IMPACT OF CONSERVATION TILLAGE ON SOIL CARBON IN THE 'OLD ROTATION'

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ABSTRACT

Soil organic carbon (SOC) changes in long-term experiments can provide valuable information regarding management impacts on carbon sequestration and sustainability. The 'Old Rotation', the oldest continuous cotton (*Gossypium hirsutum* L.) experiment in the world, provides a valuable and unique resource for researching sustainable agricultural production. The objective of this paper is to quantify the impact of conservation tillage adoption after 42 months (May 1996, last conventional tillage) on SOC in the 'Old Rotation', after 100 years of conventional tillage (1896-1996). Although the 13 plots have undergone modifications since 1925, six basic cropping systems have been maintained: 3-yr cotton-corn (*Zea Mays* L.)-small grain/soybean [*Glycine max* (L) Merr.] + legume + nitrogen; continuous cotton without legume; continuous cotton + legume; continuous cotton without legume + nitrogen; 2-yr cotton-corn + legume; and 2-yr cotton-corn + legume + nitrogen. Soil organic carbon was determined by dry combustion from samples taken in 1994 (0-8 in depth) and again in 1999, 42 months after the last tillage event, (0-2 and 2-6 in depths). Soil organic carbon stratification ratios (SOC 0-2 in/SOC 2-6 in depths) were determined from samples taken in 1999. After 42 months, conservation tillage increased SOC concentrations 39% averaged across all plots. These changes are linked to increases in yield during this period. The SOC stratification ratio in the 'Old Rotation' in 1999 suggests that changes in soil quality from adoption of conservation tillage are in the initial stages. However, the study confirms that conservation tillage had a dramatic impact on SOC and these changes occurred sooner than other research suggests.

KEYWORDS

Carbon sequestration, cropping systems, soil quality, sustainable production

INTRODUCTION

Conventional tillage practices can result in significant losses of soil organic matter (SOM), inducing an increase in soil erosion and loss of soil structure (Dalal and Mayer, 1987). Soil organic carbon is a decisive component in maintaining the quality of agricultural soils (Doran *et al.*, 1994; Reeves, 1997). Soil organic carbon - SOM conversion factors for surface soils range from 1.724 to 2.000 (Nelson and Sommers, 1982). Soil organic carbon or SOM is linked to many soil quality indicators and is perhaps the most significant single gauge of soil quality and productivity (Reeves, 1997).

Normally, cultivated sandy Coastal Plain soils of the southern United States have very low SOC (< 1%) (Hunt *et al.*, 1995; Motta *et al.*, 2002). Studies have shown the way to increase SOC has been with the inclusion of no-till systems with increasing cropping intensity (Bruce *et al.*, 1990, Motta *et al.*, 2002). Hunt *et al.* (1995) evaluated rotations and tillage systems on sandy soils in the Coastal Plain. After 9 years of conservation tillage, the SOC in the surface layers (0-2 in) was nearly double that of conventional tillage.

The 'Old Rotation', a long-term continuous cotton experiment, provides valuable and unique information for researching sustainable agricultural production (Mitchell *et al.*, 1998). It is a cotton rotation study that includes corn, soybean and small grain. Winter legumes are included as a source of nitrogen in some treatments and to evaluate the best management practice for sustainable cotton production. Since 1997, all crops have been planted using conservation tillage and crop residues are left as surface mulch (Mitchell *et al.*, 2002). Our objectives were to quantify the effect of 42 months of conservation tillage on SOC levels. This may help to explain variations in productivity in the

IN E. van Santen (ed.) 2002. Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Auburn, AL 24-26 June 2002. Special Report no. 1. Alabama Agric. Expt. Stn. and Auburn University, AL 36849. USA.

'Old Rotation' Experiment at Auburn University as well as provide information on soil quality as a result of conservation tillage adoption.

MATERIALS AND METHODS

Site Description

The 'Old Rotation' experiment at Auburn University, Alabama, (ca. 1896) is the oldest continuous cotton experiment in the world, and the third longest-running continuous field crop experiment in the USA (Mitchell and Entry, 1998). It is located on the campus of Auburn University at the merger of Coastal Plain sediments and the southern Piedmont Plateau in east-central Alabama (32° 36'N, 85° 36'W). The area receives an average of 56.7 in of annual precipitation and the mean temperature is 65° F. The soil is mostly Pacolet fine sandy loam (fine, kaolinitic, thermic Typic Kanhapludults).

