Agroecosystem Effects on Carbon Sequestration and Soil Function in Tennessee Valley (Alabama) Paleudults

by

Andrew Lee Croy

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 7, 2012

Keywords: Soil Organic Matter, Soil Carbon Sequestration, Conservation Tillage, Soil Function, Soil Quality, Tennessee Valley, Ultisols

Approved by

Joey N. Shaw, Co-chair, Alumni Professor of Agronomy and Soils
Julie A. Howe, Co-chair, Assistant Professor of Agronomy and Soils
Charles H. Burmester, Extension Agronomist
C. Wesley Wood, Professor of Agronomy and Soils

Abstract

Agronomic management affects soil organic matter (SOM) pools that impact chemical and physical properties, soil carbon (C) sequestration, soil quality, and ultimately, soil function. Pools of SOM and management-dependent soil chemical and physical properties were measured on Decatur (Fine, kaolinitic, thermic Rhodic Paleudult) map units, a benchmark soil in the Tennessee Valley region of Alabama. These soil systems provide pedological environments for investigating the interaction of increasing SOM with relatively high near-surface quantities of sesquioxides and phyllosilicate clays. Agroecosystems investigated included long-term (≥ 15 years) pasture, conservation (reduced tillage) cotton (*Gossypium hirsutum*) with and without grain row-cropping, and conventional cotton row-cropping systems. The objectives of the study were to: 1) quantify and relate soil organic C (SOC) pools [SOC, particulate organic C (POC), and active organic C (AC)], 2) calculate soil C sequestration rates in row crop agroecosystems over a ten-year duration, 3) quantify select soil chemical and physical properties and relate these properties to management practices and SOM, and 4) relate these soil chemical and physical properties to soil quality and soil function. Soils were sampled and characterized for taxonomic placement, and sites were sampled to a 50-cm depth in four depth increments. Significant ($\alpha=0.05$) differences were observed for SOC pools near surface, but results were mixed with depth. Strong correlations existed between all SOC pools both near surface (0-5 cm) and when pooled across all depths. To a depth of 50 cm, the pasture system (73.1 Mg C ha^{-1}) and conservation row crop systems (51.3 Mg C ha^{-1}) sequestered 36 and 94% more SOC than conventional row crop systems (37.7 Mg C ha^{-1}), respectively. Soil C sequestration rates for conservation systems were on average 0.6 Mg ha^{-1} yr^{-1}, while conventional row crop systems were relatively static. Carbon sequestration rates and amounts were commensurate with other studies within the southeastern U.S. region. Several soil chemical (e.g., ion exchange capacity and extractable nutrients) and physical properties (e.g., water stable aggregates, water dispersible clay and Atterberg limits) were significantly correlated with SOC pools. Cation exchange capacity (CEC) increased 2.6 $cmol_c$ kg^{-1} per every 10 g kg^{-1} increase in SOC. The pasture system had lower anion exchange capacity than row crop systems, which suggests that SOM masks (+) charged sites on iron oxides. Plastic and liquid limits increased approximately 5% per 10 g kg^{-1} increase in SOC in the surface (0-5 cm). Near-surface (0-5 cm) aggregation was improved by increasing SOC, as water dispersible clay was decreased approximately 2% and water stable aggregates were increased approximately 2% per every 10 g kg^{-1} SOC. Similarly, differences in SOC between stable and non-stable aggregate fractions suggest aggregation in these surface horizons is more strongly related to SOM than iron oxide content. Similar to past studies, systems with decreased surface disturbance resulted in improved soil quality. This study provides quantifiable relationships among SOM and soil properties essential to soil function (e.g., nutrient and water retention and trafficability) in the Tennessee Valley region.

Acknowledgments

The author wishes to express his gratitude to Dr. Joey N. Shaw and Dr. Julie A. Howe for their guidance, wisdom and council as advisors. Appreciation is also extended to the remaining members of the advisory committee, Charles H. Burmester and C. Wesley Wood, for their knowledge and insight of theses agronomic systems and research. The author would also like to thank Mr. John Owen and Mrs. Julie Arriaga for their help both in the laboratory and the field, Dr. Mike Miller for his assistance with the scanning electron microscope, and fellow graduate students for their friendship and support. Finally, the author wishes to offer his deepest appreciation to his family, Edward Croy, Joyce Croy, and the Holbrook family, and friends for their love and support through this and all aspects of his life.

Table of Contents

List of Tables

List of Figures

I. Literature Review

Introduction

Since the initiation of monitoring programs in the late 1950's, atmospheric concentrations of carbon dioxide (CO_2) have increased at a rate of 1.4 parts per million per year (ppm yr^{-1}) (Forster et al., 2007). Currently, atmospheric carbon (C) levels are 390 ppm by volume (Keeling et al. 2005), and levels are projected to continue to rise into the next century (Solomon et al., 2009). Possible greenhouse effects associated with increasing CO_2 (and other gases) have driven researchers and policy makers to search for approaches to mitigate increasing CO_2. Terrestrial C sequestration is one approach that involves increased use of conservation management practices to increase sequestration of C into soil organic matter (SOM) (Follett, 2001; Lal, 2004).

Agroecosystem changes not only alter SOM as a whole but can also alter dynamics of the fractions and pools within soil organic C (SOC) (Six et al., 1998; Balesdent et al., 2000). This, coupled with a wealth of evidence of the role of SOC as an important component in maintaining soil quality of agroecosystems, warrants research dedicated to understanding relationships among agroecosystems, soil quality, SOC pools, and soil C sequestration (Reeves, 1997).

Agricultural management primarily affects soil quality by altering SOM accumulation and decomposition. In turn, SOM affects a wide array of other soil chemical and physical properties (Karlen et al., 1997; Reeves, 1997; Magdoff and van Es, 2000). Select soil properties related to soil quality that are affected by SOM include ion exchange capacity, bulk density, aggregation, and others. Primarily, these effects are observed near surface where the greatest management-induced changes of SOM occur. Current agricultural practices emphasize sustainable management practices. Increasing SOM, as a result of management, can improve soil quality and promote the efficacy of sustainable practices (Magdoff and van Es, 2000).

The Tennessee Valley region of Alabama is intensively utilized for agronomic production. Over the last two decades, agricultural management systems in this region have largely transitioned from conventional to conservation systems. These transitions provide an opportunity to evaluate anthropogenically induced changes in near-surface dynamic soil properties related to soil function. Furthermore, the predominant soils of this region provide a relatively unique environment to evaluate near-surface interactions among SOC, iron oxides, clay minerals, and the resulting influences on soil properties that affect soil quality.

The Tennessee Valley Region of Alabama

Geography

The Tennessee Valley region lies in the northern portion of Alabama. As suggested by its name, this region contains portions of the Tennessee River watershed and is included within the United States Department of Agriculture (USDA) National Resources Conservation Service (NRCS) Major Land Resource Area (MLRA) 128 (Southern Appalachian Ridges and Valleys) (USDA-NRCS, 2006). It is contained within the Interior Plateau (level III) and Eastern Highland Rim (level IV) eco-regions (Griffith et al., 2001). Published soil surveys for this area describe limestone valleys with units of similar soils on a low rolling or undulating plane adjacent to the Tennessee River (USDA, 1953).

Climate

Climate in the Tennessee Valley is characterized by a long growing season (approximately 200 days) with a relatively even distribution of precipitation (USDA-NRCS, 2002). The Tennessee Valley Research and Extension Center (TVREC) is located in Belle Mina, AL, and is centrally located in the region. Annual average temperature for Belle Mina is 15.5 ºC with the daily average temperature ranging from 9.1 to 21.9 ºC. Average precipitation in this area is approximately 1400 mm with greater than 100 mm in all months except August and October, which have precipitation averages greater than 75 mm per month.

Geology

Bedrock in the Tennessee Valley is composed of limestone, chert, and shale. Major geologic formations in this area are the Tuscumbia Limestone group (St. Louis Limestone) and to a lesser extent, the Fort Payne Chert group. These groups can also appear together in an undifferentiated formation (USGS, 1988). Geologic formations found in the Tennessee Valley are marine sedimentary rock deposited in the Mississippian period, the fifth period of the Paleozoic era that began about 360 million years ago and lasted about 40 million years (USGS, 2007).

Soils

Upland soils in the Tennessee Valley formed on ancient alluvial terraces from the Tennessee River and its tributaries and from residual weathering of limestone (USDA, 1953). Soils in this area are in an Udic moisture regime and a Thermic soil temperature regime (USDA-NRCS, 2006). Historically, this region has been extensively cropped with cotton (*Gossypium hirsutum* L.) using conventional tillage techniques that leave little or no plant residue. As a result of this practice, the soils in this area can be considered degraded and of low dynamic soil quality (Schwab et al., 2002).

The Decatur soil series is a benchmark soil for this area. It covers a significant portion of the MLRA, has value to the region, and is often a component of prime farmland soil map units (TVA, 2003; USDA-NRCS, 2006). It is classified as a Fine, kaolinitic, thermic Rhodic Paleudult and is correlated in MLRA 128 (the Southern Appalachian Ridges and Valleys) and MLRA 122 (Highland Rim and Pennyroyal). These soils are well drained and deeply weathered with solum depths often exceeding 2 meters (Soil Survey Staff-NRCS, 2004).

Agronomic Practices in the Tennessee Valley

Primary crops grown in the Tennessee Valley are cotton, corn (*Zea mays*), and soybean (*Glycine max*) (USDA-NRCS, 2006). Small grains including wheat (*Triticum aestivum* L.) are also produced in this area (Sullivan et al., 2005). In addition, pasture or grassland systems for livestock and hay production are common (USDA-NRCS, 2006).

Conventional tillage systems have been the traditional approach to cultivation in the Tennessee Valley, but conservation systems have increased over the last decade.

Typical management practices in conventional systems include inversion plowing post-harvest, winter mellowing, and disking to prepare a seedbed prior to spring planting. Winter cover crops are typically not utilized in conventional systems. These cultivation practices remove plant residues from the soil surface leaving the soil vulnerable to degradation, especially during the fallow winter months (Brown et al., 1985). Conventional tillage practices result in decreased SOC levels, decreased dynamic soil quality, increased susceptibility to erosion, and have the potential to reduce crop yields with long-term use (Bruce et al., 1995).

Conservation systems are defined as systems that leave at least 30% of the previous crop residue on the soil surface (USDA, 2008). These systems can result in lower SOC levels than native ecosystems, but generally better dynamic soil quality than conventional systems (Hendrix et al., 1998). Transitions from conservation to conventional systems can lead to increasing SOC (Follett, 2001; Lal, 2004) and improved soil chemical, biological, and physical properties (Karlen et al., 1994; Campbell et al., 1998). Conservation systems in the Tennessee Valley often utilize winter cover crops such as wheat or rye (*Secale cereal*) (Schwab et al., 2002). Conservation tillage combined with the use of cover crops have been shown to improve crop yields (Raper et al., 2000; Schwab et al., 2002; Balkcom et al., 2006) and increase SOC (Beare et al., 1994b; Reeves, 1997).

Soil Change, Soil Quality, and Soil Function

The National Cooperative Soil Survey (NCSS) is beginning to shift their emphasis from mapping and inventory of soil resources to improved evaluation and documentation of anthropogenic effects on near-surface dynamic soil properties (Tugel et al., 2005). Goals of these efforts are to evaluate soil change over anthropogenic time scales. Time is a soil forming factor (Jenny, 1941) that can be broadly divided into two scales. The first occurs over a geologic time-scale and is a result of the natural progression of soil development from parent material during pedogenesis (Jenny, 1941; Norfleet et al., 2003; Richter, 2007). The second occurs over a decadal to centurial time-scale and is largely a result of anthropogenically induced change (Tugel et al., 2005; Richter, 2007).

Soil function is the ability of soil properties to aid in soil processes (e.g., nutrient cycling, support soil biota, water interactions, and others) (Karlen et al., 1997; Seybold et al., 1999). Pivotal properties that affect soil function include chemical (e.g., organic C, soil nutrients, and ion exchange) and physical properties (e.g., texture, aggregation, and bulk density) (Schoenholtz et al., 2000). Soil function and the properties that affect it are intimately related to soil quality. Soil quality is the ability of a soil to serve a specific purpose (Ditzler and Tugel, 2002) including economic, environmental, and cultural applications (Lal, 1993). Soil quality has both an inherent and a dynamic aspect, and is strongly tied to near-surface properties (Norfleet et al., 2003).

Management can have a direct effect on dynamic soil quality by enhancing or degrading soil properties (Karlen et al., 1997; Ashad and Martin, 2002; Franzluebbers, 2002a; Levi et al., 2010). Near-surface soil properties are most susceptible to management practices (Grossman et al., 2001). Assessing changes in soil quality requires evaluation of many dynamic soil properties, which may be independently affected by management practices (Burger and Kelting, 1999). Many authors suggest measuring several properties for assessment of soil quality including soil biological, chemical, physical attributes (e.g., SOC, bulk density, ion exchange properties, pH and others) (Doran and Parkin, 1994; Karlen et al., 1994; Ditzler an Tugel, 2002). Soil organic matter can directly influence many of these properties and is considered the key indicator (Karlen et al., 1997; Arshad and Martin, 2002). Monitoring soil quality is important for sustainable agricultural applications (Doran and Ziess, 2000), but given the complexities and the extensive parameters used to define soil quality, it can be difficult to apply (Herrick, 2000). Therefore, when attempting to assess management-induced changes to soil quality, indicators must be chosen that are sensitive to the practices utilized (Karlen et al., 1994).

Soil Organic Matter Pools

Soil organic matter is comprised of various pools and fractions that can be categorized based on density, particle size, solubility, and susceptibility to decomposition from soil microbial communities (Stevenson, 1994). The boundaries between these fractions and pools are not rigid, and some components of these groups may comprise portions of other groups (Wander 2004).

Total Soil Organic Carbon

Total soil organic carbon (TOC), often referred to as SOC, is the total of all organically bound C within soils. This pool contains plant litter, microbial biomass, and the labile and non-labile fractions of SOC (Stevenson, 1994). Total SOC comprises between 50 to 58% of SOM (Baldock and Nelson, 2000). As detailed above, SOC is sensitive to management practices and can be increased through the use of conservation systems.

Several studies have illustrated SOC quantities as a function of agroecosystem in both the Tennessee Valley and southeastern U.S. Ultisols. In a review summarizing southeastern U.S. studies on Ultisol C sequestration, Causarano et al. (2008) reported 22.2 Mg C ha^{-1} in conventional row crop systems, 27.9 Mg C ha^{-1} in conservation row crop systems, and 38.9 Mg C ha^{-1} in pasture systems. Wood et al. (1991) found as much as a 61% increase in SOC conservation systems when compared to conventional systems on Ultisols in the Appalachian Plateau region of north Alabama. Similarly, Motta et al. (2007) reported a 3.3 Mg C ha^{-1} increase (six years in conservation management) in SOC in conservation systems compared to conventional systems under cotton production in the Tennessee Valley.

Active Carbon

Potassium permanganate ($KMnO_4$) has been used to evaluate labile C, and is considered to be representative of soil quality (Weil et al., 2003). This method defines the labile or “active” C as the fraction of SOM readily oxidized by $KMnO_4$ (Blair et al., 1995; Weil et al., 2003; Dell, 2009). This pool is largely comprised of soil microbial biomass, particulate organic C (POC), and other labile sources of C (Weil et al., 2003). However, Tirol-Padre and Ladha (2004) suggest that $KMnO_4$ can also oxidize non-labile fractions of SOC. Nevertheless, the active carbon fraction may be a critical pool of SOM for assessment of dynamic soil properties that are sensitive to management practices (Bell et al., 1998; Weil et al., 2003).

Particulate Organic Carbon

Particulate organic matter is comprised of particles of organic matter between 53 and 2000 μm in size, and is considered a SOC pool with intermediate stability (Cambardella and Elliott, 1992; Causarano et al., 2008). Conservation systems can significantly increase soil POC, which can represent a substantial portion of SOC (Baere et al., 1994a). Changes in SOM have often been attributed to POC when comparing conservation agronomic systems to conventional systems (Six et al., 1998; Sleutel et al., 2006; Motta et al., 2007). In southeastern U.S. Ultisols in row crop and pasture agroecosystems, Causarano et al. (2008) reported that 42% of SOC is attributed to POC. Franzluebbers and Stuedemann (2002) reported 57% of SOC is comprised of POC in pasture agroecosystems in southeastern U.S. Ultisols.

Soil Organic Matter and Soil Quality

Soil organic matter is likely the single most influential soil property that effects soil function and soil quality (Doran and Parkin, 1996). Aside from being a direct chemical and physical contributor, SOM affects other soil properties that are integral factors in soil function and quality (Reeves, 1997). Chemically, SOM directly contributes to cation exchange capacity (CEC), nutrient cycling, and other properties in soils. Physically, SOM contributes to water holding capacity, bulk density, and aggregation (Karlen et al., 1997; Schoenholtz et al., 2000). Many SOM effects on soil properties directly relate to agronomic production. However, the effects of increased SOM and subsequent improved soil quality are not solely limited to agronomic production, but they have larger implications by contributing to environmental quality (Bruce et al., 1995; Karlen et al., 1997; Carter, 2002).

Carbon Sequestration

Soil C sequestration is dependent on many factors including the composition of organic inputs, site characteristics, and soil conditions (Parton et al., 1987; Leirós et al., 1999). Site and soil properties that have the greatest influence on C accumulation are climate, moisture, soil texture, and soil mineralogy (Parton et al., 1987; Balddock and Skjemstad, 2000). Under certain conditions, these properties can promote protection of organic material and restrict degradation by soil microbial communities, while other times degradation by microbial activity is enhanced (Balesdent et al., 2000).

Climate controls soil temperature and moisture that affects the accumulation of SOC. Soils in warmer climates typically have lower amounts of SOC than those of cooler climates (Burke et al., 1989; Franzluebbers et al., 2001; Six et al., 2002). This is due to a more active and respiring microbial biomass, which decomposes SOM more rapidly (Amelung et al., 1997; Franzluebbers et al. 2001). Soil moisture and drainage also affect the accumulation of SOC; wetter and more poorly drained soils typically have greater quantities of SOC due to slower decomposition of SOM in these environments (Parton et al., 1987; Burke et al., 1989; Tan et al., 2004).

Fine-textured soils typically store greater amounts of SOC relative to coarse-textured soils (Burke et al., 1989; Needelman et al., 1999; Tan et al., 2004; Motta et al., 2007). Increased SOM in fine-textured soils is the result of increased aggregation, which offers the included SOM protection from microbial degradation (Hassink et al., 1993; Scott et al., 1996; Krull et al., 2003; Tan et al., 2004). Increased aggregation protects all pools of SOM, but the greatest effect may be observed in labile pools since these have the greatest susceptibility to microbial degradation (Franzluebbers et al., 1996; Jastrow and Miller, 1998; Kay, 1998).

Many soils in the Tennessee Valley have relatively fine-textured surface horizons that are mostly composed of quartz, kaolinite, hydroxy-interlayered vermiculite, and iron (Fe) oxides (Shaw et al., 2003). In addition to finer soil textures, oxides and kaolinite may further increase protection of SOM from microbial degradation through the formation of highly stable aggregates (Bayer et al 2002; Krull et al., 2003; von Lützow et al., 2006). As a result, SOM content is often strongly correlated to oxide content (Kaiser et al., 2002).

Soil Organic Matter Effects on Chemical Properties

Ion Exchange

The ion exchange properties of soil are related to mineralogy, pH, and SOM (Anderson and Sposito, 1992; Wander, 2004). Isomorphic substitution in the mineral structure is responsible for permanent charge of soil colloids. Variable charge arises from protonation and deprotonation of edges of phyllosilicate minerals, oxides, and functional groups of SOM (Bohn et al., 1985; Sposito, 2000; Essington, 2004).

In highly weathered southeastern U.S. Ultisols, both permanent and variable charge properties contribute to cation exchange capacity (CEC) (Anderson and Sposito, 1992). Variable charge can contribute greater than 50% of the total CEC in some southeastern Ultisols (Tan and Dowling, 1984), which is due to the lack of minerals with permanent charge in these soils. The CEC of soils under conservation systems can be greatly affected by increasing SOM (Duiker and Beegle, 2006). Oorts et al. (2003) found that SOM contributed greater than 75% of the total CEC in highly weathered, kaolinitic soils of Nigeria. The (-) charge on SOM related to CEC is largely pH dependent, which decreases as pH decreases. Helling et al. (1964) found that CEC for SOM can increase as much as 30 cmol kg^{-1} per increase in pH unit, while the CEC of clay minerals (e.g., kaolinite) may only increase 4.4 cmol kg^{-1}. In addition, Soil Survey Investigation Staff (1995) estimates that roughly 3 to 4 cmol$_c$ kg^{-1} CEC can be gained per 1 g organic C. In the Tennessee Valley, CEC values within surface horizons typically range from 8 to 14 cmol kg^{-1} (Soileau et al., 1990; Truman et al., 2003; Mitchell and Tu, 2006).

Ultisols that are acidic and high in oxides and kaolinite can exhibit some degree of anion exchange capacity (AEC) (Qafoku et al., 2000). Coatings of oxides on soil particles contribute to pH dependent charge (Hendershot and Lavkulich, 1983). The AEC for some southeastern U.S. Ultisols ranges from 0.02 cmol kg^{-1} for surface horizons, to 1.43 cmol kg^{-1} for subsurface horizons (Bellini et al., 1996). The AEC of a Rhodic Paleudult in the southeastern U.S. Piedmont ranged between 0.6 and 1.3 cmol kg^{-1} (Gillman and Sumner, 1987). If the pH is such that SOM is negatively charged, organic matter can bind to (+) charges on oxides and kaolinite particles reducing the potential for anions to bind to these sites (Gillman, 1985; Fernández Marcos et al., 1998).

Point of Zero Charge

The point of zero charge (PZC) is the pH at which all soil charges (positive and negative) balance (Zelazny et al., 1996). The PZC is attributed to variable charge colloids, which control the charge characteristics of many highly weathered, oxide-rich soil systems (Gillman, 1979; Gillman, 1985). Highly weathered soils tend to have higher

PZC values than other soils (Uehara and Gillman, 1981; Van Ranst et al., 1998). The reported PZC values of kaolinite vary by location and study but have been measured within the range of 3.5 to 5 (Zelazny et al., 1996; Van Ranst et al., 1998; Shaw et al., 2002). Oxides have a higher PZC that ranges between 6 and 7 (Uehara and Gillman, 1981). Gillman and Sumner (1987) found PZC values of a Rhodic Paledudult to range between 5.9 and 6.5 and between 4.0 and 4.1 for other southeastern Ultisols.

Organic matter can drastically affect soil charge characteristics (Anderson and Sposito, 1992), and binding of SOM to mineral exchange sites may shift the PZC from original values. Gillman (1985) suggests the PZC of highly weathered soils can shift as much as one pH unit per percentage increase in SOM.

Plant Nutrients

Decomposition of SOM and mineralization of nutrients contributes to soil fertility (Palm et al., 1997; Baldock and Nelson, 2000; Bohn et al., 2001). Aside from being a direct contributor of nutrients, SOM contributes to CEC which increases the amount of nutrients retained (Edwards et al., 1992; Duiker and Beegle, 2006). Increases in plant nutrients in conservation systems parallel accumulations of SOM, especially near the soil surface (Motta et al., 2002). As a result, agricultural soils under conservation systems may exhibit nutrient stratification, where nutrients accumulate at or near the soil surface. Increases in plant nutrients at the surface are attributed to reduced vertical soil mixing with reduced tillage practices (Howard et al., 1999; Hussain et al., 1999; Duiker and Beegle, 2006).

Soil Acidity

The effects of SOM on pH are mixed. Crozier et al. (1999) and Hussain et al. (1999) found that soil pH values were higher in conservation systems when compared to conventional systems. Other studies have reported no significant differences in pH between management practices (Franzluebbers and Hons, 1996; Balkcom et al., 2006; Duiker and Beegle, 2006). Pocknee and Sumner (1997) suggest differences in pH that occur may be attributed to some components of organic material acting as a liming agent.

Soil Organic Matter Effects on Soil Physical Properties

Bulk Density

Typically, as SOM increases, soil bulk density decreases (Blanco-Canqui et al., 2006). Bulk density is reduced due to the lower density of SOM compared with mineral soil, and to increased aggregation, which improves soil porosity (Franzluebbers, 2002a). The effect of accumulated SOM on bulk density is typically observed in near-surface horizons (Mielke et al., 1986).

While SOM may reduce bulk density, practices that promote increases in SOM can increase bulk density and compaction. Raper et al. (2000) and Schwab et al. (2002) found no-tillage increased compaction, as observed by soil strength, in Decatur soils of the Tennessee Valley. In fine-textured soil surface horizons of the Tennessee Valley, increases in SOM resulting from conservation systems, especially cover crops, may decrease surface bulk density (Raper et al., 2000; Schwab et al., 2002; Tolbert et al., 2002). Bulk density in Rhodic Paleudults of the Tennessee Valley may be as much as 10% lower in conservation compared to conventional systems (Truman et al., 2002).

Aggregate Stability

Aggregate stability is a measure of the ability of cohered soil particles to withstand disruption and is related to soil texture, mineralogy, and SOM content (Nimmo and Perkins, 2002). In many soils, aggregation is most strongly related to SOM content; greater SOM increases the stability of surface horizon aggregates (Beare et al., 1994a; Karlan et al., 1994; Bruce et al., 1995)

Organic materials act as strong binding agents in soils by two primary means. The first is related to the potential for SOM to have substantially greater charge than soil particles, thus increasing the attraction of soil particles to SOM (Oades, 1984). The second involves the contribution of SOM to aggregation, which is attributable to the adhesive quality of many organic compounds (e.g., polysaccharides, plant mucilage, fungal hyphae, and others) that act to accrete soil particles (Oades, 1984; Wright et al., 1999).

In Ultisols of the southeastern U.S., increased SOM from conservation systems result in greater aggregation, enhanced stability, and possibly larger aggregates when compared to soils under conventional systems (Bruce et al., 1995; Franzluebbers et al., 1999; Franzluebbers, 2002b). In the Tennessee Valley, studies of aggregation as a function of increasing SOM report mixed results. Truman et al. (2003) found aggregate stability ranged between 37 and 61% in conventional and conservation row crop systems in the Tennessee Valley, but they attributed aggregate stability to Fe content rather than SOM.

Soils in this region inherently have finer near-surface textures (silt loam and silty clay loam) and greater dithionite extractable Fe (Fe_d) quantities relative to many other southeastern U.S. soils. Dithionite extractable Fe represents free Fe in both crystalline and amorphous forms (Jackson et al., 1986). Aggregation in soils with these properties may be attributed more to the influential charge characteristics of Fe oxide minerals, which are positively charged within the normal soil pH range in this region, than the binding properties of SOM (Six et al., 2000; Shaw et al., 2003).

