotton. This beneficial impact of less soil disturbance on C sequestration has been reported for many soils and climatic conditions (Cambardella and Elliott 1992; Beare, Hendrix, and Coleman 1994; Six et al. 1998; Six, Elliott, and Paustian 1999).

Particulate Organic Matter Carbon

Like SOC, there was a tillage × depth interaction on POMc, and results are presented by depth (Table 4). The POMc content ranged from 1.4 to 10.6

and 1.0 to 3.3 g kg^{-1}, for the first and second depth layers, respectively (data no shown). This accounts for 29 to 48 and 16 to 22% of SOC as POMc for the 0- to 3- and 3- to 6-cm depths, respectively (Table 4). The percent values for POMc for the upper layer are higher than those observed by Cambardella and Elliott (1992) (18 to 25% 0–20 cm), Angers, N'Dayegamiye, and Cote (1993) (7 to 19% 0–8 cm), Beare, Hendrix, and Coleman (1994) (14 to 22% 0–5 cm, 14 to 21% 5–15 cm.), and Hussain, Olson, and Ebelhar (1999) (31 to 38% 0–5 cm and 26 to 30% for 5–15 cm) under agricultural systems. However, the use of different soil depths confounds results reported among experiments. For example, Cambardella and Elliott (1992) reported 18 to 25% POMc for the 0- to 20-cm depth, whereas Hussain, Olson, and Ebelhar (1999) obtained 31 to 38% within 0 to 5 cm. The fact that we used a shallow sample depth compared with other researchers could explain the higher values observed. Furthermore, we hypothesize that the high clay content (31%) and low initial level for SOC (<10 g kg^{-1}) could be reasons for a greater amount of POMc observed in our experiment.

Regardless of tillage and rotation systems, a reduction in POMc with depth was noticed (Table 4), which is supported by the general findings of Angers, N'Dayegamiye, and Cote (1993), Franzluebbers and Arshad (1997), and Hussain, Olson, and Ebelhar (1999). However, the reduction in POMc from the depths of 0–3 to 3–6 cm was accentuated with no-tillage systems compared to conventional-tillage systems. This result is supported by Angers, N'Dayegamiye, and Cote (1993), and Hussain, Olson, and Ebelhar (1999).

A notable increase in percentage POMc (12 to 69%) was observed under no-tillage compared to conventional-tillage continuous cotton at the 0- to 3-cm depth. Surface accumulation of POMc due to the implementation of conservation systems seems to have a wide range because increases from 13 to 76% have been reported by Cambardella and Elliott (1992), Beare, Hendrix, and Coleman (1994), Franzluebbers and Arshad (1997), Six et al. (1998), Hussain, Olson, and Ebelhar (1999), Needlman et al. (1999), and Six, Elliott, and Paustian (1999). However, neither cover cropping nor cropping intensity affected POMc within the 0- to 3-cm depth.

As opposed to the 0- to 3-cm depth, there were higher numeric values for POMc in conventional tillage than no tillage within the 3- to 6-cm depth, likely due to concentration of POMc in the 0- to 3-cm depth from the total lack of soil disturbance in the no-tillage systems and stratification of roots nearer the soil surface. Similar results were reported by Beare, Hendrix, and Coleman (1994) and Needlman et al. (1999). However, higher POMc with conventional tillage than no tillage was only observed in systems without a cover crop. It seems that cover crop use in no tillage provided a better distribution of POMc in the profile, resulting in no difference in POMc between conventional tillage and no tillage within the 3- to 6-cm depth. A higher value for conventional-tillage continuous cotton compared to no-tillage system rotations was also observed, confirming the limitation of no-tillage systems with POMc being limited to the 0- to 3-cm depth. Cropping intensity and cover crop did not affect POMc.

Microbial Biomass Carbon

Microbial biomass results are presented by depth because a tillage by depth interaction was observed. As noted by others (Carter 1986; Granatstein et al. 1987; Staley et al. 1988; Schomberg and Jones 1999), greater stratification with depth was observed for no-tillage systems compared to conventional-tillage cotton without a cover crop (Table 5). Furthermore, the use of a wheat cover crop with conventional-tillage cotton increased microbial biomass to the 6-cm depth as a result of increased soil surface residue input. The decrease in soil microbial biomass C by depth is more pronounced between the first and second layer, especially under no tillage, probably because of surface deposition of crop residue and shallow root growth. The depth variation in microbial biomass could be associated with C stratification because others have found a strong link between them (Carter 1986; Doran 1987; Banerjee, Burton, and Grant 1999). Results confirmed a strong relationship between SOC and microbial biomass C with a correlation coefficient of 0.86 over all treatments and depths (data not shown).