Site Management

A total of 13 plots, each 21.6 ft x 136.1 ft, with a 3-ft alley were established in 1896. The treatments have undergone modifications since 1925 in terms of legumes used, fertilizer applications, and varieties (Mitchell and Entry, 1998). Winter legumes used have been hairy vetch (*Vicia villosa* Roth), common vetch (*Vicia sativa* L.), and, since 1956, crimson clover (*Trifolium incarnatum* L.). Oat (*Avena sativa* L.) was used prior to the 1950s; since then, cereal rye (*Secale cereale* L.) or wheat (*Triticum aestivumi* L.) are included as small grain rotation crops. Despite these changes, six basic cropping systems have been maintained within the 13 original plots (Table 1).

Conventional tillage vs. Conservation tillage

Traditionally, all treatments were conventionally tilled using a moldboard plow and disking until 1990; chisel plowing and disking were used up to spring 1996. In-row subsoiling to a depth of 14-in has become a common practice since 1985 in all treatments. In spring of 1997, conservation tillage was implemented. This consists of planting into killed cover crop or winter weed residue. Deep tillage (non-inversion) was applied without surface soil disruption with a Paratill® (AgEquipment Group, Lockney, TX 79241) to a depth of 16-in before planting in 1997, 1998 and 1999. In 1999, corn plots were subsoiled under-the-row to a depth of 15-in with a KMC® subsoiler equipped with pneumatic-tire closing wheels (Kelley Manufacturing Co., Tifton, Ga 31793). Both deep tillage (Paratill® and KMC® subsoiler) implements result in minimal residue disturbance in a 4 to 6-in zone. Since 1996, Roundup Ready® varieties of cotton and soybean and Liberty-Link® corn have been planted (Mitchell *et al.*, 2002).

Soil Data Collection

In 1994, a composite sample from 30 cores was taken from each plot in two seasons (winter and spring) at the 0-8 in depth. Since conventional tillage had been used for 98 yr, SOC would likely have been evenly distributed through the plow layer. Samples were lightly crushed and sieved through a 2-mm screen and dried at 140° F for 12 hours. All samples were ground in a roller mill grinding apparatus (Kelley, 1994). For analysis of SOC, the average of these two measurements was used. For particle size analysis, 40 g sub-samples from a composite of these 30 cores per plot were taken. Soil texture was determined by sieving (>2 mm) and determining % clay, silt and sand content using a hydrometer (Gee and Bauder, 1986).

Table 1. Treatments used in the 'Old Rotation' Experiment in Auburn, AL. (ca. 1896) (Mitchell et al., 1996). Soil texture (0-8 in depth) sampled in 1994.

Cropping systems	Plot	Sand	Silt	Clay
		------------	%	------------
Continuous cotton – legume†	1, 6	70.0	17.5	12.5
Continuous cotton + legume†	2, 3, 8	69.6	17.9	12.5
Continuous cotton + N‡	13	57.5	17.5	25.0
2-yr cotton-corn + legume†	4, 7	67.5	21.3	11.2
2-yr cotton-corn + legume† + N‡	5, 9	60.0	22.5	17.5
3-yr cotton-corn-small grain/soybean + legume† + N§	10, 11,12	61.2	21.3	17.5

† Legume = winter cover crop; crimson clover since 1956.
‡ Nitrogen applied to cotton or corn (120 lbs $acre^{-1}$ yr^{-1})
§ Nitrogen applied to small grain (60 lbs $acre^{-1}$ yr^{-1})

In November 1999, 42 months after the last surface tillage event (May 1996); 26 locations were chosen at random from each plot and sampled at two depths (0-2 in and 2-6 in). The two depths were sampled as conservation tillage results in stratification of SOC and soil chemical properties (Franzluebbers, 2002). Each location was a composite sample from three cores centered around a 1-ft diameter area. A total of 338 locations at two depths were analyzed in 1999. Samples were prepared for analysis as in 1994. Samples were analyzed for SOC by dry combustion (Yeomans and Bremner, 1991). In addition, samples collected in 1994 were analyzed for SOM colorimetrically by the Walkey-Black technique (Walkley and Black, 1934). Soil organic carbon stratification ratios (Franzluebbers, 2002) were calculated from samples collected in 1999 (SOC 0-2 in/ SOC 2-6 in depths).