Atterberg Limits

Atterberg limits are gravimetric water contents where a soil transitions to plastic or liquid states. The liquid limit (LL) is the minimum gravimetric water content where a soil sample will begin to flow (changes from plastic to liquid state), while the plastic limit (PL) is the gravimetric water content where a soil sample can be deformed without rupture when rolled into a 3-mm thread as outlined by ASTM standards (McBride, 2002).

The LL, PL, and derived plasticity index (PI) are strongly related to mineralogy and texture, but they can also be influenced near-surface by SOM (Odell et al., 1960; McBride et al., 1994). At water contents approaching the PL, soils tolerate trafficking and can be effectively plowed. However, in wetter conditions (up to the LL) soils can easily compact from tillage and trafficking. Beyond the LL, compaction is less of a threat, but smearing and associated issues become a concern (Gill and Reaves, 1957; Raper and Kirby, 2006)

Atterberg limits can be affected by changing agroecosystems and the resulting changes in SOM. Blanco-Canqui et al. (2006) reported that conservation practices had greater LL and PL (up to 85 and 100%, respectively) than conventional agroecosystems. Limited results are available for Atterberg limits in the Tennessee Valley. However, Gill and Reaves (1957) reported a water content of 18% at the PL and 31% at the LL (resulting in a PI of 13) on a surface horizon sample taken from a Decatur soil with 2.5% SOM.

Soil Water Retention

Soil water retention is dependent on soil texture, structure, and in the near surface, SOM content (Klute, 1986). Organic matter increases soil water retention by increasing aggregation and structure, which increases pore space (Klute, 1986; Kern, 1995). In addition, SOM directly holds water and can absorb many times its weight in water (Baldock and Nelson, 2000). Soils with greater SOM content typically have greater water content and reduced water loss by evaporation (Mielke et al., 1986), which allows the soil to remain at field capacity for longer durations (Hudson, 1994). Although SOM increases soil water holding capacity, it does not affect the rate that soils release water (De Jong et al., 1983). Soil Survey Investigation Staff (1995) estimates that 1 g SOC can roughly increase the water holding capacity by 1.5 and 3.5 g water at 1500 and 33 kPa, respectively.

Rationale

The Tennessee Valley of Alabama is an intensively cropped (> 50,000 harvested ha per year) region that is a primary producer of many row crops (Alabama Agricultural Experiment Station, 2010). Traditionally, agronomic systems in the Tennessee Valley have been cultivated using conventional tillage practices (Schwab et al., 2002). Over the last two decades, conservation practices utilizing reduced tillage with cover crops have increased. Transitioning from conventional to conservation systems affects SOC, a key component directly related to soil quality (Reeves, 1997). Timely information on C dynamics of prime farmland soils is essential from a management and policy standpoint. In addition, studies measuring the major C pools and sequestration as a result of management in common agroecosystems of this region are limited.

The soils of this area typically have finer-textured surface horizons (silt loam and silty clay loam) and relatively higher concentrations of free iron (Fe_d) compared to other southeastern U.S. Ultisols (Shaw et al., 2003). The inherent properties of these soils offer a somewhat unique pedological environment to study the effects of management-induced soil C sequestration and the subsequent effects of SOC on select soil chemical and physical properties, and ultimately, dynamic soil quality and function.

Therefore, the objectives of this study are to: 1) quantify and relate commonly measured SOC pools in long-term (≥15 years) conventional, conservation, and pasture systems in Tennessee Valley Paleudults; 2) calculate C sequestration rates over the last decade as a function of management; 3) assess differences in some chemical and physical soil properties as a function of agroecosystem (pasture, conventional row cropping, and conservation row cropping); 4) relate soil chemical and physical properties to SOM; and 5) qualify agroecosystems in terms of soil quality based on soil chemical and physical properties.

References

Alabama Agricultural Experiment Station. 2010. Alabama Agriculture and Forestry, Special Report No. 9. Available at: http:// www.aaes.auburn.edu/comm/pubs/. (Verified 27 Sep. 2011). Alabama Agricultural Experiment Station, Ag Communications & Marketing, Auburn, AL.

Amelung, W., K.W. Flach, and W. Zech. 1997. Climatic effects on soil organic matter composition in the Great Plains. Soil Sci. Soc. Am. J. 61:115-123.

Anderson, S.J., G. Sposito. 1992. Proton surface-charge density in soils with structural and pH-dependent charge. Soil Sci. Soc. Am. J. 56:1437-1443.

Arshad, M.A. and S. Martin. 2002. Identifying critical limits for soil quality indicators in agro-ecosystems. Agric. Ecosyst. Environ. 88:153-160.

Baldock, J.A. and P.N. Nelson. 2000. Soil Organic Matter. Section B p. 25-84. *In* Sumner, M.E. (ed.) Handbook of Soil Science. CRC Press LLC. Boca Raton, FL.

Balesdent, J., C. Chenu, and M. Balabane. 2000. Relationships of soil organic matter dynamics to physical protection and tillage. Soil Tillage Res. 53:215-230.

Balkum, K.S., D.W. Reeves, J.N. Shaw, C.H. Burmester, L.M. Curtis. 2006. Cotton yield and fiber quality from irrigated tillage systems in the Tennessee Valley. Agron. J. 98:596-602.

Bayer, C., J. Mielniczuk, L. Martin-Neto, and P.R. Ernani. 2002. Stocks and humification degree of organic matter fractions as affected by no-tillage on a subtropical soil. Plant Soil. 238:133-140.

Bayer, C., L. Martin-Neto, J. Mielniczuk, S.C. Saab, D.M.P. Milori, and V.S. Bagnato. 2002. Tillage and cropping system effects on soil humic acid characteristics as determined by electron spin resonance and fluorescence spectroscopies. Geoderma. 105:81-92.

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

Beare, M.H., M.L. Cabrera, P.F. Hendrix, and D.C. Coleman. 1994b. Aggregate-protected and unprotected organic matter pools in conventional- and no-tillage soils. Soil Sci. Soc. Am. J. 58:787-795.

Bell, M.J., P.W. Moody, R.D. Connolly, and B.J. Bridge. 1998. The role of active fractions of soil organic matter in physical and chemical fertility of Ferrosols. Aust. J. Soil Res. 36:809-819.

Bellini, G., M.E. Sumner, D.E. Radcliffe, and N.P. Qafoku. 1996. Anion transport through columns of highly weathered acid soil: adsorption and retardation. Soil Sci. Soc. Am. J. 60:132-137.

Blair, G.J., R.D. Lefroy, and L. Lisle. 1995. Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Aust. J. Soil Res. 46:1459-1466.

Blanco-Canqui, H., L.R. Stone, A.J. Schlegel, D.J. Lyon, M.F. Vigil, M.M. Mikha, P.W. Stahlman, and C.W. Rice. 2009. No-till induced increase in organic carbon reduces maximum bulk density of soils. Soil Sci. Soc. Am. J. 73:1871-1879.

Blanco-Canqui, H., R. Lal, W.M. Post, R.C. Izaurralade, and M.J. Shipitalo. 2006. Organic carbon influences on soil particle density and rheological properties. Soil Sci. Soc. Am. J. 70:1407-1414.

Bohn H.L., B.L. McNeal, and G.A. O'Connor. 1985. Soil Chemistry, 2nd ed. John Wiley and Sons, Inc. New York.

Brown, S.M., T. Whitwell, J.T. Touchton, and C.H. Burmester. 1985. Conservation tillage systems for cotton production. Soil Sci. Soc. Am. J. 49:1256-1260.

Bruce, R.R., G.W. Langdale, L.T. West, and W.P. Miller. 1995. Surface soil degradation and soil productivity restoration and maintenance. Soil Sci. Soc. Am. J. 59:654-660.

Burger, J.A. and D.L. Kelting. 1999. Using soil quality indicators to assess forest stand management. For. Ecol. Manage. 122:155-166.

Burke, I.C., C.M. Yonker, W.J. Parton, C.V. Cole, K. Flach, and D.S. Schimel. 1989. Texture, climate, and cultivation effects on soil organic matter content in U.S. grassland soils. Soil Sci. Soc. Am. J. 53:800-805.

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

Cambardella, C.A. and E.T. Elliott. 1993. Methods for physical separation and characterization of soil organic matter. Geoderma. 56:449-457.

Campbell, C.A., V.O. Biederbeck, B.G. McConkey, D. Curtin, and R.P., Zenter, 1999. Soil quality-effect of tillage and fallow frequency. Soil Biol. Biochem. 31:1-7.

Carter, M.R. 2002. Soil quality for sustainable land management: Organic matter and aggregation interactions that maintain soil functions. Agron. J. 94:38-47.

Causarano, H.J., A.J. Franzluebbers, J.N. Shaw, D.W. Reeves, R.L. Raper, and C.W. Wood. 2008. Soil organic carbon fractions and aggregation in the Southern Piedmont and Coastal Plain. Soil Sci. Soc. Am. J. 72:221-230.

Crozier, C.R., G.C. Naderman, M.R. Tucker, and R.E. Sugg. 1999. Nutrient and pH stratification with conventional and no-till management. Commun. Soil Sci. Plant Anal. 30:65-74.

De Jong, R., C.A. Campbell, and W. Nicholaichuk. 1983. Water retention equations and their relationship to soil organic matter and particle size distribution for disturbed samples. Can. J. Soil Sci. 63:291-302.

Dell, C.J. 2009. Potential for quantification of biologically active soil carbon with potassium permanganate. Comm. Soil Sci. Plant Anal. 40:1604-1609.

Ditzler, C.A. and A.J. Tugel. 2002. Soil quality field tools: Experiences of USDA-NRCS Soil Quality Institute. Agron. J. 94:33-38.

Doran, J.W. and M.R. Zeiss. Soil health and sustainability: managing the biotic component of soil quality. Appl. Soil Ecol. 15:3-11.

Doran, J.W., and T.B. Parkin. 1994. Defining and assessing soil quality. p. 3-21. *In* J.W. Doran et al., (ed.) Defining soil quality for a sustainable environment. SSSA Spec. Publ. No. 35, Soil Sci. Soc. Am., Inc. and Am. Soc. Agron., Inc., Madison, WI.

Doran, J.W. and Parkin, T.B. 1996. Quantitative indicators of soil quality: a minimum data set. p. 25–37. *In* Doran, J.W., Jones, A.J. (eds.), Methods for Assessing Soil Quality. Soil Science Society of America, Special Publication 49, Madison, WI.

Duiker, S.W. and D.B. Beegle. 2006. Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. Soil Tillage Res. 88:30-41.

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

Essington, M.E. 2004. Soil and Water Chemistry: An integrative Approach. CRC Press LLC. Boca Raton, FL.

Fernández Marcos, M.L., P. Buurman, and E.L. Meijer. 1998. Role of organic matter and sesquioxides on variable charge of three soils from Galicia, Spain. Commun. Soil Sci. Plant Anal. 29(15/16):2441-2457.

Follett, R.F. 2001. Soil management concepts and carbon sequestration zin cropland soils. Soil Tillage Res. 61:77-92.

Franzluebbers, A.J. 2002a. Soil organic matter ratio as an indicator of soil quality. Soil Tillage Res. 66:95-106.

Franzluebbers, A.J. 2002b. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil Tillage Res. 66:197-205

Franzluebbers, A.J. and F.M. Hons. 1996. Soil-profile distribution of primary and secondary plant-available nutrients under conventional and no tillage. Soil Tillage Res. 39:229-239.

Franzluebbers, A. J. and J.A. Stuedemann. 2002. Particulate and non-particulate fractions of soil organic carbon under pastures in the Southern Piedmont USA. Environ. Pollut. 116:S53-S62.

Franzluebbers, A.J., G.W. Langdale, and H.H. Schomberg. 1999. Soil carbon, nitrogen, and aggregation in response to type and frequency of tillage. Soil Sci. Soc. Am. J. 63:349-355.

Franzluebbers, A.J., R.L. Haney, C.W. Honeycutt, M.A. Arshad, H.H. Schomberg, and F.M. Hons. 2001. Climatic influences on active fractions of soil organic matter. Soil Biol. Biochem. 33:1103-1111.

Franzluebbers, A.J., R.L. Haney, F.M. Hons, and D.A. Zuberer. 1996. Active fractions of organic matter in soils with different texture. Soil Biol. Biochem. 28:1367-1372.

Gill, W.R. and C.A. Reaves. 1957. Relationships of Atterberg Limits and cation-exchange capacity to some physical properties of soils. Soil Science Society Proc. p. 491-494.

Gillman, G.P. 1979. A proposed method for the measuring of exchange properties of highly weathered soils. Aust. J. Soil Res. 17:129-139.

Gillman, G.P. 1985. Influence of organic matter and phosphate content on the point of zero charge of variable charge components in oxidic soils. Aust. J. Soil Res. 23:643-643.

Gillman, G.P. and M.E. Sumner. 1987. Surface charge characterization and soil solution composition of four soils from the southern piedmont in Georgia. Soil Sci. Soc. Am. J. 51:589-594.

Griffith, G.E., J.M. Omernik, and L.D. Clough. Ecoregions of Alabama and Georgia. 2008. *In* C. J. Cleveland (eds.). Encyclopedia of Earth. Available at: http://www.eoearth.org/article/Ecoregions_of_Alabama_and_Georgia_(EPA) (Verified 7 Jan. 2011). Environmental Information Coalition, National Council for Science and the Environment, Washington, D.C.

Grossman, R.B., D.S. Harms, C.A. Seybold, and J.E. Herrick. 2001. Coupling use-dependent and use-invariant data for soil quality evaluation in the United States. J. Soil Water Conserv. 56:63-68.

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

Hassink, J., L.A. Bouwman, K.B. Zwart, J. Bloem, and L. Brussaard. 1993. Relationships between soil texture, physical protection of organic matter, soil biota, and C and N mineralization in grassland soils. Geoderma. 57:105-128.

Helling, C.S., G. Chesters, and R.B. Corey. 1964. Contribution of organic matter and clay to soil cation-exchange capacity and affected by the pH of the saturating solution. Soil Sci. Soc. Proc. p.517-520.

Hendershot, W.H. and L.M. Lavkulich. 1983. Effect of sesquioxide coatings on surface charge of standard mineral and soil samples. Soil Sci. Soc. Am. J. 47:1252-1260.

Hendrix, P.F., A.J. Franzluebbers, and D.V. McCracken. 1998. Management effects on C accumulation and loss in soils of the southern piedmont of Georgia. Soil Tillage Res. 47:245-251

Herrick, J.E. 2000. Soil quality: an indicator of sustainable land management? Appl. Soil Ecol. 15:75-83.

Howard, D.D., M.E. Essington, and D.D. Tyler. 1999. Vertical phosphorus and potassium stratification in no-till cotton soils. Agron. J. 91:266-269.

Hudson, B.D. 1994. Soil organic matter and available water capacity. J. Soil Water Conserv. 49(2):189-194.

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

Jackson, M.L., C.H.Lim, and L.W. Zelazny. 1986. Oxides, hydroxides, and aluminosilicates. p. 113-119. *In* A. Klute (ed.). Methods of Soil Analysis, Part 2, 2nd Ed. Am. Sco. Agron. and Soil Sci. Soc. Am. Book No. 9. Madison, WI.

Jastrow, J.D. and Miller, R.M., 1998. Soil aggregate stabilization and carbon sequestration: feedbacks through organomineral associations. p. 207–223. *In* Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (eds.), Soil Processes and the Carbon Cycle. CRC Press, Boca Raton, FL

Jenny, H. 1941. Factors of soil formation. McGraw-Hill Book Co., Inc. New York.

Kaiser, K., K. Eusterhues, C. Rumpel, G. Guggenberger, and I. Kögel-Knabner. 2002. Stabilization of organic matter by soil minerals – investigations of density and particle-size fractions from two acid forest soils. J. Plant Nutr. Soil Sci. 165:451-459.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation (A guest editorial). Soil Sci. Soc. Am. J. 61:4-10.

Karlen, D.L., N.C. Wollenhaupt, D.C. Erbach, E.C. Berry, J.B. Swan, N.S. Eash, and J.L. Jordahl. 1994. Long-term tillage effects on soil quality. Soil Tillage Res. 32:313-327.

Kay, B.D. 1998. Soil structure and organic carbon: A review. p. 169-198. *In* Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (eds.), Soil Processes and the Carbon Cycle. CRC Press, Boca Raton, FL

Keeling, C.D., S.C. Piper, R.B. Bacastow, M. Wahlen, T.P. Whorf, M. Heimann, and H.A. Meijer. 2005. Atmospheric CO2 and 13CO2 exchange with the terrestrial biosphere and oceans from 1978 to 2000: observations and carbon cycle implications. p. 83-113. *In* J.R. Ehleringer, T.E. Cerling, and M.D. Dearing (eds.). A History of

Atmospheric CO2 and its effects on Plants, Animals, and Ecosystems. Springer, New York.

Kern, J.S. 1995. Evaluation of soil water retention models on basic soil physical properties. Soil Sci. Soc. Am. J. 59:1134-1141.

Klute, A. 1986. Water retention: Laboratory Methods. p. 635-662. *In* A. Klute (ed.) Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods, 2nd ed. Am. Sco. Agron. Soil Sci. Soc. Am. Book No. 9. Madison, WI.

Krull, E.S., J.A. Baldock, and J.O. Skjemstad. 2003. Importance of mechanisms and processes of the stabilization of soil organic matter for modeling carbon turnover. Functional Plant Biology. 30:207-222.

Lackner, K.S. 2003. A guide to CO2 sequestration. Science. 300:1677-1678.

Lal, R. 1993. Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. Soil Tillage Res. 27:1-8

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. Geoderma. 123:1-22.

Leirós, M.C., C. Trasar-Cepeda, S. Seoane, and F. Gil-Sotres. 1999. Dependence of mineralization of soil organic matter on temperature and moisture. Soil Biol. Biochem. 31:327-335.

Levi, M.R., J.N. Shaw, C.W. Wood, S.M. Hermann, E.A. Carter, and Y. Feng. 2009. Land management effects on near-surface soil properties of Southeastern U.S. Coastal Plain Kandiudults. Soil Sci. Soc. Am. J. 74:258-271.

Magdoff, F. and H. van Es. 2000. Building soils for better crops. Sustainable Agriculture Network. Handbook, Series No. 4. Beltsville, MA.

McBride, M.B. 1994. Environmental Chemistry of Soils. Oxford University Press, Inc. New York.

McBride, R.A. 2002. Atterberg Limits. P. 389-398. *In* J.H. Dane and G.C. Topp (eds.) Methods of Soil Analysis: Part 4 Physical Methods. Am. Sco. Agron. Soil Sci. Soc. Am. Book No. 5. Madison, WI.

McBride, R.A., D.W. Veenhof, G.C. Topp, Y.T. Galganov, and J.L.B. Culley. 1994. Assessing changes in soil physical properties. *In* D.F. Acton(ed.), A Program to Assess and Monitor Soil Quality in Canada. Soil Quality Evaluation Program Summary Report. Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Ottawa, Canada.

Mielke, L.N., J.W. Doran, and K.A. Richards. 1986. Physical environment near the surface of plowed and no-tilled soils. Soil Tillage Res. 7:355-366.

Mitchell, C.C. and S. Tu. 2006. Nutrient accumulation and movement from poultry litter. Soil Sci. Soc. Am. J. 70:2146-2153.

Motta, A.C.V., 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.

Motta, A.C.V., D.W. Reeves, C. Burmester, and Y. Feng. 2007. Conservation tillage, rotations, and cover crop affecting soil quality in the Tennessee Valley: Particulate organic matter, organic matter, and microbial biomass. Commun. Soil Sci. Plant Anal. 38:2831-2847.

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

Nimmo, J.R. and K.S. Perkins. 2002. Aggregate stability and size distribution. p. 317-328. *In* J.H. Dane and G.C. Topp (eds.), Methods of Soil Analysis: Part 4 Physical Methods. Am. Sco. Agron. Soil Sci. Soc. Am. Book No. 5. Madison, WI.

Norfleet, M.L., C.A. Ditzler, W.E. Puckett, R.B. Grossman, and J.N. Shaw. 2003. Soil quality and its relationship to pedology. Soil Sci. 168(3):149-155.

Odell, R.T., T.H. Thornburn, and L.J. McKenzie. 1960. Relationships of Atterberg Limits to some properties of Illinois soils. Soil Sci. Soc. Proc. p. 297–300.

Oades, J.M. 1984. Soil organic matter and structural stability: Mechanisms and implications for management. Plant and Soil. 76:319-337.

Oorts, K., B. Vanlauwe, and R. Merckx. 2003. Cation exchange capacities of soil organic matter fractions in a Ferric Lixisol with different organic matter inputs. Agric. Ecosys. Environ. 100:161-171.

Palm, C.A., R.J.K. Myers, and S.M. Nandwa. 1997. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. p. 193-219 *In* R.J. Buresh et al. Replenishing soil fertility in Africa. American Society of Agronomy and Soil Science Society of America. Madison, WI.

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima. 1987. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Sci. Soc. Am. J. 51:1173-1179.

Pocknee, S. and M.E. Sumner. 1997. Cation and nitrogen contents of organic matter determine its soil liming potential. Soil Sci. Soc. Am. J. 61:86-92.

Qafoku, N.P., M.E. Sumner, and D.E. Radcliffe. 2000. Anion transport in columns of variable charge subsoils: nitrate and chloride. J. Environ. Qual. 29:484-493.

Raper, R.L., Kirby, J.M. 2006. Soil compaction: how to do it, undo it, or avoid doing it. Distinguished Lecture Series. ASABE, St. Joseph, Michigan.

Raper, R.L., D.W. Reeves, E.B. Schwab, and C.H. Burmester. 2000. Reducing soil compaction of Tennessee Valley soils in conservation tillage systems. J. Cotton Sci. 4:84-90.

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

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas Jr. and P.E. Rasmussen. 1995. Soil organic matter changes resulting from tillage and biomass production. J. Soil Water Conserv. 50(3):253-259.

Richter, D.D. 2007. Humanity’s transformation of earth’s soil: Pedology’s new frontier. Soil Sci. 172(12):957-967.

Schoenholtz, S.H., H. Van Miegroet, and J.A. Burger. 2000. A review of chemical and physical properties as indicators of forest soil quality: Challenges and opportunities. For. Ecol. Manage. 138:335-265.

Schwab, E.B., D.W. Reeves, C.H. Burmester, and R.L. Raper. 2002. Conservation tillage systems for cotton in the Tennessee Valley. Soil Sci. Soc. Am. J. 66:569-577.

Scott, N.A., C.V. Cole, E.T. Elliott, and S.A. Huffman. 1996. Soil texture control on decomposition and soil organic matter dynamics. Soil Sci. Soc. Am. J. 60:1102-1109.

Seybold, C.A., J.E. Herrick, and J.J. Brejda. 1999. Soil resilience: A fundamental component of soil quality. Soil Sci. 164(4):224-234.

Shaw, J.N., D.W. Reeves, and C.C. Truman. 2003. Clay mineralogy and dispersibility of soil and sediment derived from Rhodic Paleudults. Soil Sci. 168(3):209-217.

Shaw, J.N., D.W. Reeves, C.C. Truman, and P.A. Mitchell. 2002. Management effects on clay dispersibility of a Rhodic Paleudult in the Tennessee Valley region, Alabama. p. 201-206. *In* E. van Santen (ed.) Making Conservation Tillage Conventional: Building a Future on 25 Years of Research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Special Report no. 1. Alabama Agric. Expt. Stn. And Auburn University, AL.

Six, J., C. Feller, K. Denef, S.M. Ogle, J.C. Moraes Sa, and A. Albrecht. 2002. Soil organic matter, biota and aggregation in temperate and tropical Soils – effects of no-tillage. Agronomie. 22:755-775.

Six, J., E.T. Elliott, K. Paustian, and J.W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Sci. Soc. Am. J. 62:1367-1377.

Six, J., K. Paustian, E.T. Elliott, and C. Combrink. 2000. Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate-associated carbon. Soil Sci. Soc. Am. J. 64:681-689.

Sleutel, S., S. De Neve, B. Singier, and G. Hofman. 2006. Organic C levels in intensively managed arable soils – long-term regional trends and characterization of fractions. Soil use Manage. 22:188-196.

Soil Survey Investigation Staff. 1995. Soil Survey Laboratory Information Manual. Soil Surv. Inv. Rep. 45. USDA-SCS, National Soil Survey Center, Lincoln, NE.

Soil Survey Investigation Staff. 2004. Soil survey laboratory methods manual. Soil Surv. Inv. Rep. 42. USDA-SCS, National Soil Survey Center, Lincoln, NE.

Soileau, J.M., B.F. Hajek, and J.T. Touchton. 1990. Soil erosion and deposition evidence in a small watershed using fallout cesium-137. Soil Sci. Soc. Am. J. 54:1712-1719.

Sposito G. 2000. Ion exchange phenomena. Section B p. 241-263. *In* Sumner, M.E. (ed.) Handbook of Soil Science. CRC Press LLC. Boca Raton, FL.

Stevenson, F.J. 1994. Humus chemistry. John Wiley and Sons, Inc. New York.

Sullivan, D.G., C.C. Truman, H.H. Schomberg, D.M. Endale, and D.H. Franklin, 2007, Potential impact of conservation tillage on conserving water resources in Georgia. J. Soil Water Cons. 62(3):145-152.

Sullivan, D.G., J.N. Shaw, and D. Rickman. 2005. IKONOS imagery to estimate surface soil property variability in two Alabama physiographies. 69(6):1789-1798.

Tan, K.H. and P.S. Dowling. 1984. Effect of organic matter on CEC due to permanent and variable charges in selected temperate region soils. Geoderma. 32:89-101.

Tan, Z.X., R. Lal, N.E. Smeck, and F.G. Calhoun. 2004. Relationships between surface soil organic carbon pool and site variables. Geoderma. 121:187-195.

Tennessee Valley Authority. 2003. Operations study, Appendix E. Prime farmland technical report. Available at: www.tva.gov/environment/reports. (Verified 1-21-2011). Knoxville, TN.

Tolbert, V.R., D.E. Todd Jr., L.K. Mann, C.M. Jawdy, D.A. Mays, R. Malik, W. Bandaranayake, A. Houston, D. Tyler, and D.E. Pettry. 2002. Changes in soil quality and below-ground carbon storage with conversion of traditional agricultural crop lands to bioenergy crop production. Environ. Pollut. 116:S97-S106.

