# LONG-TERM TILLAGE SYSTEM EFFECTS ON CHEMICAL SOIL QUALITY INDICATORS IN THE SOUTHEASTERN COASTAL PLAIN

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## ABSTRACT

The impact of tillage intensity on chemical soil quality indicators has not been evaluated in the long-term for soils of the Southeastern Coastal Plain. The long-term influence of four tillage systems [no-tillage (NT), disk, moldboard plow (MP), and chisel plow (CP)] on chemical soil quality indicators after 17 years was evaluated on a Benndale fine sandy loam (coarse-loamy, siliceous, thermic, Typic Paleudults) and a Lucedale very fine sandy loam (fine-loamy, siliceous, thermic, Rhodic Paleudults) in the Coastal Plain region of Alabama. Soil pH, effective cation exchange capacity ($CEC_{eff}$), soil organic carbon (SOC), and soil N, P, Zn, and Mn were determined on soil samples collected at depths of 0-1, 1-3,3-6, 6-9, and 9-12 inches. An accumulation of SOC occurred primarily in the top **1** inch with values of 2.76,1.31,1.27, and 1.04%C with NT, disk, CP, and MP, respectively, for the Benndale soil and 1.67, 1.00, 0.98, and 0.69% C, respectively, for the Lucedale soil. A slight decrease in pH (0.3 units) was observed at 6 to12 inches with NT compared with other tillage treatments on the Lucedale soil. Extractable P was higher with NT than MP at the 9-inch depth on the Lucedale soil. On the Benndale soil, NT resulted in the greatest extractable P at the 6- to 9-inch depth. Regression showed that SOC and pH combined predicted 73 and 86% of the variation in CEC, for the Benndale and Lucedale soils, respectively. Soil organic carbon and pH were also tightly correlated to nutrient availability. The results suggest that no-tillage and double cropping are effective in increasing SOC on Coastal Plain soils, especially in the critical area at the soil surface. Surface applications of lime maintained soil pH at an acceptable level within the plow layer of both soils and all tillage systems. As determined from chemical indicators of soil quality, adoption of conservation tillage with double cropping promotes sustainability for these soils.

## INTRODUCTION

Common indicators of soil properties, i.e., a Minimum Data Set, are recommended to evaluate soil quality (Doran and Parkin, 1996). Soil organic C, total organic N, pH, and extractable N, P, and K have been recommended as useful chemical soil quality indicators Doran and Parkin, 1996).

Many years are required to reach equilibrium for some soil properties after changing tillage systems. Therefore, long-term studies are recommended in order to evaluate changes in soil quality. But, long-term studies comparing tillage system effects on soil quality indicators have largely been conducted in temperate climates (Reeves, 1997), and only a few long-term studies have been reported under thermic conditions found in the Southeast. Additionally, studies have not been conducted over a range of tillage intensities.

Increasing SOC with no-tillage has been generally associated with an accumulation near the soil surface (Motta et al., 1999; Hunt et al., 1996). However, this accumulation is critical to restoring soil productivity (Bruce et al., 1995).

Another important soil quality indicator affected by tillage systems is soil pH. Surface lime application in no-tillage often does not ameliorate decreased soil acidity deep within the profile due to limits in lime mobility (Hargrove et al., 1982; Edwards and Beegle, 1988). However, results from the only long-term study conducted in the Coastal Plain region that reported soil chemical properties showedmaintenance of soil pH at an acceptable level for crop production after 8 years with no-tillage using surface applications of lime (Karlen et al., 1989).

Like SOC, soil extractable P accumulates more at the surface with no-tillage than conventional tillage (Hargrove et al., 1982; Edwards et al., 1992). However, increased P mobility as organic P with no-tillage was reported by Ismail et al. (1994). Changes in micronutrient distribution within the soil profile have also been reported for different tillage systems for Zn (Hargrove et al., 1982; Edwards et al., 1992) and Mn (Blevins et al., 1983; Edwards et al., 1992). However, micronutrient distribution as affected by tillage in long-term studies for Coastal Plain soils has not been reported.

The objective of our research was to evaluate the long-term effect of four tillage systems on some chemical indicators of soil quality for two Coastal Plain soils in Alabama after 17 years.