There is considerable variation in soil texture on the site, as a thin cap of unconsolidated Coastal Plain sediment overlies residual Piedmont soil (Table 1). Because of the variation in soil texture, data were analyzed using an analysis of covariance model (SAS Institute, 1996). Clay content was taken as a covariant for all analyses. Statistical analyses, including analyses of variance, and separation of least square means by least significant differences ($LSD_{0.10}$), was performed using the General Linear Models (GLM) procedure in the SAS system (SAS Institute, 1999). In addition, preplanned single degree of freedom contrasts (Table 2) were used for means comparisons. Like most nineteenth century experiments, treatments were not always replicated. The continuous cotton without legume + nitrogen (plot 13) was not replicated; therefore, it was not included in the single degree of freedom comparisons analysis.

Table 2. Single degree of freedom contrasts analyzed among principal cropping systems in the 'Old Rotation' Experiment, Auburn, AL.

Contrasts	Plot
Continuous cotton + legume† vs. 2-yr cotton-corn + legume†	2, 3, 8 vs. 4, 7
2-yr cotton-corn + legume† vs. 2-yr cotton-corn + legume† + N‡	4,7 vs. 5,9
2-yr cotton-corn + legume† vs. 3-yr cotton-corn-small grain/ soybean + legume†+ N§	4,7 vs. 10,11,12
Continuous cotton + legume† vs. 3-yr cotton-corn-small grain/ soybean + legume† + N§	2, 3, 8 vs. 10,11,12
Continuous cotton – legume† vs. Continuous cotton + legume†	1, 6 vs. 2, 3, 8

† Legume = winter cover crop; crimson clover since 1956.

‡ N applied to cotton or corn (120 lbs $acre^{-1}$ yr^{-1})

§ N applied to small grain (60 lbs $acre^{-1}$ yr^{-1})

RESULTS AND DISCUSION

Soil Organic Carbon and Texture Analysis

Differences between soil textures (Table 1) may have affected carbon dynamics and storage in the experiment. Bajracharya *et al.* (1998) suggested that a strong association between micro-aggregates and clay keeps SOC more stable, resistant, and protected from decomposition. The potential for a soil to sequester carbon appears to be linked to formation of organo-mineral complexes leading to the stabilization of aggregates, thus increasing SOC resistance to breakdown by physical and chemical agents (Bajracharya *et al.*, 1998).

Relationship Between SOC and SOM in 1994

As expected, a highly significant linear relationship was observed between SOC determined by dry combustion and SOM determined by Walkley and Black in 1994 (Fig. 1). Soil organic matter is frequently estimated from SOC determinations and the conversion factor is soil specific, ranging from 1.724 to 2.00 (Nelson and Sommers, 1982; Tabatabai, 1996). The 1.724 value is most frequently used to convert SOC determinations to SOM. An average multiplier of 2.01 best estimated SOM using SOC values determined by dry combustion on samples from the 'Old Rotation' collected in 1994. Due to inaccuracies associated with determination of SOM, either directly through wet chemistry procedures, or indirectly through SOC determination/conversion from various methodologies, it is recommended that researchers determine and report SOC directly, rather than report values for SOM (Nelson and Sommers, 1982; Tabatabai, 1996). Dry combustion techniques, coupled with improved soil processing (Kelley, 1994) offer a rapid and convenient method for determining SOC. However, many producers, technical advisors, and consultants are more comfortable with values for SOM being reported, rather than reporting SOC. For acid, weathered soils like those in the 'Old Rotation', our results suggest a conversion factor of 2.02 is more accurate than the commonly quoted factor of 1.724.

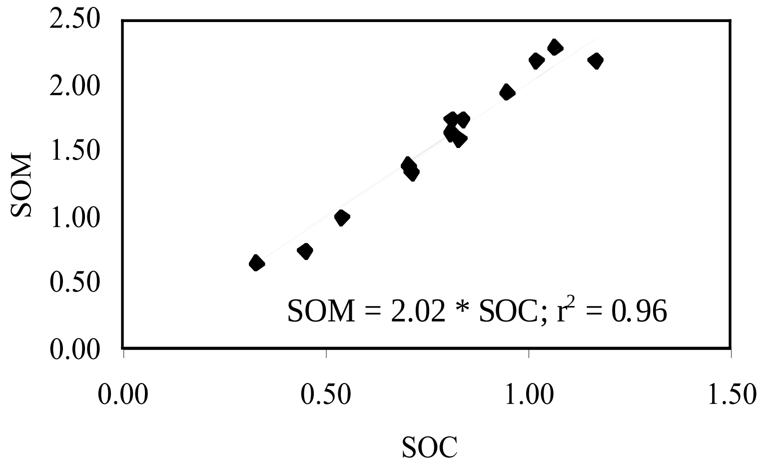

Fig.1. Comparison of SOC determined by dry combustion technique and SOM determined by Walkey-Black procedure from soil samples in the ‘Old Rotation’ Experiment, Auburn, AL., 1994.