Triol-Padre, A. and J.K. Ladha. 2004. Assessing the reliability of permanganate-oxidizable carbon as an index of soil labile carbon. Soil Sci. Soc. Am. J. 68:969-978.

Truman, C.C., D.W. Reeves, J.N. Shaw, A.C. Motta, C.H. Burmester, R.L. Raper, and E.B. Schwab. 2003. Tillage impacts on soil property, runoff, and soil loss variations from a Rhodic Paleudult under simulated rainfall. J. Soil Water Conserv. 58(5):258-267.

Truman, C.C., D.W. Reeves, J.N. Shaw, and C.H. Burmester. 2002. Soil management effects on interrill erodibility of two Alabama soils. P. 288-295. *In* E. van Santen (ed.) Making conservation tillage conventional: Building a future on 25 years of research. Proc. of 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Special Report no. 1. Alabama Agric. Expt. Stn. And Auburn University, AL.

Tugel, A.J., J.E. Herrick, J.R. Brown, M.J. Mausbach, W. Puckett, and K. Hipple. 2005. Soil change, soil survey, and natural resources decision making: A blueprint for action. Soil Sci. Soc. Am. J. 69:738-747.

Tugel, A.J., S.A. Wills, J.E. Herrick. 2008. Soil Change Guide: Procedures for Soil Survey and Resource Inventory, Version 1.1. USDA, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

U.S. Department of Agriculture, Natural Resources Conservation Service.2010. Technical Soil Services Handbook. Available at: http://soils.usda.gov/technical/tssh. (Verified 23 Jan. 2011). USDA-NRCS, Washington, DC.

Uehara, G. & G. Gillman. 1981. The Mineralogy, Chemistry, and Physics of Tropical Soils with Variable Charge Clays. Westview Press, Boulder, Co.

United States Departmaent of Agriculture - Natural Recourses Conservation Service. 2008. Conservation tillage practice guide, a guide to USDA-NRCS practice standards 329 No Till/Strip Till/Direct Seed and 345 Mulch Till. Available at http://www.pa.nrcs.usda.gov/technical/329_vs_345_eqmt_photos.pdf (verified 8 Jan. 2010). USDA-NRCS. Washington, DC.

United States Department of Agriculture, Natural Resource Conservation Service. 2006. Land resource regions and major land resource areas of the United States, the Caribbean, and the Pacific Basin. U.S Dept. of Agriculture Handbook 296.

United States Department of Agriculture. 1953. Soil Survey: Limestone County, Alabama. Series 1941. No. 5. Available at http://soils.usda.gov/survey/online_surveys/alabama/ (Verified 7 Jan. 2010). USDA-NRCS, Washington, DC.

United States Geological Survey Geologic Names Committee. 2007. Divisions of geologic time - Major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2007-3015.

Unites States Geological Survey. 1988. Geological Survey of Alabama. Available at http://ngmdb.usgs.gov/ngmdb/ngm_catalog.ora.html (Verified 7 Jan. 2010). U.S. Department of the Interior, U.S. Geological Survey, Reston, VA.

Unites States Geological Survey. 1988. Geological Survey of Alabama. Available at http://ngmdb.usgs.gov/ngmdb/ngm_catalog.ora.html (Verified 7 Jan. 2010). U.S. Department of the Interior, U.S. Geological Survey, Reston, VA.

USDA-NRCS National Water and Climate Center. 2002. WETS tables. Available at ftp://ftp.wcc.nrcs.usda.gov/support/climate/wetlands/al/ (Verified 4 Jan. 2010). USDA-NRCS NWCC, Portland, OR.

Van Ranst, E., J. Shamshuddin, G. Baert, and P.K. Dzwowa. 1998. Charge Characteristics in Relation to Free Iron and Organic Matter of Soils from Bambouto Mountains, Western Cameroon. E. J. of Soil Science. 49:243-252.

von Lützow, M., I. Kögel-Knabner, Ekschmitt, E. Matzner, G. Guggenberger. 2006. Stabilization of organic matter in temperate soils: Mechanisms and their relevance under different soil conditions – a review. E. J. Soil Sci. 57:426-445.

Wander, M. 2004. Soil Organic matter fractions and their relevance to soil function. p 67-102. *In* F. Magdoff and R.R. Weil (eds.), Soil organic matter in sustainable agriculture. CRC Press, Boca Raton, FL.

Weil, R.R., K.R. Islam, M.A. Stine, J.B. Gruver, and S.E. Samson-Liebig. 2003. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. Am. J. Alt. Agric. 18(1):3-17

Wood, C.W., J.H. Edwards, and C.G. Cummins. 1991. Tillage and crop rotation effects on soil organic matter in a Typic Hapludult of Northern Alabama. J. Sust. Agric. 2(2):31-41.

Wright. S.F., J.L. Starr, and I.C. Paltineanu. 1999. Changes in aggregate stability and concentration of glomalin during tillage management transitions. Soil Sci. Soc. Am. J. 63:1825-1829.

Zelazny, L.W., L. He, and A. Vanwormhoudt. 1996. Charge Analysis of Soils and Anion Exchange. P. 1231-1253. *In* D.L. Sparks (ed.), Methods of Soil Analysis: Part 3 Chemical Methods. Soil Sci. Soc. Am. Book No. 5. Madison, WI.

II. Agroecosystem Effects on Soil Organic Carbon Pools and Sequestration in Tennessee Valley (Alabama) Paleudults

Abstract

Increasing atmospheric carbon dioxide has increased interest in terrestrial carbon (C) sequestration as a function of agroecosystem. Agronomic management affects soil organic carbon (SOC) pools and soil C sequestration. The Tennessee Valley region of Alabama is intensively utilized for agronomic production and long-term conventional management has led to degradation of soil quality. However, conservation management has greatly increased over the last decade. The objectives of the study were to: 1) quantify and relate soil organic C (SOC) pools [SOC, particulate organic C (POC), and active organic C (AC)], and 2) calculate soil C sequestration rates in row crop agroecosystems over a ten-year duration. Soils in conventional cotton (*Gossypium hirsutum*), conservation (no-tillage) cotton, and grazed pasture agroecosystems were evaluated, and SOC, particulate organic carbon (POC), and active organic carbon (AC) were measured to a 50-cm depth in four depth increments. Carbon sequestration rates were calculated using a prior study conducted ten years earlier at the same site as a reference. Significant (α=0.05) differences were observed for SOC pools near-surface, but results were mixed with depth. Strong correlations existed among all SOC pools both near surface (0-5 cm) and when pooled across all depths. The labile pool of SOC (AC) comprised approximately 4% of SOC, and the intermediate pool (POC) comprised 53% of SOC. To a depth of 50-cm, the pasture system (73.1 Mg C ha^{-1}) and conservation row crop systems (51.3 Mg C ha^{-1}) sequestered 36 and 94% more SOC than conventional row crop systems (37.7 Mg C ha^{-1}), respectively. Conservation row crop systems that utilized winter wheat (*Triticum aestivum* L.) sequestered 16% more SOC than conservation row crop systems without winter cover crops. Soil C sequestration rates for conservation systems were on average 0.6 Mg ha^{-1} yr^{-1}, while conventional row crop systems were relatively static. This suggests that equilibrium in SOC storage has not been reached after 15 to 20 years in these conservation systems. Carbon sequestration rates and amounts were commensurate with other studies within the southeastern U.S. region. The SOC content at 30-50 cm ranged between 10.0 and 14.8 Mg ha^{-1} and contributed substantially (between 20 and 25%) to the total mass of C stored within the sampled depth (0-50 cm), indicating sampling to at least 0.5 m is vital to quantifying C storage in this region. Evaluation of stratification ratios indicated soil quality decreases with increasing soil disturbance.

Introduction

Atmospheric carbon dioxide (CO_2) concentrations have increased at a rate of 1.4 parts per million per year (ppm yr^{-1}) since the initiation of monitoring programs in the late 1950's (Forster et al., 2007). Currently, atmospheric carbon (C) levels are 390 ppm by volume (Keeling et al. 2005), and levels are projected to continue to rise into the next century (Solomon et al., 2009). Possible greenhouse effects associated with increasing CO_2 (and other gases) have driven researchers and policy makers to search for possible means to mitigate increasing CO_2. One approach for mitigation is terrestrial C sequestration, where agronomic soils are managed to sequester C through conservation practices (Follett, 2001; Lal, 2004). This strategy, coupled with a wealth of evidence of the role of SOC as an important component in maintaining soil quality of agroecosystems, warrants research dedicated to understanding relationships among agroecosystems, soil quality, SOC and soil C sequestration (Reeves, 1997).

The Tennessee Valley of Alabama is an intensively cropped (> 50,000 harvested ha) region that has historically been cropped to cotton using conventional tillage management (conventional cotton) (Alabama Agricultural Experiment Station, 2010). Over the last two decades, conservation practices utilizing reduced tillage with cover crops have increased in the region. Soils in this area offer a somewhat unique environment to study C sequestration and soil C pool dynamics due to their relatively finer surface horizon textures (silt loam and silty clay loam) and relatively higher oxide content in comparison to other heavily cultivated soils in Alabama (e.g., Coastal Plain soils) (Shaw et al., 2003).

Recognizing the importance of the region, several agronomic studies have been conducted in the Tennessee Valley (Schwab et al., 2002; Motta et al., 2007; Reiter et al., 2008 and others). At the same site of our study, Motta et al. (2007) found soil organic carbon (SOC) values ranged between 23.0 to 30.7 Mg ha^{-1} (0-24 cm) in 2000, with conservation row crop systems having 3.4 Mg ha^{-1} greater SOC than conventional row crop systems. Saniju et al. (2008a) reported between 37.4 to 43.7 Mg ha^{-1} SOC (0-20 cm) for conventional and conservation row crop systems under variable fertility management.

Soil C sequestration measurement requires that not only total amounts be measured, but also quantification of pools that represent portions of totals with different residence times (Six et al., 1998; Balesdent et al., 2000). Active soil organic carbon (AC) is a pool of SOC that is easily oxidized by potassium permanganate ($KMnO_4$), represents a measure of labile SOC, and has been shown to be indicative of soil quality (Weil et al., 2003). Studies quantifying AC have been conducted in other regions of the United States (US) as well as in other countries (Mirsky et al, 2008; DuPont et al., 2010; Spargo et al. 2011), but little investigation of AC has been done in southeastern U.S. Ultisols. Arriaga et al. (2009) found differences in AC among conservation row crop systems in Tennessee Valley Paleudults as a function of cover crop and irrigation. Other studies on agroecosystem effects on AC have reported mixed results (Mirsky et al., 2008; López-Garrido et al., 2011; Spargo et al., 2011).

Particulate organic carbon (POC) is an intermediately labile pool of SOC (Cambardella and Elliott, 1992; Cambardella and Elliott, 1993) that has been shown to be relatively sensitive to management practices (Wander, 2004). The POC pool often accounts for most of the increase in SOC following conservation system adoption (Causarano et al., 2008; Franzluebbers and Stuedemann, 2002). Motta et al. (2007) found POC represented 48% of SOC, which was concentrated near the soil surface of Tennessee Valley Paleudults. Other studies have reported similar values in other southeastern U.S. Ultisols (Beare et al., 1994; Franzluebbers and Stuedemann, 2002; Causarano et al., 2008).

Reported C sequestration rates in the southeastern U.S. range from 0.45 to 0.84 Mg C ha^{-1} yr^{-1} for conservation row crop and pasture systems, respectively (Franzluebbers, 2010). Evidence suggests Tennessee Valley Ultisols under conservation row crop systems may sequester considerably more (0.78 Mg C ha^{-1} yr^{-1}) than their southeastern U.S. counterparts (Causarano et al., 2006). In addition, total SOC estimates from past studies in the region are often reported relatively shallow depths (0-30 cm and shallower) (Franzluebbers, 2005; Causarano et al., 2006; Franzluebbers, 2010). Admittedly, most changes occur near-surface (<30 cm), but deeper sampling is sometimes warranted for more reliable total stock accounting, particularly when deep inversion tillage is employed or perennial forage systems are evaluated (Franzluebbers, 2010).

Traditionally, agronomic systems in the Tennessee Valley have been cultivated by conventional tillage practices (Schwab et al., 2002). However, many producers have transitioned to conservation agronomic systems within the last two decades. Transitioning from conventional to conservation systems affects SOC, a key component directly related to soil quality (Reeves, 1997). Considering the importance of this region from an agronomic production standpoint, timely information on C dynamics of prime farmland soils is essential from a management and policy standpoint. In addition, studies measuring carbon pools and sequestration rates in common agroecosystems, particularly pasture systems, are limited in this region and warrant further study. Therefore, the objectives of this study are to: 1) quantify and relate some commonly measured SOC pools in long-term (≥ 15 years) conventional, conservation, and pasture systems in Tennessee Valley Paleudults and 2) calculate C sequestration rates over the last decade as a function of management using data from 2000 (Motta et al., 2007) as a baseline.

Material and Methods

Site Characterization

The research site was located at the Tennessee Valley Research and Extension Center in Belle Mina, Alabama. In order to verify map unit and soil taxonomic placement of the research site, pedons were described, sampled and characterized within row crop and pasture plots (descriptions in Appendix). For laboratory characterization, samples were air dried, manually crushed, and passed through a 2-mm sieve. Soil organic matter (SOM) was removed using a 30% hydrogen peroxide solution, and soils were dispersed using a sodium metaphosphate / sodium carbonate solution prior to particle size analysis using the < 2-mm pipette method (Soil Survey Investigation Staff, 2004). Cation exchange capacity (CEC) and extractable bases [calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na)] were determined using the ammonium acetate (NH_4OAC) (pH 7) method (Soil Survey Investigation Staff, 2004). Extractable aluminum (Al) was determined using the 1.0 *M* potassium chloride (KCl) method and measured with inductively coupled plasma (ICP) spectrometry (Soil Survey Investigation Staff, 2004). Effective cation exchange capacity (ECEC) was determined by summing extractable Al and NH_4OAC (pH 7) extractable bases. Soil pH was determined 1:1 (w/v) with water and 1:2 (w/v) with 0.01 *M* calcium chloride ($CaCl_2$) (Soil Survey Investigation Staff, 2004).

Agroecosystems

The agroecosystem managements investigated included:

1) Conventional cotton (Conv Ct): Conventional tillage system with continuous cotton and no cover crop; established in 1979 (31 years).
2) No-till cotton, corn rotation (NT Ct-Crn): Conservation tillage system in a cotton-corn rotation with no cover crop; cotton planted even years, corn (Zea mays L.) planted odd years; established in 1995 (15 years).
3) No-till cotton, wheat cover crop (NT Ct w/C): Conservation tillage system with continuous cotton and a winter wheat (Triticum aestivum L.) cover crop; established in 1988 (22 years).
4) No-till cotton-wheat-soybean, rotation (NT Ct-W-Soy): Conservation tillage system in cotton, followed by harvested wheat crop, followed by soybean (Glycine max) rotation; established in 1995 (15 years).
5) No-till cotton (NT Ct): Conservation tillage system with continuous cotton and no cover crop; established in 1988 (22 years).
6) Pasture: Grazed grassland system with mixed tall fescue (Festuca arundinacea) and bermudagrass (Cynodon dactylon) (≥ 20 years, reseeded once in that time period).

Experimental Design

The selected agronomic sites, except for pasture sites, were part of an existing long-term experiment with systems as described above (see Motta et al., 2007). The experimental design is a randomized complete block design with four replications. Using GPS, measurements of plot dimensions from the existing experiment were superimposed on an aerial photograph of a pasture site located on the research station 2.4 km from the agronomic site. Soils were described and sampled on the pasture site to ensure same soil (taxonomically) as those found on the agronomic experiment described above. Once plots were established on the pasture sites, four plots were selected at random for sampling using the same procedures as the agronomic trial. Although pasture sites were not in exact same location as agronomic plots, attention was paid to superimposing the agronomic and pasture plots as accurately as possible.

Sample Collection and Laboratory Procedures

Composite samples were collected for the 0-5, 5-15, 15-30, and 30-50 cm depths. Each composite sample was comprised of 12 samples per repetition and was collected using a Giddings Hydraulic Probe (Giddings Machine Co., Inc., Fort Collins, CO, USA). Samples were air dried, manually crushed, and passed through a 2-mm sieve prior to analyses. For SOC and soil organic nitrogen (SON) analyses, samples were ground with a mortar and pestle and analyzed using dry combustion (Yeomans and Bremner, 1991). The POC and mineral associated carbon (MC) pools were separated following the wet sieving method of Cambardella and Elliot (1992), and C contents were determined by dry combustion (Yeomans and Bremner, 1991). Masses of each pool were calculated using the C concentrations, the bulk density, and the depth of the sample increment. Incremental masses were summed resulting in a mass of C for a given pool within a total depth of 50 cm.

Active carbon samples were collected at 0-5, 5-15, and 15-30 cm depths. The AC samples were taken from the composite sample, sealed in a plastic bag, and placed in cold storage until analysis (within 72 hours of sampling). After passing samples through a 2-mm sieve, AC was determined using the $KMnO_4$ technique outlined by Weil et al. (2003). The mass of AC was calculated to a depth of 30 cm (see above).

Three bulk density samples were taken per plot at 0-5, 5-15, 15-30, and 30-50 cm depths using the Giddings Hydraulic Probe and measured using the core method procedure outlined by Blake and Hartge (1986). Measurements represent averages within plots.

Data Analyses

Data were analyzed using analysis of variance by PROC GLIMMIX in $SAS^{®}$ (SAS Institute Inc., 2008) to compare agroecosystem main effects for all parameters by depth. Pearson correlation coefficients were calculated using $SAS^{®}$ PROC CORR (SAS Institute Inc., 2008) for the surface horizon (0-5 cm) and by pooling across all depths. Significance for all analysis was based on $\alpha = 0.05$.

In a previous study, Motta et al. (2007) collected samples in the same location during the year 2000. For their study, soil samples were incrementally tested for SOC, POC, and microbial biomass to 24-cm within five of the same systems (pasture not included). Using these data as a reference, computation of changes in SOC pools (SOC and POC) and sequestration rates over a decade was made. Results from Feng et al. (2003) at the same location were also used for comparison of SOC and SON in mutual conventional and conservation systems.

Results and Discussion

Site Characterization

A soil survey of the Tennessee Valley Experiment Station (Montgomery et al., 1984) indicated sites were located in a Decatur (fine, kaolinitic, thermic Rhodic Paleudults) silt loam, 0 to 2 percent slope, soil map unit. Pedon observations and laboratory characterization verified that Decatur soils were predominant at all sites. These Decatur map units are identified as prime farmland in the region.

Total Soil Organic Carbon and Nitrogen

Significant differences in SOC concentrations were found among agroecosystems (Table 1). Pasture systems had the highest SOC concentrations for all depths. The most profound differences in SOC concentrations were noted in the soil surface (0-5 cm), where conservation row crop and pasture systems ranged from 1.8 to 4.8x greater than the conventional row crop system. The SOC concentrations and variability among systems decreased with depth. Conventional row crop systems had the lowest SOC at all depths. At the deepest depth sampled (30-50 cm), the pasture was 34% higher in SOC concentration than no-till cotton and 56% higher than conventional row crop systems. At this depth the pasture had a significantly greater mass of SOC (14.6 Mg ha^{-1}) when compared to row crop systems (11.0 Mg ha^{-1}). These amounts constituted between 20 to 25% of the total C sequestered (data not shown). These data indicate the significance of sampling to deeper depths in similar circumstances.

Generally, SOC concentrations are consistent with those reported by Motta et al. (2007) at the same location. However, conservation row crop systems that utilize winter wheat were greater than concentrations found in the year 2000 study. These differences are likely due to the effects of cover crop management over the last decade, and the fact these systems had not reached equilibrium with regard to SOC in 2000. The cotton-corn rotation and cotton-wheat-soybean rotation had only been established five years in 2000, while the no-till cotton and no-till cotton with wheat cover crop had been established 12 years.

On a mass basis, SOC (0-50 cm) was affected by management (Figure 1). The mass of SOC found in conservation and pasture systems ranged between 1.2 to 1.9x higher than conventional row crop systems. Conservation row crop systems averaged 13.6 Mg C ha^{-1} more than conventional cotton systems (51.3 versus 37.7 Mg C ha^{-1}, respectively). The pasture system, which had the highest mass of SOC, contained 73.1 Mg C ha^{-1}. This is 43 and 94% greater than conservation and conventional row crop systems, respectively (Figure 1).

We found higher masses of sequestered C (0-50 cm) compared to other studies in this region. In part, due to greater sampling depths in this compared with other studies. Motta et al. (2007) reported 23.0 Mg ha^{-1} SOC in conventional row crop systems and a range between 26.3 to 30.7 Mg C ha^{-1} for conservation row crop systems (0-24 cm). Saniju et al. (2008a) reported between 37.4 and 43.7 Mg C ha^{-1} for conventional row crop systems, and 40.1 to 43.7 Mg C ha^{-1} for conservation row crop systems (0-20 cm). From data compiled by Franzluebbers (2010), row crop systems in southeastern U.S. Ultisols typically sequester 25.6 (0-20 cm) and 30.2 Mg C ha^{-1} (0-30 cm) in conventional and conservation row crop systems, respectively. Our data for the pasture system was between 10 and 57% greater than that reported by Franzluebbers and Stuedemann (2009), who reported between 46.6 and 66.3 Mg C ha^{-1} (0-60 cm) for southeastern U.S. Piedmont Ultisols.

Differences in SON concentrations among agroecosystem were observed at the 0-5, 5-15, and 15-30 cm depths (Table 1). At the surface (0-5 cm), the pasture and conservation row crop systems that utilized winter wheat had the highest concentration of SON. These results largely agree with Feng et al. (2003) (same location as current study) and other studies in southeastern U.S. Ultisols (Beare et al., 1994). The SON pool was strongly correlated ($r \geq 0.90$) with SOC pools both near surface (0-5 cm) and across all depths (Table 2). Correlation was expected, given the relationship between SOC and nitrogen (N) (Schnitzer, 1991).

On a total mass basis, SON (0-50 cm) was greatest in the pasture and conservation cotton with a wheat cover crop (Figure 1). Conservation row-crop and pasture systems were 28 and 56% greater than conventional row crop systems, respectively. The other sampled conservation row crop systems were statistically similar but greater than conventional row crop systems (Figure 1). The SON in these agroecosystems was greater than much of the relevant literature, which again is largely attributed to depth of sampling (mass of SON in the 30-50 cm depth contributed substantially to the total mass from 0-50 cm). Results ranged between 88 and 93% greater than Sainju et al. (2008a), who reported SON (0-20 cm) ranging between 3.1 to 4.1 Mg N ha^{-1} for both conservation and conventional row crop systems on Decatur soils in the Tennessee Valley. Franzluebbers and Stuedemann (2009) reported between 4.1 to 5.8 Mg N ha^{-1} for SON (0-60 cm) in pasture systems of southeastern US Piedmont Ultisols, which is between 62 and 129% lower than results from our study.

Differences in C:N ratios were detected both near surface (0-5 cm) and at 30-50 cm depth (Table 1). Ratios ranged between 9:1 and 10:1 at the surface (0-5 cm) and 4:1 and 8:1 at lower depths. Conservation and pasture systems had a greater C:N ratio than conventional systems. Results for conventional and no-till cotton systems agree with those calculated from data published by Feng et al.(2003), suggesting minimal differences in this ratio for these selected systems over the past decade (other systems were not included for comparison). Literature suggests typical near-surface C:N ratios range between 10:1 to14:1 in the Tennessee Valley and other highly weathered soils under row crop systems (Freixo et al., 2002; Feng et al., 2003; Reiter et al., 2008).

Active Carbon

Significant differences were found among AC concentrations at all depths (Table 1). The pasture had the greatest AC concentration at all depths, but significant differences from row crop agroecosystems occurred only in the upper two depths (0-5 and 5-15 cm). Conventional row crop systems had the lowest AC concentrations at 0-5 and 15-30 cm depths. Conservation row crop systems were generally intermediate in AC concentration between pasture and conventional row crop agroecosystems. However, at the surface (0-5 cm), AC concentrations from conservation row crop systems without a winter wheat crop did not differ from the conventional row crop system. At the surface, AC increased 2.0 to 2.5x from conventional to conservation row crop systems with cover crops, and 4.5x from conventional row crop to pasture systems.

Generally, AC concentrations in this study were greater than much of the published research. Arriaga et al. (2009) reported AC concentrations between 407 and

509 mg kg^{-1} (0-10 cm) in irrigated and non-irrigated conservation cotton systems in the Tennessee Valley. Mirsky et al. (2008) found between 521 and 547 mg kg^{-1} (0-15 cm) AC under corn cultivation using various management practices in Pennsylvania Alfisols. Spargo et al. (2011) reported between 419 and 483 mg kg^{-1} (0-20 cm) AC in corn and soybean cultivation under several management practices in Maryland Ultisols. Differences in concentrations are largely attributed to differences in near-surface sampling depths. However, these data are within values reported by Stiles et al. (2011) in a nationwide assessment of AC under a variety of cultivated and natural environments.

The AC ranged from 2 to 5% of SOC (data not shown), and differences in this percentage among agroecosystems were minimal. Significant correlation ($r \geq 0.89$) existed among AC and other SOC pools at 0-5 cm and when pooled across all depths ($r \geq 0.91$) (Table 2). This agrees with other authors that this pool is partially contained within several SOC pools (e.g., microbial biomass, carbohydrates, and POC) (Weil et al., 2003; Tirol-Padre and Ladha, 2004).

Differences in total AC (0-30 cm) were detected among agroecosystems (Figure 2a). The greatest AC was found in pasture systems, which were twice that of conventional row crop systems (2.0 and 1.0 Mg AC ha^{-1}, respectively). The AC in no-till cotton (without cover crops) systems was similar to conventional row crop systems, while other conservation row crop systems that either had corn in the rotation or utilized winter wheat had between 43 and 67% greater AC than conventional row crop systems. Average AC (0-30 cm) in conservation row crop systems were 0.4 Mg AC ha^{-1} greater than conventional row crop systems.

Particulate and Mineral Associated Organic Carbon

Differences in POC and MC concentrations generally followed SOC trends, especially near surface (0-5 cm) (Table 1). At the 0-5 cm depth, the pasture had the highest POC and MC concentrations followed by conservation row crop systems with winter wheat, conservations systems without a winter cover, and conventional row crop systems. With depth (5-15 and 15 to 30 cm), POC and MC content were highest in the pasture system. Percentage of POC and MC in SOC ranged from 44 to 57% in pasture and conservation row crop systems, but interestingly, the POC was 38% and MC was 66% of SOC in the conventional row crop system. This may be indicative of more recalcitrant SOM in in conventional system as a result of intensive tillage management practices.