## MATERIALS AND METHODS

Two tillage experiments were conducted for 17 years in the Coastal Plain region of southwestern Alabama. Wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.), triticale (*Triticum aestivum* L. x *Secale cereale* L.), and white lupin (*Lupinus albus* L.) were cropped during winters and soybean [*Glycine max* (L.) Merr.], grain sorghum [*Sorghum bicolor* (L.) Moench], cotton (*Gossypium hirsutum* L.), tropical corn (*Zea mays* L.), and pearl millet [*Pennisetum americanum* (L.) Leeke] were cropped during summers since 1981.

The experimental design at both locations was a randomized complete block with four replications. Treatments consisted of four tillage systems applied prior to the winter crop each year. Tillage systems were: no-tillage, Qsk, chisel plow, and moldboard plow. The no-tillage treatment consisted of planting into dessicated crop residue. The disk treatment consisted of one pass with an offset tandem disk. For the chisel plow, shanks on the front and rear tool bars were offset so that the actual distance between chisel points was 8 inches. The moldboard plow was used as a total soil inversion treatment. Chisel plow and moldboard plow treatments had a secondary tillage of disking and leveling with a disk harrow and drag board. It was estimated that disk, chisel plow, and moldboard plow reached an average depth of 3-5, 6-8, and 8-10 inches, respectively. Summer crops were planted without tillage using a no-till planter each year. Lime, P, and K fertilizers were applied according to Auburn University soil test recommendations, based on fertility levels for the top 6 inches of soil collected during the fall prior to planting the winter crop.

In the fall of 1997, 20 soil cores were collected (hand probe, 0.8-inch diameter) per plot and composited by depth (0-1, l-3, 3-6, 6-9, and 9-12 inches). Samples were air-dried and sieved (2 mm). Soil P, Mn, and Zn were extracted using Mehlich-1 (double acid) solution (Hue and Evans, 1986) and determined by Inductively Coupled Air Plasma Emission Spectrometry [ICAP]. The CEC, was obtained through the sum of bases ($Ca^{++} + Mg^{++} + K^{+} + Na^{+}$). Soil pH was determined on 1:1 soil/water suspension with a glass electrode pH meter. Total organic C and N were determined using a Nitrogen/Carbon analyzer (Fisons Instruments, Beverly, MA 01915).

Analyses of variance were conducted prior to determination of protected least significant difference (LSD) values at the 95% level of confidence. Sampling depths were analyzed as a split in the design. The soil type or location was initially included in the analysis model and proved to have interactive effects with tillage and/or depth on dependent variables; therefore, data were analyzed separately and are presented by soil type. Correlation and stepwise regression were used to analyze relationships among chemical soil quality variables.

## RESULTS AND DISCUSSION

Soil organic carbon, a key indicator of soil quality, was affected by an interaction of soil type, tillage, and depth. Soil carbon accumulation occurred within the first inch of soil at both locations and was inversely related to soil disturbance (Figure 1). This increase on SOC plays an important role in soil quality due to improvement in infiltration and crop-available soil water (Bruce et al., 1995). Furthermore, the surface buildup of SOC occurred under adverse conditions of climate (Hargrove et al., 1982; Hunt et al., 1996) and low clay content (Havlin et al., 1990; Campbell et al., 1996). Our results confirm that cropping intensity and high production of crop residues combined with conservation systems can enhance or sustain SOC under thermic regimes (Reeves and Wood, 1994; Hunt et al., 1996; Reeves, 1997).

Soil N distribution mirrored the variation in SOC among treatments for both soils (data not shown). Combined over all treatments and depths, soil N was highly correlated to SOC for the Benndale ($R^2$ = 0.93) and Lucedale ($R^2$ = 0.95) soils. The results suggest that intensive cropping combined with conservation tillage may enhance the soil's ability to supply a greater portion of crop N (Wienhold and Halvorson, l999).