The influence of treatments was more pronounced for the upper layer where conventional-tillage cotton had the smallest value microbial biomass C for all sampling dates. No-tillage systems increased microbial biomass C 15 to 96% compared to conventional-tillage cotton without a cover crop. This increase is comparable to reports of increases with conservation tillage from 10 to 87% reported by others (Carter 1986; Doran 1987; Granatstein et al. 1987; Staley et al. 1988; Schomberg and Jones 1999; Staley 1999) using depths ranging from 0–2 to 0–15 cm.

The high values for the maximum percentage increase between systems could be associated with the soil type, tillage, and crop history. It is important to note that it is not unusual to have (for this region) soil with more than a century of cotton monocropping, and conventional systems have been shown to have negative effects on soil microbial biomass (Anderson and Domsch 1989). Anderson and Domsch (1989) suggest that a more diversified microorganism community and larger population are expected under polyculture systems. Furthermore, long-term monocropping under intensive tillage depleted soil organic matter, which could be favorable to rapid organic matter accumulation and increases in soil microbial biomass C. Another factor that could also contribute to a large increase in soil microbial biomass was the clayey soil texture, which also provides favorable conditions for SOC improvement and consequent increased soil microbial biomass (Powlson and Brookes 1987; Banerjee, Burton, and Grant 1999).

Table 5. Effect of tillage system, rotation, and cover crop on soil microbial biomass carbon (mg kg^{-1}) concentration for a Decatur silt loam soil located in northern Alabama

	Depths (cm)			
Parameter	0–3	3–6	6–12	12–24
Treatments				
CTcot[a]	221	165	113	63
NTcot	388	187	104	75
CTcot-cov	323	230	141	93
NTcot-cov	434	183	119	84
NTcot-soy	326	172	111	91
NTcot-wht/soy	360	207	117	110
NTcot-crn	255	161	137	74
$LSD_{0.05}$	106	47	45 ns	23
Contrasts				
CTcot vs. NTcot	221 vs. 388*	165 vs. 187	113 vs. 104	63 vs. 75
CTcot-cov vs. NTcot-cov	323 vs. 434*	230 vs. 183*	141 vs. 119	93 vs. 84
CTcot vs. CTcot-cov	221 vs. 323*	165 vs. 230*	113 vs. 141	63 vs. 93*
NTcot vs. NTcot-cov	388 vs. 434	187 vs. 183	104 vs. 119	75 vs. 84
NTcot-wht/soy vs. NTcot-crn + NTcot-soy	360 vs. 291*	207 vs. 166*	117 vs. 124	110 vs. 83*
CTcot vs. NTcot-wht/soy + NTcot-cov + NTcot-soy	221 vs. 314*	165 vs. 180	113 vs. 122	63 vs. 92*

*Significant at $P \leq 0.05$.

[a] CTcot = conventional-tillage cotton with winter fallow, CTcot-cov = conventional-tillage cotton with wheat cover crop, NTcot = no-tillage cotton with winter fallow, NTcot-cov = no-tillage cotton with wheat cover crop, NTcot-wht/soy = no-tillage cotton double-cropped wheat/soybean, NTcot-soy = no-tillage cotton rotated with soybean, NTcot-crn = no-tillage cotton rotated with corn. $LSD_{0.05}$ = least significant difference value refers to comparison between treatments in each depth; ns = no significant at $P \leq 0.05$.

The use of wheat as a cover crop had a significant improvement on soil microbial biomass C under conventional tillage within the 0- to 6- and 12- to 24-cm depths (Table 5). These results opposed the SOC observation, which showed no significant increases in SOC conventional tillage with a cover crop compared to conventional tillage without a cover crop the 3-cm depth (Table 3). It is also important to add that historically the cover crop had been killed at an early stage of development and added only a small amount of crop residue to the system. However, the length of the experiment (21 years) could have an important influence on the positive result.

In contrast to conventional tillage, cover cropping did not significantly affect soil microbial biomass C under no tillage at any depth. These results agree with the cover crop effect on SOC under no tillage discussed previously. No tillage may have overshadowed the influence of cover cropping.

A significant increase in microbial biomass was obtained for the top layer with no-tillage compared to conventional-tillage cotton, regardless of cover crop. Root growth within the soil surface and crop residue deposition on the soil surface could be reasons for higher soil microbial biomass C near in the soil surface. Increased rooting has been reported with no tillage compared to plow systems within the first few centimeters depth of the soil surface (Kaspar, Brown, and Kassmeyer 1991). Furthermore, accumulation of larger-sized crop residues on the soil surface as well as the small size in the soil surface as particulate organic matter (Cambardella and Elliott 1992) under no-tillage systems provides a constant food supply for microorganism growth.