Near-surface (0-5 cm) concentrations of POC for row crop systems (ranging between 3.4 and 12.2 g kg^{-1}) largely agree with other values reported for the Tennessee Valley and the southeastern U.S. (Causarano et al. 2008; Motta et al., 2007). Pasture POC concentrations (21.3 g kg^{-1}) were also within values reported for pasture systems in southeastern US Piedmont Ultisols (Franzluebbers et al., 2000). Studies have demonstrated that between 42 to 57% of SOC may be attributed to POC (Franzluebbers and Stuedemann, 2002; Causarano et al. 2008). Our results indicate a similar value (53%) of SOC is POC in these soil systems ($POC = -1.87 + 0.53\ SOC$; $R^2 = 0.94$, $n = 96$), when pooled across all agroecosystems and depths. Significant correlation ($r \geq 0.89$) among POC and MC and other pools of SOC (SOC and AC) exist at 0-5 cm and when pooled across all depths (Table 2). Other authors have reported similar relationships (Beare et al., 1994; Causarano et al. 2008).

The pasture system and conservation row crop systems with winter wheat had the greatest total POC (0-50 cm) (Figure 2b). Conservation row crop and pastures systems had 5.8 and 14.0 Mg ha^{-1}more POC and 7.4 and 21.8 Mg ha^{-1} more MC than conventional row crop systems, respectively (Figure 2c). Results agree with Saniju et al. (2008b), who found an average POC (0-20 cm) content of 11 Mg ha^{-1} for conventional and conservation row crop systems. However, direct comparisons are confounded by differences in sampling depth. For the pasture, our results were 1.7 to 3.2x greater than Franzluebbers et al. (2000) for pasture systems in Piedmont Ultisols, which again is somewhat due to greater sampling depth.

Stratification Ratios

Stratification ratios, a proposed measure of soil quality, are the ratio of SOC pool concentrations between surface and subsurface depths (e.g., 0-5:30-30 cm) (Franzluebbers, 2002). Stratification ratios for SOC and SON had similar trends; the pasture had the greatest ratio (9.9 and 5.3, respectively), followed by conservation row crop systems that utilize winter wheat (6.4 and 2.8, respectively), conservation row crop systems that do not use cover crops (4.4 and 2.2, respectively), and conventional row crop systems (2.7 and 1.4, respectively) (Figure 3). The pasture was the only system that differed from other agroecosystems, and it was the most highly stratified agroecosystem for AC (9.5). Stratification ratios for POC did not differ significantly among agroecosystems, although the mean POC ratios for the agroecosystems followed a similar trend as ratios from other organic pools. Stratification ratios for MC followed a similar pattern as SOC, with the pasture having the greatest stratification ratio (5.2) followed by conservation row crop systems that use winter wheat (3.5), conservation row crop systems that do not use cover crops (2.8), and the conventional row crop system (2.0).

Stratification ratios are dependent on the calculation depths. Using shallower depths (e.g., 0-5:5-15 or 0-5:15-30 cm) to calculate SOC and AC stratification ratios for comparison sakes illustrates the conventional row crop system has disturbed soil characteristics (stratification ratio < 2 as per Franzluebbers, 2002). The MC stratification ratios calculated in this manner in row crop systems that do not use cover crops also suggest disturbed soil conditions (Franzluebbers, 2002).

Soil Carbon Sequestration

Changes in SOC (0-24 cm Mg ha^{-1}) and rates of sequestration for the row crop systems were calculated for a ten-year period (2000 to 2010) using results published by Motta et al. (2007) for the same sites as a reference. There was no change in SOC under conventional row crop systems during this period, while conservation row crop systems sequestered an average of 0.6 Mg C ha^{-1} yr^{-1} over the same ten-year period. Conservation row crop systems that did not incorporate winter wheat sequestered on average 0.3 Mg C ha^{-1} yr^{-1} compared to 0.9 Mg C ha^{-1} yr^{-1} for systems that utilized wheat (either for cover or harvest) (Table 3). In addition, the continuous cotton conservation system without a cover crop sequestered the least over this period (0.2 Mg C ha^{-1} yr^{-1}). Data compiled by Causarano et al. (2006) suggest that it is possible for soils in conservation row crop systems in the Tennessee Valley to sequester amounts up to 0.78 Mg C ha^{-1} yr^{-1}. Conservation row crop systems that utilized winter wheat met or exceeded this rate, which is in agreement with Causarano et al. (2006) that inclusions of small grains and cover crops increase C sequestration. Sequestration rates for conservation row crop system that did not use cover crops were similar to C sequestration rates from other studies in the Tennessee Valley and southeastern U.S. (Causarano et al., 2006; Sainju et al., 2008a; Franzluebbers, 2010).

Lack of change in the conventional system suggests these agroecosystems reached equilibrium prior to the year 2000 sampling (approximately 20 years of establishment). Conservation systems that do not incorporate winter wheat may be approaching equilibrium, which is illustrated by lower C sequestration rates. Conservation systems that incorporate winter wheat continue to sequester substantial amounts of C (at least 15 years of establishment). This is consistent with literature that suggests that in some environments, mature conservation row crop systems (reduced tillage) may reach equilibrium, while those that incorporate cover crops and rotation diversity may continue to sequester C for the next several decades (West and Post, 2002). Conservation row crop systems in these soils may continue to be a viable means to sequester C for decades to come.

Conclusions

Generally, the pasture had the greatest amount of all SOC pools followed by conservation row crop systems that use winter wheat, conservation row crop systems without cover crops, and conventional row crop systems. As expected, the most profound differences in SOC pools were observed near surface (0-5 cm). However, significant differences were observed with depth for some SOC pools. A majority (53%) of SOC can be attributed to POC, and all SOC pools were strongly correlated with each other.

Evaluation of SOC, AC, and stratification ratios indicate soil quality decreases with increasing soil disturbance.

Total sequestered C amounts for reported agroecosystems (0-50 cm) were generally greater than quantities reported for the Tennessee Valley and southeastern U.S. regions. The pasture had 51% more than row crop systems, illustrating their potential for C sequestration. The significant amount of SOC in the 30-50 cm depth increment (ranging between 10.0 and 14.8 Mg ha^{-1}), which comprises between 20 and 25% of the 0-50 cm mass, suggests sampling to at least a 50-cm depth is warranted in soil systems in this region. Over the last decade, conservation row crop systems sequestered an average of 0.6 Mg C ha^{-1} yr^{-1}, whereas conventional row crop systems had essentially stabilized by year 2000 with no net change in SOC over the last decade. Conservation row crop systems that incorporated winter wheat sequestered more (0.9 Mg ha^{-1} yr^{-1}) than those that did not (0.3 Mg ha^{-1} yr^{-1}). Although not definitive, collectively these data suggest that equilibrium in SOC storage has not been reached after 15 to 20 years in these conservation systems. Considering the current demand for terrestrial C sequestration in agricultural settings, Tennessee Valley region soils under pasture and conservation row crop systems that utilize cover cropping can significantly contribute to soil C sequestration.

References

Alabama Agricultural Experiment Station. 2010. Alabama Agriculture and Forestry, Special Report No. 9. Available at: http:// www.aaes.auburn.edu/comm/pubs/. (Verified 27 Sep. 2011). Alabama Agricultural Experiment Station, Ag Communications & Marketing, Auburn, AL.

Arriaga, J.S.S., J.N. Shaw, J.P. Fulton, and R.L. Raper. 2009. Cotton conservation system and irrigation effects on soil carbon pools of Tennessee Valley (Alabama) Paleudults. ASA-CSA-SSSA International Annual Meeting. Nov. 3, 2009. Pittsburg, PA.

Balesdent, J., C. Chenu, and M. Balabane. 2000. Relationships of soil organic matter dynamics to physical protection and tillage. Soil Tillage Res. 53:215-230.

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

Blake, G.R. and K.H. Hartge. 1986. Bulk density p. 363-375. *In* A. Klute (ed.). Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods, 2nd ed. Am. Soc. Agron. and Soil Sci. Soc. Am. Book No. 9. Madison, WI.

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

Cambardella, C.A. and E.T. Elliott. 1993. Methods for physical separation and characterization of soil organic matter. Geoderma. 56:449-457.

Causarano, H.J., A.J. Franzluebbers, D.W. Reeves, and J.N. Shaw. 2006. Soil organic carbon sequestration in cotton production systems of the southeastern United States: A review. J. Environ. Qual. 35:1374-1383.

Causarano, H.J., A.J. Franzluebbers, J.N. Shaw, D.W. Reeves, R.L. Raper, and C.W. Wood. 2008. Soil organic carbon fractions and aggregation in the Southern Piedmont and Coastal Plain. Soil Sci. Soc. Am. J. 72:221-230.

DuPont, S.T., S.W. Culman, H. Ferris, D.H. Buckley, and J.D. Glover. 2010. No-tillage conversion of harvested perennial grassland to annual cropland reduces root biomass, decreases active carbon stocks, and impacts soil biota. Agric. Ecosyst. Eviron. 137:25-32.

Feng, Y., A.C. Motta, D.W. Reeves, C.H. Burmester, E. van Santen, and J.A. Osborne. 2003. Soil microbial communities under conventional-till and no-till continuous cotton systems. Soil Biol. Biochem. 35:1693-1703.

Follett, R.F. 2001. Soil management concepts and carbon sequestration zin cropland soils. Soil Tillage Res. 61:77-92.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland. 2007. Changes in atmospheric constituents and in radioactive forcing. *In* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.). Climate Change. The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. New York.

Franzluebbers, A.J. 2002. Soil organic matter ratio as an indicator of soil quality. Soil Tillage Res. 66:95-106.

Franzluebbers, A.J. 2005. Soil organic carbon sequestration and agricultural greenhouse gas emissions in the southeastern USA. Soil Tillage Res. 83:120-147.

Franzluebbers, A. J. 2010. Achieving soil organic carbon sequestration with conservation agricultural systems in the Southeastern United States. Soil Sci. Soc. Am. J. 74(2):347-357.

Franzluebbers, A. J. and J.A. Stuedemann. 2002. Particulate and non-particulate fractions of soil organic carbon under pastures in the Southern Piedmont USA. Environ. Pollut. 116:S53-S62.

Franzluebbers, A. J. and J.A. Stuedemann. 2009. Soil-profile organic carbon and total nitrogen during 12 years of pasture management in the Southern Piedmont USA. Agric. Ecosyst. Eviron. 129:28-36.

Franzluebbers, A. J., J.A. Stuedemann, and S.R. Wilkinson. 2001. Bermudagrass management in the Southern Piedmont USA: I. Soil and surface residue carbon and sulfur. Soil Sci. Soc. Am. J. 65:834–841.

Franzluebbers, A.J., J.A. Stuedemann, H.H. Schomberg, S.R. Wilkinson. 2000. Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA. Soil Biol. Biochem. 32:469-478.

Freixo, A.A., P.L.O.A. de Machado, H.P. dos Santos, C.A. Silva and F.S. de Fadigas. 2002. Soil organic carbon and fractions of a Rhodic Ferrasol under the influence of tillage and crop rotation systems in southern Brazil. Soil Tillage. Res. 64:221-230.

Keeling, C.D., S.C. Piper, R.B. Bacastow, M. Wahlen, T.P. Whorf, M. Heimann, and H.A. Meijer. 2005. Atmospheric CO2 and 13CO2 exchange with the terrestrial biosphere and oceans from 1978 to 2000: observations and carbon cycle implications. p. 83-113. *In* J.R. Ehleringer, T.E. Cerling, and M.D. Dearing (eds.). A History of Atmospheric CO2 and its effects on Plants, Animals, and Ecosystems. Springer Verlag, New York.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. Geoderma. 123:1-22.

López-Garrido, R., E. Madejón, J. M. Murillo,and F. Moreno. 2011. Short and long-term distribution with depth of soil organic carbon and nutrients under traditional and conservation tillage in a Mediterranean environment (southwest Spain). Soil Use Manage. 27:177-185.

Mirsky, S.B., L.E. Lanyon, and B.A Needelman. 2008. Evaluating soil management using particulate and chemically labile soil organic matter fractions. Soil Sci. Soc. Am. J. 72:180-185.

Montgomery, C.F., G.W. Hurt, and B.F. Hajek. 1984. Soil survey of the Tennessee Substation Belle Mina, Alabama. Agronomy and Soils Dept., Auburn Univ., Series No. 93. Auburn, AL.

Motta, A.C.V., D.W. Reeves, C. Burmester, and Y. Feng. 2007. Conservation tillage, rotations, and cover crop affecting soil quality in the Tennessee Valley: Particulate organic matter, organic matter, and microbial biomass. Commun. Soil Sci. Plant Anal. 38:2831-2847.

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

Reiter, M.S., D.W. Reeves, C.H. Burmester, and H.A. Torbert. 2008. Cotton nitrogen management in a high-residue conservation system: cover crop fertilization. Soil Sci. Soc. Am. J. 72(5):1321-1329.

Sainju, U.M., Z.N. Senwo, E.Z. Nyakatawa, I.A. Tazisong, and K.C. Reddy. 2008a. Soil carbon and nitrogen sequestration as affected by long-term tillage, cropping systems, and nitrogen fertilizer sources. Agric. Ecosyst. Eviron. 127:234-240.

Sainju, U.M., Z.N. Senwo, E.Z. Nyakatawa, I.A. Tazisong, and K.C. Reddy. 2008b. Tillage, cropping systems, and nitrogen fertilizer source effects on soil carbon sequestration and fractions. J. Environ. Qual. 880-888.

SAS Institute Inc. 2008. SAS/STAT® 9.2 User's Guide. SAS Institute Inc. Cary, NC.

Schnitzer, M. 1991. Soil organic matter - the next 75 years. Soil Sci. 151:41-58.

Schwab, E.B., D.W. Reeves, C.H. Burmester, and R.L. Raper. 2002. Conservation tillage systems for cotton in the Tennessee Valley. Soil Sci. Soc. Am. J. 66:569-577.

Shaw, J.N., D.W. Reeves, and C.C. Truman. 2003. Clay mineralogy and dispersibility of soil and sediment derived from Rhodic Paleudults. Soil Sci. 168(3):209-217.

Six, J., E.T. Elliott, K. Paustian, and J.W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Sci. Soc. Am. J. 62:1367-1377.

Soil Survey Investigation Staff. 2004. Soil survey laboratory methods manual. Soil Surv. Inv. Rep. 42. USDA-SCS, National Soil Survey Center, Lincoln, NE.

Solomon, S., G.K. Plattner, R. Knuttic, and P. Friedlingstein. 2009. Irreversible climate change due to carbon dioxide emissions. Proc. Natl. Acad. Sci. USA. 106:1704-1709.

Spargo, J.T., M.A. Cavigelli, S.B. Mirsky, J.E. Maul, and J.J. Meisinger. 2011. Mineralizable soil nitrogen and labile soil organic matter in diverse long-term cropping systems. Nutr. Cycl. Agroecosyst. 90:253–266.

Stiles, C.A., R.D. Hammer, M.G. Johnson, R. Ferguson, J. Galbraith, T. O'Geen, J. Arriaga, J. Shaw, A. Falen, P. McDaniel, and R. Miles. 2011. Validation testing of a portable kit for measuring an active carbon fraction. Soil Sci. Soc. Am. J. 75:1-11.

Tirol-Padre, A. and J.K. Ladha. 2004. Assessing the reliability of permanganate-oxidizable carbon as an index of soil labile carbon. Soil Sci. Soc. Am. J. 68:969-978.

Wander, M. 2004. Soil Organic matter fractions and their relevance to soil function p 67-102. *In* F. Magdoff and R.R. Weil (eds.), Soil organic matter in sustainable agriculture. CRC Press, Boca Raton, FL.

Weil, R.R., K.R. Islam, M.A. Stine, J.B. Gruver, and S.E. Samson-Liebig. 2003. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. Am. J. Alt. Agric. 18(1):3-17

West, T.O. and W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. Soil Sci. Soc. Am. J. 66:1930–1946.

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.

Tables

Table 1. Soil carbon and nitrogen pools for Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under six agroecosystems in the Tennessee Valley region of Alabama. Letters represent simple effects of agroecosystem. Values with different letters are significantly different at α = 0.05.

Agroecosystem†	SOC‡	SON	C:N	AC	POC	MC
	------- g kg^{-1} ------		g g^{-1}	mg kg^{-1}	------- g kg^{-1} -------	
			0 – 5 cm			
Conv Ct	8.9 D	1.0 D	8.8 C	389 C	3.4 D	5.9 D
NT Ct-Crn	16.3 C	1.7 C	9.5 B	683 BC	7.8 C	8.9 C
NT Ct-W-Soy	22.1 B	2.3 B	9.7 AB	986 B	11.1 B	11.2 B
NT Ct w/C	25.7 B	2.5 B	10.3 A	791 B	12.2 B	11.5 B
NT Ct	16.3 C	1.7 C	9.7 B	661 BC	7.1 C	9.3 C
Pasture	43.2 A	4.3 A	10.0 AB	1761 A	21.3 A	20.3 A
ANOVA	-------------------------------------		P > F	--		
Agroecosystem (A)	<0.0001	<0.0001	0.0004	<0.0001	<0.0001	<0.0001
			5 – 15 cm			
Conv Ct	7.2 C	0.9 C	8.1	329 B	1.6 B	5.6 B
NT Ct-Crn	7.5 C	1.0 BC	7.8	318 B	1.9 B	5.6 B
NT Ct-W-Soy	9.0 B	1.1 B	8.1	355 B	2.4 B	6.7 B
NT Ct w/C	9.1 B	1.1 B	8.3	338 B	2.5 B	6.7 B
NT Ct	7.6 BC	1.0 BC	7.5	270 B	1.5 B	6.2 B
Pasture	15.0 A	1.8 A	8.1	533 A	4.4 A	10.7 A
ANOVA	-------------------------------------		P > F	--		
(A)	<0.0001	<0.0001	0.0876	0.0005	0.0023	0.0004
			15 – 30 cm			
Conv Ct	5.1 C	0.8 B	6.5	122 B	0.8	4.3 B
NT Ct-Crn	5.5 BC	0.8 B	6.8	176 A	0.9	4.6 B
NT Ct-W-Soy	6.0 B	0.9 B	7.1	191 A	0.9	5.2 B
NT Ct w/C	6.2 B	1.3 A	6.0	164 A	1.2	5.1 B
NT Ct	6.0 B	0.9 B	6.9	173 A	0.9	5.2 B
Pasture	7.3 A	1.0 AB	7.0	199 A	1.3	6.9 A
ANOVA	-------------------------------------		P > F	--		
(A)	<0.0001	0.0226	0.3588	0.0087	0.1654	0.0049
			30 – 50 cm			
Conv Ct	3.3 B	0.7	4.4 B	-	0.3	3.0
NT Ct-Crn	3.6 B	0.8	4.6 B	-	0.5	3.2
NT Ct-W-Soy	3.8 B	0.8	4.7 B	-	0.6	3.3
NT Ct w/C	3.7 B	0.9	4.2 B	-	0.5	3.3
NT Ct	3.8 B	0.8	4.7 B	-	0.5	3.4
Pasture	5.1 A	0.8	6.0 A	-	0.8	4.4
ANOVA	-------------------------------------		P > F	--		
(A)	0.0113	0.0909	0.0173	-	0.2167	0.3181

†Conv Ct = conventional tillage cotton; NT Ct-Crn = no-till cotton-corn; NT Ct-W-Soy = no-till cotton-wheat-soybean; NT Ct w/C = no-till cotton with wheat cover crop; NT Ct = no-till cotton; Pasture = grazed pasture.

‡ SOC = soil organic carbon; SON = soil organic nitrogen; C:N = soil carbon to nitrogen ratio; POC = particulate (> 53 µm) organic carbon; MC = mineral associated (< 53 µm) carbon; AC = active soil organic carbon.

Table 2. Pearson linear correlation coefficients relating soil organic carbon pools for six combined agroecosystems for the surface (0-5 cm) and pooled across all depths (0-5, 5-15, 15-30 and 30-50 cm) for Tennessee Valley Paleudults.

Surface (0-5 cm)					
†	SOC	SON	AC	POC	MC
SOC	-				
SON	0.99*	-			
AC	0.90*	0.90*	-		
POC	0.95*	0.94*	0.89*	-	
MC	0.98*	0.98*	0.89*	0.92*	-
Pooled Across all Depths					
	SOC	sON	AC	POC	MC
SOC	-				
SON	0.96*	-			
AC	0.95*	0.91*	-		
POC	0.97*	0.93*	0.94*	-	
MC	0.97*	0.93*	0.91*	0. 91*	-

† SOC = soil organic carbon (g kg^{-1}); SON = soil organic nitrogen (g kg^{-1}); AC = active soil organic carbon (mg kg^{-1}); POC = particulate (>53 μm) organic carbon (g kg^{-1}); MC = mineral (< 53 μm) associated carbon (g kg^{-1}).

* Significant correlation at α = 0.05

Table 3. Annual carbon sequestration rates averaged over the last decade calculated from 2000 (Motta et al., 2007) and 2010 (current study) data for common agroecosystems in the Tennessee Valley region of Alabama.

Agroecosystem†	SOC_{2000}‡	SOC_{2010}	Agroecosystem Duration by 2010	Carbon Sequestration
	---- Mg ha^{-1} ----		yr	Mg ha^{-1} yr^{-1}
Conv Ct	23.0	23.0	31	0.0
NT Ct-Crn	27.2	31.2	15	0.4
NT Ct-W-Soy	27.3	36.8	15	1.0
NT Ct w/C	30.7	39.0	22	0.8
NT Ct	29.3	31.2	22	0.2
Pasture	-	51.4	≥ 20	-

†Conv Ct = conventional tillage cotton; NT Ct-Crn = no-till cotton-corn; NT Ct-W-Soy = no-till cotton-wheat-soybean; NT Ct w/C = no-till cotton with wheat cover crop; NT Ct = no-till cotton; Pasture = grazed pasture.

‡ SOC_{2000} = soil organic carbon (0-24 cm) as reported by Motta et al. (2007); SOC_{2010} = soil organic carbon collected in 2010 (0-24 cm); Agroecosystem Duration by 2010 = duration of each agroecosystem in 2010 from initial implementation; Carbon Sequestration = rate of sequestration over the 2000-2010 period.

Figures

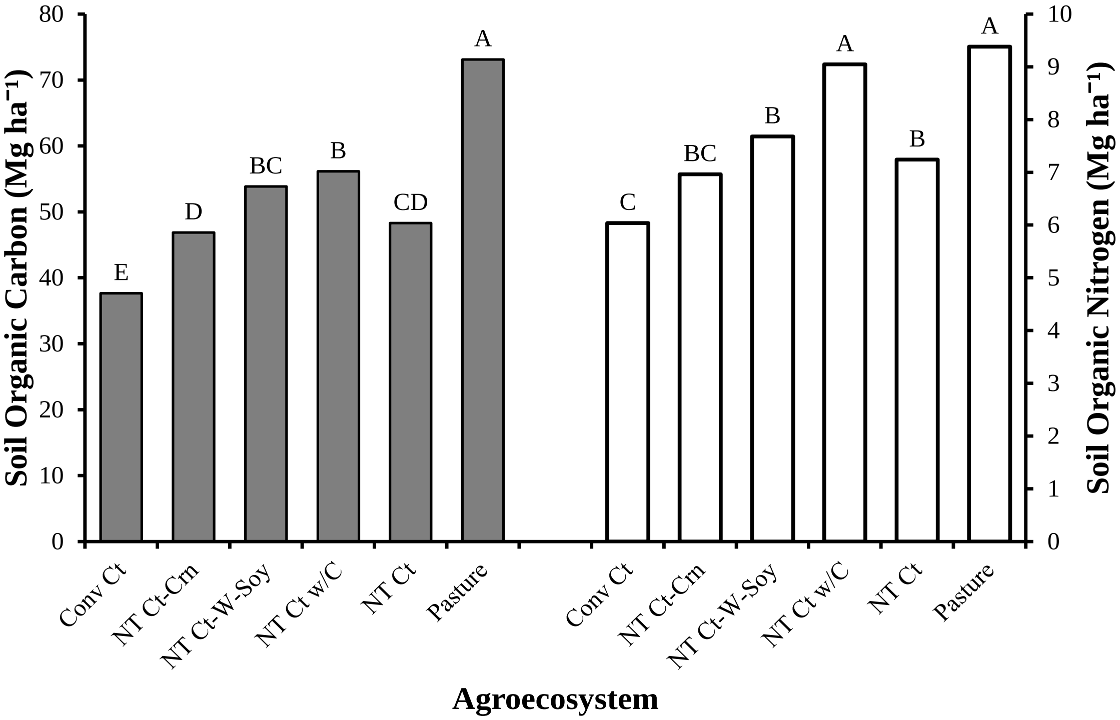

Figure 1. Soil organic carbon and soil organic nitrogen (0-50 cm) averaged by agroecosystem. Conv Ct = conventional tillage cotton, NT Ct-Crn = no-till cotton-corn rotation, NT Ct-W-Soy = no-till cotton-wheat-soybean rotation, NT Ct w/C = no-till with winter wheat cover, NT Ct = no-till cotton, Pasture = grazed pasture. Values with different letters are significantly different at α = 0.05.

