Conservation System Impacts on Soil Properties and Water-Use Efficiency in the Southeastern U.S. Coastal Plain

by

Kelsey Lynn Hoegenauer

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Approved by

Julie A. Howe, Chair, Associate Professor of Crop, Soil and Environmental Sciences
Kipling S. Balkcom, Affiliate Associate Professor of Crop, Soil and Environmental Sciences
Elizabeth A. Guertal, Professor of Crop, Soil and Environmental Sciences
Joey Shaw, Alumni Professor of Crop, Soil and Environmental Sciences

Abstract

Conservation practices, such as cover cropping, crop rotation, and conservation tillage, have become an integral part in improving and sustaining cropping systems in the Coastal Plain region of the southeastern U.S., where soil quality is degrading and crop productivity is declining due to intensive tillage and row crop production on highly erodible soils. Planting winter cover crops instead of leaving row crop fields fallow can decrease erosion, increase water infiltration, and improve soil quality by adding organic matter. This study was conducted in the southeastern U.S. Coastal Plain region on a Dothan fine sandy loam to analyze soil properties and crop water-use efficiency as affected by conservation systems. The first objective of this study was to evaluate the effects of long-term (>20 years) cover cropping with oat (*Avena sativa* L.), rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), and fallow treatments and short-term (<1 year) cover cropping with oat, crimson clover (*Trifolium incarnatum* L.), oat/rye mixture, and fallow treatments on soil macroporosity, bulk density, saturated hydraulic conductivity (Ksat), and carbon (C), nitrogen (N), phosphorus (P), and sulfur (S) distributions. Soil under oat and rye had significantly higher Ksat values than soil under fallow. When data from the two trials were compared, Ksat in soils under oat was significantly higher in the short-term trial than in the long-term trial. Differences in Ksat between trials were likely due to differences in soil management of the two areas. The presence of oat, rye, and wheat cover crops increased total soil C and N in the top 0- to 5-cm depth over the fallow treatment in the long-term trial, which indicates that cover crops can improve C and N storage in Coastal Plain soils at the surface layer over time. Soil P and S were not affected by cover crop species or duration of cover cropping. Other farming practices in the Coastal Plain region have also impacted soil and crop properties. Farmers in the region have frequently used the traditional rotation (TR), which includes peanut (*Arachis hypogaea* L.) rotated with cotton (*Gossypium hirsutum* L.) and intensive tillage with a moldboard plow (MP). Since this system facilitates the degradation of soil quality through increased erosion and loss of organic matter, a sod-based rotation (SBR) with the use of conservation strip tillage (ST) was investigated. The SBR implemented two years of bahiagrass (*Paspalum notatum* Flueggé) into the peanut-cotton rotation, which decreased disease, improved soil quality, and increased peanut yields. The second objective of this study was to analyze the effects of crop rotation (SBR and TR) and tillage (ST and MP) on yield and water-use efficiency (WUE) of peanut and cotton in the Coastal Plain region. Cotton yield did not differ by rotation or tillage, while peanut yield was highest in the sod-based rotation under strip tillage and lowest in the traditional rotation under strip tillage and moldboard plow tillage. Rotation and tillage did not affect WUE in peanut or cotton, suggesting that WUE did not influence the increase in peanut yield in the sod-based rotation. However, it can be concluded that the sod-based rotation, especially managed with strip tillage, can significantly improve peanut yield compared to the traditional rotation.

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CT	Computed Tomography
Ksat	Saturated Hydraulic Conductivity
MP	Moldboard Plow
SBR	Sod-based Rotation
SLA	Specific Leaf Area
SPAD	Soil and Plant Analysis Development
ST	Strip Tillage
TR	Traditional Rotation
WUE	Water-use Efficiency

I. LITERATURE REVIEW

INTRODUCTION

Modern agriculture faces a great challenge of producing more food on less land with fewer resources for a growing global population. Conservation agriculture is becoming an instrumental part of restoring and preserving natural resources without sacrificing crop yield. Refining the management of conservation practices such as crop rotation, conservation tillage, and cover crops is critical in maximizing the environmental and economic benefits.

Evaluation of traditional and conservation practices is needed in the Coastal Plain region of southeast Alabama where the climate is warm and humid and the soil is prone to erosion and nutrient loss (Schomberg et al., 2006). Traditional production methods include a peanut (*Arachis hypogaea* L.) -cotton (*Gossypium hirsutum* L.) rotation and intensive tillage with a moldboard plow. This system continues to be productive in the Coastal Plain region; however, it contributes to the decline of soil quality over time (Katsvairo et al., 2006; Reeves, 1997). Conservation production practices, such as minimal tillage and cover cropping, are slowly being adopted to improve soil quality (Al-Kaisi et al., 2005; Cambardella and Elliott, 1993; Schomberg et al., 2006). Cover cropping reduces erosion, runoff, and nutrient leaching, and supplies organic matter to the soil, which improves the overall health and productivity of cropping systems (Blanco-Canqui et al., 2011; Dabney et al., 2001; Fae´ et al., 2009; Kuo et al., 1997; Reeves, 1997). In order to further improve conservation practices, the addition of two years of perennial grass, such as bahiagrass (*Paspalum notatum* Flueggé), to the peanut-cotton rotation has been proposed and is being evaluated. This sod-based rotation system was established on the premise that perennial grasses increase the biological diversity of a cropping system and can be advantageous to soil quality. Benefits of the sod-based rotation include improvements in pest and disease control, nutrient cycling, and crop yields (Brenneman et al., 1995; Brodie et al., 1970; Johnson et al., 1999; Katsvairo et al., 2007b; Rodríguez-Kábana et al., 1994; Sudini et al., 2011). Conservation tillage provides added benefits to cropping systems by conserving soil moisture and improving soil stability by reducing organic matter degradation and erosion (Katsvairo et al., 2006; Reeves, 1997). Research has revealed valuable benefits of conservation practices. However, farmers are often reluctant to implement such techniques due to social traditions, initial costs of establishment (e.g., new equipment), and the delay in observing benefits (Franzluebbers, 2007).

CONSERVATION AGRICULTURE

Cover Crops

Cover crops are planted when crop fields would normally lay fallow and are often terminated and retained as surface residue.   The living cover crop and its residue form a protective, semi-permeable layer on the soil surface (Dabney et al., 2001) that allows rainfall to enter but reduces evaporation from the soil surface. Cover crops are intended to reduce erosion and increase soil organic matter (Blanco-Canqui et al., 2011; Dabney et al., 2001). Soil loss and pollution of nearby water sources can be reduced through the use of cover crops (Dabney et al., 2001; Fae´ et al., 2009). The roots of cover crops anchor soil, particularly during the winter when soil is often left fallow. Vegetation and residue covering the soil surface reduces the impact and detachment of soil particles by rain drops (Dabney et al., 2001; Hillel, 1998).

Decayed cover crops contribute organic matter, which reinforces soil structure and improves infiltration, percolation, and water retention. In a study by Blanco-Canqui et al.

(2011), 15 years of sunn hemp (*Crotalaria juncea* L.) as a cover crop increased total water infiltration into a silt loam by 300%, compared to fallow soil. Organic matter is also a source of nutrients, as well as a site for nutrient retention. Degradation of residues and subsequent release of organic forms of N, S, and P enhance soil fertility and crop productivity (Bauer and Black, 1994; Blanco-Canqui et al., 2011; Hillel, 1998; Kuo et al., 1997; Reeves, 1997). In addition, soil organic matter is known for its high cation exchange capacity, which increases retention of cationic nutrients such as Ca, Mg, and K.

Crop Rotation

Monocropping systems deplete soil nutrients and contribute to pathogen and pest populations (Causarano et al., 2006; Jordan et al., 2002; Sudini et al., 2011). Crop rotation is intended to increase the diversity of a system in order to break disease and pest cycles and vary fertility demands of a soil (Katsvairo et al., 2006). Some rotations are simple and involve only two crops, such as the traditional rotation (TR) that is common in the southern Coastal Plain; however, rotations involving a perennial grass, such as the sod-based rotation (SBR) are being investigated to maximize the productivity and sustainability of peanut and cotton systems in the southeast U.S. Perennial grasses typically have large root biomasses that, along with their surface residue, contribute to soil organic matter. In addition, they break disease cycles (Brenneman et al., 1995; Brodie et al., 1970; Johnson et al., 1999; Rodríguez-Kábana et al., 1994; Sudini et al., 2011) and stimulate beneficial earthworm populations (Katsvairo et al., 2007a). Generally, row crop yields following perennial grasses are higher (Balkcom et al., 2007; Gates, 2003; Johnson et al., 1999; Katsvairo et al., 2007b). The sod based rotations system proposed for the southeastern U.S. rotates two consecutive years of bahiagrass followed by peanut and then cotton. Between crops, a mixture of oat (*Avena sativa* L.) and rye (*Secale cereale* L.) is grown as a cover crop each winter.

Bahiagrass is widely grown in the southeastern Coastal Plain region. It was selected for the sod based rotation because of its drought tolerance and adaptability to a variety of soil types (Katsvairo et al., 2006). Bahiagrass is effective in penetrating deep or compacted soil horizons and creating channels for subsequent crop roots through "biological drilling" (Cresswell and Kirkegaard, 1995; Katsvairo et al., 2007a). Plant roots are more likely to grow through existing macropores when they reach soil with high bulk density or restricting horizons (de Freitas et al., 1999). Deeper root systems improve utilization of nutrients and water in the soil (Katsvairo et al., 2009).

Conservation Tillage

Tillage is designed to invert the soil for reasons including the incorporation of crop residue, disruption of impermeable soil layers, and preparation of the seedbed (Addiscott and Dexter, 1994).   However, different tillage practices have varying consequences on soil structure, soil-water, nutrients, organic matter (Al-Kaisi et al., 2005; Kong et al., 2009), and crop yield (Balkcom et al., 2007; Campbell et al., 1984).   Conservation tillage includes tillage and or planting methods that maintains 30% cover from the previous crop as residue on the soil surface (Endale et al., 2002). The variety of tillage implements have increased greatly over the last several decades, allowing for a wide range of tillage intensities ranging from no-till to deep inversion.

Farmers have traditionally used a moldboard plow for intensive soil tillage. This is often the preferred tillage method due to the effectiveness in managing weed populations prior to crop establishment (Buhler, 1995). However, intensive tillage dries soil by increasing evaporation, reducing a plant's ability to withstand drought stress (Blevins et al., 1971; Hatfield et al., 2001). This technique also buries plant residues, which expedites organic matter decomposition (Al-Kaisi et al., 2005). Loss of organic matter results in greater soil loss through erosion and runoff, as well as reduction in soil quality through negative impacts on soil structure, nutrient retention, and water-holding capacity (Pikul and Zuzel, 1994).

Many agronomists encouraged farmers to transition to a conservation tillage system to combat the negative long-term effects of intensive tillage. Balkcom et al. (2007) concluded that transitioning from conventional tillage to strip tillage could benefit farmers by decreasing energy costs. The effects of conservation tillage on soil varied among tillage methods. Al-Kaisi et al. (2005) observed an increase in soil organic carbon and total nitrogen in soils under no-tillage compared with chisel plowing after 7 years in Iowa. In the southeastern Coastal Plain, soybean (*Glycine max* L.) grown under conservation tillage had yields greater than or equal to those of soybean grown under conventional tillage (Campbell et al., 1984). Despite the many benefits of conservation tillage over conventional tillage, farmers are reluctant to implement conservation tillage practices due to the relatively small yield advantage compared to the costs associated with purchase of new equipment and the possible increased reliance on herbicides for weed control in some systems (Buhler, 1995; Franzluebbers, 2007).

AGRICULTURE IN SOUTHEAST ALABAMA

Conservation practices must be refined and tailored for each agricultural region in order to be effective in improving the health and productivity of cropping systems. The climate, soil type, and crops grown influence which conservation practices are utilized and effective in a region. The Coastal Plain region in southeastern Alabama, for instance, supports a productive agriculture industry, where peanut and cotton are prominent agronomic crops. The soil type and climate of the Coastal Plain governs which conservation methods are needed to produce cotton and peanut sustainably.