Better aeration and nutrient supply could also enhance the potential for microorganism growth in the upper soil layers. By affecting soil water infiltration (Lal 1976), it is also possible that variation in soil moisture among tillage systems could be a relevant factor. Differences between tillage systems were also noticed when a wheat cover crop was used, with increased microbial biomass for no tillage compared to conventional tillage within the 0- to 3-cm depth. However, a sharper reduction in soil microbial biomass C under no tillage compared to conventional tillage from the first to the second layer was observed. This resulted in a higher microbial biomass for conventional tillage than no tillage at the 3- to 6-cm depth. Granatstein et al. (1987) found less soil microbial biomass C in conservation-tillage systems than with conventional tillage.

The positive influence of cropping intensity on microbial biomass was also seen. The higher intensity cropping system (no-tillage cotton–wheat/soybean) had higher soil microbial biomass C compared to no-tillage cotton–soybean and no-tillage cotton–corn (Table 5). A significant enhancement of microbial biomass C was observed within 0- to 6- and 12- to 24-cm depths. These results suggest that higher additions of crop residues, root decomposition, and other increased activity factors associated with increased cropping intensity are able to increase microbial biomass with depth despite the lack of change in SOC. This suggests a higher sensitivity of soil microbial biomass to soil management compared to SOC. This has been reported by Carter (1991) and Powlson and Brookes (1987).

These results also suggest that adoption of no tillage with crop rotations can improve microbial biomass C compared to the standard system (conventional-tillage cotton in monoculture) because a significantly higher value for microbial biomass was noticed for no-tillage with crop rotation compared to conventional-tillage cotton within the 0- to 3- and 12- to 24-cm depth as well as a trend within 3- to 12-cm depth.

CONCLUSIONS

These results indicate that an appreciable improvement in SOC for this soil, cropped to cotton, can be attained with no tillage, cover cropping, and more diverse and intensive cropping systems. The effect of tillage, cover cropping, rotation, and cropping intensity is even more evident for microbial biomass, which showed treatment effects below the 0- to 3-cm depth. Therefore, microbial biomass is a more sensitive indicator (compared to SOC) of management impacts and can provide better information for soil-management decisions. The increase in SOC observed near the soil surface was mainly associated with POMc.

In summary, our results showed a clear benefit of no tillage, cover cropping, and crop rotations that enhance crop residue production on soil quality for this soil cropped to cotton. These improvements in soil quality offer a likely explanation for the 9 to 17% increase in cotton yields with these treatments over a 6-year period reported for this site (Burmester, Motta, and Reeves 2002).

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REFERENCES

Allmaras, R.R., Schomberg, H.H., Douglas, C.L., and Dao, T.H. (2000) Soil organic carbon sequestration potential of adopting conservation tillage in U.S. croplands. *J. Soil Water Conserv.*, 55 (3): 365–373.

Anderson, T. and Domsch, K.H. (1989) Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biol. Biochem.*, 21 (4): 471–479.

Angers, D.A., N'Dayegamiye, A., and Cote, D. (1993) Tillage-induced differences in organic matter of particle-size fractions and microbial biomass. *Soil Sci. Soc. Am. J.*, 57: 512–516.

Banerjee, M.R., Burton, D.L., and Grant, C.A. (1999) Influence of urea fertilization and urease inhibitor on the size and activity of the soil microbial biomass under conventional and zero tillage at two sites. *Can. J. Soil Sci.*, 79: 255–263.

Beare, M.H., Hendrix, P.F., and Colema, D.C. (1994) Water-stable aggregates and organic matter fractions in conventional and no-tillage soils. *Soil Sci. Soc. Am. J.*, 58: 777–786.

Blevins, R.L., Thomas, G.W., Smith, M.S., Frye, W.W., and Cornelius, P.L. (1983) Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. *Soil Tillage Res.*, 3: 135–146.

Bordovsky, J.P., Lyle, W.M., and Keeling, J.W. (1994) Crop rotation and tillage effects on soil water and cotton yield. *Agron. J.*, 86: 1–6.

Burmester, C., Motta, A.C.V., and Reeves, D.W. (2002) Effects of long term rotations on cotton yields and soil physical properties. In *Proceedings Conservation Tillage Cotton and Rice Conferences*, Mid America Farm Publications: Tunica, Miss., 24–25.