Another key indicator of soil quality, soil pH, was not affected by tillage, regardless of depth, on the Benndale soil (Figure 2). This suggests that surface lime with no-tillage is as effective as lime incorporation by moldboard plowing in maintaining pH at acceptable levels. Similar results were obtained by Ismail et al. (1994), who reported a slight decrease in soil pH down to 12 inches with no-tillage compared with moldboard plow. In contrast to the Benndale soil, the Lucedale soil maintained a lower pH with no-tillage compared with other tillage systems at the 6- to 12-inch depth increment. Hargrove et al. (1982) reported lower pH with no-tillage than moldboard plow at depths between 3 and 12 inches after 5 years on a sandy loam soil in Georgia.

As observed for SOC, $CEC_{eff}$ increased within the first inch for the Benndale soil and within 3 inches for the Lucedale soil (data not shown). In our study, the influence of SOC and pH on soil CEC, was demonstrated using multiple regression techniques for both soils types (data not shown). The results indicated that maintenance of SOC through intensive cropping and conservation tillage and with adequate lime application may inhibit cation loss.

In contrast to other studies (Hargrove et al., 1982; Edwards et al., 1992), no-tillage did not result in P accumulation in the uppermost soil layer of the Benndale soil (data not shown). However, there was an accumulation of P at the soil surface (0-1 inch) of the Lucedale soil, which was inversely related to the intensity of tillage disturbance Movement of P within the soil profile due to leaching processes is usually considered insignificant in agrosystems. However, P movement by leaching or other processes needs to be considered in our study due to several factors. First, combined low P adsorption capacity and high levels of extractable P can contribute to P mobility. Second, surface SOC accumulation decreases P adsorption capacity (Guertal et al., 1991), as well as contributing to maintenance of soil pH between 5.5 to 7.0. Third, the long-term addition of plant residues under favorable conditions for decomposition and abundant rainfall could result in ideal conditions leading to leaching of organic P (Mozaffari and Sims, 1994; Mottaet al., 1999). Fourth, preferential pathways for movement of water and nutrients are common with conservation tillage due to earthworm activity

(Edwards and Beegle, 1988) and root channels (Kanwar et al., 1997).

Regression results indicated variation in extractable Zn was strongly related to SOC, pH, and $CEC_{eff}$ (data not shown) for the Lucedale soil. For the Benndale soil, only SOC affected extractable Zn. Relationships between Zn and SOC (Edwards et al., 1992), Zn and pH (Edwards et al., 1992; Mahler et al., 1985), and Zn and CEC (Davis-Carter and Shuman, 1993) have been reported. Effective CEC, SOC, and pH combined predicted extractable Zn on the Lucedale soil. In contrast to other reports (Mahler et al., 1985; Edwards et al., 1992), pH had no affect on Mn distribution in our study; however, SOC proved a good predictor of Mn.

## CONCLUSIONS

Tillage systems affected chemical indicators of soil quality interacting with soil type. Surface SOC accumulation occurred within the first inch and was inversely related to soil disturbance (no-tillage>disk >chisel plower>moldboard plow), regardless of the adverse condition of climate and coarse soil texture. In contrast to SOC, pH was slightly affected by tillage systems for the Lucedale soil, with lower pH occurring at depths below the plow layer ( $\geq$ 9 inches) under no-tillage relative to other tillage systems. However, broadcast application of lime maintained pH at an acceptable level within the plow layer for both soils, even with no-tillage. Accumulation of P in the surface soil layer with no-tillage occurred only on the Lucedale soil, and downward movement of P was indicated with reduced tillage systems in both soils. Significant changes in $CEC_{eff}$ , total N, Zn, and Mn accumulation in the surface soil mirrored the distribution pattern of SOC. Soil organic C and pH served as co-predictors of $CEC_{eff}$, alone or in combination. These two soil quality indicators were also highly correlated to Mn and Zn. Our results show that, as determined from chemical indicators of soil quality, adoption of conservation tillage with doublecropping offers long-term sustainability for managing Coastal Plain soils.

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FIGURE 1. Effect of tillage system after 17 years on soil organic carbon in a Benndale and a Lucedale soil in the coastal plain of Alabama. Horizontal bars indicate LSD0.05 and ns= nonsignificant at $P \leq 0.05$.