One of the most common soil series in southeast Alabama is Dothan fine sandy loam (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults). Dothan soils are acidic in nature with an average pH of 5.3 to 5.6. The soil usually requires periodic addition of lime to raise the pH to a suitable range for peanut and cotton production. Dothan soils are well drained with moderate infiltration due to its coarse texture, but are often prone to erosion and nutrient leaching. Water and nutrient retention is limited in Coastal Plain soils. Organic matter content, which contributes to cation and water-holding capacity, is low in Coastal Plain soils, with values less than 1% (USDA-NRCS, 2012). Although the region receives an average 1140 to 1400 mm of rainfall each year, low water-holding capacities combined with warm annual air temperatures of 16 to 19C increases the demand for irrigation during droughts (USDA-NRCS, 2012). Root growth and water movement is often restricted by a hard pan layer around the 15 to 30 cm layer, which reduces nutrient and water acquisition from deeper horizons (Kashirad et al., 1967; USDA-NRCS, 2012). Chemical fertilizer and irrigation inputs are needed in order to maintain proper nutrient and moisture status for crop. Management practices such as cover crops, crop rotations, and conservation tillage are necessary to maintain or improve overall soil quality and productivity in southeast Alabama.

COVER CROPS

Cover Crop Effects on Macroporosity

Macropores are large, inter-aggregate pores that contribute to infiltration and rapid water flow within soil (Angers and Caron, 1998; Hillel, 1998). The precise definition of a macropore varies greatly within the literature (Beven and Germann, 1982). Jarvis (2007) defined macropores as pores with diameters greater than 0.3 to 0.5 mm, while McDonald (1967) classified macropores as having capillary potential > -6.0 kPA. Macropores include cracks from shrinking and swelling events, burrows constructed by soil fauna such as earthworms, and biopores created by plant roots (Beven and Germann, 1982). Cover crops affect macroporosity mainly through root growth and decay; however, this effect is not well established. Obi and Nnabude (1988) found that a *Panicum maximum* cover significantly increased macroporosity of a sandy loam soil compared to that of fallow soils. Conversely, a study by Wagger and Denton (1989) showed that macroporosity of a Goldsboro fine sandy loam (fine-loamy, siliceous, thermic Aquic Paleudults) was not significantly affected by cover treatments of wheat (*Triticum aestivum* L.), crimson clover (*Trifolium incarnatum* L.) and hairy vetch (*Vicia villosa* Roth.) in a no-tillage system.

Cover Crop Effects on Water Movement

In saturated soils, or during heavy rainfall events, water flows preferentially through macropores, bypassing the soil matrix (Beven and Germann, 1982). Soils with many macropores or a coarse texture generally move water more rapidly than fine-textured soils with a majority of micropores (Hillel, 1998; Shaw et al., 2000). Because cover crops affect macroporosity, they can influence water movement within a soil; however, the resulting effect on water movement by cover crops varies. Carof et al. (2007) observed an increase in macropores under cover crops (red fescue (*Festuca rubra L.*), bird's-foot trefoil (*Lotus corniculatus L.*), and alfalfa (*Medicago sativa L.*)), but no effect on saturated hydraulic conductivity. Steele et al. (2012) concluded that winter annual cereal crops increase water infiltration and hydraulic conductivity in the second growing season, but not the first. Cover crops also contribute to the creation of macropores indirectly by providing favorable conditions for burrowing soil fauna such as earthworms. In a study by Blanco-Canqui et al. (2011), sunn hemp plots had six times more earthworms than fallow plots, which correlated with an increase in water infiltration; the authors concluded that the increase in earthworm population created more macropores, resulting in greater water flow into the soil.

Cover Crop Effects on Nutrients

Root and plant residue can affect nutrient movement through the profile and cycling of nutrients (Fae´ et al., 2009; Sainju et al., 1998). Living cover crops sequester nutrients that would otherwise be unused, which diminishes nutrient loss via leaching (Dabney et al., 2001; Fae´ et al., 2009; Hillel, 1998). Leaching of NO_3–N can be reduced by 20 to 80% through the use of cover crops (Fageria et al., 2005). Kaspar et al. (2012) found that oat (*Avena sativa* L.) and rye (*Secale cereale* L.) significantly decreased NO_3–N concentration in drainage water by 26 and 48%, respectively. Sainju et al. (1998) concluded that cereal cover crops, such as rye, are more effective at scavenging excess nitrate than legume cover crops such as crimson clover or hairy vetch, possibly due to greater root growth and extension and greater demand for soil-based N than legumes. The authors also attributed the improved uptake of excess nitrate to the earlier planting date and greater shoot biomass of rye.

Decomposition of cover crop residue releases nutrients that are potentially available to subsequent crops. Legume cover crops, in particular, contribute significant quantities of N to following crops, which decreases chemical N fertilization requirements. In a study by Hargrove (1986), soil under legume cover crops contained 9 to 21 mg N kg^{-1} compared to 4 to 8 mg N kg^{-1} under fallow and rye; the author estimated that legume cover crops could conserve an average amount of 72 kg N fertilizer ha^{-1}. However, the effectiveness of nutrient cycling by cover crops depends largely on species due to varying C/N ratios. Cover crops with higher C/N ratios often immobilize N, making the nutrient unavailable for subsequent crops (Doran and Smith, 1991).

CROP ROTATION

Crop Rotation Effects on Yield and Diseases

Rotations using proper cropping sequences can often improve crop yields by breaking pest and disease cycles. The TR has been successful in increasing peanut yield in some studies (Causarano et al., 2006; Jordan et al., 2002). Rodríguez-Kábana et al. (1987) found that populations of *Meloidogyne arenaria* (root-knot nematode) were significantly reduced in the traditional peanut-cotton rotation, which improved peanut yields in the absence of nematacides. However, some studies did not see reduced infection with a peanut-cotton rotation, since some diseases and pests utilize peanut and cotton as hosts. For example, Leaf spot disease in peanut was not significantly reduced in a peanut-cotton rotation (Hagan et al., 2003). Tsigbey et al. (2007) also found that peanut in a peanut-cotton rotation experienced more thrip damage than peanut in a SBR.

Researchers have also seen an increase in subsequent row crop yields and decreased pest and disease infection when a perennial grass was used as a part of the rotation (Hagan et al., 2003; Karlen et al., 2006; Katsvairo et al., 2007a, 2007b). Peanut and cotton that were grown after at least two years of perennial grass produced greater yields than peanut and cotton grown in a peanut-cotton rotation (Gates, 2003; Hagan et al., 2003; Johnson et al., 1999; Tsigbey et al., 2007). Some researchers have attributed the increase in peanut and cotton yields to suppression of or protection from pests such as leaf spot, southern stem rot, root knot nematodes, and aflatoxin-producing fungi (Brenneman et al., 1995; Brodie et al., 1970; Gates, 2003; Hagan et al., 2003; Rodríguez-Kábana et al., 1994; Sudini et al., 2011). Peanut yield was 29 to 33% greater when grown after two years of bahiagrass, corn (*Zea mays* L.), and cotton (Johnson et al., 1999). Brodie et al. (1970) showed that nematode populations were reduced in bahiagrass rotations with corn and cotton as compared to bermudagrass (*Cynodon dactylon* (L.) Pers.) and monocropping systems. The reduction in nematode populations contributed to enhanced corn and cotton yields. Yield increases could also have resulted from improved nutrient availability. However, recent studies in the Coastal Plain region showed a plateau in cotton lint yields under the bahiagrass SBR, likely due to excess N uptake, which promoted more vegetative than reproductive growth (Katsvairo et al., 2007a; 2007b).

Crop Rotation Effects on Water and Nutrients

Integrating a perennial grass into a crop rotation can also affect available water and nutrients. Infiltration rates were higher in peanut and cotton following bahiagrass than in a traditional peanut-cotton rotation, especially in naturally compacted horizons in Florida (Katsvairo et al., 2007a). The authors concluded that improved infiltration rates were likely attributable to root pores and stabilized soil structure due to the perennial grass. Cotton grown after bahiagrass also had greater root biomass than cotton grown in the TR (Katsvairo et al., 2007b; 2009). Plants with deeper root systems were less prone to heat stress due to increased availability of water and nutrients (Katsvairo et al., 2006). Uptake of N, P, and K was improved in cotton in the SBR compared to the TR (Katsvairo et al., 2009), which was likely a result of higher amounts of nutrients released from bahiagrass residues and a more extensive cotton root system following bahiagrass.

Rotation systems also influenced water-use efficiency of crops. Zhao et al. (2008) found that water-use efficiency of peanut and cotton was greater in the SBR than in the TR over a span of 6 years, especially under non-irrigated conditions. A study by Varvel (1994) found that the water-use efficiency for corn was improved in rotation with soybeans or grain sorghum (*Sorghum bicolor* (L.) Moench), as compared to corn in a monocropping system.

CONSERVATION TILLAGE

Conservation Tillage Effects on Soil Quality

Organic matter, a key factor in soil quality, is greatly affected by conservation tillage practices. Cambardella and Elliot (1993) concluded that conservation tillage minimized organic matter loss and enhanced aggregate stability. Tillage practices also influence nutrient retention and cycling in soils. Retention of crop residue in a reduced tillage system provides a suitable environment for populations of soil fauna, such as earthworms, which are instrumental in bioturbation processes and macropore formation (Hangen et al., 2002). Earthworm populations increased in soil under a sod-based rotation as compared to populations in a peanut-cotton rotation (Katsvairo et al., 2007a).

Conservation tillage can reduce nutrient loss compared to conventional tillage due to a decreased rate of oxidation of organic nutrients, and diminished leaching losses (Linn and Doran, 1984; Power and Peterson, 1998). Power and Peterson (1998) illustrated that total N loss was lowest in no-till at 3% after 13 years, while total N loss increased to 8 and 19% under sub-till and moldboard plow tillage, respectively. However, the authors also observed greater N immobilization under no-till compared to moldboard plow and sub-till. Kong et al. (2009) found that minimum tillage improved stability of N in the soil, as well as the nitrogen use efficiency (NUE) of maize. However, some conservation tillage systems can decrease nutrient availability to crops. A study by Power and Peterson (1998) demonstrated that long-term use of no-till immobilized significant amounts of nutrients compared to sub-till and plow systems over the span of 13 years.

Water infiltration, retention, and efficiency have also been affected by the use of conservation tillage practices. Use of no-till increased volumetric water content to a depth of 60 cm and overall water-holding capacity compared to conventional tillage (Blevins et al., 1971). While no-till is a widely-used conservation practice, some tillage is necessary for certain soils. Siri-Prieto et al. (2007) found that only 36% of the water applied to a loamy sand under no-tillage entered the soil, whereas 83% of the water applied to the same soil in a paratill system infiltrated. No-till management of soil has also been shown to improve water-use efficiency of barley (*Hordeum vulgare* L.) and wheat in the northern Great Plains (Aase and Pikul, 1995).

Conservation Tillage Effects on Crop Yield

The use of conservation tillage often results in varying crop yield responses. Cotton yields increased by 192 kg ha^{-1} under strip-tillage compared to no-till on a Coastal Plain soil due to the increased amount of available water caused by the strip-tillage disrupting compacted layers (Schomberg et al., 2006). Soybeans in conservation tillage plots had yield greater than or equal to that under conventional tillage (Campbell et al., 1984). Enhanced water-holding capacity of a sandy loam soil under no-till improved cotton lint yield over conventional tillage in the Southeast U.S (Endale et al., 2002). However, a study in the Coastal Plain found that peanut yield was on average less under strip-tillage than under conventional tillage over the 4-year study (Balkcom et al., 2007). A study by Marois and Wright (2003) found that strip-tillage increased peanut yields over conventional tillage in a dry year only, indicating that weather conditions might influence the effectiveness of strip-tillage on improving crop yields.

WATER-USE EFFICIENCY

Crops need a sufficient supply of water in order to grow and develop. Irrigation is often extensively used to supplement water when rainfall is insufficient to meet the moisture needs of crops. Water is often a scarce and expensive resource, so optimizing plants' water-use efficiency (WUE) is an important agronomic challenge. Water-use efficiency is defined as the unit of water used by a plant per unit of dry matter or yield produced (Hatfield et al., 2001). The WUE of a plant can reflect the effectiveness of conservation management practices.

Factors Influencing WUE

Water-use efficiency is affected by soil and environmental conditions such as temperature, water deficit, and soil management practices. Craufurd et al. (1999) found that high average temperatures near 34°C resulted in reduced WUE in peanut, while water deficit improved WUE of peanut. However, Aase and Pikul (1995) suggested that increasing available water in the soil through reduced tillage practices can improve WUE. The amount of N supplied also impacts how water is used by plants. Shangguan et al. (2000) showed that high levels of N (15 mM nitrate solution) decreased the WUE of winter wheat to a greater extent than lower N rates (1.5 mM nitrate solution). Proper N rates, which optimize NUE and crop yield, can improve WUE (Hatfield et al., 2001). The WUE of corn in rotation was only slightly increased when N fertilizer was applied (Varvel, 1994). Improvements in WUE when fertilizer N is applied are likely due to greater crop biomass (Hatfield et al., 2001).