Burmester, C.H., Patterson, M., and Reeves, D.W. (1993) Cover system and starter fertilizer placement for no-till cotton. In *Proceedings Beltwide Cotton Conferences*, National Cotton Council of America: Memphis, Tenn., 1292–1294.

Cambardella, C.A. and Elliott, E.T. (1992) Particulate soil organic-matter changes across a grassland cultivation sequence. *Soil Sci. Soc. Am. J.*, 56: 777–783.

Campbell, C.A., McConkey, B.G., Biederbeck, V.O., Zentner, R.P., Tessier, S., and Hahn, D.L. (1997) Tillage and fallow frequency effects on selected soil quality attributes in a coarse-textured Brown Chernozem. *Can. J. Soil Sci.*, 77: 497–505.

Carter, M.R. (1991) The influence of tillage on the proportion of organic carbon and nitrogen in the microbial biomass of medium-textured soil in a humid climate. *Biol. Fertil. Soils*, 11: 135–139.

Carter, M.R. (1986) Microbial biomass as an index for tillage-induced changes in soil biological properties. *Soil Tillage Res.*, 7: 29–40.

Cope, J.T., Evans, C.E., and Williams, H.C. (1981) Soil test fertilizer recommendations for Alabama crops. Ala. Agric. Exp. Stn. Circ. 251, Auburn University: Auburn, Ala.

Doran, J.W. (1987) Microbial biomass and mineralizable nitrogen distributions in no-tillage and plowed soils. *Biol. Fertil. Soils*, 5: 68–75.

Edwards, J.H., Wood, C.W., Thurlow, D.L., and Ruf, M.E. (1992) Tillage and crop rotation effects on fertility status of a Hapludult soil. *Soil Sci. Soc. Am. J.*, 56: 1577–1582.

Follett, R.F. and Peterson, G.A. (1988) Surface soil nutrient distribution as affected by wheat–fallow tillage systems. *Soil Sci. Soc. Am. J.*, 52: 141–147.

Franzluebbers, A.J. and Arshad, M.A. (1997) Particulate organic carbon content and potential mineralization as affected by tillage and texture. *Soil Sci. Soc. Am. J.*, 61: 1382–1386.

Franzluebbers, A.J., Hons, F.M., and Zuberer, D.A. (1994) Long-term changes in soil carbon and nitrogen pools in wheat management systems. *Soil Sci. Soc. Am. J.*, 58: 1639–1645.

Franzluebbers, A.J., Haney, R.L., and Hons, F.M. (1999) Relationships of chloroform fumigation–incubation to soil organic matter polls. *Soil Biochem.*, 31: 395–405.

Granatstein, D.M., Bezdicek, D.F., Cochran, V.L., Elliott, L.F., and Hammel, J. (1987) Long-term tillage and rotation effects on soil microbial biomass, carbon and nitrogen. *Biol. Fertil. Soils*, 5: 265–270.

Hargrove, W.L., Reid, J.T., Touchton, J.T., and Gallaher, R.N. (1982) Influence of tillage practices on the fertility status of an acid soil double-cropped to wheat and soybeans. *Agron. J.*, 74: 684–687.

Havlin, J.L., Kissel, D.E., Maddux, L.D., Claassen, M.M., and Long, J.H. (1990) Crop rotation and tillage effects on soil organic carbon and nitrogen. *Soil Sci. Soc. Am. J.*, 54: 448–452.

Hussain, I., Olson, K.R., and Ebelhar, S.A. (1999) Long-term tillage effects on soil chemical properties and organic matter fractions. *Soil Sci. Soc. Am. J.*, 63: 1335–1341.

Ismail, I., Blevins, R.L., and Frye, W.W. (1994) Long-term no-tillage effects on soil properties and continuous corn yields. *Soil Sci. Soc. Am. J.*, 58: 193–198.

Jorgensen, R.G. (1995) Microbial biomass. In *Methods in Applied Soil Microbiology and Biochemistry*; Alef, K. and Nannipieri, P. (eds.); Academic Press: London.

Kaspar, T.C., Brown, H.J., and Kassmeyer, E.M. (1991) Corn root distribution as affected by tillage, wheel traffic, and fertilizer placement. *Soil Sci. Soc. Am. J.*, 55: 1390–1394.

Lal, R. (1976) No-tillage effects on soil properties under different crops in western Nigeria. *Soil Sci. Soc. Am. J.*, 40: 762–768.

Littell, R.C., Freud, R.J., and Spector, P.C. (1991) SAS system for linear models, *SAS Series in Statistical Applications*, 3rd edn; SAS Institute, Inc.: Cary, N.C., 67–68, 130–133.