SOC in 1994

In 1994, after 98 years of conventional tillage, the 3-yr rotation of cotton-corn-small grain/soybean with winter legume, and the 2-yr rotation of cotton-corn with winter legume and 120 lbs N $acre^{-1}$ $year^{-1}$ had the highest SOC in the plow layer (0-8 inches) (Fig. 2). The continuous cotton with winter fallow and no N had the lowest SOC. Continuous cotton is detrimental to soil quality because cotton is a low residue crop. Without significant inputs of carbon from residues and with conventional tillage, the loss of SOC was dramatic.

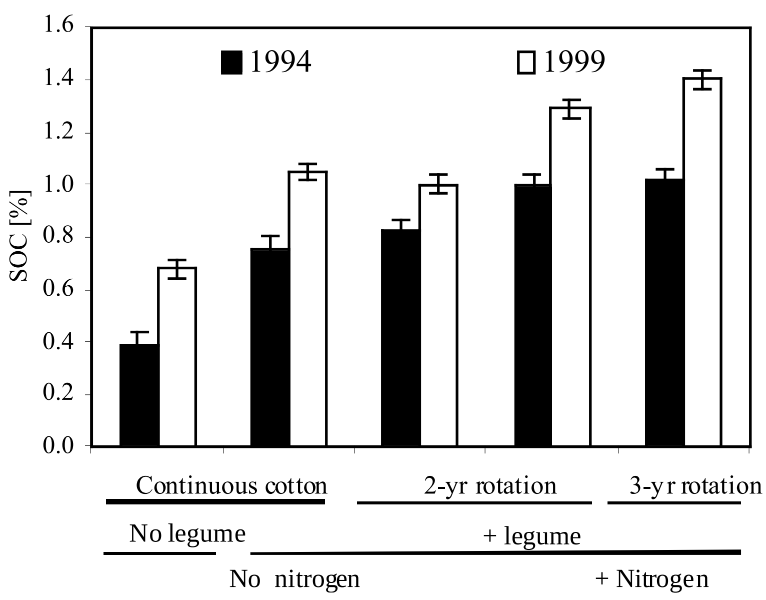

Fig. 2. Soil organic carbon in 1994 (0-8 in depth) and 1999 (0-6 in depth) among principal cropping systems in the ‘Old Rotation’ Experiment, Auburn, AL. The last conventional tillage was performed in spring 1996.

The 3-yr rotation of cotton-corn-small grain/soybean with winter legume and the 2-yr rotations of cotton-corn with winter legume with or without N had historically higher seed cotton yields than other treatments (Mitchell and Entry, 1998). These authors indicated that winter legumes increased both C and N in the soil, which ultimately contributed to higher cotton yields.

Changes in SOC Between 1994 and 1999

From May 1996 until November 1999 (42 months after the last conventional tillage) plots were managed using conservation tillage, and the impact of these practices was exceptionally large. All cropping systems increased SOC values between 21 and 73% (Fig. 2).

Conservation tillage on Coastal Plain soils has been reported to increase both SOC and crop yields after 17 years (Motta et al., 2002), but the time necessary to demonstrate these effects depends on soil type and climate (Reeves, 1997). Karlen *et al.* (1989) concluded that 8 years were required for conservation tillage systems to increase SOC significantly in the Coastal Plain. After 42 months, conservation tillage increased SOC an average of 39% in the ‘Old Rotation’, indicating a dramatic change in a short time period in a thermic humid regime

The rate of SOC change between 1994 and 1999 varied significantly with cropping system (Table 3, Fig. 2). The greatest increase in SOC occurred with the most-degraded system (continuous cotton without a winter legume). Although this system had the lowest SOC value for all cropping systems in 1999, it had the highest ratio of change between 1999 and 1994. This was due to a very low SOC value in 1994 (0.39%). Reeves (1997) stated that without significant input of carbon from crop residues, conservation tillage alone could only slow the loss of SOC, not halt or reverse it. Across a wide range of climatic conditions, research has shown that SOC increases with increased cropping intensity in conservation tillage systems. The actual increase in SOC between 1994 and 1999 was actually higher in the 3-yr rotation of cotton-corn-small grain/soybean + legume + nitrogen (Δ 0.39%), supporting the premise that cropping inten-

Table 3. Percent soil organic carbon (SOC) in 1994 (0 – 8 inch depth) and 1999 (0 – 6 inch depth) and the change in SOC expressed as the ratio of 1999 data divided by 1994 data among principal cropping systems in the 'Old Rotation' Experiment, Auburn, AL.