Methods of Estimating WUE

Estimation of WUE can be calculated by quantifying a plant's water use and yield; however, this method can be tedious and time-consuming. Researchers have studied rapid and accurate techniques for estimating WUE, including specific leaf area (SLA), chlorophyll content, and carbon isotopic ratios in plant material. Specific leaf area is the amount of leaf area (cm^2) per gram of leaf dry matter and indicates leaf thickness (Songsri et al., 2009). Photosynthetic capabilities are often higher in thicker leaves since chlorophyll tends to be denser than in thinner leaves (Craufurd et al., 1999). Specific leaf area can be used as an estimate of photosynthesis and WUE (Songsri et al., 2009). Several studies have concluded that SLA correlates negatively with WUE in peanut; therefore, the lower the SLA (the thicker the leaf), the higher the WUE (Craufurd et al., 1999; Nageswara Rao et al., 2001; Rowland et al., 2012; Songsri et al., 2009). Most research also indicates that the correlation between SLA and WUE can be strengthened by adjusting specific leaf area measurements for vapor pressure deficit and solar radiation (Nageswara Rao et al., 2001; Rowland et al., 2012).

Another useful estimation of photosynthesis and WUE is chlorophyll content measured by a soil and plant analysis development (SPAD) meter. The output is referred to as a SPAD chlorophyll meter reading since the chlorophyll measurement from this instrument is unitless (Nageswara Rao et al., 2001). Previous studies on peanut have determined that SPAD chlorophyll readings had a negative relationship with SLA, and a positive correlation with WUE

(Nageswara Rao et al., 2001; Rowland et al., 2012; Songsri et al., 2009). The negative correlation of SLA with WUE is consistent with the theory that thicker leaves are denser with chlorophyll, which provides a greater potential for increased photosynthesis (Craufurd et al., 1999).

The third and most expensive method for measuring WUE is the carbon isotopic ratio of plant tissue, which is represented by $\delta^{13}C$. The amount of each carbon isotope is determined by isotope ratio mass spectrometry and calculated from the following equation:

$$\delta^{13}C=[\frac{R_{sample}}{R_{standard}}]-1 \text{ x } 1000 \text{ ‰} \qquad [1]$$

The R_{sample} in equation 1 refers to the ratio of ^{13}C to ^{12}C of the plant sample, and $R_{standard}$ refers to the internationally recognized Vienna Pee Dee Belemnite standard ratio of ^{13}C to ^{12}C (Farquhar et al., 1982). Plants with C_3 pathways discriminate against $^{13}CO_2$ during CO_2 fixation, while there is less discrimination in the C_4 pathway (Farquhar et al., 1982; Farquhar and Richards, 1984). The $\delta^{13}C$ values for C_3 plant tissues are more negative than C_4 plant tissues, indicating the preference for ^{12}C (Craufurd et al., 1999; Rowland et al., 2012). Crops with less ^{13}C discrimination assimilate more carbon per unit of water taken up by the plant. It has been demonstrated that $\delta^{13}C$ positively correlates with WUE in crops such as wheat (Farquhar and Richards, 1984), cotton (Saranga et al., 1998), and peanut (Hubick et al., 1986).

OBJECTIVES

Evaluating the role of perennial grass rotations and conservation tillage on crop WUE is needed in understanding how water use contributes to peanut and cotton yield in a SBR. Specifically, research which estimates cotton and peanut WUE in the SBR and TR under strip tillage and moldboard plow tillage using SLA, SPAD chlorophyll readings, and carbon isotope ratios is lacking in the Coastal Plain region. There is little research evaluating differences among specific cover crops, and their effect on soil physical properties. More research is particularly needed to assess the influence of cover crop species and duration of cover cropping on nutrients, macroporosity and water movement within a Coastal Plain soil.

Therefore, the objectives of this study were to: 1) determine the contribution of winter crop species (crimson clover, wheat, oat, rye, oat/rye mixture, fallow) and duration of cover crop use on bulk density, macroporosity, saturated hydraulic conductivity, and nutrient distribution in a Coastal Plain soil, and, 2) evaluate the effect of crop rotation and tillage on yield and water use efficiency of peanut and cotton.

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II. INFLUENCE OF COVER CROPS ON SOIL AND WATER PROPERTIES IN A COASTAL PLAIN SOIL

ABSTRACT

Cover cropping has become an important conservation practice in Southeast Alabama, where soils are highly weathered and prone to erosion and nutrient loss. While cover crops have been shown to improve soil quality by decreasing erosion, contributing organic matter and increasing water infiltration, few studies have focused on cover crop effects on soil physical and chemical properties. This study evaluated soil physical properties (macroporosity, bulk density, and saturated hydraulic conductivity (Ksat)) and nutrient distributions (C, N, P, S) in a Dothan fine sandy loam (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) under long-term (> 20 years) and short-term (<1 year) cover cropping. Four cover crop treatments were included in the long-term trial: oat (*Avena sativa* L.), rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), and fallow. Short-term cover cropping included four cover crop treatments: oat, crimson clover (*Trifolium incarnatum* L.), oat/rye mixture, and fallow. The impact of each cover crop treatment on soil properties were evaluated in each trial. The only soil physical property significantly affected by cover crop treatment was saturated hydraulic conductivity in the long-term trial, where Ksat was greater in soil under rye and oat than under fallow. This indicates that long-term cover cropping with rye and oat can increase the rate of water movement through a saturated soil. In the long-term trial, cover crop treatment also impacted total soil N and C. At the 0- to 5-cm depth, both total soil N and C were higher under wheat, oat, and rye than under fallow. Since similar trends were not observed with inorganic N analyses, most of the N was most likely in the organic form. These results indicate that oat, rye and wheat cover crops improve N storage in this Coastal Plain soil at the surface layer over time. The influence of cover cropping duration

on soil properties was also evaluated by comparing results in the oat and fallow treatments of the long-term trial with those of the short-term trial. Soil NO_3–N increased under long-term fallow at the 30- to 60-cm depth, indicating that Coastal Plain soils continuously left bare in the winter for several years could be more susceptible to NO_3–N leaching.

INTRODUCTION

Most agronomic crops in the Coastal Plain region in the southeast U.S. are grown in the summer, leaving fields fallow during the winter. The sandy loam soils of the region are especially prone to degradation when left fallow. Fallow soils, especially with coarse textures and weak surface structure, are highly susceptible to wind and water erosion. Nutrient loss through leaching and erosion is also a concern with uncovered coarse soils. Conservation practices that cover the soil, such as cover crops, protect and reinforce soil structure, reduce nutrient loss, and improve soil quality by adding organic matter (Dabney et al., 2001). Detachment of soil particles is minimized as cover crops intercept raindrops and as roots anchor to soil aggregates (Hillel, 1998). Cover crops reduce nutrient leaching of by sequestering excess nutrients (Dabney et al., 2001; Fae´ et al., 2009; Fageria et al., 2005; Hillel, 1998; Kaspar et al., 2012). Decomposition of cover crop residue releases nutrients for subsequent crops and enhances soil quality by supplying organic matter (Bauer and Black, 1994; Blanco-Canqui et al., 2011; Kuo et al., 1997b; Reeves, 1997). Cover crops also have impacts on macroporosity, water movement, and nutrient distribution over time (Blanco-Canqui et al., 2011; Kaspar et al., 2012; Willoughby and Kladivko, 2002). Since cover crop species differ in root extension and biomass, it is necessary to evaluate the consequences of different species on soil, water, and nutrient properties.

Living and decayed cover crops impact soil macroporosity. Macropores are directly formed as cover crop roots grow and expand (Beven and Germann, 1982). Large pores remain in the soil after roots decompose. Earthworms, which thrive in soil where cover crops are grown, also create macropores while burrowing through the soil. Consequently, macroporosity is often increased in soils where cover crops are grown (Blanco-Canqui et al., 2011; Willoughby and Kladivko, 2002). Visual and quantitative evaluations of macroporosity can be determined rapidly in undisturbed soil cores using x-ray computed tomography (CT) (Luo et al., 2008). The technology produces two-dimensional grayscale images of cross-sectional slices. Each pixel in the image reflects the degree of x-ray absorbance by the medium, which is measured as attenuation coefficients (Anderson and Hopmans, 1994; Hounsfield, 1973). Attenuation coefficients, which have a positive correlation with atomic number and bulk density, are then used to determine the macroporosity of the soil sample (Anderson et al., 1990). Attenuation coefficients can be converted to Hounsfield units (HU), with reference attenuation coefficient values of 0 and -1000 HU for water and air, respectively. Macropores generally have an attenuation coefficient of less than 1200 HU (Anderson and Hopmans, 1994).

Macropores also have potential to impact water movement in the soil by facilitating preferential or bypass flow, especially in saturated conditions when rainfall or irrigation intensity is high. Because cover crops often affect macroporosity, it is necessary to investigate the impacts of cover crops on saturated hydraulic conductivity. Although macropores often impact water movement in saturated soils, field studies of cover crop influence on macroporosity and saturated hydraulic conductivity have varied. Cover crops (sunn hemp (*Crotalaria juncea* L.), hairy vetch (*Vicia villosa* Roth.), and soybean ((*Glycine max* L.)) increased macroporosity but had no effect on saturated hydraulic conductivity after 15 years in a study by Blanco-Canqui et al. (2011). In a similar study, rye did not improve water infiltration and hydraulic conductivity until the second growing season (Steele et al., 2012).

Cover crops also influence nutrient loss and availability for subsequent crops. During periods that fields are usually fallow, soil nutrients are prone to leaching and runoff. Cover crops minimize nutrient losses and maintain soil fertility by scavenging and recycling nutrients (Dabney et al., 2001; Fae´ et al., 2009; Hillel, 1998). In a study by Kaspar et al. (2012), oat and rye reduced nitrate leaching by 26 and 48%, respectively. The sequestered nutrients are released after decomposition of cover crops. Hargrove (1986) found that legume cover crops supplied 9 to 21 mg N kg^{-1}, which could save a farmer an estimated 72 kg N fertilizer ha^{-1} yr^{-1} for sorghum under no-till management.

Cover crops are known to reduce erosion, increase infiltration, and reduce nutrient loss. However, the effects of different cover crop species and duration of cover crop use on macroporosity, saturated hydraulic conductivity, and nutrients in a Coastal Plain soil are largely unknown. Macroporosity and saturated hydraulic conductivity are useful in assessing how water and nutrients move in a soil. Evaluating major soil nutrients at various depths may provide insight into the cycling and movement of nutrients over time under cover crops. The objective of this study was to determine the contribution of cover crop species (crimson clover, wheat, oat, rye, oat/rye mixture, fallow) and duration of cover crop use on bulk density, macroporosity, saturated hydraulic conductivity, and nutrient distribution in a Coastal Plain soil.

MATERIALS AND METHODS

Experimental Design

Plots for this study were located at the Wiregrass Research and Extension Center in Headland, AL (31°30'N, 85°17'W). Two trials were evaluated to compare systems with different durations of cover crop influence. The first trial was established 20 years ago. Plots were arranged in a randomized complete block design with four replications of four cover crop treatments: oat, rye, wheat, and fallow. A ryegrass (*Lolium multiflorum* L.) cover crop was included for the first 10 years of this trial but was not included in the past 10 years. Cover crops were planted on December 14, 2012 using a no-till drill. The cover crop plots were a component of an existing rotation study, in which peanut and cotton are grown after cover crop termination. To make treatments and experimental designs comparable, only plots that were planted in peanut in summer 2012 (and planted in cotton in 2013) were selected for sampling. Fallow plots were disked, subsoiled to a depth of 30 to 36 cm, and rolled prior to summer crop planting. Plots under cover crops were subsoiled to a depth of 30 to 36 cm with a strip-tillage rig before summer crop planting. All plots received 45 kg N ha^{-1} and 7 kg S ha^{-1} on January 24, 2013, as well as, 34 kg N ha^{-1} and 5 kg S ha^{-1} on March 8, 2013 (Table 2-1).

The second trial was established in 2013 at the same location. Soil was subsoiled to a depth of 30 to 36 cm before planting cover crops on January 15, 2013 (Table 2-1). Treatments were arranged in a randomized complete block design with four replications of seven treatments: oat, rye, oat/rye mixture, crimson clover, wheat, annual ryegrass, and fallow. Although seven cover crop treatments were established in this experiment, data from only the oat, oat/rye mixture, crimson clover, and fallow treatments were analyzed due to limitations in extracting sufficient soil cores from treatment plots. Soil for both trials were classified as a Dothan sandy loam (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults). All plots were irrigated and received best management practices appropriate for the area. Plots were fertilized with 33.6 kg N ha^{-1} on February 6, 2013.