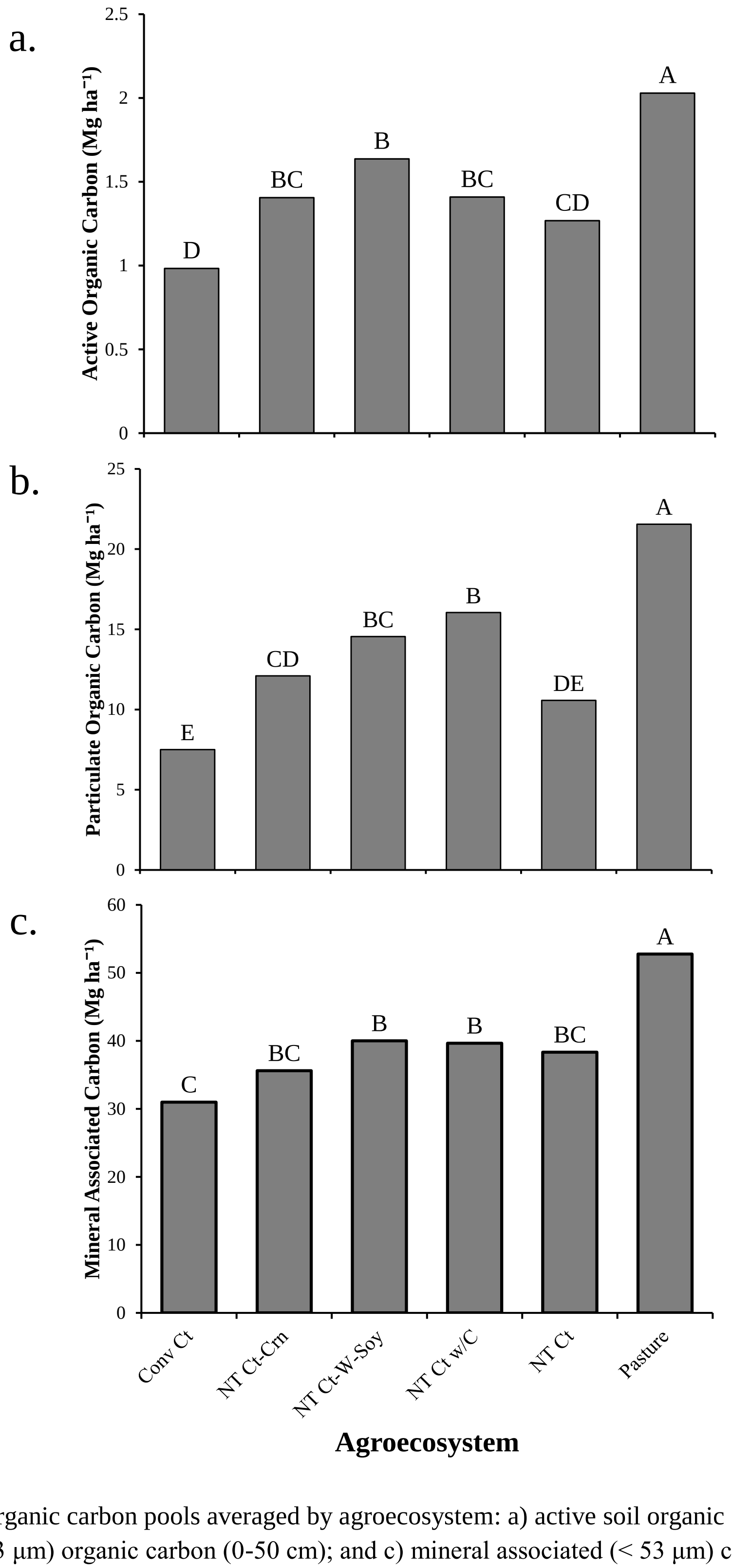

Figure 2. Soil organic carbon pools averaged by agroecosystem: a) active soil organic carbon (0-30 cm); b) particulate (> 53 μm) organic carbon (0-50 cm); and c) mineral associated (< 53 μm) carbon (0-50 cm). Conv Ct = conventional tillage cotton, NT Ct-Crn = no-till cotton-corn rotation, NT Ct-W-Soy = no-till cotton-wheat-soybean rotation, NT Ct w/C = no-till with winter wheat cover, NT Ct = no-till cotton, Pasture = grazed pasture. Values with different letters are significantly different at α = 0.05.

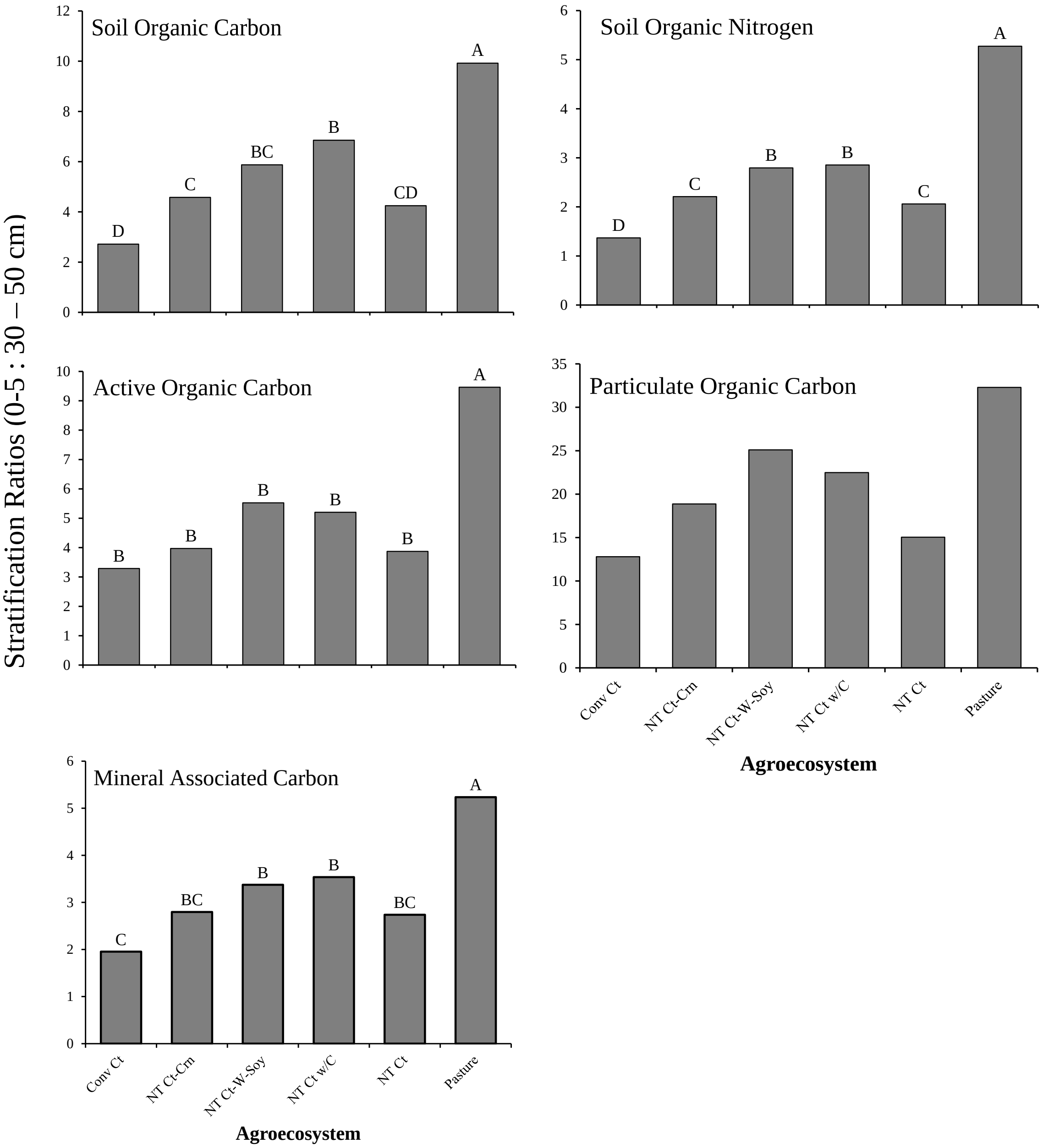

Figure 3. Stratification ratios (0-5:30-50 cm depth, 0-5:15-30 cm depth for active organic carbon) of soil organic carbon (g kg^{-1}), soil organic nitrogen (g kg^{-1}), active organic carbon (mg kg^{-1}), particulate (> 53 μm) organic carbon, and mineral associated (< 53 μm) carbon (g kg^{-1}) averaged by agroecosystem. Conv Ct = conventional tillage cotton, NT Ct-Crn = no-till cotton-corn rotation, NT Ct-W-Soy = no-till cotton-wheat-soybean rotation, NT Ct w/C = no-till with winter wheat cover, NT Ct = no-till cotton, Pasture = grazed pasture. Values with different letters are significantly different at $\alpha = 0.05$.

III. Soil Organic Matter Effects on Soil Properties, Soil Quality, and Soil Function in Tennessee Valley (Alabama) Paleudults

Abstract

Agronomic management affects soil organic matter (SOM) pools that impact chemical and physical properties, soil quality, and ultimately, soil function. Soil organic carbon (SOC) is a key component of soil quality both as a direct contributor and because SOM affects many other soil chemical and physical properties. The Tennessee Valley region of Alabama is intensively utilized for agronomic production, and long-term conventional management has led to degradation of soil quality. However, over the last two decades, conservation management has greatly increased. The objectives of this research were to quantify select soil chemical and physical properties, relate these properties to SOC pools and soil function, and assess soil quality in common agroecosystems of the Tennessee Valley region of Alabama. Long-term (≥ 15 years) conventional cotton (*Gossypium hirsutum*), conservation (no-tillage) cotton, and grazed pasture agroecosystems were sampled to a 50-cm depth in four depth increments (three depth increments for select properties). Select soil chemical (e.g., ion exchange capacity and extractable nutrients) and physical (e.g., water stable aggregates, water dispersible clay and Atterberg limits) properties were measured. Significant ($\alpha=0.05$) differences were observed for some commonly measured SOC pools, but results were mixed with depth. Many soil chemical and physical properties were significantly correlated with SOC pools. Differences in soil chemical properties as a function of agroecosystem were observed in extractable nutrients and cation exchange capacity (CEC) in the surface (0-5 cm), which were largely greater in agroecosystems that had more SOC. The CEC increased 2.6 cmol$_c$ kg^{-1} per every 10 g kg^{-1} increase in SOC. Agroecosystems that had more SOM had greater Atterberg limits and increased aggregate stability. Water content at both the liquid and plastic limits increased at least 4.8% per 10 g kg^{-1} increase of SOC in the surface (0-5 cm). At the 0-5 cm depth, water dispersible clay decreased 1.7% per 10 g kg^{-1} increase of SOC, and water stable aggregates increased 2.4% per 10 g kg^{-1} increase in SOC. Similarly, differences in SOC between stable and non-stable aggregate fractions suggest aggregation in these surface horizons is more strongly related to SOM than iron oxide content. Increased bulk density and soil strength were observed near surface (0-5 and 5-15 cm) in conservation row crop systems. Nonetheless, bulk density was decreased 0.1 g cm^{-3} per 10 g kg^{-1} increase in SOC. Similar to past studies, systems with decreased surface disturbance results in improved soil quality. This study provides quantifiable relationships among SOM and soil properties essential to soil function (e.g., nutrient and water retention, trafficability) in the Tennessee Valley region.

Introduction

The improvement of soil quality, basically defined as how well a soil serves a specific purpose (Soil Science Society of America, 1997), can enhance the efficacy of sustainable agricultural practices (Magdoff and van Es, 2000). Managing soil organic carbon (SOC) by conservation management practices is one method used to maintain or improve soil quality due to the effects of SOC on many soil chemical and physical properties (Karlen et al., 1997; Reeves, 1997; Magdoff and van Es, 2000).

The Tennessee Valley of Alabama is a vital agronomic region. Cotton (*Gossypium hirsutum*), corn (*Zea mays* L.), soybean (*Glycine max*), and wheat (*Triticum aestivum* L.) are produced in this region, with an appreciable area devoted to grazed pasture (Alabama Agricultural Experiment Station, 2010). Historical conventional management practices in the area have included inversion plowing post-harvest, winter mellowing, and disking to prepare a seedbed for spring planting (Brown et al., 1985). Over the past two decades, conservation practices using reduced tillage and winter cover crops have increased (Schwab et al., 2002). With the adoption of conservation systems, SOC levels are increasing in these agronomic systems (Causarano, et al., 2006)

Soil organic matter (SOM) contributes directly to nutrient availability through decomposition, but it also retains ions on variable charge binding sites, which enhances cation exchange capacity (CEC), anion exchange capacity (AEC), and phosphorus (P) retention (Baldock and Nelson, 2000; Bohn et al., 2001). Edwards et al. (1992) and Duiker and Beegle (2006) reported increased extractable nutrients in conservation systems, which was attributed to increased CEC from increased SOM. Ultisols that are acidic and high in oxides and kaolinite, such as those found in the Tennessee Valley, have some capacity to exhibit AEC (Gillman, 1979; Qafoku et al., 2000). In several Piedmont Ultisols, Gillman and Sumner (1987) reported AEC values that ranged between 0.1 and 1.3 $\text{cmol}_c\ \text{kg}^{-1}$. However, SOM has the potential to bind to variable charge minerals and reduce AEC (Gillman, 1985).

Soil physical properties are also affected by management of SOM. Bulk density and compaction can be decreased by increasing SOM (Franzluebbers et al., 2000a). However, management practices that induce increases in SOM (e.g., reduced tillage) can create compacted soil conditions near surface through repeated trafficking without disruption (e.g., tillage) (Raper et al., 2000; Schwab et al., 2002). Atterberg limits are a measure of soil consistence, where soils exhibit transitions between plastic and liquid states (McBride, 2002). The liquid limit (LL), plastic limit (PL), and plasticity index (PI) are strongly related to mineralogy and texture, but can be influenced by SOM (Odell et al., 1960; McBride et al., 1994). At water contents up to the PL, soils tolerate trafficking (without structure disturbance). However, in wetter conditions (up to the LL), soils are easily compactable from both tillage and trafficking. Beyond the LL, compaction is less evident but smearing occurs (Gill and Reaves, 1957; Raper and Kirby, 2006). Blanco-Canqui et al. (2006) found that conservation practices that increase SOM also increased Atterberg limits compared to conventional management practices.

In most soils, SOM is considered a principal soil particle binding agent that promotes soil structure development (Beare et al., 1994; Karlan et al., 1994; Bruce et al., 1995). Organic materials increase charge characteristics which bind soil particles (Oades, 1984), and many organic constituents (e.g., polysaccharides, plant mucilage, glomalin, and others) have an adhesive quality that accretes soil particles (Oades, 1984; Wright et al., 1999). As several studies in the southeastern U.S. region have shown, soils with greater SOM (conservation and pasture agroecosystems) often have greater and more stable aggregates than soils under conventional management (Bruce et al., 1995; Franzluebbers et al., 1999; Causarano et al., 2008). However, in Tennessee Valley soils, inherent soil properties [high iron (Fe) oxide quantities] may have a greater influence on aggregation than SOM as a result of positive (+) charges on oxide surfaces under normal soil pH ranges (Shaw et al., 2003).

Tennessee Valley soils have finer textures (silt loam and silty clay loam) and greater oxide mineral (Fe and manganese (Mn) oxides) content in surface horizons relative to many other cultivated southeastern U.S. Ultisols (e.g., Coastal Plain) (Shaw et al., 2003). The inherent properties of these soils offer a somewhat unique pedological environment to study the effects of management-induced soil carbon (C) sequestration on select soil chemical and physical properties. Some of these soil properties are routinely measured (e.g., CEC and bulk density) and are a staple in the assessment of soil quality, but few studies have assessed these common measures in soils under a range of long-term agroecosystems in the Tennessee Valley. Although it is recognized that increasing SOM improves dynamic soil quality, little attempt has been made to quantify the impacts of increasing SOC on soil properties related to soil function. Furthermore, select soil properties that emphasize organo-mineral interactions in these systems (e.g., Atterberg limits and AEC) are not commonly assessed and have received little investigation in this region.

Thus, the objectives of this study are to: 1) quantify select soil chemical and physical properties, 2) relate these properties to SOC pools and soil function, and 3) assess soil quality in common agroecosystems of the Tennessee Valley region of Alabama.

Materials and Methods

Site Characterization

The research site was located at the Tennessee Valley Research and Extension Center in Belle Mina, Alabama. In order to verify map unit and soil taxonomic placement of research site, pedons were described, sampled and characterized within row crop and pasture plots (descriptions in Appendix). For laboratory characterization, samples were air dried, manually crushed, and passed through a 2-mm sieve. Soil organic matter was removed using a 30% hydrogen peroxide solution, and soils were dispersed using a sodium metaphosphate / sodium carbonate solution prior to particle size analysis using the < 2-mm pipette method (Soil Survey Investigation Staff, 2004). Cation exchange capacity and extractable bases [calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na)] were determined using the ammonium acetate (NH_4OAC) (pH 7) method (Soil Survey Investigation Staff, 2004). Extractable aluminum (Al) was determined using the 1.0 *M* potassium chloride (KCl) method and measured with inductively coupled plasma (ICP) spectrometry (Soil Survey Investigation Staff, 2004). Effective cation exchange capacity (ECEC) was determined by summing extractable Al and NH_4OAC (pH 7) extractable bases. Soil pH was determined in water (1:1 w/v) and in 0.01 *M* calcium chloride ($CaCl_2$) (1:2 w/v) (Soil Survey Investigation Staff, 2004).

Agroecosystems

The agroecosystem managements investigated included:

1) Conventional cotton (Conv Ct): Conventional tillage system with continuous cotton and no cover crop; established in 1979 (31 years).
2) No-till cotton, corn rotation (NT Ct-Crn): Conservation tillage system in a cotton-corn rotation with no cover crop; cotton planted even years, corn (*Zea mays* L.) planted odd years; established in 1995 (15 years).

3) No-till cotton, wheat cover crop (NT Ct w/C): Conservation tillage system with continuous cotton and a winter wheat (*Triticum aestivum* L.) cover crop; established in 1988 (22 years).
4) No-till cotton-wheat-soybean, rotation (NT Ct-W-Soy): Conservation tillage system in cotton, followed by harvested wheat crop, followed by soybean (*Glycine max*) rotation; established in 1995 (15 years).
5) No-till cotton (NT Ct): Conservation tillage system with continuous cotton and no cover crop; established in 1988 (22 years).
6) Pasture: Grazed grassland system with mixed tall fescue (*Festuca arundinacea*) and bermudagrass (*Cynodon dactylon*) (≥ 20 years, reseeded once in that time period).

Experimental Design

The selected agronomic sites, except for pasture, were part of an existing long-term experiment with systems as described above and by Motta et al. (2007). The experimental design was a randomized complete block design with four replications. Using GPS, measurements of plot dimensions from the existing experiment were superimposed on an aerial photograph of a pasture site located on the research station 2.4 km from the agronomic site. Soils were described and sampled on the pasture site to ensure same soil (taxonomically) as those found on the agronomic experiment listed above. Once plots were established on the pasture sites, four plots were selected at random for sampling using the same procedures as the agronomic trial. Although pasture sites were not in exact same location as agronomic plots, attention was paid to superimposing the agronomic and pasture plots as validly as possible.

Sample Collection and Laboratory Procedures

Composite samples were collected for the 0-5, 5-15, 15-30, and 30-50 cm depths. Each composite sample was comprised of 12 samples per repetition and was collected using a Giddings Hydraulic Probe (Giddings Machine Co., Inc., Fort Collins, CO, USA). Samples were air dried, manually crushed, and passed through a 2-mm sieve prior to analyses. For SOC analyses, samples were ground with a mortar and pestle and analyzed using dry combustion (Yeomans and Bremner, 1991). The POC and mineral associated C (MC) pools were separated following the wet sieving method of Cambardella and Elliot (1992), and C contents were determined by dry combustion (Yeomans and Bremner, 1991). Active organic C (AC) samples were collected at 0-5, 5-15, and 15-30 cm depths. The AC samples were taken from the composite sample, sealed in a plastic bag, and placed in cold storage until analysis (within 72 hours of sampling). After passing sample through a 2-mm sieve, AC was determined using the potassium permanganate ($KMnO_4$) technique of Weil et al. (2003).

Soil Chemical Properties

Free soil Fe and manganese (Mn) were extracted using sodium dithionite (Fe_d and Mn_d, respectively) and acid ammonium oxalate (Fe_o and Mn_o, respectively) procedures (Soil Survey Investigation Staff, 2004) at the 0-5, 5-15 and 15-30 cm depths. Cation exchange capacity, AEC, ECEC, extractable bases, extractable aluminum (Al), and point of zero charge (PZC) were determined for samples from selected agroecosystems (conventional cotton, no-till cotton with wheat cover crop, and pasture) at 0-5, 5-15, and 15-30 cm depths. These select agroecosystems constitute a subset that encompass the range of SOC. Cation exchange capacity (at pH 5 and 6), AEC, and PZC were determined using the procedure outlined by Gillman (2007). Other methods are described above. Mehlich-1 extractable nutrients were obtained from a double-acid extraction (Mehlich, 1953) and analyzed by inductively coupled plasma spectrometry (ICP).

Soil Physical Properties

For all agroecosystems at 0-5, 5-15, 15-30, and 30-50 cm depths, PSD was determined using the < 2-mm pipette method (see above). Atterberg limits (plastic limit and liquid limit) were determined using the methodology described in McBride (2002), and plasticity indices were calculated from the two limits. Water dispersible clay (WDC) was determined through a modification of the < 2-mm pipette method used for PSD analysis (see above). Three bulk density cores were taken per plot at all depths using a Giddings Hydraulic Probe, and measured using the procedure outlined by Blake and Hartge (1986). Measurements represent averages within plots. Soil strength (0-50 cm) was recorded using a CP40II cone penetrometer (ICT International Pty Ltd, Armidale, New South Wales, Australia). Values for soil strength represent averages of ten readings per plot.

Water stable aggregates (WSA) samples were taken at the 0-5 and 5-15 cm depths in three field replications. The stable fraction was determined by the wet sieving method described by Kemper and Rosenau (1986) for three laboratory replications. Values represent averages within plots. In a separate analysis, WSA samples for a subset of low, medium and high SOC values (conventional cotton, no-till cotton with wheat cover crop, and pasture agroecosystems) were collected at 0-5 and 5-15 cm in January, 2011. In this study, samples were slaked using the same method, with sieving times being increased to five minutes. Slaked and un-slaked fractions were retained for SOC and Fe_d measurement (see above).

For scanning electron microscopy analysis (SEM), aggregates (1-2 mm) from surface (0-5 cm) samples (conventional row crop, conservation row crop cotton with a wheat cover crop, and pasture systems) were oven-dried, sputter coated with gold, and examined with backscatter imaging using a Zeiss EVO 50VO (Carl Zeiss NTS, LLC, MA, USA) scanning electron microscope.

Data Analyses

Data were analyzed using analysis of variance by PROC GLIMMIX in SAS$^{®}$ (SAS Institute Inc., 2008) to compare differences in soil properties among agroecosystem main effects by depth. Pearson correlation coefficients were calculated using SAS$^{®}$ PROC CORR (SAS Institute Inc., 2008) for the surface horizon (0-5 cm) and by pooling across all depths. Select soil properties were regressed with SOC pools using PROC REG (SAS Institute Inc., 2008) for the surface horizon (0-5 cm). Paired t-tests were used to compare constituents with WSA using PROC TTEST (SAS Institute Inc., 2008). Significance for all analyses was based on $\alpha = 0.05$.

Results and Discussion

Soils

These Tennessee Valley Experiment Station sites were located in a Decatur (fine, kaolinitic, thermic Rhodic Paleudult) silt loam, 0 to 2 percent slope, soil map unit. These

Decatur map units are identified as prime farmland in the region. Soil textures for all depths were silt loam; however, significant differences were found among agroecosystems in the sand (0.05- 2.0 mm) and clay (< 0.002 mm) fractions at certain depths (Table 4). Sand was greatest in the surface (0-5 cm), and ranged between 7 and 10% among agroecosystems. The clay size fraction differed among agroecosystems only at the 0-5 cm depth, with the pasture having 3 to 6% lower clay than the conservation and conventional agroecosystems, respectively. Slightly higher clay content in surface horizons of conventional systems is expected due to vertical mixing of subsoil material.

Sodium dithionite extractable Fe and Mn represent free (non-silicate bound) Fe and Mn in the soil system. Acid ammonium oxalate extractable Fe and Mn represent poorly crystalline and organically bound forms of Fe and Mn (Jackson et al, 1986). Sodium dithionite extractable Fe did not differ among agroecosystems, except in the surface (0-5 cm) (Table 4). At this depth, the pasture had greater Fe_d than row crop systems (1.8 versus 1.4%, respectively). In the remaining depths (5-15 and 15-30 cm), Fe_d ranged between 1.5 and 2.3% for all agroecosystems. The Fe_o ranged between 0.3 and 0.6% solid, and did not differ among systems (Table 4). Sodium dithionite extractable Mn_d was significantly lower in the pasture than row crop systems (0.2 versus 0.4%, respectively) in all depths (Table 4).

Soil Organic Carbon Pools

Carbon in all SOC pools was generally greater in the pasture system, followed by the conservation row crop system that utilized winter wheat, the conservation row crop systems that did not utilize winter wheat, and the conventional row crop system (Table 5). Major differences among agroecosystems were in the surface depths. In the surface

(0-5 cm), SOC concentrations in conservation row crop and pasture systems ranged from 1.8 to 4.8x greater than the conventional row crop systems. The SOC was also significantly greater in the pasture than all row crop systems at the 30-50 cm depth.

Concentrations of AC (0-5 cm) in conservation row crop and pasture systems ranged between 1.8 and 4.5x greater than conventional row crop systems (Table 5). Generally, AC concentrations in this study were greater than much of the published research on Ultisols. Arriaga et al. (2009) reported AC concentrations between 407 and 509 mg kg^{-1} (0-10 cm) in irrigated and non-irrigated conservation cotton systems in the Tennessee Valley, while Spargo et al. (2011) reported between 419 and 483 mg kg^{-1} (0-20 cm) AC under several management practices in Maryland Ultisols. However, our data are within values reported by Stiles et al. (2011) in a nationwide assessment of AC under a variety of cultivated and natural environments.

In the 0-5 cm depth, pasture and conservation row crop systems that utilize cover crops had the highest POC (2.8 and 6.3x greater than conventional systems, respectively) and MC (1.7 and 3.4x greater than conventional systems, respectively) concentrations (Table 5). Near-surface (0-5 cm) concentrations of POC for row crop systems (ranging between 3.4 and 12.2 g kg^{-1}) largely agree with other values reported for the Tennessee Valley and the southeastern U.S. (Motta et al., 2007; Causarano et al. 2008). Pasture POC concentrations (21.3 g kg^{-1}) were also within values reported for pasture systems in southeastern U.S. Piedmont Ultisols (Franzluebbers et al., 2000b).

Ion Exchange and Point of Zero Charge

Between pH 5 and 6, AEC did not differ among agroecosystems (Table 6). In this pH range, AEC for all agroecosystems ranged between 0 and 0.11 $\mathrm{cmol_c\ kg^{-1}}$ for the surface (0-5 cm) depth. Results for the surface depth (0-5 cm) are in agreement with Bellini et al. (1996), who reported 0.02 $\mathrm{cmol_c\ kg^{-1}}$ AEC in Piedmont Ultisol surface horizons. At deeper depths (5-15 and 15-30 cm), results were largely in agreement with values reported by Gillman and Sumner (1987), who found 0.1 to 0.9 $\mathrm{cmol_c\ kg^{-1}}$ AEC at the 15-30 cm depth in several Piedmont Ultisols. Interestingly, near-surface (0-5 cm) AEC was not observed in the pasture system, which could be the result of organic coatings masking (+) charges present on oxide surfaces or edges of kaolinite crystals (Gillman, 1985).