Contrasts	1994	1999	Change
	---------- % ---------		
Continuous cotton + legume† vs. 2-yr cotton-corn + legume†	ns	ns	**
2-yr cotton-corn + legume† vs. 2-yr cotton-corn + legume† + N‡	ns	***	**
2-yr cotton-corn + legume† vs. 3-yr cotton-corn-small grain/ soybean + legume†+ N§	ns	***	***
Continuous cotton + legume† vs. 3-yr cotton-corn-small grain/ soybean + legume† + N§	ns	***	ns
Continuous cotton – legume† vs. Continuous cotton + legume†	***	***	**

*. **, *** significant at $P = 0.10$, 0.05 and 0.01, respectively

† Legume = winter cover crop; crimson clover since 1956.

‡ Nitrogen applied to cotton or corn (120 lbs $acre^{-1}$ yr^{-1})

§ Nitrogen applied to small grain (60 lbs $acre^{-1}$ yr^{-1})

sity is critical for increasing SOC in conservation systems. Studies by Varvel *et al.* (1994) concluded that positive affects of crop rotations on physical, chemical and biological soil properties are related to higher carbon inputs and diversity of plant residues returned to soils. Langdale *et al.* (1992) showed that no-till management of grain sorghum [*Sorghum bicolor* (L.) Moench], coupled with winter cover cropping increased SOC by an average of 2020 lbs $acre^{-1}$ $year^{-1}$ over conventional tillage in the Georgia Piedmont.

In 1994, only 1 of the 5 rotations subjected to analysis had significant differences in SOC. In 1999, 4 of 5 rotations resulted in a significant differences after only 42 months of conservation tillage. Thus, our data validate the conclusion by Bruce (1990) and Reeves (1997) that tillage practices negate cropping system affects. Our data suggests that simultaneous use of conservation tillage and crop rotations can rapidly improve soil quality and productivity.

SOC Stratification Ratio in 1999

The stratification of SOC with soil depth is common in many ecosystems. Franzluebbers (2002) developed a concept of using a SOC stratification ratio as an indicator of dynamic soil quality. In our study, the SOC stratification ratio (SOC 0-2 in/SOC 2-6 in depths) for 1999 data showed that the smallest SOC stratification ratio was with continuous cotton without winter legume but values were statistically similar to any rotation that included corn (Table 4). Our data generally agrees with Franzluebbers (2002), who found larger SOC stratification ratios with increasing cropping intensity. Contrary to this, however, the 3-yr and 2-yr rotations that included corn had lower SOC stratification ratios than continuous cotton with winter legume. The overall average SOC stratification ratio in 1999 was 1.31; closer to values found with conventional tillage than for conservation tillage as reported by Franzluebbers (2002). This indicates that the 'Old Rotation' is only in the beginning stages of change regarding SOC and associated properties. Franzluebbers (2002) concluded that a good SOC stratification ratio is between 2 to 3, depending on soil type and climatic conditions.

CONCLUSION

Soil organic carbon in the 'Old Rotation' was dramatically affected by use of conservation tillage for three years. The rapid change in SOC among cropping systems with conservation tillage mirrors yield increases reported by Mitchell *et al.*, 2002a,b). The study confirms that conservation tillage systems with crop rotation and winter legume cover crops had the largest impact on SOC. Changes in SOC occurred more quickly than other research suggests. Conservation tillage has induced changes in the distribution of SOC and these changes depended on the cropping system implemented. The SOC stratification ratios in the 'Old Rotation' are low, indicating a severely degraded soil. The full impact of conservation tillage on soil quality may take years to reverse this degradation.

Table 4. Soil organic carbon stratification ratio among principal cropping systems (0-2 / 2-6 in depth) in the 'Old Rotation' Experiment, Auburn, AL

Cropping Systems	SOC Stratification Ratio
Continuous cotton - legume†	1.17
Continuous cotton + legume †	1.52
2-yr cotton-corn + legume †	1.21
2-yr cotton-corn + legume† + N‡	1.28
3-yr cotton-corn-small grain /soybean + legume† + N§	1.26
$LSD_{0.10}$	0.32

† Legume = winter cover crop; crimson clover since 1956.