Field Methods

Prior to cover crop termination, soil cores 5.1 cm in diameter and 90 cm long were extracted in triplicate from each plot in both trials in May 2013 using a truck-mounted Giddings probe (Giddings Machine Company, Windsor, CO). Samples were collected at random locations from each plot to a maximum depth of 90 cm, avoiding tire and irrigation tracks. Styrofoam packing peanuts were packed in the void areas of the cores between the soil surface and caps to minimize soil disturbance during transport. Cores were transported and stored in an upright position at room temperature until scanned using x-ray computed tomography (CT).

Shortly after soil core extraction, Ksat readings were obtained in triplicate from each plot using a compact constant head permeameter (Ksat, Inc., Raleigh, N.C.) in May 2013. The methods of Amoozegar and Warrick (1986) were used, whereby a hole was created using a bucket auger to a desired depth (20 cm). Permeameter reservoirs were filled with water and calibrated according to the water height desired in the auger hole. The desired height of water in the hole for this study was 5 cm below the surface of the soil or 15 cm from the bottom of the auger hole. Water was allowed to flow from the permeameter to the auger hole until steady-state flow at the designated height was achieved. Water flowed continuously into each auger hole for 9 min, and the change in water level in the permeameter was recorded every 3 min to determine the flow rate. Three flow rates were averaged to obtain a mean flow rate per hole. The Ksat for each auger hole was then calculated using the Glover solution (Zanger, 1953), as shown by equations 1 and 2, where the coefficient, A, is multiplied by the mean flow rate, Q (m s^{-1}), and A is calculated using H, the desired height of water in the hole, and r, the radius of the hole.

$$Ksat = AQ \qquad [1]$$

$$A = \{\sinh^{-1}\left(\frac{H}{r}\right) - \left[\left(\frac{r}{H}\right)^2 + 1\right]^{\frac{1}{2}} + \left(\frac{r}{H}\right)\} \,/\, (2\pi H^2) \qquad [2]$$

The Ksat for the three replicates in each plot were averaged to obtain a mean Ksat value for each plot.

Laboratory Methods

Shortly after extraction (< 2 wks), cores were transported to the Auburn University Veterinary Diagnostic Laboratory for x-ray CT scanning. Cores were laid horizontally on the examination table, aligned by the soil surface, and scanned with 1 mm slices consecutively to a depth of 60 cm using a GE Highspeed CT/I scanner (GE, Cincinnati, OH). A maximum of 20 cores were scanned simultaneously with a contrast of 2500 x -125 cd m^{-2} at 120 kV and 120 mA. Scans were then evaluated for macroporosity and bulk density at 0- to 5-, 5- to 10-, and 10- to 15-cm depths using ERDAS Imagine (Intergraph Corp., Cobham, U.K.) and calibrated values. These values were previously obtained by scanning artificial cores comprised of loam, loam with 5% peat, and 100% peat. Drinking straws, coffee stirrers, lab tubing, and capillary tubing were placed in each artificial core to represent macropores (Prevatt, 2012). A grayscale ranging from -2000 to 2048 was used, where -2000 was the background fill value and the real data ranged from 0 to 2048. Pixels with grayscale values <72 and at least 1.1 mm were defined as macropores. Macroporosity was calculated as the percentage of total pixels that were classified as macropores. Values for macroporosity and bulk density for triplicate cores in each plot were averaged to obtain composite samples for each plot. Bulk density and macroporosity measurements were averaged for each depth increment in each plot to compare values.

Cores were then divided into 0- to 5-, 5- to 10-, 10- to 15-, 15- to 30-, and 30- to 60-cm interval depths. To evaluate the bulk density manually, soil samples were oven dried for 48 h at 60°C and weighed. Soils were ground with a mortar and pestle, before passing through a 2-mm sieve. Rock fragment weight and volume were recorded upon sieving. The core volume for each corresponding interval depth was determined, and the bulk density (g cm^{-3}) of each sample was calculated using equation 3:

$$\text{Bulk Density} = \frac{(\text{oven dry weight - rock fragment weight})}{(\text{core volume - rock fragment volume})} \qquad [3]$$

Soil samples underwent further processing in coffee grinders to obtain particle sizes (<1 mm) suitable for C and N analysis. Samples from each depth increment weighing approximately 20 mg were then evaluated for total C and N using dry combustion with a CN LECO 2000 analyzer (LECO Corp., St. Joseph, MI). Values were converted to Mg C ha^{-1} and Mg N ha^{-1} by multiplying the total C and N by the core bulk density and soil volume. Anion concentrations in each sample were determined by extracting 5 g of each sample with 20 mL of deionized water (Dick and Tabatabai, 1979; Tabatabai and Dick, 1983). Extracted solutions were analyzed for NO_3–N, PO_4–P, and SO_4–S using an ICS-3000 Ion Chromatography System (Dionex, Corp., Sunnyvale, CA). To evaluate NH_4–N at each depth, 5 g soil samples were extracted with 20 mL of 2 M KCl. Whatman no. 42 filter paper (GE Healthcare Ltd., Little Chalfont, UK) was rinsed with 2 M KCl and allowed to air dry to remove any NH_4–N present in the paper before filtering sample solutions. Procedures outlined in Sims et al. (1995) were used to analyze for NH_4–N.

Sample solutions were pipetted into microplate wells. Citrate (5 g L^{-1} trisodium citrate and 2 g L^{-1} sodium hydroxide), salicylate-nitroprusside (7.813 g L^{-1} sodium salicylate and 0.125 g L^{-1} sodium nitroprusside), and hypochlorite (1 g L^{-1} sodium (tribasic) phosphate, 2 mL 2 M sodium hydroxide, and 10 mL 6% hypochlorite bleach) reagents and 2 M KCl were added to each well, stirred, and allowed to develop color for 30 min. A spectrophotometer with a microplate reader (Bio Tek FLx800, Bio Tek Instruments, Inc., Winooski, VT) was used to evaluate NH_4^+–N at 695 nm.

Data Analysis

Data were analyzed in SAS® PROC MIXED using mixed models. Both trials were analyzed individually with block considered as a random effect. Cover crop, depth, and the interactions between these two variables were considered fixed effects. The oat and fallow treatments of the long-term trial were also compared with the oat and fallow treatments of the short-term trial at each increment depth by the same analytical method. For the comparison, blocks was considered a random effect, and trial, depth, cover crop, and all interactions among or between the variables were fixed effects. Repeated measures were used to account for depth increments. Depth was excluded in the analysis of Ksat since all Ksat measurements were taken at one depth only. Akaike's Information Criterion (AIC) was used to select the best-fit model for each response variable. Differences among or between variables were considered significant at α=0.05.

RESULTS & DISCUSSION

Bulk Density

Bulk density as determined by the core and CT method was not significantly affected by cover crop treatment in either trial. This is consistent with the findings of Wagger and Denton (1989) who found that bulk density was not impacted by cover crops. The average core bulk density of all cover crop treatments in the long-term trial increased consistently with increasing depth from 1.04 g cm^{-3} in the 0- to 5-cm depth to 1.49 g cm^{-3} in the 30- to 60-cm depth (Figure 2-1). The value in the 0- to 5-cm depth is lower than the 1.31 g cm^{-3} measured by Balkcom et al. (2013) at the 0- to 5-cm depth in a fine sandy loam. However, bulk density in the 30- to 60-cm depth was similar to 1.51 g cm^{-3} measured at the 5- to 45-cm depths in the same study. In the short-term trial, mean core bulk density across all treatments did not exhibit a consistent trend, but increased significantly from 1.22 g cm^{-3} in the 0- to 5-cm depth to 1.33 and 1.34 g cm^{-3} in the 5- to 10- and 10- to 15-cm depths, respectively. Mean bulk density across all treatments in the short-term trial decreased slightly to 1.30 g cm^{-3} in the 15- to 30-cm depth before increasing to 1.35 g cm^{-3} in the 30- to 60-cm depth. This trend is similar to the trend observed by Gamble (2014) in the same soil type. The less consistent trend in the short-term trial is likely due to differences in management practices before the trial was established. When the oat and fallow treatments were compared in the two trials, core bulk density was higher in soil under short-term oat than under long-term oat at the 0- to 5-cm depth but lower than under long-term oat at the 30- to 60-cm depth (Table 2-2). Similar differences were observed in the fallow treatments, where core bulk density in soil under short-term fallow was greater than long-term fallow at the 0- to 5-cm depth but less than under long-term fallow at the 15- to 30- and 30- to 60-cm depths (Table 2-2).

The CT bulk density in the long-term trial increased consistently from 1.10 g cm^{-3} in the 0- to 5-cm to 1.32 g cm^{-3} in the 10- to 15-cm depth, while the CT bulk density in the short-term trial increased significantly only from the 0- to 5-cm depth to the 5- to 10-cm depth and remained constant in the 10- to 15-cm depth (Figure 2-2). Average CT bulk density of oat and fallow was greater under long-term than under short-term cover cropping at the 10- to 15-cm depth (Table 2-2). Since CT and core bulk density increased in lower depths under long-term oat and fallow, the change in bulk density was not likely attributable to cover cropping. Other factors such as local soil characteristics or long-term tillage practices may have resulted in these differences.

Bulk density methods were compared by plotting CT bulk densities against core bulk densities from the 0- to 5-cm, 5- to 10-cm, and 10- to 15-cm depths and formulating a best-fitting linear regression model (Figure 2-3). The data show a weak correlation between the two methods with an r^2 value of 0.26, which was not significant. Inconsistency between bulk density methods could have also arisen from error in aligning soil cores during CT scanning and human error in determining increment depths while cutting cores. The spread of points also reveals a greater variability among the core bulk densities than the CT bulk densities and most likely reflects disturbances caused during transportation and horizontal positioning of cores after CT scanning.

Macroporosity

Cover crop treatment did not influence macroporosity in either trial (Figure 2-4). This is similar to the findings of Wagger and Denton (1989), who did not observe differences in macroporosity in a fine sandy loam under wheat, crimson clover, and hairy vetch after 3 years.

Differences among cover crop treatments were likely not observed due to high variability in macroporosity, especially in the short-term trial. Mean macroporosity of all cover crop treatments decreased consistently from 4.2% in the 0- to 5-cm depth to 1.6% in the 10- to 15-cm depth in the long-term (Figure 2-4). In the short-term trial, macroporosity was highest in the 0- to 5-cm depth at 1.4% and lowest in the 5- to 10- and 10- to 15-cm depths at 0.8% and 0.6%, respectively. Macroporosity did not significantly differ between trials at any depth. These results are comparable to the average macroporosity of 1.14% measured by Prevatt, (2012) in a Dothan sandy loam. All macroporosity values were greater than the value of 0.005% in a sandy loam managed under rye (Buczko et al., 2006). Results in this study were likely different from the study by Buczko et al., (2006) due to differences in soil properties. Macroporosity in the long-term trial could have been affected by the tillage-like inversion of soil during peanut harvesting. Soil disturbance can disrupt existing macropores and also produce more non-continuous macropores in the form of cracks (Beven and Germann, 1982).

Saturated Hydraulic Conductivity

Cover crops significantly influenced saturated hydraulic conductivity at 20 cm in the long-term trial but not in the short-term trial. This is comparable to the findings of Keisling et al. (1994) who observed an increase in Ksat in silt loam and loam soils under rye, hairy vetch, and crimson clover after 17 years of cover cropping. Soil under rye and oat treatments in the long-term trial had a significantly higher Ksat (5.10×10^{-5} m s^{-1}) than under fallow, which had the lowest Ksat at 2.60×10^{-5} m s^{-1}. Soil under wheat had an average Ksat value similar to soil under oat, rye and fallow at 4.10×10^{-5} m s^{-1} (Figure 2-5). The average Ksat across all treatments in the short-term trial was 5.48×10^{-5} m s^{-1}. These values were higher than the values of 4.40×10^{-7} and 3.72×10^{-7} m s^{-1} for a silt loam under fallow and sunn hemp, respectively, that were reported in a study by Blanco-Canqui et al. (2011). Results from this study were comparable to the average Ksat of 3.1×10^{-5} m s^{-1} in a sandy loam observed by Buczko et al. (2006). It is unclear why cover crops affected saturated hydraulic conductivity but did not affect macroporosity, since macropores can influence saturated hydraulic conductivity (Beven and Germann, 1982). Average Ksat was also lower in soil under long-term oat than under short-term oat (Figure 2-5). The difference in Ksat between the trials is likely due to differences in soil management practices.