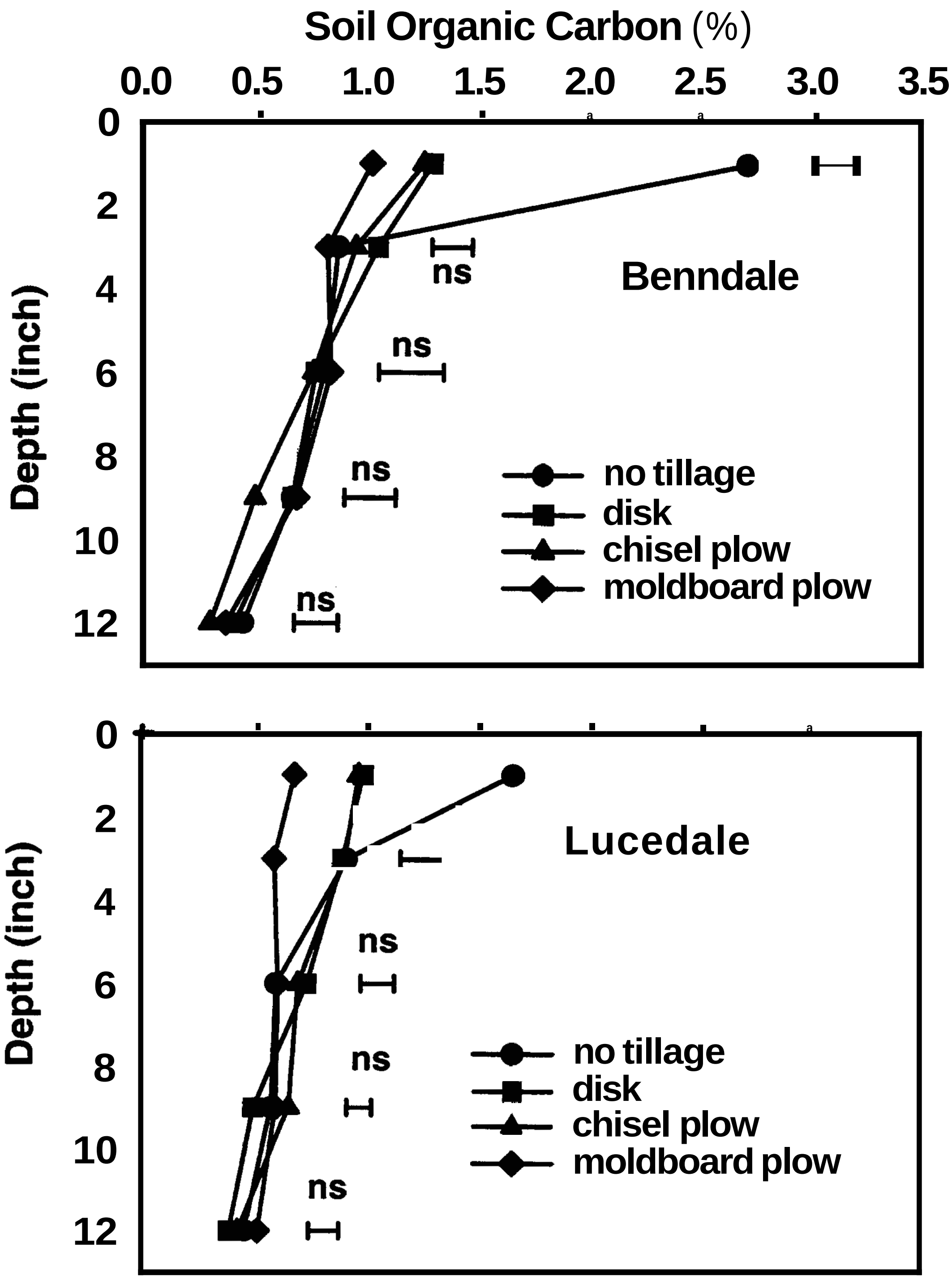

FIGURE 2. Effect of tillage system after 17 years on soil pH in a Benndale and a Lucedale soil in the coastal plain of Alabama. Horizontal bars indicate $LSD_{0.05}$ and ns= nonsignificant at $P \leq 0.05$.