Within the same range of pH values (5 and 6), CEC also did not differ among agroecosystems. Cation exchange capacity ranged between 5.70 and 14.13 $\mathrm{cmol_c\ kg^{-1}}$ for the surface depth (0-5 cm). At deeper depths (5-15 and 15- 30 cm), CEC decreased (between 4.61 and 7.85 $\mathrm{cmol_c\ kg^{-1}}$) (Table 6).

The standard CEC (ammonium acetate pH 7) was significantly greater in pasture compared to row crop systems at the 0-5 cm depth (17.6 versus 10.6 $\mathrm{cmol_c\ kg^{-1}}$, respectively) (Table 6). The pasture system had greater CEC values than much of the previously reported values from the area, which is likely attributed to greater SOM. Results for row crop systems were in agreement with other results from the Tennessee Valley at similar depths. For example, Shaw et al. (2003) and Mitchell and Tu (2006) reported CEC values ranging between 9-12 $\mathrm{cmol_c\ kg^{-1}}$.

The point of zero charge (PZC) is the pH at which all soil charges (positive and negative) balance (Zelazny et al., 1996). The PZC was not significantly different at any depth (Table 6), and ranged between 4.82 and 6.12. These values agree with results of Gillman and Sumner (1987), who reported a PZC range from 4.0 to 6.5 in some southeastern U.S. Ultisols.

When pooled across all depths, significant correlations existed among SOC pools, CEC (pH 5 and 6), AEC (pH 5), and PZC (Table 8). When evaluated for surface depths, (0-5 cm) which exhibited the largest variation in SOC as a function of management, PZC and AEC (pH 5 and 6) did not exhibit a significant relationship with SOC (Figures 4a and 4b), but CEC (pH7) was highly correlated with all SOC pools ($r \geq 0.88$) (Table 8). Regression analyses indicated CEC (pH 7) increased 2.6 $\text{cmol}_c\ \text{kg}^{-1}$ per every 10 g kg^{-1} increase in SOC (Figure 4c). This increase in CEC is slightly lower than National Resource Conservation Service (NRCS) estimates (3 to 4 $\text{cmol}_c\ \text{kg}^{-1}$ CEC gained per 1 g organic C) (Soil Survey Investigation Staff, 1995).

Extractable Nutrients and Aluminum

Mehlich-1 extractable Ca and K did not differ among agroecosystem at any depth; however, differences in Mg and P were observed at most sampling depths (Table 7). Pasture, no-till cotton-corn rotation, and the no-till cotton-wheat-soybean rotation were greater in Mg than all other agroecosystems at the 0-5, 5-15, and 15-30 cm depths. Extractable P in the pasture system was equal to or less than all other agroecosystems. This trend was consistent across all depths evaluated and was significant at 0-5 and 5-15 cm depths. Overall, differences in nutrients between pasture and agronomic systems were largely due to differences in fertilization and nutrient management.

Mehlich-1 extractable divalent cations at the surface (0-5 cm) were generally greater in conservation versus conventional row crop systems (Table 7) and were significantly correlated with SOC pools and CEC at pH 7 (Table 8). Edwards et al. (1992) also found increased Ca and Mg in conservation row crop systems and attribute some of these differences to the increased CEC from SOM in some Alabama Ultisols. Relative increases in near-surface extractable nutrients in systems that have increased SOM (i.e., conservation and pasture systems) are also due to lack of incorporation from tillage (Duiker and Beegle, 2006). These data are in agreement with multiple other studies that have found that nutrients become concentrated in the upper portions of the soil profile under no-till management, which results in nutrient stratification (Franzeluebbers and Hons, 1996; Duiker and Beegle, 2006)

Total (0-50 cm) Mehlich-1 extractable Ca (236.4 Mg ha^{-1}) and K (15.5 Mg ha^{-1}) were not significantly different, while Mg (12.1 Mg ha^{-1}) and P (1.7 Mg ha^{-1}) did differ among agroecosystem (data not shown). Any differences are likely attributed to fertilization and nutrient management among the systems. Total masses of extractable nutrients (0-50 cm), except K, were in general agreement with Franzluebbers and Hons (1996), who reported values for extractable nutrients in conservation and conventional row crop systems in southeastern U.S. Piedmont Ultisols.

Extractable Al did not differ among agroecosystem at any depth. Values ranged between 0.03 and 0.06 $\text{cmol}_c\ \text{kg}^{-1}$ (Table 7). These values are relatively low and reflect proper lime management.

Bulk Density

The pasture system had the lowest bulk density compared to other agroecosystems, except for the 5-15 cm depth, where pasture and conventional cotton systems were similar (Table 9). At the surface (0-5 cm), conservation systems that utilize wheat cover crops and the conventional row crop system had the next lowest bulk density, followed by conservation row crop systems that do not use cover crops. Bulk density was significantly correlated with SOC pools both near surface (0-5 cm) and when pooled across all depths, suggesting bulk density was decreased by increased SOC in these soils (Table 10). Through regression analysis of the 0-5 cm depth, bulk density decreased 0.1 g cm^{-3} per 10 g kg^{-1} increase in SOC (Figure 5a).

Results for row crop systems (0-5 cm) generally agree with Schwab et al. (2002), who reported bulk densities that ranged between 1.31 and 1.44 g cm^{-3} under conventional and conservation row crop systems in the Tennessee Valley. They also reported higher bulk densities in no-till row crop systems (1.44 g cm^{-3}) than in conventional row crop systems (1.33 cm^{-3}). In the pasture system, bulk density was lower than values reported by Franzluebbers et al. (2000a) at the 0-5 cm depth (0.95 versus 1.10 g cm^{-3}) for southeastern U.S. Piedmont Ultisols.

Soil Strength

Significant differences in soil strength were observed among agroecosystems at the 5 and 15 cm depths, with the pasture and conventional row crop systems being lower than conservation row crop systems (Figure 6). Overall, conservation row crop systems were 32% greater in soil strength than the conventional row crop system and 40% greater than the pasture system. The conventional row crop system had average soil strength (0-50cm) of 1840 kPa, with the greatest soil strength near the 20-cm depth, suggesting some degree of compaction from management practices. The pasture had an average soil strength of 1739 kPa (0-50 cm) and remained relatively constant below 10 cm. Conservation row crop systems had an average soil strength of 2434 kPa (0-50 cm), and all followed a similar trend: the greatest soil strength was near 5-cm, with a secondary zone of compaction near 20-cm. These zones of higher soil strength suggest both contemporary and possibly a legacy compaction (from conventional tillage prior to experiment establishment) as a result of management practices. Soil strength was nearly, but not significantly, related to SOC ($P = 0.0570$) (Figure 5b).

Our soil strength data were lower than values reported by Schawb et al. (2002), who reported a range of values between 4905 and 6563 kPa in various conventional and conservation row crop systems in the Tennessee Valley. However, our results were similar to Raper et al. (2005), who reported soil strength values between 1000 and 2500 kPa in non-trafficked row crops in the Tennessee Valley. Considering soil strength data are closely related to soil moisture conditions, the variability among studies is not surprising.

Atterberg limits

Differences in water contents at the PL and LL among agroecosystems were most apparent in the 0-5 cm depth (Table 9). The pasture system had greater PL at 0-5 and 15-30 cm depths, and greater LL at the 0-5 and 5-15 cm depths, compared to row crop systems. In the surface (0-5 cm), the pasture system PL was 52 and 59% greater than conservation and conventional row crop systems, respectively. For the LL, the pasture system was 44% greater than all row crop systems in the 0-5 cm depth. There was no significant effect of agroecosystem on the PI (Table 9). Direct comparison between the results from this study and those reported from different soils is not feasible due to the effects of inherent pedological properties (e.g., texture and mineralogy) on Atterberg limits. However, Blanco-Canqui et al. (2006) reported greater Atterberg limits in conservation row crop and pasture systems when compared to conventional row crop systems in Ohio Ultisols.

In the 0-5 cm depth, the PL and LL were strongly correlated ($r \geq 0.81$) with SOC pools and clay content (Table 10). Atterberg limits had a significant ($P < 0.0001$ for both LL and PL) positive relationship with SOC in the surface (0-5 cm) (Figure 5c). Liquid limits increased 5.5% per 10 g kg^{-1} increase of SOC, while PL was increased 4.8% per 10 g kg^{-1} increase of SOC. The PI was less strongly related to SOC ($P = 0.0380$), but was increased by 0.7% per 10 g kg^{-1} increase of SOC. A strong relationship between SOC and Atterberg limits is in agreement with Lal (1979) and Blanco-Canqui et al. (2006).

Atterberg limits are sometimes estimated using equations developed by the NRCS, which are largely based on clay content (equations emphasize subsoils and do not consider SOM content) (Soil Survey Investigation Staff, 1995). Measured values for PL and LL in systems with lower SOM contents were in general agreement (± 5%) with estimates derived from NRCS equations. In agroecosystems that had greater SOM (pasture and conservation systems that utilize winter wheat), measured values for PL and LL were greater than estimated values. This suggests that equations for estimating Atterberg limits for surface horizons can be improved by incorporation of SOM.

Water Dispersible Clay

Differences in WDC were observed in the 0-5 cm depth (Table 9). The conventional row crop system had the greatest WDC (17.4%), followed by conservation row crop systems (13.4%), and the pasture system (10.2%). Similarly, the WDC:clay ratio (WCR) was also greater in conventional systems when compared to conservation and pasture systems in the 0-5 and 5 to 15 cm depths (Table 9). Near-surface WDC was correlated with all SOC pools, but was not correlated with Fe_d (Table 10). Pooled across all depths, WDC was correlated with Fe_d and only the AC SOC pool. These trends suggest SOM predominantly controls the amount of dispersible clay near surface, and to some degree, aggregation. Collectively, aggregation is promoted by charge characteristics imparted to soils by Fe oxides (Shaw et al., 2003) and the adhesive nature of some SOC pools (Wright et al., 1999; Daigh, 2011). Results generally agree with Shaw et al. (2003), who reported little difference in WDC (ranging between 14 and 18%) in some Tennessee Valley Ultisols. However, Shaw et al. (2003) reported no correlation between WDC, SOC, and Fe content. This was likely due to less difference in SOC among the systems analyzed compared to this study.

Water Stable Aggregates

Differences in WSA were limited to the 0-5 cm depth. The pasture system and no-till cotton-wheat-soybean rotation had greater water stable aggregates when compared to other row crop systems (97 and 93%, respectively). At the 0-5 cm depth, the pasture was 13 and 14% greater than conventional and no-till cotton conservation row crop systems, respectively (Table 9). Significant correlations exist between WSA and all SOC pools; however, unlike WDC, WSA were not correlated with Fe content (Table 10).

In a companion study, 1-2 mm aggregates from three agroecosystems that represent high (pasture), intermediate (no-till cotton with winter wheat cover), and low (conventional cotton) SOC content were subjected to wet sieving as per Kemper and Rosenau (1986). Agitation times were increased to five minutes due to the amount of Fe in these soils. Slaked and non-slaked materials were retained for SOC and Fe_d analysis. In the slaked material (non-stable fraction), SOC was 12.6 g kg^{-1} with 1.7% Fe. In the non-slaked portion (stable fraction), SOC was 18.9 g kg^{-1} with 1.6% Fe. Thus, the stable fraction had significantly higher SOC than the non-stable fraction with no difference between Fe_d (Table 11), suggesting that SOC is the relatively more important binding agent in these soils within these agroecosystems. This is somewhat contrary to the results of Shaw et al. (2003), who concluded that Fe was significant to near-surface aggregation in these soils. However, differences in our results are likely due to the fact the range of SOC (due to differences and maturity of agroecosystems) is much greater in our study than that used in Shaw et al. (2003).

Aggregation parameters were plotted against SOC and Fe_d (Figures 7a and 7b). Using regression analysis, WDC in the 0-5 cm depth had a significant ($P = 0.0010$) relationship with SOC and decreased 1.7% per 10 g kg^{-1} increase of SOC. Similarly, WSA were observed to increase 2.4% per 10 g kg^{-1} increase of SOC. When compared to Fe_d, the relationships between both WDC and WSA were not significant ($P = 0.1979$ and 0.1826, respectively) (data not shown).

In the surface (0-5 cm), aggregation parameters were also related to AC, a measure of labile soil organic C (polysaccharides, mucilage, and others) (Weil et al., 2003; Tirol-Padre and Ladha, 2004). These compounds affect aggregation in some soils due to their adhesive nature (Wright et al., 1999; Daigh, 2011). Both WDC and WSA had a significant relationship with the AC pool ($P = 0.0226$ and 0.0319, respectively). For every 10 g kg^{-1} increase of AC, WDC decreased 0.03% and WSA increased 0.06% (Figures 7c and 7d). These relationships further suggest that near-surface aggregation in these mature agroecosystems is largely attributed to SOC than Fe oxides.

Scanning Electron Microscope Analysis

Aggregates (1-2 mm) from select agroecosystems (pasture, conventional row crop, and conservation row crop systems that use no-till and winter wheat) were examined using SEM. Although results are preliminary, visual, qualitative differences were observed in some images among agroecosystems using secondary electron (backscatter) techniques. When compared to row crop systems, pastures appeared to have more material between individual grains and less resolution of individual grains (Figure 8). Although qualitative in nature, the images suggest organic coatings are more visible on silicate grains of the pasture compared to the other systems. This has also been reported by other authors (Sullivan and Koppi, 1987).

Conclusions

Differences in soil chemical properties as a function of agroecosystem were observed in extractable nutrients and CEC in the surface (0-5 cm), which were largely greater in agroecosystems that had more SOC. Increases of extractable nutrients in conservation systems near-surface are also likely attributed to lack of mixing through tillage. The CEC was shown to increase 2.6 $\text{cmol}_c\ \text{kg}^{-1}$ per every 10 g kg^{-1} increase in SOC. Several chemical properties (extractable Al, CEC at pH 5 and 6, and AEC at pH 5 and 6) were largely unaltered by increased SOC. However, lack of AEC in pasture systems is likely owed to masking of (+) sites on oxide surface by SOM.

Soil physical properties were generally more affected by management than chemical properties in these agroecosystems. Increased bulk density and soil strength were observed near surface (0-5 and 5-15 cm) in conservation row crop systems. Nonetheless, bulk density was decreased 0.1 g cm^{-3} per 10 g kg^{-1} increase in SOC. Greater SOM resulted in higher water contents at the Atterberg limits (PL and LL), increasing trafficking tolerances without structure disruption across a wider range of soil water contents. Atterberg limits were increased approximately 5% per 10 g kg^{-1} increase in SOC in the surface (0-5 cm). Our results indicate that equations estimating Atterberg limits in surface horizons should include SOM contents along with texture data.

Agroecosystems that had more SOM had increased aggregate stability. At the 0-5 cm depth, WDC decreased 1.7% per 10 g kg^{-1} increase of SOC, and WSA increased 2.4%

per 10 g kg^{-1} increase in SOC. Significantly greater SOC in stable versus non-stable aggregate fractions suggests aggregation in these surface horizons is attributed more to SOM than Fe oxide content.

Although well documented, this study further illustrates decreased surface disturbance results in improved soil quality. In addition, this study provides quantifiable relationships among SOM and dynamic soil properties essential to soil function (e.g., nutrient and water retention, trafficability, and water quality) in the Tennessee Valley region. These quantifiable relationships will also facilitate model parameterization in these and associated soils.

References

Alabama Agricultural Experiment Station. 2010. Alabama Agriculture and Forestry, Special Report No. 9. Available at: http:// www.aaes.auburn.edu/comm/pubs/. (Verified 27 Sep. 2011). Alabama Agricultural Experiment Station, Ag Communications & Marketing, Auburn, AL.

Arriaga, J.S.S., J.N. Shaw, J.P. Fulton, and R.L. Raper. 2009. Cotton conservation system and irrigation effects on soil carbon pools of Tennessee Valley (Alabama) Paleudults. ASA-CSA-SSSA International Annual Meeting. Nov. 3, 2009. Pittsburg, PA.

Baldock, J.A. and P.N. Nelson. 2000. Soil Organic Matter. Section B p. 25-84. *In* Sumner, M.E. (ed.) Handbook of Soil Science. CRC Press LLC. Boca Raton, FL.

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

Bellini, G., M.E. Sumner, D.E. Radcliffe, and N.P. Qafoku. 1996. Anion transport through columns of highly weathered acid soil: adsorption and retardation. Soil Sci. Soc. Am. J. 60:132-137.

Blake, G.R. and K.H. Hartge. 1986. Bulk density p. 363-375. *In* A. Klute (ed.). Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods, 2nd ed. Am. Soc. Agron. and Soil Sci. Soc. Am. Book No. 9. Madison, WI.

Blanco-Canqui, H., R. Lal, W.M. Post, R.C. Izaurralade, and M.J. Shipitalo. 2006. Organic carbon influences on soil particle density and rheological properties. Soil Sci. Soc. Am. J. 70:1407-1414.

Bohn H.L., B.L. McNeal, and G.A. O’Connor. 1985. Soil Chemistry, 2nd ed. John Wiley and Sons, Inc. New York.

Brown, S.M., T. Whitwell, J.T. Touchton, and C.H. Burmester. 1985. Conservation tillage systems for cotton production. Soil Sci. Soc. Am. J. 49:1256-1260.

Bruce, R.R., G.W. Langdale, L.T. West, and W.P. Miller. 1995. Surface soil degradation and soil productivity restoration and maintenance. Soil Sci. Soc. Am. J. 59:654-660.

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

Causarano, H.J., A.J. Franzluebbers, D.W. Reeves, and J.N. Shaw. 2006. Soil organic carbon sequestration in cotton production systems of the southeastern United States: A review. J. Environ. Qual. 35:1374-1383.

Causarano, H.J., A.J. Franzluebbers, J.N. Shaw, D.W. Reeves, R.L. Raper, and C.W. Wood. 2008. Soil organic carbon fractions and aggregation in the Southern Piedmont and Coastal Plain. Soil Sci. Soc. Am. J. 72:221-230.

Daigh, A.L. 2011. Bioenergy cropping systems effects on soil quality. Soil Surv. Horiz. 52:31-34.

Duiker, S.W. and D.B. Beegle. 2006. Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. Soil Tillage Res. 88:30-41.

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

Franzluebbers, A.J. and F.M. Hons. 1996. Soil-profile distribution of primary and secondary plant-available nutrients under conventional and no tillage. Soil Tillage Res. 39:229-239.

Franzluebbers A.J., S.F. Wright, and J.A. Stuedemann. 2000a. Soil aggregation and glomalin under pastures in the Southern Piedmont USA, Soil Sci. Soc. Am. J. 64:1018–1026.

Franzluebbers, A.J., G.W. Langdale, and H.H. Schomberg. 1999. Soil carbon, nitrogen, and aggregation in response to type and frequency of tillage. Soil Sci. Soc. Am. J. 63:349-355.

Franzluebbers, A.J., J.A. Stuedemann, H.H. Schomberg, S.R. Wilkinson. 2000b. Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA. Soil Biol. Biochem. 32:469-478.

Gill, W.R. and C.A. Reaves. 1957. Relationships of Atterberg Limits and cation-exchange capacity to some physical properties of soils. Soil Sci. Soc. Am. Proc. p. 491-494.

Gillman, G.P. 1979. A proposed method for the measuring of exchange properties of highly weathered soils. Aust. J. Soil Res. 17:129-139.

Gillman, G.P. 1985. Influence of organic matter and phosphate content on the point of zero charge of variable charge components in oxidic soils. Aust. J. Soil Res. 23:643-643.

Gillman, G.P. 2007. An analytical tool for understanding the properties and behavior of variable charge soils. Aus. J. Soil Res. 45:83-90.

Gillman, G.P. and M.E. Sumner. 1987. Surface charge characterization and soil solution composition of four soils from the southern piedmont in Georgia. Soil Sci. Soc. Am. J. 51:589-594.

Jackson,M.L., C.H. Lim, and L.W. Zelazny. 1986. Oxides, hydroxides, and aluminosilicates. p. 113-119. *In* Methods of Soil Analysis, Part 2, 2nd Ed. A. Klute (ed.). Am. Sco. Agron. and Soil Sci. Soc. Am. Book No. 9. Madison, WI.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil quality: A concept, definition, and framework for evaluation (A guest editorial). Soil Sci. Soc. Am. J. 61:4-10.

Karlen, D.L., N.C. Wollenhaupt, D.C. Erbach, E.C. Berry, J.B. Swan, N.S. Eash, and J.L. Jordahl. 1994. Long-term tillage effects on soil quality. Soil Tillage Res. 32:313-327.

Kemper, W. D. and R. C. Rosenau. 1986. Aggregate Stability and Size Distribution. p. 425-462. *In* A. Klute (ed.), Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods, 2nd ed. Am. Soc. Agron. and Soil Sci. Soc. Madison, WI.

Klute, A. 1986. Water Retention: Laboratory Methods. p. 635-662. *In* A. Klute (ed.) Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods, 2nd ed. Am. Sco. Agron. and Soil Sci. Soc. Am. Book No. 9. Madison, WI.

Lal, R. 1979. Physical properties and moisture retention characteristics of some Nigerian soils. 21:209-223.

Lowery B. and J.E. Morrison, JR. 2002. 2.8 Soil Penetrometers and Penetrability. p.363-388. *In* J.H. Dane and G.C. Topp (eds.), Methods of Soil Analysis: Part 4 Physical Methods. Soil Sci. Soc. Am. Book No. 5 Madison, WI.

Magdoff, F. and H. van Es. 2000. Building soils for better crops. Sustainable Agriculture Network. Handbook, Series No. 4. Beltsville, MA.

McBride, R.A. 2002. 2.9 Atterberg Limits. p. 389-398. *In* J.H. Dane and G.C. Topp (eds.), Methods of Soil Analysis: Part 4 Physical Methods. Soil Sci. Soc. Am. Book No. 5 Madison, WI.

McBride, R.A., D.W. Veenhof, G.C. Topp, Y.T. Galganov, and J.L.B. Culley. 1994. Assessing changes in soil physical properties. *In* D.F. Acton (ed.), A program to assess and monitor soil quality in Canada. Soil Quality Evaluation Program Summary Report. Centre for Land and Biological Resources Research, Research Branch, Agriculture and Agri-Food Ottawa, Canada.

Mehlich A. 1953. Determination of P, Ca, Mg, K, Na, NH_4. Raleigh (NC): North Carolina Department of Agriculture, Agronomic Division. Soil Testing Division Publication No. 1-53.

Mitchell, C.C. and S. Tu. 2006. Nutrient accumulation and movement from poultry litter. Soil Sci. Soc. Am. J. 70:2146-2153.

Motta, A.C.V., D.W. Reeves, C. Burmester, and Y. Feng. 2007. Conservation Tillage, Rotations, and Cover Crop Affecting Soil Quality in the Tennessee Valley: Particulate Organic Matter, Organic Matter, and Microbial Biomass. Commun. Soil Sci. Plant Anal. 38:2831-2847.

Oades, J.M. 1984. Soil organic matter and structural stability: Mechanisms and implications for management. Plant and Soil. 76:319-337.

Odell, R.T., T.H. Thornburn, and L.J. McKenzie. 1960. Relationships of Atterberg Limits to some properties of Illinois soils. Soil Sci. Soc. Proc. p. 297–300.

Qafoku, N.P., M.E. Sumner, and D.E. Radcliffe. 2000. Anion transport in columns of variable charge subsoils: nitrate and chloride. J. Environ. Qual. 29:484-493.

Raper, R.L., Kirby, J.M. 2006. Soil compaction: how to do it, undo it, or avoid doing it. Distinguished Lecture Series. ASABE, St. Joseph, Michigan.

Raper, R.L., D.W. Reeves, E.B. Schwab, and C.H. Burmester. 2000. Reducing soil compaction of Tennessee Valley soils in conservation tillage systems. J. Cotton Sci. 4:84-90.

Raper, R.L., E.B. Schwab, K.S. Balkcom, C.H. Burmester, and D.W. Reeves. 2005. Effect of annual, biennial, and triennial in-row subsoiling on soil compaction and cotton yield in Southeastern U.S. silt loam soils. Appl. Eng. Agri. 21(3): 337−343.

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

Schwab, E.B., D.W. Reeves, C.H. Burmester, and R.L. Raper. 2002. Conservation tillage systems for cotton in the Tennessee Valley. Soil Sci. Soc. Am. J. 66:569-577.

Shaw, J.N., D.W. Reeves, and C.C. Truman. 2003. Clay mineralogy and dispersibility of soil and sediment derived from Rhodic Paleudults. Soil Sci. 168(3):209-217.

Soil Science Society of America (SSSA). 1997. Glossary of soil science terms. American Society of Agronomy, Madison, WI

Soil Survey Investigation Staff. 1995. Soil Survey Laboratory Information Manual. Soil Surv. Inv. Rep. 45. USDA-SCS, National Soil Survey Center, Lincoln, NE.

Soil Survey Investigation Staff. 2004. Soil survey laboratory methods manual. Soil Surv. Inv. Rep. 42. USDA-SCS, National Soil Survey Center, Lincoln, NE.

Spargo, J.T., M.A. Cavigelli, S.B. Mirsky, J.E. Maul, and J.J. Meisinger. 2011. Mineralizable soil nitrogen and labile soil organic matter in diverse long-term cropping systems. Nutr. Cycl. Agroecosyst. 90:253–266.

Stiles, C.A., R.D. Hammer, M.G. Johnson, R. Ferguson, J. Galbraith, T. O’Geen, J. Arriaga, J. Shaw, A. Falen, P. McDaniel, and R. Miles. 2011. Validation testing of a portable kit for measuring an active carbon fraction. Soil Sci. Soc. Am. J. 75:2330-2340.

Sullivan, L.A., and A.J. Koppi, A. J. 1987. In-situ soil organic matter studies using scanning electron microscopy and low temperature ashing. Geoderma 40: 317-332.

Tirol-Padre, A. and J.K. Ladha. 2004. Assessing the reliability of permanganate-oxidizable carbon as an index of soil labile carbon. Soil Sci. Soc. Am. J. 68:969-978.

Weil, R.R., K.R. Islam, M.A. Stine, J.B. Gruver, and S.E. Samson-Liebig. 2003. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. Am. J. Alt. Agric. 18(1):3-17

Wright. S.F., J.L. Starr, and I.C. Paltineanu. 1999. Changes in aggregate stability and concentration of glomalin during tillage management transitions. Soil Sci. Soc. Am. J. 63:1825-1829.

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.

Zelazny, L.W., L. He, and A. Vanwormhoudt. 1996. Charge Analysis of Soils and Anion Exchange. p. 1231-1253. *In* D.L. Sparks (ed.), Methods of Soil Analysis: Part 3 Chemical Methods. Soil Sci. Soc. Am. Book No. 5. Madison, WI.