Soil Carbon

Cover crop treatment significantly impacted total soil C in the long-term trial but had no effect on soil C in the short-term trial. At the 0- to 5-cm depth in the long-term trial, soil C was greater in oat, rye, and wheat than in fallow (Table 2-3). Soil C averaged 17.32 Mg ha^{-1} under oat, rye, and wheat and 12.15 Mg ha^{-1} under fallow at the 0- to 5-cm depth in the long-term trial. The increase in soil C at the surface is likely due to additional organic matter from cover crops (Dabney et al., 2001) and is consistent with Kuo et al. (1997b) who found a significant increase in soil C under cover crops compared to soil with no cover crops. Soil C under oat in the long-term trial was significantly higher than only the lowest value under wheat, at the 15- to 30-cm depth. At the 30- to 60-cm depth, oat had significantly more soil C than wheat and fallow treatments in the long-term trial. This could be indicative of a more extensive root system in oat or differences in total C in belowground biomass among cover crop species (Kuo et al., 1997b). Average soil C across all treatments in the short-term trial ranged from12.00 Mg ha^{-1} in the 0- to 5-cm depth to 6.65 Mg ha^{-1} in the 30- to 60-cm depth. Increases in soil C under cover crops compared to fallow soils in the short-term trial was likely not observed due to the short duration of the study due to lack of significant C accumulation and cycling from cover crop residue during the single cover crop growing season. Analysis of total soil C of entire sampling depth (0- to 60-cm) did not show significant differences among cover crop species in either trial (Table 2-3), indicating that cover crops affect localized soil C but not total C for the top 60 cm of Coastal Plain soils. When the two trials were compared, soil C under oat and fallow did not differ between long-term and short-term trials, respectively.

Soil Nitrogen

Soil NH_4–N was not significantly affected by cover crop treatment in either trial. An overall decreasing trend in NH_4–N was observed from the 0- to 5-cm depth to the 30- to 60-cm depth in both trials. In the long-term trial, average NH_4–N of all cover crop treatments was highest in the 0- to 5-cm depth at 42.9 mg kg^{-1} and lowest in the 30- to 60-cm depth at 4.2 mg kg^{-1}. Average NH_4–N ranged from 19.8 mg kg^{-1} in the 0- to 5-cm depth to 2.7 mg kg^{-1} in the 30- to 60-cm depth in the short-term trial. Comparison of the trials revealed a significant trial x depth interaction under the fallow treatment only. Average NH_4–N was significantly higher in soil under long-term fallow than under short-term fallow at the 0- to 5-, 5- to 10-, and 10- to 15-cm depths (Table 2-4), which could be attributable to different fertilization application timing and frequency. The lack of difference in NH_4–N between soil under long-term and short-term oat was likely attributable to the plants' uptake of NH_4–N over time, differences in soil properties, or variations in previous management of soil used for the short-term trial.

Cover crop treatments did not influence NO_3–N concentration in either trial at any depth. Soil nitrate-N concentration was also not affected by depth in both trials. Soil NO_3–N averaged across all treatments and depths was 0.51 mg kg^{-1} in the long-term trial and 0.77 mg kg^{-1} in the short-term trial. Tabatabai and Dick (1983) determined a higher level of soil NO_3–N at 17.3 mg

kg^{-1} in the top 15 cm of soils in Iowa. Significant trial × depth interactions were found with a comparison analysis of the two trials. While soil NO_3–N under oat was unaffected by trial, soil NO_3–N increased significantly under long-term fallow compared to short-term fallow at the 30- to 60-cm depth (Table 2-5). This might suggest that lack of cover cropping over several years could facilitate leaching of NO_3– N in a Coastal Plain soil over time. Crop uptake and variations in soil properties and fertilization practices could explain the lack of differences in NO_3– N between long-term and short-term oat. In a study by Kessavalou and Walters (1999), soil NO_3–N was significantly reduced under rye in a silty clay loam due to high uptake of N.

Long-term cover crop treatments significantly affected total soil N. At the 0- to 5-cm depth in the long-term trial, soil N was significantly higher in the wheat, oat, and rye treatments than in the fallow treatment (Table 2-6). Total N averaged 1.32 Mg ha^{-1} under all oat, rye, and wheat, and 0.77 Mg ha^{-1} under fallow soil at the 0- to 5-cm depth in the long-term trial. Cover crop treatments in the short-term trial did not influence soil N at any depth where total N averaged 0.70 Mg ha^{-1} across all treatments at the 0- to 5-cm depth.

The increase in total soil N under cover crops is most likely due to cover crops adding organic matter to the surface over time, since inorganic N sources (NH_4^+ and NO_3^-) did not differ in concentrations among cover crop treatments. Thus, changes in N were likely attributable to organic forms of N. This was similar to the findings of Kuo et al. (1997a) who concluded that non-leguminous cover crops, such as rye and annual ryegrass, were effective in increasing long-term soil N, especially in organic N forms. Both trials exhibited a significant decrease in average soil N with increasing depth. No significant differences were observed in soil N between the long-term and short-term trials.

Soil C/N ratio did not differ among cover crop treatments within each depth in either trial, suggesting that cover cropping alone did not influence the N cycling in this soil. However, soil C/N ratio varied significantly with depth in both trials. In the long-term trial, the average C/N ratio across all cover crop treatments was higher in the 5- to 10- and 10- to 15-cm depths at 18.6 and 21.5, respectively, than in the 0- to 5-cm depth at 14.0 (Table 2-7). Similar results were observed in the short-term trial, in which soil C/N ratios were higher in the 10- to 15- and 15- to 30-cm depths at 26.4 and 26.8, respectively, than in the 0- to 5-cm depth at 18.5 (Table 2-7).

Soil PO_4–P and SO_4–S

Soil PO_4–P was not significantly affected by cover crop treatments in either trial (Table 2-8). Average PO_4–P across cover crop treatments was influenced by depth only in the long-term trial. Mean soil PO_4–P ranged from 1.01 mg kg^{-1} in the 15- to 30-cm depth to not detectable in the 30- to 60-cm depth in the long-term trial. Soil PO_4–P in the short-term trial averaged 0.18 mg kg^{-1} across all treatments and depths with no significant differences between depths. No difference in soil PO_4–P was observed between long-term and short-term trials under oat or fallow treatments.

Cover crops did not affect soil SO_4–S in either trial (Table 2-9); however, a more distinct trend in average SO_4–S across depths in the long-term trial was observed compared to soil PO_4–P. The highest SO_4–S mean value occurred in the 0- to 5- and 30- to 60-cm depths at 5.12 and 5.44 mg kg^{-1}, respectively, while the middle depths (5- to 10-, 10- to 15-, and 15- to 30-cm depths) had the lowest SO_4–S at 3.77, 3.02, and 3.35 mg kg^{-1}, respectively. Soil SO_4–S in the short-term trial ranged from 4.45 mg kg^{-1} in the 0- to 5-cm depth to 5.18 mg kg^{-1} in the 30- to 60-cm depth across all treatments with no significant differences between depths. These values are lower than the 6.3 mg SO_4–S mg kg^{-1} reported by Sharpley (1990) in the top 10 cm of a Bernow fine sandy loam (fine, siliceous, thermic Glossic Paleudalf). Differences in PO_4–P and SO_4–S concentrations among depths in the long-term trial indicate a greater mixing or cycling of the nutrients over time. Comparison of the two trials did not show any differences between soil SO_4^{2-}–S under long-term and short-term oat or long-term and short-term fallow. This might suggest that soil PO_4–P and SO_4–S are more influenced by fertilization practices and soil properties, such as texture, pH, and the presence of Fe and Al oxides than cover cropping.

CONCLUSIONS

Bulk density was not significantly impacted by cover crop treatments, suggesting that oat, rye, wheat, clover and mixtures of oat and rye do not alter bulk density more than soil under no cover crops. Differences in bulk density between the two trials under oat and fallow demonstrate that factors other than cover crop species are affecting soil properties over time. Inconsistencies between CT and core bulk density measurements reflect difficulty in obtaining accurate bulk density assessments using these techniques. Problems are likely due to transportation of these sandy soils. The only soil physical property affected by cover crop treatment was saturated hydraulic conductivity, indicating that long-term cover cropping (>20 years) of oat and rye, specifically, is effective in increasing the rate of water movement through a saturated Coastal Plain soil. Increases in saturated hydraulic conductivity without corresponding increases in macroporosity suggest that other soil properties are influencing the rate of water movement through this sandy soil. Total soil N and C were the only soil nutrient properties influenced by cover crop treatment. An increase in total soil N and C at the 0- to 5-cm depth under oat, rye, and wheat reveals that long-term cover crops are effective in improving soil fertility at the surface horizon. Since the same effects were not observed in the analysis of inorganic soil N, it could be suggested that the majority of soil N at the surface is in the organic form. Increases in soil NO_3– N at the 30- to 60-cm depth under long-term fallow indicate that leaving fields fallow in the winter for several consecutive years could contribute to NO_3– N leaching in Coastal Plain soils over time. Lack of differences in soil properties under short-term cover cropping and changes in soil physical and chemical properties under long-term cover cropping suggest that farmers will not likely see the benefits of cover cropping after the first season of cover cropping.

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Table 2-1. Management practices (cover crop treatments, cover crop planting dates, tillage methods, and fertilizer applications) of long-term and short-term cover crop trials for 2012-2013 growing season. Wiregrass Research and Extension Center, Headland, AL.

	Long-Term Trial	**Short-Term Trial**
Cover Crop Treatments	Rye Wheat Oat Fallow	Crimson Clover Oat/Rye Mixture Oat Fallow
Planting Date	Dec.14, 2012	Jan. 15, 2013
Tillage Methods	subsoil/strip tillage (cover crop plots)	subsoil tillage (all plots)
	disk, subsoil tillage (fallow plots)	
Fertilizer Application(s)	45 kg N ha^{-1} 7 kg S ha^{-1} (Jan. 24, 2013)	33.6 kg N ha^{-1} (Feb. 6, 2013)
	34 kg N ha^{-1} 5 kg S ha^{-1} (March 8, 2013)	

Table 2-2. Comparison of bulk density determined by the core method and the CT method in long-term and short-term trials under oat and fallow treatments at 0- to 5-, 5- to 10-, 10- to 15-, 15- to 30-, and 30- to 60-cm depths. Wiregrass Research and Extension Center, Headland, AL, 2013.

Depth	**Core Method**				**CT Method**			
	Fallow		**Oat**		**Fallow**		**Oat**	
	Long-term	**Short-term**	**Long-term**	**Short-term**	**Long-term**	**Short-term**	**Long-term**	**Short-term**
cm	g cm^{-3}							
0-5	0.98	1.25 *	1.01	1.24 *	1.13	1.14	1.09	1.16
5-10	1.26	1.29	1.28	1.34	1.25	1.21	1.21	1.21
10-15	1.33	1.35	1.34	1.34	1.35 *	1.18	1.30 *	1.20
15-30	1.47 *	1.26	1.41	1.32	-	-	-	-
30-60	1.51 *	1.33	1.47 *	1.35	-	-	-	-

*Mean bulk densities under long-term and short-term trials differ significantly for a given cover crop treatment and a given bulk density method within a depth (α=0.05).

Table 2-3. Soil C under cover crop treatments in long-term and short-term trials at 0- to 5-, 5- to 10-, 10- to 15-, 15- to 30-, and 30- to 60-cm depths and total soil C for entire sampling depth (0- to 60-cm). Wiregrass Research and Education Center, Headland, AL, 2013.

Depth	**Long-Term Trial**				**Short-Term Trial**			
	Fallow	**Oat**	**Rye**	**Wheat**	**Fallow**	**Oat**	**Clover**	**Oat/Rye**
cm	Mg C ha^{-1}							
0-5	12.2 b†	17.3 a	16.1 a	18.6 a	11.6	12.7	11.6	12.2
5-10	13.9	15.1	14.1	14.7	11.5	12.7	12.3	12.3
10-15	14.5	13.2	12.6	11.6	11.7	12.0	12.3	11.9
15-30	12.7 ab	13.2 a	11.4 ab	10.6 b	10.5	11.2	10.9	11.7
30-60	6.0 b	7.0 a	6.4 ab	6.2 b	6.3	6.5	6.9	7.0
Total	34.6	37.6	34.2	33.8	30.8	32.5	32.2	33.2

† Means within a row proceeded by a different lowercase letter differ significantly for a given trial within a depth (α=0.05).