‡ Nitrogen applied to cotton or corn (120 lbs $acre^{-1}$ yr^{-1})

§ Nitrogen applied to small grain (60 lbs $acre^{-1}$ yr^{-1})

LITERATURE CITED

Bajracharya, R.M., R. Lal, and J.M. Kimble. 1997. Long-term tillage effects on soil organic carbon distribution in aggregates and primary particle fractions of two Ohio soils. pp.113-124. *IN* Lal et al. (eds.) Management of Carbon Sequestration in Soil. Advances in Soil Science. CRC Press, Boca Raton, Fl.

Bruce, R.R., G.W. Langdale, and A.L. Dillard. 1990. Tillage and crop rotation effect on characteristics of a sandy surface soil. Soil Sci. Soc. Am. J. 54:1744-1747.

Dalal, R.C., and R.J. Mayer. 1987. Long-term trends in fertility of soils under continuous cultivation and cereal cropping in southern Queensland. II. Total organic carbon and its rate of loss from the soil profile. Aust. Journal Soil Res. 24: 281-292.

Doran, J.W., and T.B. Parkin. 1994. Defining and assessing soil quality. pp. 3-21. *IN* Doran et al. (eds.) Defining Soil Quality for a Sustainable Environment, SSSA Spec. Publ. 35. Madison WI.

Franzluebbers A.J. 2002. Soil organic matter stratification ratio as an indicator of soil quality. Soil Tillage Res. (in press).

Gee, G.W., and J.W. Bauder. 1986. Particle-size-analysis. pp. 383-411. *IN* A. Klute (ed.) Methods of Soil Analysis. Part 1. 2nd ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Hunt, P.G, D.L. Karlen, T.A. Matheny, and V.L. Quisenberry. 1995. Changes in carbon content of a Norfolk loamy sand after 14 years of conservation or conventional tillage. J. Soil and Water Conserv. 51:255-258.

Karlen, D.L., W.R. Berti, P.G. Hunt, and T.A. Matheny. 1989. Soil-test values after eight years of tillage research on a Norfolk loamy sand. Commun. Soil Sci. Plant Anal. 20:1413-1426.

Kelley, K.R. 1994. Conveyor-belt apparatus for fine grinding of soil and plant materials. Soil Sci. Soc. Am. J. 58:144-146.

Langdale, G.W., L.T. West, R.R. Bruce, W.P. Miller, and A.W. Thomas. 1992. Restoration of eroded soil with conservation tillage. Soil Technol. 5:81-90.

Mitchell, C.C, and J.A. Entry. 1998. Soil C, N and crop yield in Alabama's long-term "Old Rotation" cotton experiment. Soil Tillage Res. 47:331-338.

Mitchell, C.C., D.W. Reeves, and D. Delaney. 2002a. Breaking records-sensible management helps Alabama's long-term experiments net record yields. Highlights On Line, Ala. Agric, Exper. Stn. (AAES). Available at http://www.ag.auburn.edu /resinfo /highlightsonline/fall01/fall-mitchell.html (verified 20 May 2002).

Mitchell, C.C., D.W. Reeves, and D. Delaney. 2002b. Conservation tillage in Alabama's Old Rotation. (These proceedings).

Motta, A.C., D.W. Reeves, and J.T. Touchton. 2002. Tillage intensity effects on chemical indicators of soil quality in two Coastal Plain Soils. Commun. Soil. Sci. Plant Anal. 33:913-932.

Nelson, D.W, and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. pp. 539-579. *IN* A.L. Page et al. (eds.) Methods of Soil Analysis. Part 2. 2nd ed. SSSA Book Ser. 5. SSSA, Madison, WI.

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

SAS Institute 1999. Release 8.2 (TS2MO). SAS Inst., Cary, NC, USA.

Tabatabai, M. A. 1996. Soil organic matter testing: an overview. pp. 1-9. *IN* F.R. Magdoff et al. (eds.) Soil Organic Matter: Analysis and Interpretation. SSSA Spec Publ. 46. ASA, CSSA, and SSSA, Madison, WI.

Varvel, G. E. 1994. Rotation and nitrogen fertilization effects on changes in soil carbon and nitrogen. Soil Sci. Soc. Am. J. 86:319-325.

Walkley, A., and I.A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37:29-38.

Yeomans, J. C., and J.M. Bremner. 1991. Carbon and nitrogen analysis of soils by automated combustion techniques. Commun. Soil Sci. Plant Anal. 22:843-850.