Tables

Table 4. Soil particle size distribution and dithionite and acid ammonium oxalate extractable iron and manganese for Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under six agroecosystems in the Tennessee Valley region of Alabama. Letters represent simple effects of agroecosystem. Values with different letters are significantly different at $\alpha = 0.05$.

Agroecosystem†	Sand‡	Silt	Clay	Fe$_d$	Mn$_d$	Fe$_o$	Mn$_o$
	------------ % ------------			----------- % solid ------------			
	0 – 5 cm						
Conv Ct	13.5 BC	63.2	23.3 A	1.4 BC	0.4 A	0.5	0.5
NT Ct-Crn	15.4 BC	62.3	22.2 AB	1.5 BC	0.4 A	0.3	0.4
NT Ct-W-Soy	16.4 B	62.9	20.7 ABC	1.3 C	0.4 A	0.3	0.5
NT Ct w/C	15.4 BC	64.9	19.7 BC	1.4 BC	0.4 A	0.4	0.4
NT Ct	13.3 C	65.3	21.4 AB	1.6 B	0.4 A	0.3	0.4
Pasture	23.3 A	59.0	17.7 C	1.8 A	0.2 B	0.4	0.3
ANOVA	------------------------------------ P > F --						
Agroecosystem (A)	< 0.001	0.139	0.050	0.005	0.005	0.142	0.174
	5 – 15 cm						
Conv Ct	12.7 B	62.0	25.3	1.5	0.4 A	0.5	0.5 A
NT Ct-Crn	13.1 B	60.9	26.0	1.5	0.4 A	0.3	0.5 A
NT Ct-W-Soy	13.0 B	61.9	25.2	1.6	0.4 A	0.4	0.5 A
NT Ct w/C	11.7 B	62.8	25.5	1.5	0.4 A	0.5	0.5 A
NT Ct	11.4 B	63.5	25.1	1.6	0.4 A	0.3	0.5 A
Pasture	15.6 A	57.9	26.5	1.9	0.3 B	0.4	0.3 B
ANOVA	------------------------------------ P > F --						
(A)	0.003	0.331	0.994	0.209	0.003	0.308	0.007
	15 – 30 cm						
Conv Ct	11.1 BC	58.4	30.6	1.8	0.3 A	0.5	0.5 A
NT Ct-Crn	12.0 A	58.9	29.1	1.8	0.4 A	0.3	0.5 A
NT Ct-W-Soy	11.8 AB	59.8	28.5	1.7	0.4 A	0.4	0.5 A
NT Ct w/C	10.6 CD	62.7	26.8	1.6	0.4 A	0.5	0.5 A
NT Ct	11.2 ABC	61.7	27.1	1.6	0.4 A	0.3	0.5 A
Pasture	10.1 D	53.9	35.9	2.3	0.2 B	0.4	0.3 B
ANOVA	------------------------------------ P > F --						
(A)	0.002	0.261	0.190	0.974	0.003	0.134	0.058
	30 – 50 cm						
Conv Ct	10.0	46.0	44.0	-	-	-	-
NT Ct-Crn	9.8	45.0	45.2	-	-	-	-
NT Ct-W-Soy	9.7	47.4	42.9	-	-	-	-
NT Ct w/C	9.0	51.3	39.7	-	-	-	-
NT Ct	9.0	51.1	39.9	-	-	-	-
Pasture	9.2	47.0	43.8	-	-	-	-
ANOVA	------------------------------------ P > F --						
(A)	0.084	0.647	0.766	-	-	-	-

†Conv Ct = conventional tillage cotton; NT Ct-Crn = no-till cotton-corn; NT Ct-W-Soy = no-till cotton-wheat-soybean; NT Ct w/C = no-till cotton with wheat cover; NT Ct = no-till cotton; Pasture = grazed pasture.

‡ Sand, Silt, and Clay = 0.05-2.0, 0.002-0.05, <0.002 mm particle size separates, respectively; Fe$_d$ and Mn$_d$ = sodium dithionite extractable iron and manganese, respectively; Fe$_o$ and Mn$_o$ = acid ammonium oxalate extractable iron and manganese, respectively.

Table 5. Soil carbon pools for Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under six agroecosystems in the Tennessee Valley region of Alabama. Letters represent simple effects of agroecosystem. Values with different letters are significantly different at $\alpha = 0.05$.

Agroecosystem†	SOC‡	POC	MC	AC
	------------ g kg^{-1} ------------			mg kg^{-1}
	0 – 5 cm			
Conv Ct	8.9 D	3.4 D	5.9 D	389 C
NT Ct-Crn	16.3 C	7.8 C	8.9 C	683 BC
NT Ct-W-Soy	22.1 B	11.1 B	11.2 B	986 B
NT Ct w/C	25.7 B	12.2 B	11.5 B	791 B
NT Ct	16.3 C	7.1 C	9.3 C	661 BC
Pasture	43.2 A	21.3 A	20.3 A	1761 A
ANOVA	------------------------ P > F ----------------------------			
Agroecosystem (A)	< 0.001	< 0.001	< 0.001	< 0.001
	5 – 15 cm			
Conv Ct	7.2 C	1.6 B	5.6 B	329 B
NT Ct-Crn	7.5 C	1.9 B	5.6 B	318 B
NT Ct-W-Soy	9.0 B	2.4 B	6.7 B	355 B
NT Ct w/C	9.1 B	2.5 B	6.7 B	338 B
NT Ct	7.6 BC	1.5 B	6.2 B	270 B
Pasture	15.0 A	4.4 A	10.7 A	533 A
ANOVA	---------------------- P > F -------------------------			
(A)	< 0.001	0.002	0.004	0.005
	15 – 30 cm			
Conv Ct	5.1 C	0.8	4.3 B	122 B
NT Ct-Crn	5.5 BC	0.9	4.6 B	176 A
NT Ct-W-Soy	6.0 B	0.9	5.2 B	191 A
NT Ct w/C	6.2 B	1.2	5.1 B	164 A
NT Ct	6.0 B	0.9	5.2 B	173 A
Pasture	7.3 A	1.3	6.9 A	199 A
ANOVA	---------------------- P > F -------------------------			
(A)	< 0.001	0.165	0.005	0.009
	30 – 50 cm			
Conv Ct	3.3 B	0.3	3.0	-
NT Ct-Crn	3.6 B	0.5	3.2	-
NT Ct-W-Soy	3.8 B	0.6	3.3	-
NT Ct w/C	3.7 B	0.5	3.3	-
NT Ct	3.8 B	0.5	3.4	-
Pasture	5.1 A	0.8	4.4	-
ANOVA	---------------------- P > F -------------------------			
(A)	0.011	0.217	0.318	-

†Conv Ct = conventional tillage cotton; NT Ct-Crn = no-till cotton-corn; NT Ct-W-Soy = no-till cotton-wheat-soybean; NT Ct w/C = no-till cotton with wheat cover; NT Ct = no-till cotton; Pasture = grazed pasture.

‡ SOC = soil organic carbon; POC = particulate (> 53 µm) organic carbon; MC = mineral associated (< 53 µm) carbon; AC = active soil organic carbon.

Table 6. Soil ion exchange properties for Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under three agroecosystems in the Tennessee Valley region of Alabama. Letters represent simple effects of agroecosystem. Values with different letters are significantly different at α = 0.05.

Agroecosystem†	pH‡	PZC	--- CEC ---			--- AEC ---	
			5§	6	7	5	6
	------------------- $\mathrm{cmol_c\ kg^{-1}}$ --------------------						
	0 – 5 cm						
Conv Ct	6.70	5.96	5.70	7.09	8.6 B	0.07	0.05
NT Ct w/C	6.39	5.89	11.42	12.65	12.5 B	0.11	0.04
Pasture	6.34	6.12	12.44	14.13	17.6 A	0.00	0.00
ANOVA	------------------------ P > F -------------------------						
Agroecosystem (A)		0.494	0.074	0.052	0.017	0.140	0.335
	5 – 15 cm						
Conv Ct	6.56	5.67	5.48	6.88	8.2	0.11	0.07
NT Ct w/C	5.90	4.92	4.94	6.01	8.5	0.06	0.05
Pasture	5.85	5.38	6.80	7.85	10.9	0.01	0.00
ANOVA	------------------------ P > F -------------------------						
(A)		0.106	0.094	0.210	0.080	0.202	0.228
	15 – 30 cm						
Conv Ct	6.12	5.26	5.49	6.55	8.7	0.21	0.13
NT Ct w/C	5.97	4.82	4.61	5.34	8.2	0.07	0.03
Pasture	5.82	5.44	6.75	7.56	9.8	0.07	0.00
ANOVA	------------------------ P > F -------------------------						
(A)		0.136	0.144	0.244	0.075	0.221	0.194

†Conv Ct = conventional tillage cotton; NT Ct w/C = no-till cotton with wheat cover; NT Ct = no-till cotton; Pasture = grazed pasture.

‡ pH = soil pH in 1:10 soil:0.1 *M* $\mathrm{CaCl_2}$ (w:v); PZC= point of zero charge (CEC=AEC); CEC and AEC = cation exchange capacity and anion exchange capacity, respectively.

§ 5, 6, and 7 = range of pH for CEC and AEC; CEC at pH 7 = cation exchange capacity using ammonium acetate (pH 7)

Table 7. Mehlich-1 extractable nutrients and potassium chloride extractable aluminum for Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under six agroecosystems in the Tennessee Valley region of Alabama. Letters represent simple effects of agroecosystem. Values with different letters are significantly different at $\alpha = 0.05$.

Agroecosystem†	Ca‡	K	Mg	P	Al
	------------- mg kg^{-1} -------------				cmol$_c$ kg^{-1}
	0 – 5 cm				
Conv Ct	478	49	14 B	9 BC	0.04
NT Ct-Crn	679	49	53 A	9 C	-
NT Ct-W-Soy	823	43	32 AB	8 C	-
NT Ct w/C	813	48	21 B	14 A	0.05
NT Ct	692	54	19 B	13 AB	-
Pasture	792	56	52 A	6 C	0.06
ANOVA	-------------------------- P > F ---------------------------				
Agroecosystem (A)	0.072	0.494	0.020	0.016	0.393
	5 – 15 cm				
Conv Ct	373	32	13 B	4 A	0.02
NT Ct-Crn	303	27	30 A	2 B	-
NT Ct-W-Soy	334	26	24 A	2 B	-
NT Ct w/C	306	30	11 B	3 AB	0.02
NT Ct	335	32	12 B	3 AB	-
Pasture	330	35	26 A	2 B	0.03
ANOVA	-------------------------- P > F ---------------------------				
(A)	0.236	0.921	0.007	0.044	0.293
	15 – 30 cm				
Conv Ct	292	14	11 B	2	0.02
NT Ct-Crn	272	14	17 A	2	-
NT Ct-W-Soy	260	16	17 A	2	-
NT Ct w/C	266	17	9 B	2	0.03
NT Ct	274	20	10 B	2	-
Pasture	265	26	18 A	1	0.02
ANOVA	-------------------------- P > F ---------------------------				
(A)	0.771	0.679	0.014	0.073	0.621
	30 – 50 cm				
Conv Ct	251	8	12 B	1 B	-
NT Ct-Crn	265	9	13 B	0 B	-
NT Ct-W-Soy	281	9	14 AB	0 B	-
NT Ct w/C	262	12	11 B	0 B	-
NT Ct	263	12	13 B	0 B	-
Pasture	253	15	17 A	1 A	-
ANOVA	-------------------------- P > F ---------------------------				
(A)	0.853	0.681	0.027	0.008	-

†Conv Ct = conventional tillage cotton; NT Ct-Crn = no-till cotton-corn; NT Ct-W-Soy = no-till cotton-wheat-soybean; NT Ct w/C = no-till cotton with wheat cover; NT Ct = no-till cotton; Pasture = grazed pasture.

‡ Ca, K, Mg, and P = Mehlich-1 extractable calcium, potassium, magnesium, and phosphorus, respectively; Al = potassium chloride extractable aluminum.

Table 8. Pearson linear correlation coefficients relating soil organic carbon pools, mineralogy, and select soil chemical properties for six combined agroecosystems for the surface (0-5 cm) and pooled across all depths. Values represent significant linear correlation coefficients at $\alpha = 0.05$.

	Surface (0-5 cm)															
	SOC†	AC	POC	MC	Fe$_d$	pH	Ca	K	Mg	P	PZC	CEC$_5$	CEC$_6$	CEC$_7$	AEC$_5$	AEC$_6$
SOC	-															
AC	0.90	-														
POC	0.95	0.89	-													
MC	0.98	0.88	0.92	-												
Fe$_d$	0.54	0.48	0.46	0.62	-											
pH	-0.48	ns	ns	-0.54	ns	-										
Ca	0.55	0.62	0.63	0.57	ns	ns	-									
K	ns	ns	ns	ns	0.50	ns	0.52	-								
Mg	0.48	0.53	0.52	0.48	0.54	ns	0.46	ns	-							
P	ns	-0.47	ns	ns	ns	ns	ns	0.51	ns	-						
PZC	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-					
CEC$_5$	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-				
CEC$_6$	ns	ns	ns	0.68	ns	ns	ns	ns	ns	ns	ns	1.00	-			
CEC$_7$	0.98	0.93	0.89	0.99	0.88	-0.92	0.84	ns	0.92	ns	ns	ns	ns	-		
AEC$_5$	ns	ns	ns	ns	ns	ns	ns	ns	0.72	ns	ns	ns	ns	ns	-	
AEC$_6$	ns	ns	ns	ns	ns	ns	ns	ns	0.71	ns	ns	ns	ns	ns	1.00	-

	Pooled across all depths															
	SOC	AC	POC	MC	Fe$_d$	pH	Ca	K	Mg	P	PZC	CEC$_5$	CEC$_6$	CEC$_7$	AEC$_5$	AEC$_6$
SOC	-															
AC	0.95	-														
POC	0.97	0.94	-													
MC	0.97	0.91	0.91	-												
Fe$_d$	ns	ns	ns	ns	-											
pH	0.32	ns	0.36	0.29	-0.32	-										
Ca	0.81	0.81	0.87	0.77	-0.24	0.57	-									
K	0.68	0.61	0.65	0.71	ns	0.48	0.71	-								
Mg	0.63	0.65	0.66	0.63	ns	0.38	0.59	0.55	-							
P	0.61	0.43	0.63	0.59	ns	0.54	0.79	0.76	0.35	-						
PZC	0.52	0.51	0.58	0.45	ns	0.68	0.73	ns	0.48	0.43	-					
CEC$_5$	0.74	0.71	0.75	0.73	ns	ns	0.74	ns	0.64	ns	0.48	-				
CEC$_6$	0.76	0.73	0.77	0.74	ns	ns	0.77	0.39	0.66	0.39	0.52	0.99	-			
CEC$_7$	0.95	0.92	0.89	0.96	ns	ns	0.79	0.60	0.94	ns	0.48	0.69	0.70	-		
AEC$_5$	0.50	0.51	0.50	0.50	ns	ns	0.45	ns	0.55	ns	0.46	ns	ns	0.51	-	
AEC$_6$	ns	ns	ns	ns	ns	ns	ns	ns	0.41	ns	0.42	ns	ns	ns	0.94	-

† SOC = soil organic carbon (g kg^{-1}); AC = active soil organic carbon (mg kg^{-1}); POC = particulate (>53 μm) organic carbon (g kg^{-1}); MC = mineral (< 53 μm) associated carbon (g kg^{-1}); Fe$_d$ = sodium dithionite extractable iron (% solid), respectively; pH = pH in 1:1 soil:water (w:v); Ca, K, Mg, and P = Mehlich I extractable calcium, potassium, magnesium, and phosphorus (mg kg^{-1}), respectively; PZC= point of zero charge (pH); CEC$_5$, CEC$_6$, AEC$_5$, and AEC$_6$ = cation exchange capacity at pH 5 and 6 and anion exchange capacity at pH 5 and 6 (cmol$_c$ kg^{-1}), respectively. CEC$_7$ = cation exchange capacity using ammonium acetate (pH 7) (cmol$_c$ kg^{-1}).

Table 9. Soil physical properties for Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under six agroecosystems in the Tennessee Valley region of Alabama. Letters represent simple effects of agroecosystem. Values with different letters are significantly different at $\alpha = 0.05$.

Agroecosystem†	ρ_b‡	WSA	WDC	WCR	PL	LL	PI
	g cm^{-3}	--------------- % ----------------			-------- g g^{-1} --------		
				0 – 5 cm			
Conv Ct	1.27 B	84 CD	17.4 A	75 A	22 CD	34 C	12
NT Ct-Crn	1.40 A	93 ABC	13.8 B	62 BC	19 D	29 D	10
NT Ct-W-Soy	1.25 B	93 AB	13.7 B	65 B	25 BC	38 B	13
NT Ct w/C	1.25 B	90 BCD	11.6 BC	59 C	26 B	37 B	11
NT Ct	1.31 AB	83 D	14.5 B	67 B	20 D	33 C	12
Pasture	0.95 C	97 A	10.2 C	58 C	35 A	49 A	14
ANOVA				P > F			
Agroecosystem (A)	< 0.001	0.003	0.002	0.001	< 0.001	< 0.001	0.067
				5 – 15 cm			
Conv Ct	1.42 C	93	20.7	82 A	18	31 B	12
NT Ct-Crn	1.62 A	97	19.3	74 B	19	31 B	12
NT Ct-W-Soy	1.59 AB	95	18.1	72 BC	19	32 B	13
NT Ct w/C	1.57 B	94	16.6	68 C	19	33 B	13
NT Ct	1.61 AB	91	17.7	70 BC	18	32 B	13
Pasture	1.45 C	97	18.5	69 BC	22	38 A	16
ANOVA				P > F			
(A)	< 0.001	0.102	0.071	0.002	0.072	< 0.001	0.090
				15 – 30 cm			
Conv Ct	1.56 AB	-	21.8	72	18 B	34	16
NT Ct-Crn	1.55 AB	-	19.9	68	19 B	35	16
NT Ct-W-Soy	1.56 A	-	20.4	72	19 B	35	16
NT Ct w/C	1.56 AB	-	18.8	70	18 B	32	14
NT Ct	1.53 B	-	18.1	68	18 B	33	15
Pasture	1.44 C	-	24.9	66	23 A	42	19
ANOVA				P > F			
(A)	< 0.001	-	0.277	0.489	0.001	0.054	0.326
				30 – 50 cm			
Conv Ct	1.52 A	-	3.9	9	25	51	26
NT Ct-Crn	1.50 A	-	3.7	8	25	53	27
NT Ct-W-Soy	1.50 A	-	6.8	17	24	48	24
NT Ct w/C	1.53 A	-	5.6	14	24	48	23
NT Ct	1.52 A	-	8.0	20	22	47	25
Pasture	1.47 B	-	9.0	27	24	48	24
ANOVA				P > F			
(A)	0.006	-	0.574	0.372	0.380	0.409	0.787

†Conv Ct = conventional tillage cotton; NT Ct-Crn = no-till cotton-corn; NT Ct-W-Soy = no-till cotton-wheat-soybean; NT Ct w/C = no-till cotton with wheat cover; NT Ct = no-till cotton; Pasture = grazed pasture.

‡ ρ_b = bulk density; WSA= water stable aggregates; WDC= water dispersible clay; WCR= dispersible clay ratio (WDC:clay); PL, LL, and PI = Atterberg limits (plastic limit, liquid limit, and plastic index, respectively).

Table 10. Pearson linear correlation coefficients relating soil organic carbon pools, mineralogy, and select soil physical properties for six combined agroecosystems for the surface (0-5 cm) and pooled across all depths for Tennessee Valley Paleudults. Values are significant linear correlation coefficients at $\alpha = 0.05$.

Surface (0-5 cm)													
	SOC	AC	POC	MC	Clay	Fe$_d$	Mn$_d$	ρ_b	WSA	WDC	PL	LL	PI
SOC	-												
AC	0.90	-											
POC	0.95	0.89	-										
MC	0.98	0.88	0.92	-									
Clay	-0.56	ns	-0.63	-0.54	-								
Fed	0.54	0.48	0.46	0.62	ns	-							
Mnd	-0.74	-0.71	-0.72	-0.74	ns	ns	-						
ρ_b	-0.66	-0.60	-0.62	-0.67	ns	ns	0.78	-					
WSA	0.39	0.51	0.55	0.54	ns	ns	-0.58	-0.49	-				
WDC	-0.63	-0.46	-0.75	-0.56	0.85	ns	ns	ns	ns	-			
PL	0.95	0.81	0.89	0.95	-0.59	0.54	-0.76	-0.70	0.54	-0.63	-		
LL	0.97	0.87	0.92	0.98	-0.59	0.52	-0.73	-0.66	0.55	-0.59	0.95	-	
PI	0.43	0.51	0.43	0.47	ns	ns	ns	ns	ns	ns	ns	0.52	-

Pooled across all depths													
	SOC	AC	POC	MC	Clay	Fe$_d$	Mn$_d$	ρ_b	WSA	WDC	PL	LL	PI
SOC	-												
AC	0.95	-											
POC	0.97	0.94	-										
MC	0.97	0.91	0.91	-									
Clay	-0.60	-0.54	-0.57	-0.65	-								
Fe$_d$	ns	ns	ns	ns	0.39	-							
Mn$_d$	-0.36	-0.33	-0.32	-0.41	-0.32	-0.28	-						
ρ_b	-0.80	-0.77	-0.81	-0.75	0.39	ns	0.41	-					
WSA	ns	ns	ns	ns	ns	ns	-0.37	ns	-				
WDC	ns	-0.59	ns	ns	-0.36	0.28	ns	ns	ns	-			
PL	0.62	0.83	0.62	0.55	ns	ns	-0.50	-0.61	ns	-0.50	-		
LL	ns	0.61	ns	ns	0.71	0.37	-0.70	ns	ns	-0.62	0.64	-	
PI	0.42	ns	-0.38	-0.48	0.88	0.45	0.25	0.25	ns	-0.48	0.21	0.85	-

† SOC = soil organic carbon (g kg^{-1}); AC = active soil organic carbon (mg kg^{-1}); POC = particulate (>53 µm) organic carbon (g kg^{-1}); MC = mineral (< 53 µm) associated carbon (g kg^{-1}); Clay = <0.002 mm particle size separate (%); Fe$_d$ and Mn$_d$ = sodium dithionite extractable iron and manganese (% solid), respectively; ρ_b = bulk density (g cm^{-3}); WSA= water stable aggregates (%); WDC= water dispersible clay (%); PL, LL, and PI = Atterberg limits (plastic limit, liquid limit, and plastic index, respectively) (%).

Table 11. Analyses of water stable aggregate separates for the surface (0-5 cm) of Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under three agroecosystems in the Tennessee Valley region of Alabama. Agroecosystems represent high (pasture), intermediate (no-till cotton with winter wheat cover), and low (conventional cotton) soil organic carbon content.

Stable Fraction†	SOC‡		Fe_d§	
	slake§	stable	slake	stable
%	------ g kg^{-1} ------		--------% Solid--------	
80	12.6	18.9	1.70	1.60
	------------- P > t -------------			
	< 0.001		0.797	

† Stable fraction = fraction of aggregates stable in water.

‡ SOC = soil organic carbon.

§ Fe_d = DCB extractable iron.

¶ slake and stable = portions of aggregates that were not stable and stable in water, respectively.

Figures

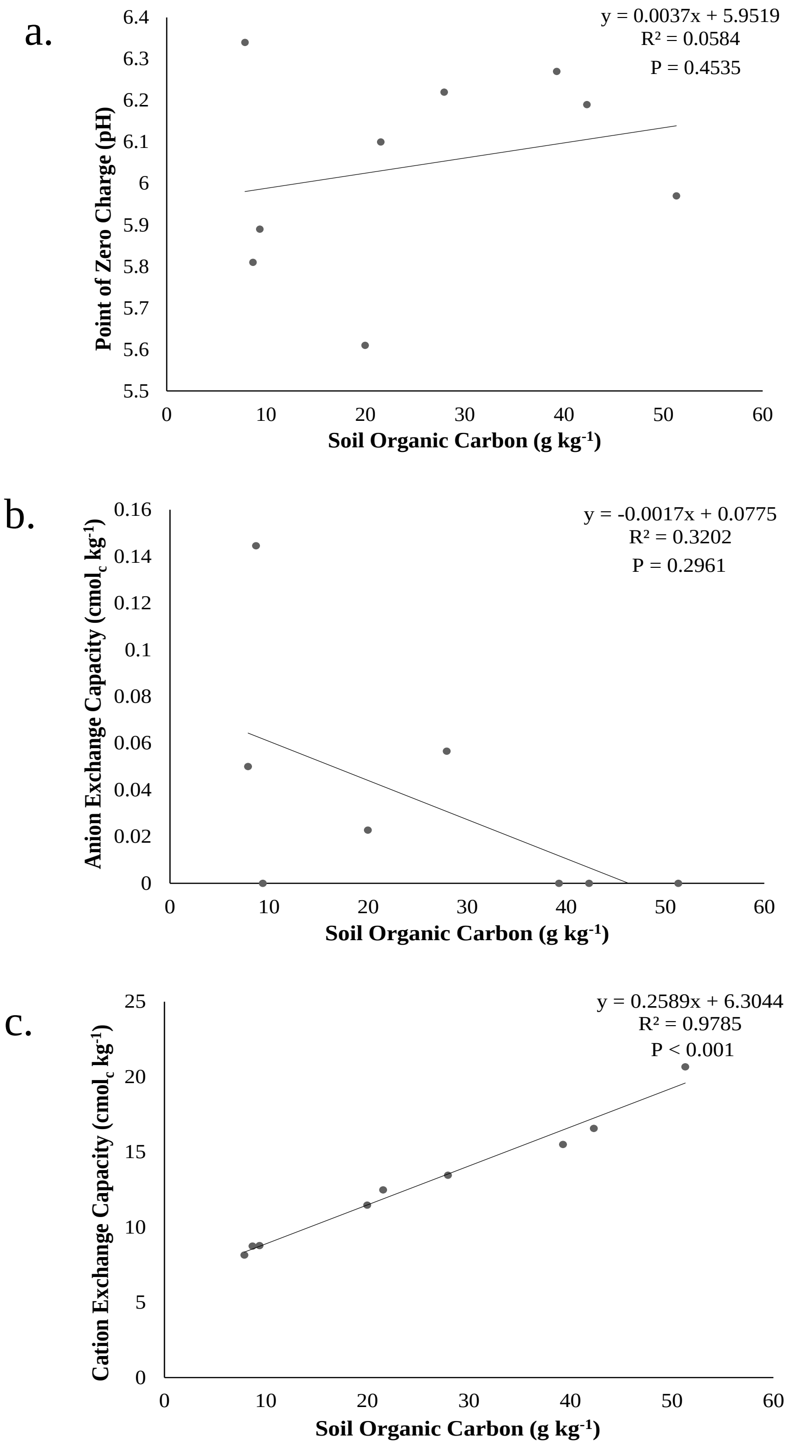

Figure 4. Relationships between select soil chemical properties and soil organic carbon for the surface (0-5 cm) of Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under three agroecosystems: a) point of zero charge; b) anion exchange capacity at pH 5; and c) cation exchange capacity at pH 7.