Table 2-4. Comparison of soil NH_4–N in long-term and short-term trials under oat and fallow treatments at 0- to 5-, 5- to 10-, 10- to 15-, 15- to 30-, and 30- to 60-cm depths. Wiregrass Research and Extension Center, Headland, AL, 2013.

Depth	**Fallow**		**Oat**	
	Long-term	**Short-term**	**Long-term**	**Short-term**
cm	———————mg NH_4–N kg^{-1}———————			
0-5	44.1 *	25.0	42.5	18.5
5-10	14.4 *	6.5	14.5	6.7
10-15	9.5 *	5.8	9.4	5.9
15-30	5.0	4.1	5.6	3.6
30-60	2.9	2.8	3.2	2.7

*Mean NH_4–N under long-term and short-term trials differ significantly for a given cover crop treatment within depth (α=0.05).

Table 2-5. Comparison of soil NO_3–N in long-term and short-term trials under oat and fallow treatments at 0- to 5-, 5- to 10-, 10- to 15-, 15- to 30-, and 30- to 60-cm depths. Wiregrass Research and Extension Center, Headland, AL, 2013.

Depth	**Fallow**		**Oat**	
	Long-term	**Short-term**	**Long-term**	**Short-term**
cm	———— mg NO_3–N kg^{-1} ————			
0-5	0.6	0.8	0.6	0.5
5-10	0.5	0.7	0.5	0.6
10-15	0.4	0.8	0.5	0.7
15-30	0.6	0.7	0.6	0.7
30-60	2.7 *	1.1	0.9	0.6

*Mean NO_3–N under long-term and short-term trials differ significantly for a given cover crop treatment within a depth (α=0.05).

Table 2-6. Soil N under cover crop treatments in long-term and short-term trials at 0- to 5-, 5- to 10-, 10- to 15-, 15- to 30-, and 30- to 60-cm depths. Wiregrass Research and Extension Center, Headland, AL, 2013.

Depth	**Long-Term Trial**				**Short-Term Trial**			
	Fallow	**Oat**	**Rye**	**Wheat**	**Fallow**	**Oat**	**Clover**	**Oat/Rye**
cm	Mg N ha^{-1}							
0-5	0.8 b†	1.3 a	1.2 a	1.5 a	0.7	0.6	0.9	0.6
5-10	1.0	0.7	0.9	1.1	0.6	0.4	0.8	0.5
10-15	0.7	0.8	0.7	0.5	0.6	0.6	0.6	0.4
15-30	1.0	0.9	0.7	0.6	0.6	0.5	0.5	0.5
30-60	0.5	0.6	0.6	0.3	0.4	0.5	0.4	0.4

† Means within a row proceeded by a different lowercase letter differ significantly for a given trial within a depth (α=0.05).

Table 2-7. Average C/N ratio of soil across all cover crop treatments in long-term and short-term trials at 0- to 5-, 5- to 10-, 10- to 15-, 15- to 30-, and 30- to 60-cm depths. Wiregrass Research and Extension Center, Headland, AL, 2013.

Depth	**Long-Term Trial**	**Short-Term Trial**
cm	C/N	
0-5	14.0 b†	18.5 c
5-10	18.6 a	26.2 ab
10-15	21.5 a	26.4 a
15-30	20.0 ab	26.8 a
30-60	16.5 ab	21.8 bc

†Mean C/N ratios proceeded by different lowercase letters differ significantly among depths within a trial (alpha=0.05).

Table 2-8. Soil PO_4–P under cover crop treatments in long-term and short-term trials at 0- to 5-, 5- to 10-, 10- to 15-, 15- to 30-, and 30- to 60-cm depths. Wiregrass Research and Extension Center, Headland, AL, 2013. Mean soil PO_4–P did not significantly differ among cover crop treatments within a depth in either trial (α=0.05).

Depth	**Long-Term Trial**				**Short-Term Trial**			
	Fallow	**Oat**	**Rye**	**Wheat**	**Fallow**	**Oat**	**Clover**	**Oat/Rye**
cm	mg PO_4–P kg^{-1}							
0-5	0.4	0.5	1.0	0.9	0.6	0.0	0.5	0.2
5-10	0.4	0.3	0.9	0.0	0.2	0.0	0.5	0.1
10-15	0.3	0.5	0.8	1.0	0.4	0.0	0.5	0.1
15-30	0.4	1.1	1.2	1.7	0.5	0.3	0.4	0.3
30-60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 2-9. Soil SO_4–S under cover crop treatments in long-term and short-term trials at 0- to 5-, 5- to 10-, 10- to 15-, 15- to 30-, and 30- to 60-cm depths. Wiregrass Research and Extension Center, Headland, AL, 2013. Mean soil SO_4–S did not significantly differ among cover crop treatments within a depth in either trial (α=0.05).

Depth	Long-Term Trial				Short-Term Trial			
	Fallow	Oat	Rye	Wheat	Fallow	Oat	Clover	Oat/Rye
cm	mg SO_4–S kg^{-1}							
0-5	3.8	5.4	6.3	5.1	5.0	4.4	6.1	2.9
5-10	2.7	3.8	4.3	4.4	3.3	2.9	5.0	2.1
10-15	2.8	2.9	3.2	3.2	5.5	5.3	4.4	3.6
15-30	2.0	3.8	3.9	4.0	5.0	4.4	4.6	3.9
30-60	4.3	5.4	4.6	7.8	4.6	6.9	8.2	2.7

Figure 2-1. Bulk density determined by the core method under cover crop treatments in (a) long-term and (b) short-term trials at 0- to 5-, 5- to 10-, 10- to 15-, 15- to 30-, and 30- to 60-cm depths. For clarity, all values are plotted at the halfway point of each depth increment. Wiregrass Research and Extension Center, Headland, AL, 2013. Mean bulk density measured by the core method did not significantly differ among cover crop treatments within a depth in either trial (α=0.05).

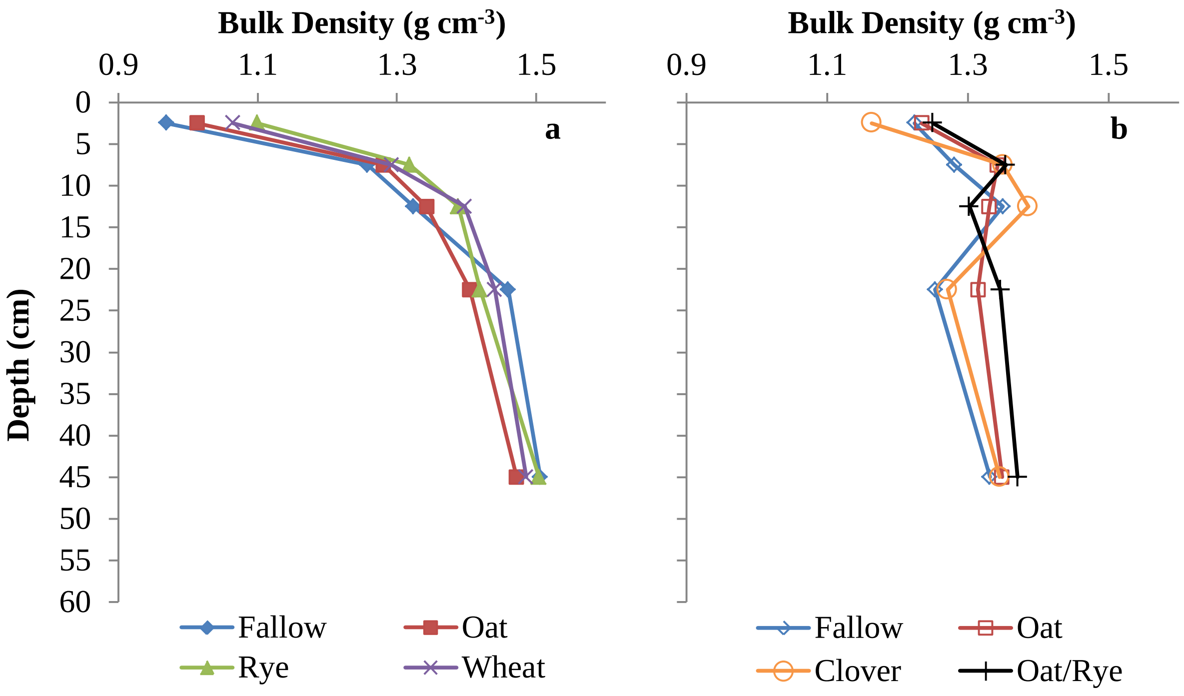


Figure 2-2. Bulk density analyzed by CT under cover crop treatments in (a) long-term and (b) short-term trials at 0- to 5-, 5- to 10-, and 10- to 15-cm depths. For clarity, values are plotted at the halfway point for each depth increment. Wiregrass Research and Extension Center, Headland, AL, 2013. Mean bulk density analyzed by CT did not significantly differ among cover crop treatments within a depth in either trial (α=0.05).

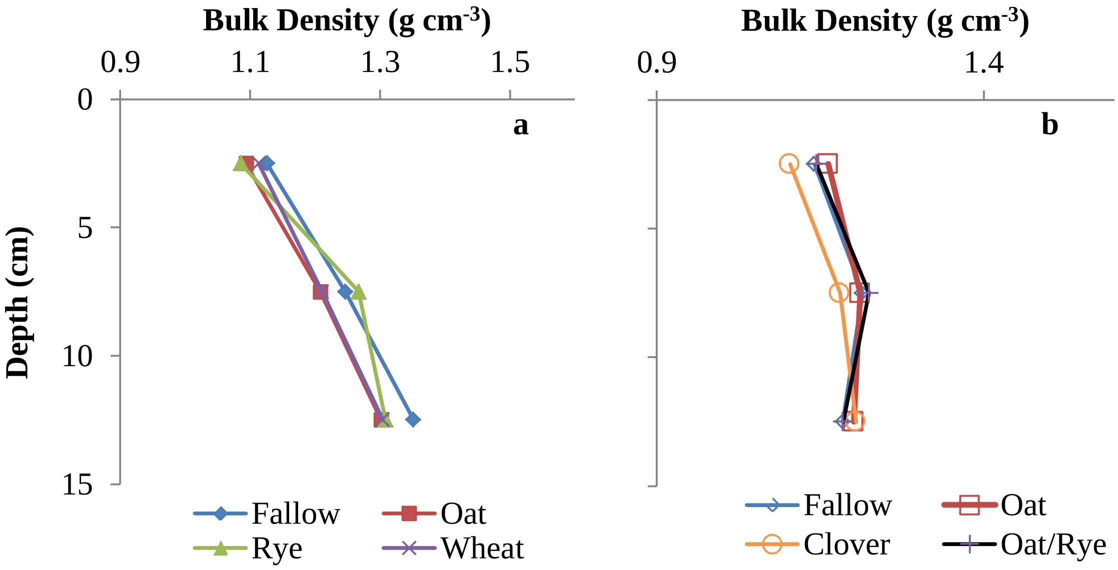


Figure 2-3. Linear regression model of the comparison of core and CT methods for measuring bulk density under cover crops in long-term and short-term trials.

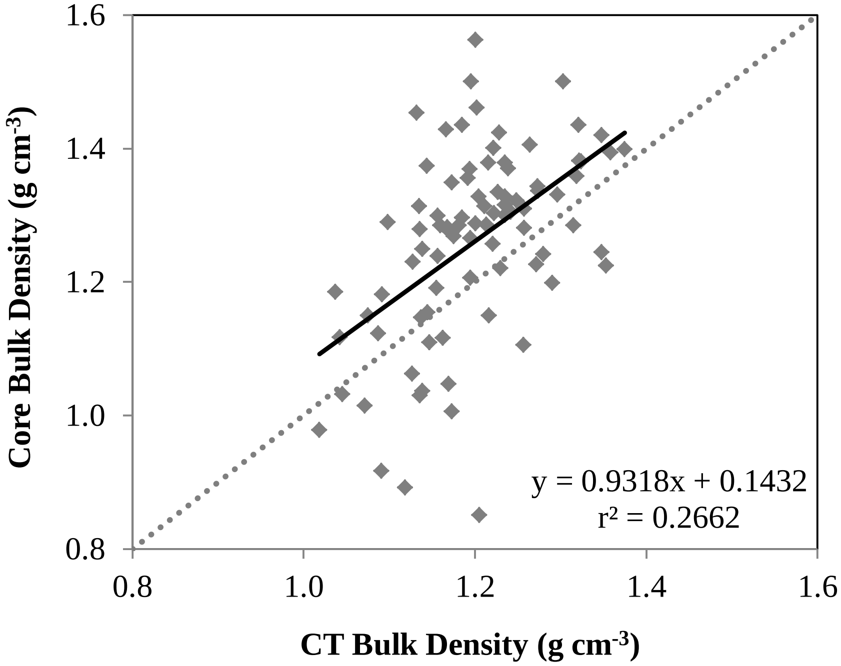


Figure 2-4. Macroporosity under cover crop treatments in (a) long-term and (b) short-term trials at 0- to 5-, 5- to 10-, and 10- to 15-cm depths. Values are plotted at halfway point of each depth increment for clarity. Wiregrass Research and Extension Center, Headland, AL, 2013. Mean macroporosity did not significantly differ among cover crop treatments within a depth in either trial (α=0.05).