McVay, K.A., Radcliffe, D.E., and Hargrove, W.L. (1989) Winter legume effects on soil properties and nitrogen fertilizer requirements. *Soil Sci. Soc. Am. J.*, 53: 1856–1862.

Mitchell, C.C., Arriaga, F.J., Entry, J.A., Goodman, W.R., Novak, J.L., Reeves, D.W., Runge, M.W., and Traxler, G.J. (1996) The old rotation, 1896–1996: 100 years of sustainable cropping research. *Alabama Agric. Exp. Stn. Bull.*, Auburn University: Ala., 26.

Motta, A., Reeves, D.W., and Touchton, J. (2002) Tillage intensity effects on chemical indicators of soil quality in two coastal plain soils. *Commun. Soil Sci. Plant Anal.,*, 33: 913–931.

Needelman, B.A., Wander, M.M., Bollero, G.A., Boast, C.W., Sims, G.K., and Bullock, D.G. (1999) Interaction of tillage and soil texture: Biologically active soil organic matter in Illinois. *Soil Sci. Soc. Am. J.*, 63: 1326–1334.

Powlson, D.S. and Brookes, P.C. (1987) Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. *Soil Biol. Biochem.*, 19 (2): 159–164.

Prior, S.A. and Rogers, H.H. (1992) Portable soil coring system that minimizes plot disturbance. *Agron. J.*, 84 (6): 1073–1077.

Raper, R.L., Reeves, D.W., and Burt, E.C. (1998) Using in-row subsoiling to minimize soil compaction caused by traffic. *J. Cotton Sci.*, 2: 130–135.

Reeves, D.W. (1994) Cover crops and rotations. In *Advances in Soil Science—Crops Residue Management*; Hatfield, J.L. (ed.); Lewis Publishers, CRC Press: Boca Raton, Fl., 125–172.

Reeves, D.W. and Wood, C.W. (1994) A sustainable winter-legume conservation tillage system for maize: effects on soil quality. In *Soil Tillage for Crop Production and Protection of the Environment*; Jensen, H.E. (ed.); Royal Veterinary and Agricultural University and Danish Institute of Plant and Soil Science: Aalborg, Denmark, Vol. 2, 1011–1016.

Reeves, D.W. (1997) The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil Tillage Res.*, 43: 131–167.

Schomberg, H.H. and Jones, O.R. (1999) Carbon and nitrogen conservation in dryland tillage and cropping systems. *Soil Sci. Soc. Am. J.*, 63: 1359–1366.

Schwab, E.B., Reeves, D.W., Burmester, C.H., and Raper, R.L. (2002) Conservation tillage systems for cotton in the tennessee valley. *Soil Sci. Soc. Am. J*, 66: 569–577.

Six, J., Elliott, E.T., and Paustian, K. (1999) Aggregate and soil organic matter dynamics under conventional and no-tillage systems. *Soil Sci. Soc. Am. J.*, 63: 1350–1358.

Six, J., Elliott, E.T., Paustian, K., and Doran, J.W. (1998) Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Sci. Soc. Am. J.*, 1998: 1367–1377.

Staley, T.E. (1999) Soil microbial biomass alterations during the maize silage growing season relative to tillage method. *Soil Sci. Soc. Am. J.*, 63: 1845–1847.

Staley, T.E., Edwards, W.M., Scott, C.L., and Owens, L.B. (1988) Soil microbial biomass and organic component alterations in a no-tillage chronosequence. *Soil Sci. Soc. Am. J.*, 52: 998–1005.

Voroney, R.P. and Paul, E.A. (1984) Determination of K_C and K_N in situ for calibration of the chloroform fumigation–incubation method. *Soil Biol. Biochem.*, 16: 9–14.

Wesley, R.A., Elmore, C.D., and Spurlock, S.R. (2001) Deep tillage and crop rotation effects on cotton, soybean, and grain sorghum on clayey soils. *Agron. J.*, 93: 170–178.

Wood, C.W., Westfall, D.G., Peterson, G.A., and Burke, I.C. (1990) Impacts of cropping intensity on carbon and nitrogen mineralization under no-till dryland agroecosystems. *Agron. J.*, 82: 1115–1120.

Wood, C.W., Westfall, D.G., and Peterson, G.A. (1991) Soil carbon and nitrogen changes on initiation of no-till cropping systems. *Soil Sci. Soc. Am. J.*, 55: 470–476.

Wood, C.W. and Edwards, J.H. (1992) Agroecosystem management effects on soil carbon and nitrogen. *Agric. Ecosyst. Environ.*, 39: 123–138.