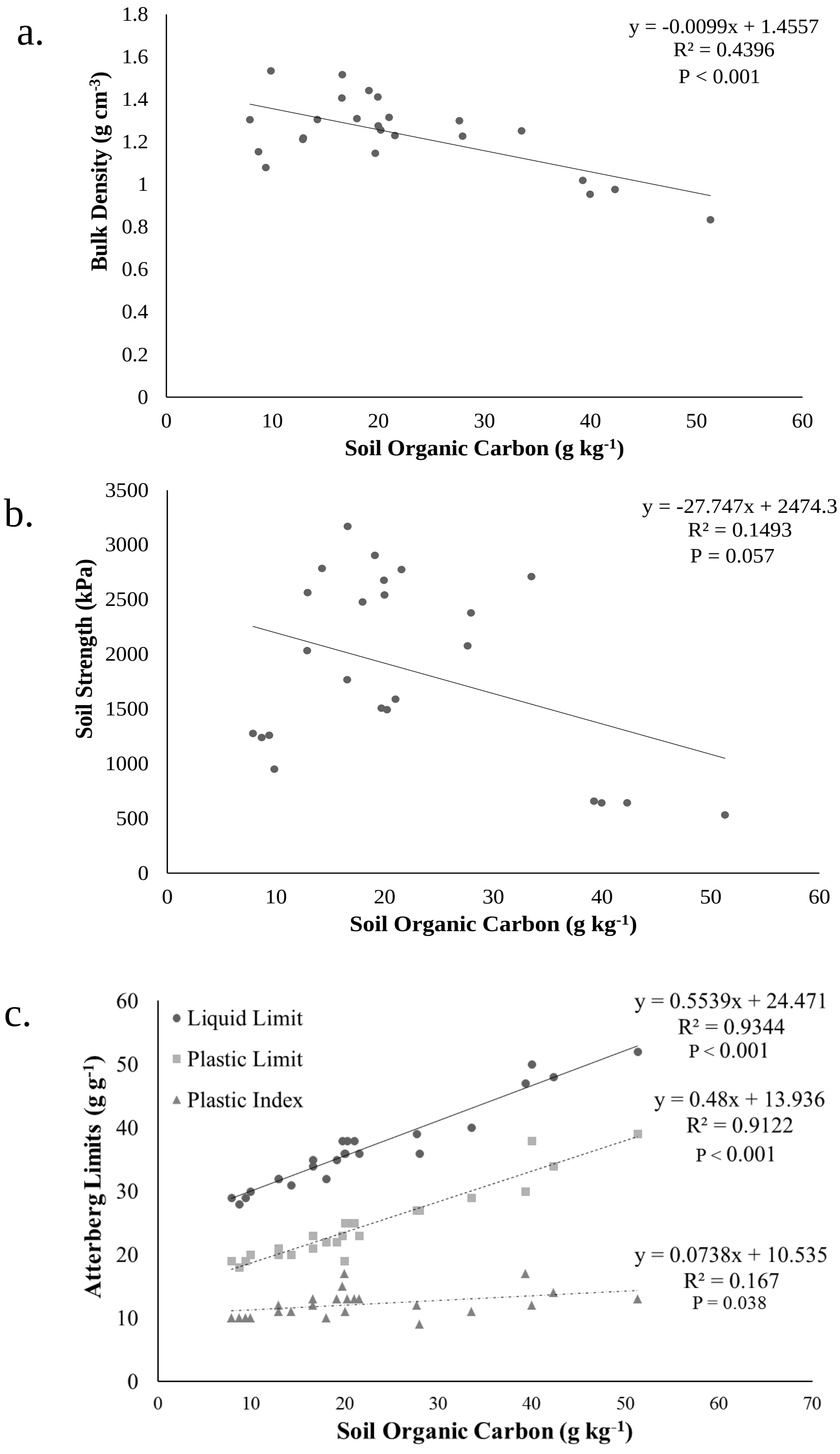

Figure 5. Relationships between select soil physical properties and soil organic carbon for the surface (0-5 cm) of Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under six agroecosystems: a) bulk density; b) soil strength; and c) Atterberg limits (LL, PL, PI are the liquid limit, plastic limit, and plasticity index, respectively).

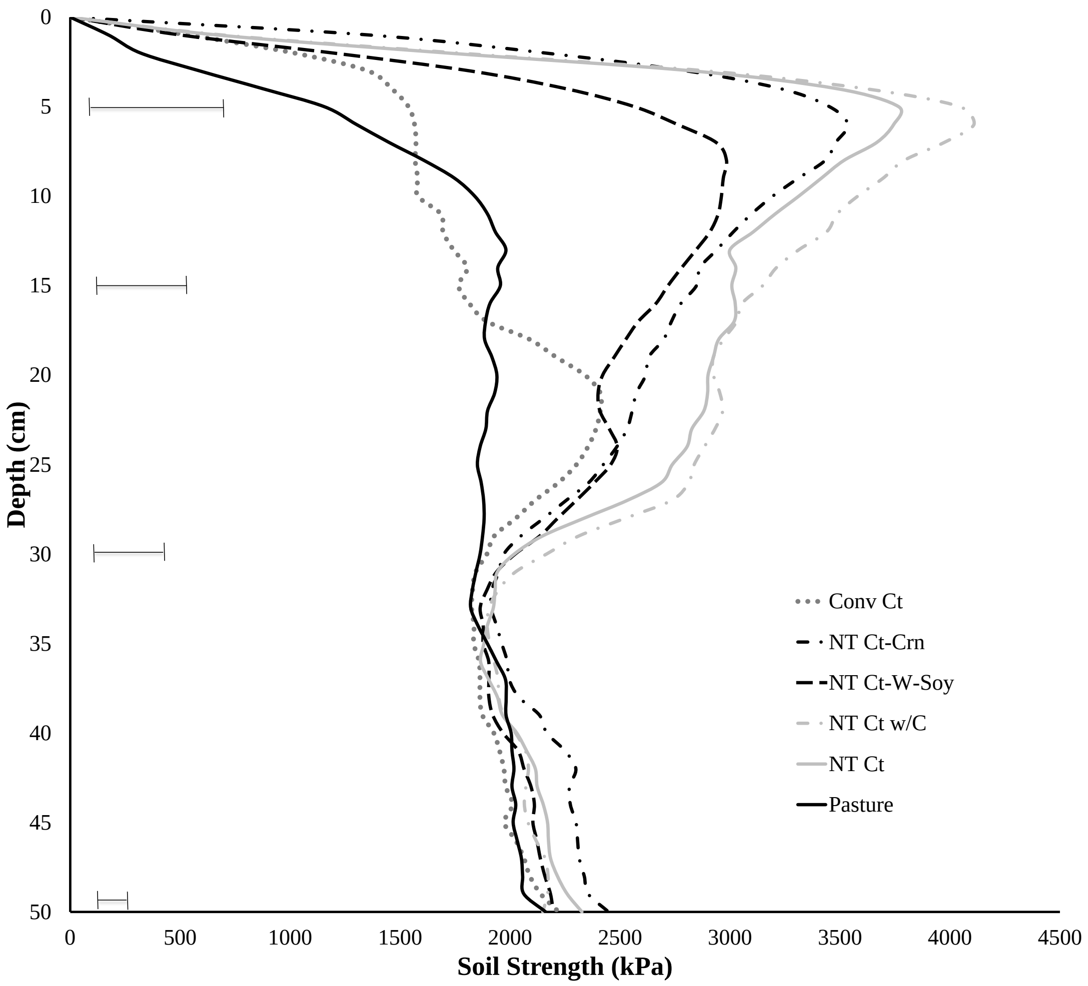

Figure 6. Soil strength (0-50 cm) for Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under six agroecosystems in the Tennessee Valley region of Alabama. Bars represent Fisher's LSD at α = 0.05. Conv Ct = conventional tillage cotton, NT Ct-Crn = no-till cotton-corn rotation, NT Ct-W-Soy = no-till cotton-wheat-soybean rotation, NT Ct w/C = no-till with wheat cover crop, NT Ct = no-till cotton, Pasture = grazed pasture.

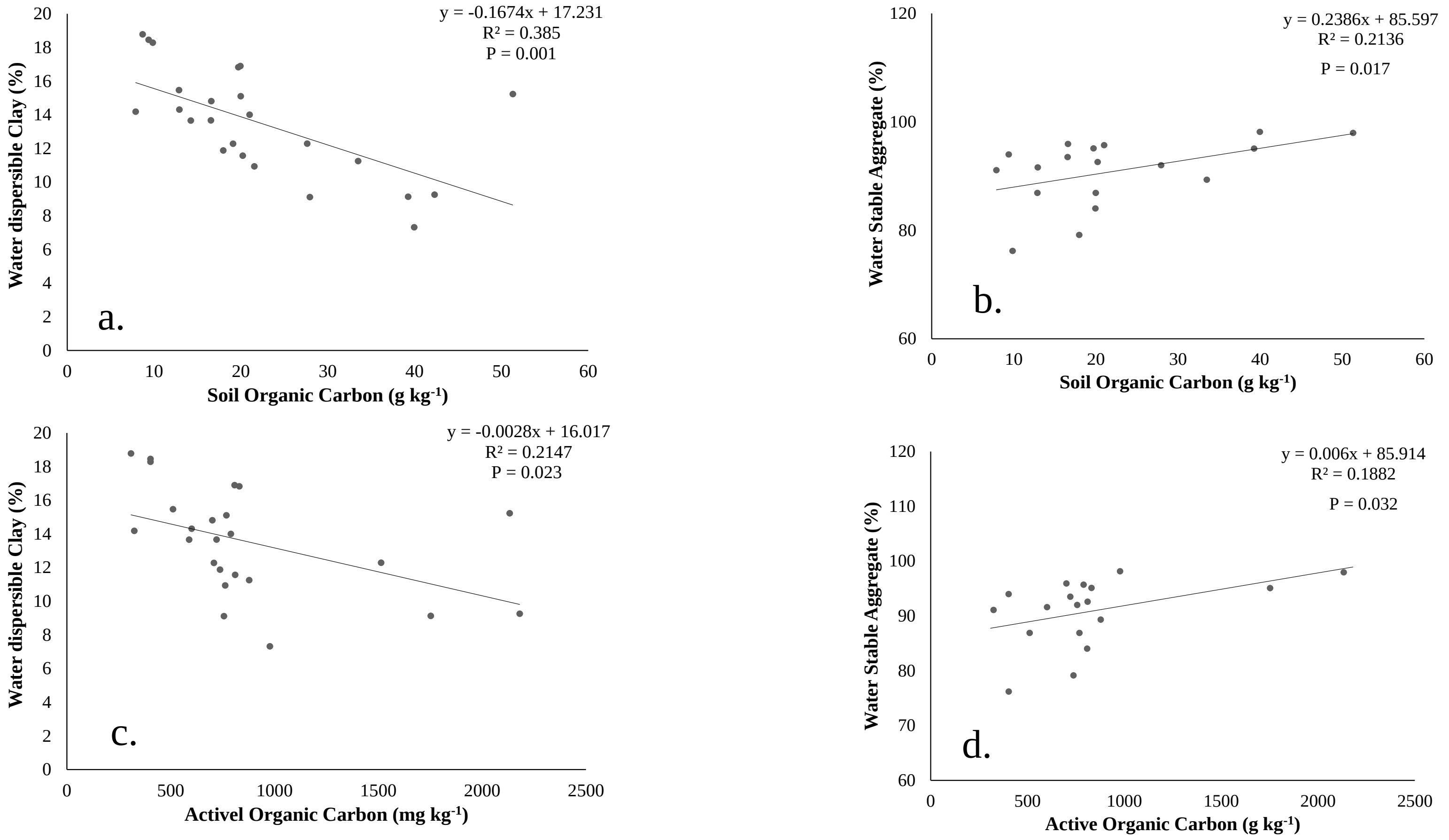

Figure 7. Relationships between: a) water dispersible clay and soil organic carbon; b) water dispersible clay and active organic carbon; c) water stable aggregates and soil organic carbon; and d) water stable aggregates and active organic carbon for the surface (0-5 cm) of Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under six agroecosystems.

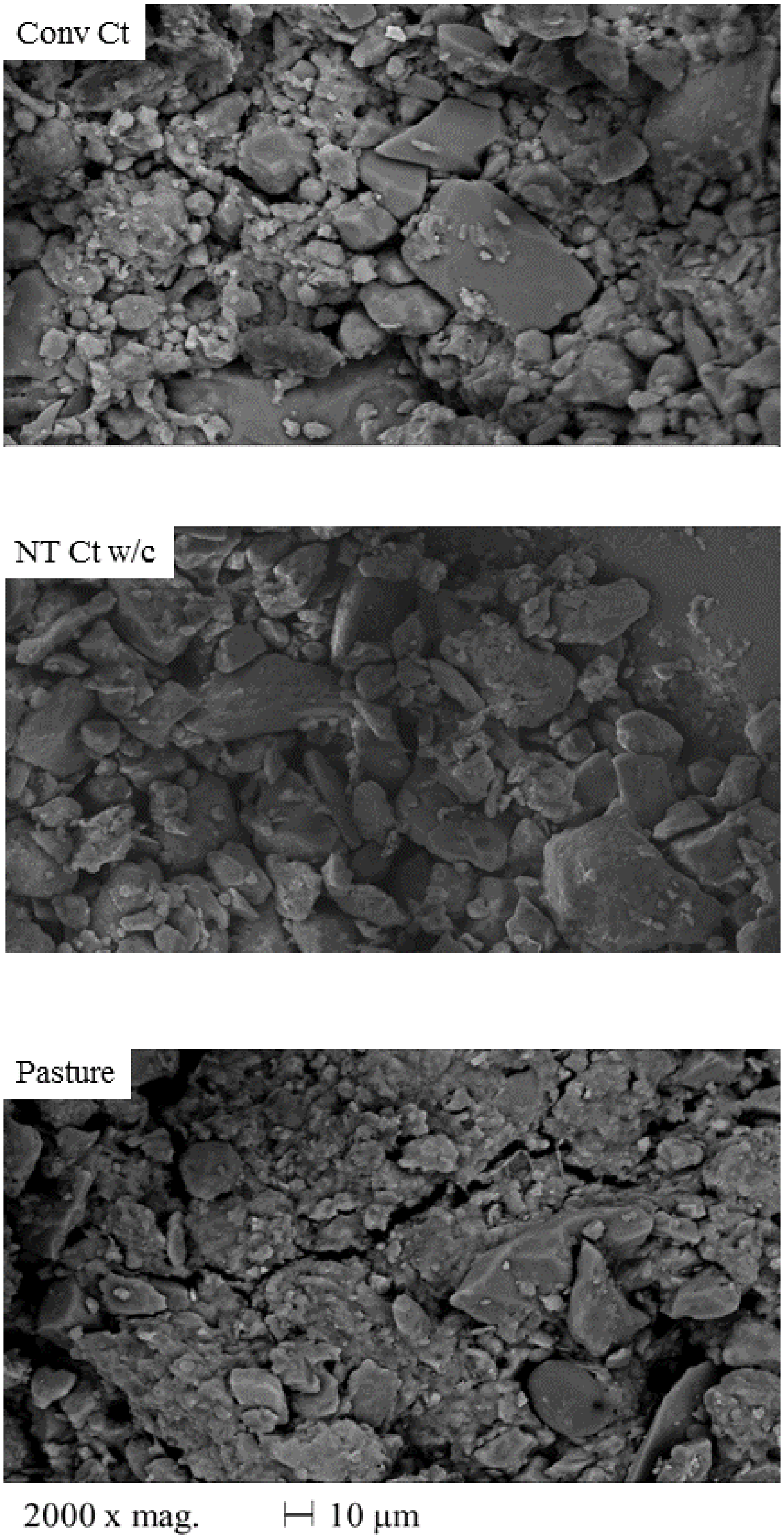

Figure 8. Scanning electron microscope images of surface (0-5 cm) soil aggregates (1-2 mm) for Decatur soils (Fine, kaolinitic, thermic Rhodic Paleudult) under three agroecosystems at 2000x magnification using back scatter imaging. Conv Ct = conventional cotton; Nt Ct w/c = no till cotton with wheat cover crop; Pasture = grazed pasture. Bar = 10 µm.

IV. Appendix

Soil Description; S10AL-083-2 (Tennessee Valley Research and Extension Center, Cotton Systems Rotation), Limestone County, Alabama, March 15, 2010.

Ap -- 0 to 24 centimeters; dark reddish brown (5YR 3/4) silt loam; weak medium granular structure; friable; slightly acid (pH 6.11).

BA -- 24 to 39 cm; dark reddish brown (2.5YR 3/4) silty clay loam; weak medium subangular blocky structure; friable; slightly acid (pH 6.09).

Bt1 -- 39 to 70 cm; dark red (2.5YR 3/6) silty clay; moderate medium subangular blocky structure; friable; common faint clay films on ped faces; moderatly acid (pH 5.67).

Bt2 -- 70 to 115 cm; dark red (2.5YR 3/6) clay; moderate medium subangular blocky structure; friable; common distinct clay films on ped faces; common fine manganese nodules; extremely acid (pH 4.43).

Bt3 -- 115 to 149 cm; dark red (2.5YR 3/6) clay; moderate medium subangular blocky structure; friable; common distinct clay films on ped faces; common fine manganese nodules; extremely acid (pH 4.22).

Bt4 -- 149 to 181+ cm; dark red (2.5YR 3/6) clay; moderate medium subangular blocky structure; friable; common distinct clay films on ped faces; common fine manganese nodules; extremely acid (pH 4.23).

Table 12. Pedon S10AL-083-2 (cotton rotation) soil characterization data from a pedon sampled at the Tennessee Valley Research and Extension Center, Limestone County, Alabama.

Sample	Horizon	Lower Depth	Particle Size Distribution†			Sand Size Distribution‡					pH§	
			Sand	Silt	Clay	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	H_2O	$CaCl_2$
		cm	------------------------------- % < 2 mm soil -----------------------------------									
S10AL-083-2-1	Ap	24	12	64	24	0	1	2	5	3	6.1	5.8
S10AL-083-2-2	BA	39	9	53	38	0	1	1	4	3	6.1	5.8
S10AL-083-2-3	Bt1	70	10	43	47	0	2	2	4	2	5. 7	5.5
S10AL-083-2-4	Bt2	115	10	37	53	1	1	1	4	3	4.4	4.1
S10AL-083-2-5	Bt3	149	11	33	57	0	1	2	5	3	4.2	5.9
S10AL-083-2-6	Bt4	181+	11	30	59	1	1	2	5	3	4.2	3.8

Sample	Horizon	Lower Depth	Base Saturation¶	Exchangeable Cations#							Cation Exchange Capacity††	
			NH_4OAc	Ca	Mg	K	Na	Al	CEC-7	ECEC	CEC-7	ECEC
		cm	-------- % -------	-------------------- $cmol_c$ kg $soil^{-1}$ --------------------							--- $cmol_c$ kg $clay^{-1}$ ---	
S10AL-083-2-1	Ap	24	77.7	5.9	0.6	0.6	0.2	0.1	9.4	7.3	38.5	30.1
S10AL-083-2-2	BA	39	66.0	5.6	0.7	0.3	0.1	0.0	10.2	6.8	26.9	17.8
S10AL-083-2-3	Bt1	70	63.4	6.0	1.0	0.2	0.1	0.0	11.6	7.4	24.6	15.6
S10AL-083-2-4	Bt2	115	35.3	2.6	0.9	0.2	0.1	2.1	10.7	5.9	20.1	11.1
S10AL-083-2-5	Bt3	149	22.5	1.4	0.7	0.2	0.2	3.3	10.8	5.8	19.0	10.1
S10AL-083-2-6	Bt4	181+	13.1	0.7	0.5	0.1	0.1	4.0	10.8	5.4	18.4	9.3

† Particle size distribution: Sand, Silt, Clay = 0.05-2.0, 0.002-0.05, <0.002 mm particle size separates.

‡ Sand size distribution: 2.0-1.0, 1.0-0.5, 0.5-0.25, 0.25-0.1, 0.1-0.05 mm sand size separates.

§ pH = H_2O and CaCl pH in 1:1 soil:water (w:v) and pH in 1:2 Soil:0.01 N Calcium chloride solution (w:v), respectively.

¶Base saturation: NH_4OA = extracted with 1.0 M ammonium acetate (pH 7.0).

Exchangable cations: (Ca, Mg, K, Na) = ammonium acetate extractable calcium, magnesium, potassium, and sodium; Al = potassium chloride extractable aluminum.

†† Cation Exchange Capacity: CEC-7 and ECEC = cation exchange capacity and effective cation exchange capacity, respectively, extracted using ammonium acetate (pH 7.0).

Soil Description; S10AL-083-4 (Tennessee Valley Research and Extension Center, Pasture), Limestone County, Alabama, March 15, 2010.

Ap1 -- 0 to 5 centimeters; dark reddish brown (5YR 3/4) silt loam; weak medium granular structure; friable; strongly acid (pH 5.31).

Ap2 -- 5 to 22 centimeters; dark reddish brown (5YR 3/4) silty clay loam; weak medium granular structure; friable; strongly acid (pH 5.49).

BA -- 22 to 31 cm; dark reddish brown (2.5YR 3/4) silty clay; weak medium subangular blocky structure; friable; moderately acid (pH 5.96).

Bt1 -- 31 to 62 cm; dark red (2.5YR 3/6) clay; moderate medium subangular blocky structure; friable; common faint clay films on ped faces; slightly acid (pH 6.13).

Bt2 -- 62 to 89 cm; dark red (2.5YR 3/6) clay; moderate medium subangular blocky structure; friable; common distinct clay films on ped faces; many fine manganese nodules; slightly acid (pH 6.08).

Bt3 -- 89 to 120 cm; dark red (2.5YR 3/6) clay; moderate medium subangular blocky structure; friable; common distinct clay films on ped faces; many fine manganese nodules; very strongly acid (pH 4.61).

Bt4 -- 120 to 148 cm; dark red (10R 3/6) clay; moderate medium subangular blocky structure; friable; common distinct clay films on ped faces; many fine manganese nodules; very strongly acid (pH 4.46).

Bt5 -- 148 to 175+ cm; dark red (10R 3/6) clay; moderate medium subangular blocky structure; friable; common distinct clay films on ped faces; many fine manganese nodules; extremely acid (pH 4.24).

Table 13. Pedon S10AL-083-4 (pasture) soil characterization data from a pedon sampled at the Tennessee Valley Research and Extension Center, Limestone County, Alabama.

Sample	Horizon	Lower Depth	Particle Size Distribution†			Sand Size Distribution‡					pH§	
			Sand	Silt	Clay	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	H_2O	$CaCl_2$
		cm	---------------------------------- % < 2 mm soil ----------------------------------									
S10AL-083-4-1	Ap1	5	18	56	25	1	2	4	7	4	5.3	5.0
S10AL-083-4-2	Ap2	22	15	53	33	0	1	4	7	3	5.5	5.2
S10AL-083-4-3	BA	31	10	42	49	1	1	2	4	2	6.0	5.6
S10AL-083-4-4	Bt1	62	9	36	55	1	1	1	4	3	6.1	5.9
S10AL-083-4-5	Bt2	89	10	38	52	1	1	1	5	3	6.1	5.9
S10AL-083-4-6	Bt3	120	9	35	56	0	1	2	5	2	4.6	4.2
S10AL-083-4-7	Bt4	148	9	28	63	1	1	1	4	3	4.5	3.9
S10AL-083-4-8	Bt5	175+	9	22	69	1	1	1	4	3	4.2	3.9

Sample	Horizon	Lower Depth	Base Saturation¶	Exchangeable Cations#					Cation Exchange Capacity††			
			NH_4OAc	Ca	Mg	K	Na	Al	CEC-7	ECEC	CEC-7	ECEC
		cm	-------- % -------	--------------------- $cmol_c$ kg $soil^{-1}$ --------------------							--- $cmol_c$ kg $clay^{-1}$ ---	
S10AL-083-4-1	Ap1	5	65.0	6.9	1.1	0.9	0.2	6.9	14.0	9.1	55.0	36.0
S10AL-083-4-2	Ap2	22	68.5	6.5	1.0	0.6	0.1	6.5	12.1	8.3	36.4	25.4
S10AL-083-4-3	BA	31	68.2	7.1	1.1	0.3	0.1	7.1	12.5	8.6	25.8	17.6
S10AL-083-4-4	Bt1	62	74.2	7.2	1.1	0.2	0.2	7.2	11.7	8. 7	21.4	15.9
S10AL-083-4-5	Bt2	89	69.7	5.9	1.2	0.2	0.1	5.9	10.6	7.4	20.3	14.2
S10AL-083-4-6	Bt3	120	41.8	2.7	1.2	0.1	0.2	2.9	10.0	6.1	17.9	11.0
S10AL-083-4-7	Bt4	148	24.2	1.3	1.0	0.1	0.2	1.3	10.7	6.0	16.9	10.0
S10AL-083-4-8	Bt5	175+	19.7	0.6	0.9	0.1	0.5	0.6	10.9	6.2	15.7	9.0

† Particle size distribution: Sand, Silt, Clay = 0.05-2.0, 0.002-0.05, <0.002 mm particle size separates.

‡ Sand size distribution: 2.0-1.0, 1.0-0.5, 0.5-0.25, 0.25-0.1, 0.1-0.05 mm sand size separates.

§ pH = H_2O and CaCl pH in 1:1 soil:water (w:v) and pH in 1:2 Soil:0.01 N Calcium chloride solution (w:v), respectively.

¶Base saturation: NH_4OA = extracted with 1.0 M ammonium acetate (pH 7.0).

Exchangable cations: (Ca, Mg, K, Na) = ammonium acetate extractable calcium, magnesium, potassium, and sodium; Al = potassium chloride extractable aluminum.

†† Cation Exchange Capacity: CEC-7 and ECEC = cation exchange capacity and effective cation exchange capacity, respectively, extracted using ammonium acetate (pH 7.0).