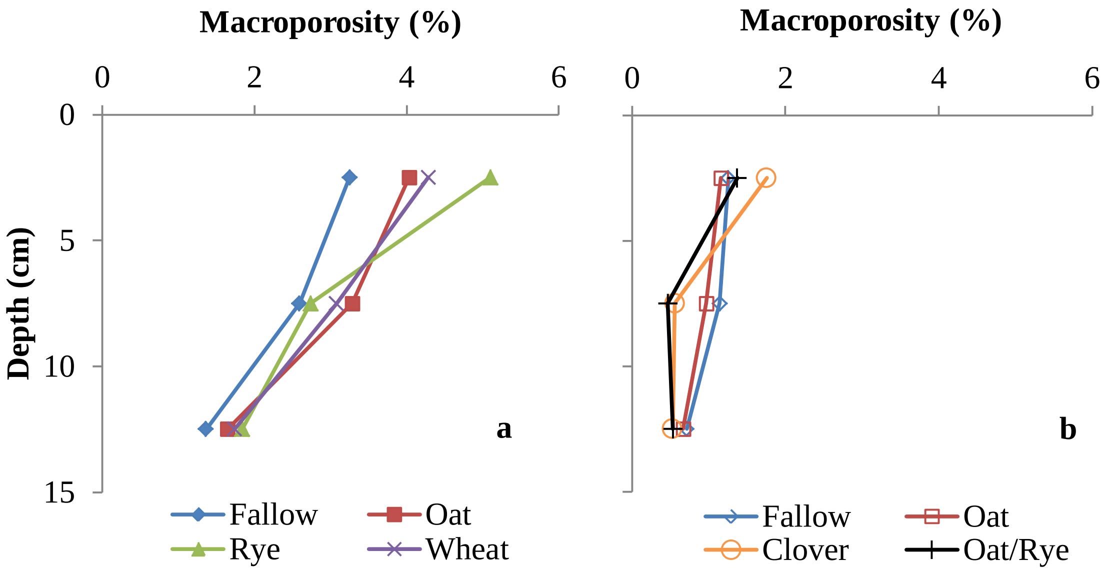
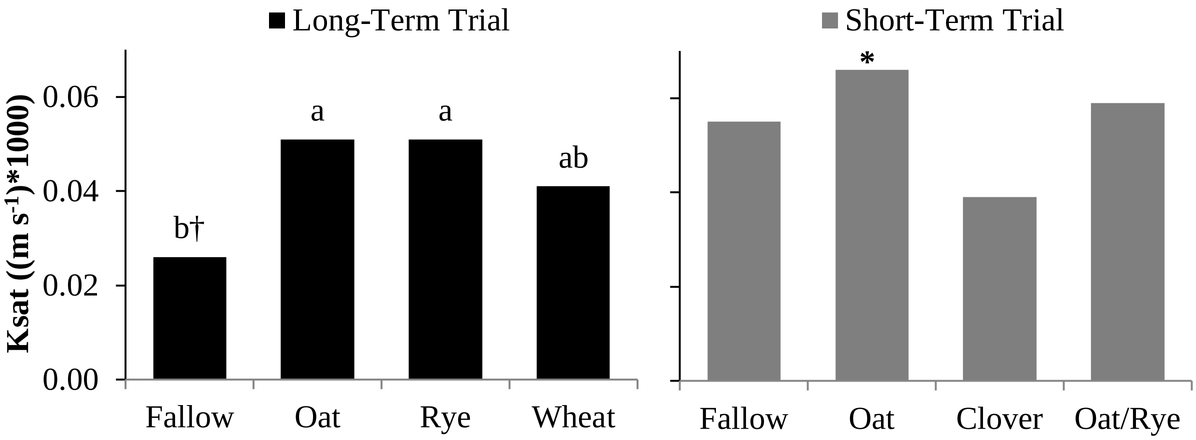


Figure 2-5. Saturated hydraulic conductivity at 20 cm under cover crop treatments in long-term and short-term trials. Wiregrass Research and Extension Center, Headland, AL, 2013.



†Means proceeded by a different lowercase letter are significantly different within a trial (α=0.05).
*Mean Ksat in soil under short-term oat was significantly higher than mean Ksat in soil under long-term oat (α=0.05).

III. IMPACT OF CROP ROTATION AND TILLAGE ON YIELD AND WATER USE EFFICIENCY OF PEANUT AND COTTON

ABSTRACT

Conservation practices are becoming important tools in improving the health of crop production systems in the Coastal Plain region of the southeastern U.S., where soils are vulnerable to erosion and nutrient loss. Farmers in this region have been productive with a traditional rotation (TR) of peanut (*Arachis hypogaea* L.)-cotton (*Gossypium hirsutum* L.) using conventional tillage with a moldboard plow (MP). Unfortunately, this system has led to the degradation of soil quality over time, so conservation practices, such as strip-tillage (ST) and cover cropping, are being adopted to help alleviate soil quality degradation. In addition, a sod-based rotation (SBR) that incorporates a perennial grass into the crop rotation has been investigated to further improve soil quality. The SBR involves a rotation of two consecutive years of bahiagrass (*Paspalum notatum* Flueggé), followed by peanut and then cotton, which is usually grown with conservation practices. Use of the sod-based rotation under strip tillage has been shown to reduce diseases in peanut, increase crop yields, and improve soil organic matter content. However, the implications of a sod-based rotation and strip tillage, as compared to a peanut-cotton rotation and moldboard tillage, on water-use efficiency (WUE) in peanut and cotton have not been studied. This study evaluated the influence of crop rotation (SBR and TR) and tillage (ST and MP) on yield and WUE of peanut and cotton grown in a long-term study established in 2002 in the Coastal Plain region of Alabama. Peanut and cotton leaf samples were collected in August 2013 and analyzed for SPAD chlorophyll content, specific leaf area (SLA), and carbon isotope ratio ($\delta^{13}C$) to estimate WUE. Response variables were statistically evaluated for rotation, tillage, and rotation × tillage effects. Cotton lint yield was not affected by rotation, tillage, or rotation × tillage interactions. However, peanut yield was highest in the SBR under ST and lowest in the peanut-cotton rotation under either ST or MP. Rotation, tillage, and the interaction of rotation and tillage did not significantly affect WUE-estimating variables in either crop (SPAD, SLA, $\delta^{13}C$), which indicates that rotation and tillage did not influence WUE of peanut or cotton. Higher than normal rainfall during the summer months of 2013 could have contributed to the lack of difference in WUE among treatments. Although WUE was not responsible for improving peanut or cotton yield, it can be concluded that the SBR managed with ST provided significant peanut yield benefits over the TR under both tillage practices.

Abbreviations: MP, moldboard plow tillage; SBR, sod-based rotation; SLA, specific leaf area; SPAD; soil plant analysis development meter; ST, strip-tillage; TR, traditional peanut-cotton rotation; WUE, water-use efficiency

INTRODUCTION

The Coastal Plain region in the southeastern U.S. is a successful peanut- and cotton-producing region. Unfortunately, crop productivity in the region can be limited by soil quality degradation, soil erosion, and nutrient loss from leaching or runoff (Schomberg et al., 2006). Traditional practices of the region typically include a peanut-cotton rotation with intensive tillage using a moldboard plow. These practices have been productive but have resulted in a decline in soil quality (Katsvairo et al., 2006; Reeves, 1997). Sustainable crop management solutions, such as crop diversification and conservation tillage, can improve soil quality and maximize crop productivity. In the southeastern U.S., a SBR with conservation tillage has been investigated as a sustainable alternative to traditional production practices. The SBR involves two consecutive years of bahiagrass followed by peanut in the third year and cotton in the fourth. Between crops, a mixture of oat (*Avena sativa* L.) and rye (*Secale cereale* L.) is grown as a cover crop each winter. The fundamental idea behind the SBR is that perennial grasses, such as bahiagrass, interrupt pest and disease cycles and build soil organic matter, which has been shown to have numerous soil quality and fertility benefits. Research has shown that the SBR combined with strip tillage improves peanut and cotton yields (Gates, 2003; Hagan et al., 2003; Johnson et al., 1999; Tsigbey et al., 2007), decreases pests and diseases (Brenneman et al., 1995; Brodie et al., 1970; Gates, 2003; Hagan et al., 2003; Rodríguez-Kábana et al., 1994; Sudini et al., 2011), and improves soil quality over time in the Coastal Plain region (Katsvairo et al., 2007a). Zhao et al. (2008) suggest that the WUE of peanut and cotton could be improved using a sod-based rotation with strip tillage, especially under the non-irrigated conditions found in their study in Florida, from 2002 to 2007. Adding a perennial grass, such as bahiagrass, to a rotation has the potential to impact the availability of water and nutrients for proceeding crops. Bahiagrass roots are effective in penetrating deep or compacted soil horizons, creating channels for subsequent crop roots through “biological drilling” (Cresswell and Kirkegaard, 1995; Katsvairo et al., 2007a). These biopores encourage subsequent crop root growth through deep or compacted horizons, increasing the volume of available water and nutrients for crops (de Freitas et al., 1999). Katsvairo et al. (2007b, 2009) found that cotton root biomass in the SBR was greater compared to the TR. Plants with deeper root systems are less prone to heat stress due to increased availability of water and nutrients (Katsvairo et al., 2006). Bahiagrass has also been shown to improve earthworm populations in the SBR (Katsvairo et al., 2007a), which increases biopores that facilitate preferential flow of water and improve water infiltration (Beven and Germann, 1982; Blanco-Canqui et al., 2011; Willoughby and Kladivko, 2002).

Another important component of cropping systems is the type and amount of tillage utilized. Traditionally, farmers in the southeast United States have used moldboard plows to intensively invert the top layer of soil. Intensive plowing contributes to greater evaporative loss and degradation of soil organic matter and soil structure in the surface horizon (Blevins et al., 1971; Cambardella and Elliott, 1993; Hatfield et al., 2001). Conservation tillage is a reduced tillage practice that retains at least 30% of crop residue on the soil surface and has been proposed as an alternative to intensive tillage (Endale et al., 2002). Retention of crop residues and reduced soil disturbance by conservation tillage practices, such as strip tillage, reduces soil moisture loss through evaporation, increases organic matter, and maintains the integrity of the surface structure (Al-Kaisi et al., 2005; Cambardella and Elliott, 1993).

Since the establishment of the SBR in the Coastal Plain region, many studies have shown that peanut and cotton yields can be improved in some years with a combination of the SBR and ST, as compared to TR and MP. Many authors have attributed the improvement in yield to the decrease in pests and diseases and the improvement in soil quality in the SBR under ST (Brenneman et al., 1995; Brodie et al., 1970; Gates, 2003; Hagan et al., 2003; Rodríguez-Kábana et al., 1994; Sudini et al., 2011).

Another possible explanation for the differences in yield could arise from how rotation and tillage affects how efficiently the crops take up and utilize water, a common limiting nutrient. Since rotation and tillage can affect soil moisture, it is useful to evaluate the WUE of peanut and cotton under different rotation and tillage treatments. Water use efficiency is a measure of the amount of yield produced compared to the amount of water used by a plant (Hatfield et al., 2001). Limited research has been conducted to investigate effects of crop rotation and tillage on WUE. A study by Varvel (1994) showed that WUE was greater for corn (*Zea mays* L.) in rotation with soybean (*Glycine max* L.) or grain sorghum (*Sorghum bicolor* (L.) Moench) compared to corn in a monocrop system. Aase and Pikul (1995) found that decreasing tillage could improve WUE of spring wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) by decreasing evaporative loss and increasing infiltration in a sandy loam over time.

Water-use efficiency can be quantified directly by measuring the amount of yield and the amount of water taken up and transpired by a plant, but this method is tedious and time consuming. Alternative methods of estimating WUE include the evaluation of the plant's chlorophyll content, specific leaf area (SLA), and carbon isotope ratio. Chlorophyll content and carbon isotope ratio, expressed as $\delta^{13}C$, correlates positively with WUE (Nageswara Rao et al., 2001; Rowland et al., 2012; Songsri et al., 2009), and SLA negatively correlates with WUE in peanut (Craufurd et al., 1999; Nageswara Rao et al., 2001; Rowland et al., 2012; Songsri et al., 2009). Since chlorophyll content, SLA, and carbon isotope ratio have strong correlations with WUE, these parameters are considered acceptable estimators of WUE in peanut. The relationships between chlorophyll content, SLA, and WUE is relatively unstudied in cotton. However, Saranga et al. (1998) found that carbon isotope ratio was positively correlated with WUE in cotton, suggesting that this method could be used to estimate WUE in cotton.

While the SBR and ST combination has been shown to increase peanut and cotton yields and improve soil quality, estimating the impact of the system on peanut and cotton WUE using SPAD chlorophyll content, SLA, and carbon isotope ratios remains relatively unexplored in Coastal Plain soils. A few studies concluded that cropping systems which increase crop yield or improve nutrient uptake to proper levels have the potential to increase WUE. The objective of this study was to evaluate the effect of crop rotation and tillage on the yield and WUE of peanut and cotton.

MATERIALS AND METHODS

Experimental Design

Field plots for this study are part of an existing experiment established in 2002 at the Wiregrass Research and Extension Center in Headland, AL (31°30'N, 85°17'W). Soil in this study was classified as a Dothan sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults). Plots (0.1 ha) were arranged in an incomplete randomized block design with five replications of each treatment. Treatments included two rotation systems, the SBR and the TR, which were managed with two tillage treatments, ST and MP. All phases of each rotation were represented each year; however, only plots containing peanut (var. Georgia 06G) or cotton (var. Deltapine 1252) in 2013 were sampled for this study. Although the treatments were replicated five times, only three replications for each treatment were selected for sampling. A mixture of oat and rye was grown in the winter as a cover crop in all plots except those between the first and second years of bahiagrass. Bahiagrass and cover crops were cut and retained as residue on the surface. All plots were irrigated and received best management practices appropriate for the area.

Field Methods

Eight leaf samples of peanut and cotton were collected from the second nodal position from the top of the plant in each plot during the period of highest photosynthetic activity expansion (Nageswara Rao et al., 2001; Rowland et al., 2012) in August 2013 for a total of 24 leaves per treatment. Upon collection, leaves were placed in plastic bags and immediately stored on ice. After all samples were collected, mean chlorophyll content was determined in the field using a chlorophyll meter SPAD-502 Plus (Spectrum Technologies, Inc., Plainfield, IL). Four readings were taken from each cotton leaf and averaged to obtain one reading. Similarly, one reading was taken from each peanut leaflet, for a total of four readings per leaf, and averaged. The average SPAD chlorophyll reading for each leaf was then recorded. Although SPAD measurements are unitless, results are reported as SPAD chlorophyll meter readings. Upon arrival to the laboratory, samples were stored in a 5°C freezer until analyzed for SLA.

Laboratory Methods

To evaluate the specific leaf area (SLA) of the peanut and cotton leaves, deionized water was added to each plastic bag, and leaves floated on water for at least 2 h prior to scanning in order to return turgor pressure for full leaf expansion (Nageswara Rao et al., 2001; Rowland et al., 2012). Leaves were then scanned for leaf area using a WinRHIZO STD 1600+ (Regent Instruments, Inc., Sainte-Foy, QC, Canada). During scanning leaves were kept on ice and returned to freezer storage after scanning until drying. Leaf samples were then dried at 60°C for 48 h and weighed. Specific leaf area ($cm^2\ g^{-1}$) was calculated using equation 1:

$$SLA = \frac{leaf\ area}{leaf\ dry\ weight} \qquad [1]$$

Corrections for total solar radiation and vapor pressure deficit were calculated as suggested by Nageswara Rao et al. (2001) and Rowland et al. (2012), but the corrections did not result in an improved correlation between SLA and chlorophyll content, or SLA and carbon isotope ratio, so the corrected values were not included in this study.

After drying, leaves from each replication were combined and finely ground to obtain a composite sample for each plot. Approximately 2 mg of each leaf sample was prepared and sent to the University of California-Davis Stable Isotope Facility to be evaluated for carbon isotope ratios. The facility analyzed the leaf samples using PZ Europa ANCA-GSL elemental analyzer coupled with a PDZ Europa 20-20 isotope ratio mass spectrometer (Secron Ltd., Cheshire, UK) and calculated from equation 2, where R_{sample} refers to the ratio of ^{13}C to ^{12}C of the plant sample, and $R_{standard}$ refers to the ^{13}C to ^{12}C ratio of the internationally accepted Vienna Pee Dee Belemnite standard (Farquhar et al., 1982).

$$\delta^{13}C = \left[\frac{Rsample}{Rstandard}\right] - 1 \times 1000‰ \qquad [2]$$

Data Analysis

Data were analyzed using mixed models in SAS® PROC MIXED. Rotation, tillage, and rotation × tillage interactions were considered fixed effects. Response variables were analyzed separately for peanut and cotton. Differences between treatments was analyzed at α=0.05 for each crop.

RESULTS & DISCUSSION

Yield

Cotton lint yield was not significantly affected by rotation × tillage interactions (Table 3-1). The average cotton lint yield across all treatments was 1712 kg ha^{-1}. A study on the sod-based rotation in the Southeast has shown that cotton yield initially increased under the rotation with strip tillage, but has yield plateaued in recent years. This is thought to be due to increased uptake of N by cotton that results in more vegetative than reproductive growth (Katsvairo et al., 2007a, b). However, peanut yield was significantly influenced by rotation × tillage interactions. Highest peanut yield occurred in the sod-based rotation under strip tillage, while peanut yield was lowest in the peanut-cotton rotation with either strip tillage or moldboard tillage (Table 3-2; Figure 3-1).

WUE-Estimating Parameters

Parameters for estimating WUE, including SPAD, SLA, and $\delta^{13}C$, were not significantly affected by crop rotation or tillage for either crop (Tables 3-1 and 3-2). The average SPAD reading of all treatments was 37.6 for cotton and 48.8 for peanut. The SPAD value for cotton is lower than the value of 47 reported by Wood et al. (1992) in Alabama cotton at mid-bloom. Literature examining the use of SPAD chlorophyll content and SLA for estimating WUE is limited in cotton but more extensive in peanut. The SPAD value for peanut is higher than 37.4 measured by Rowland et al. (2012) but lower than the value of 43.06 observed by Songsri et al. (2009). The mean SLA of all treatments was 166.2 and 163.7 $cm^2\ g^{-1}$ for cotton and peanut, respectively. The SLA observed for peanut fell within the range reported in the literature of 181.6 $cm^2\ g^{-1}$ (Songsri et al., 2009) and 130.0 $cm^2\ g^{-1}$ (Nigam and Aruna, 2007). The $\delta^{13}C$ rates in cotton averaged -28.96‰ across all treatments. This value is comparative to the average $\delta^{13}C$ value of -28.8‰ for cotton under the same rotation and tillage treatments located in Headland, AL (Gamble, 2014) and similar to the value of -27.0‰ observed by Saragna et al. (1999). The average $\delta^{13}C$ in peanut, -27.91‰, was lower (i.e., more negative) than the value of -25.58‰ reported by Rowland et al. (2012) and similar to the value of -28.21‰ previously determined at Headland, AL (Gamble, 2014). Variations in weather conditions, climate, plant development stage, and genetic variability likely contributed to deviations from results in previous studies (Rowland et al., 2012; Saranga et al., 1999). The lack of differences in SPAD chlorophyll content, SLA, and $\delta^{13}C$ among treatments in this study were possibly due to above-normal rainfall amount and frequency that persisted during the summer of 2013 prior to sampling. The total monthly precipitation during July and August 2013, as well as the precipitation frequency in July 2013 was notably greater than that of the 11 year monthly averages (2002-2012) since the establishment of the experiment (Figure 3-2) (AWIS Weather Services, 2014**;** NOAA, 2014).

Leaf C and N

Rotation and tillage did not significantly impact leaf C content in cotton or peanut (Tables 3-1 and 3-2). The average C content in peanut leaves across all rotation and tillage treatments was 43.9% for cotton and 40.6% for peanut. This value for peanut leaves is similar to the 41.3% leaf C content measured in peanut leaves at Headland, AL (Rowland et al., 2012). Leaf N content in cotton was influenced by tillage and rotation × tillage interactions. When rotation × tillage interactions were analyzed, leaf N in cotton was significantly higher in SBR/ST, SBR/MP, and TR/ST than in TR/MP (Table 3-1; Figure, 3-3), suggesting that the sod-based rotation and strip tillage improved cotton leaf N compared to traditional practices. Leaf N in peanut was not affected by rotation, tillage, or any rotation × tillage interactions. Across all treatments, the average N content in peanut leaves was 3.3%. Rowland et al. (2012) reported an average peanut leaf N content of 2.8% at Headland, AL.

CONCLUSIONS

Cotton lint yield was not affected by rotation, tillage, or rotation × tillage interactions. However, the sod-based rotation, either with strip tillage or moldboard plow, significantly increased peanut yields as compared to the peanut-cotton rotation, suggesting that the sod-based rotation was effective in improving peanut yield over time. Thus, peanut yield could be optimized when strip tillage is a part of the sod-based rotation. Rotation, tillage, and rotation × tillage interactions did not significantly impact WUE-estimating parameters (SPAD, SLA, and

$\delta^{13}C$), so it can be concluded that WUE was not affected by these variables during this year of production. Effects of rotation and tillage on WUE were probably not observed due to persistently-high rainfall and lower temperatures prior to sampling. Continued sampling during seasons with lower rainfall could provide more accurate conclusions about the effects of rotation and tillage on WUE of peanut and cotton in the southeastern U.S. Further studies about nutrient uptake as affected by rotation and tillage could also provide insight into the influence of these management practices on peanut and cotton yields.

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Table 3-1. Average values of yield, SPAD, SLA, δ ^{13}C, leaf C, and leaf N of cotton under the sod-based rotation with strip tillage (SBR/ST), sod-based rotation with moldboard plow tillage (SBR/MP), traditional rotation with strip tillage (TR/ST), and traditional rotation with moldboard plow tillage (TR/MP). Wiregrass Research and Extension Center, Headland, AL, 2013.

Variable	**SBR/ST**	**SBR/MP**	**TR/ST**	**TR/MP**
Yield (kg ha^{-1})	1062	1041	938	793
SPAD	38.3	36.3	39.3	36.5
SLA (cm^2 g^{-1})	158.70	167.85	169.63	168.58
δ ^{13}C (‰)	-29.27	-28.70	-28.68	-29.18
Leaf C (%)	44.1	43.6	44.4	43.6
Leaf N (%)	3.1 a†	3.1 a	3.1 a	2.6 b

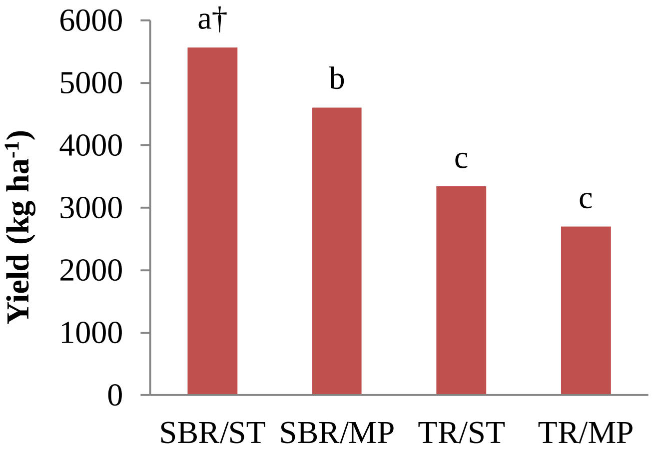
†Values proceeded by a different lowercase letter are significantly different for a given response variable within a crop (α=0.05).

Table 3-2. Average values of yield, SPAD, SLA, $\delta\ ^{13}C$, leaf C, and leaf N of peanut under the sod-based rotation with strip tillage (SBR/ST), sod-based rotation with moldboard plow tillage (SBR/MP), traditional rotation with strip tillage (TR/ST), and traditional rotation with moldboard plow tillage (TR/MP). Wiregrass Research and Extension Center, Headland, AL, 2013.

Variable	**SBR/ST**	**SBR/MP**	**TR/ST**	**TR/MP**
Yield (kg ha^{-1})	5570 a†	4608 b	3341 c	2697 c
SPAD	50.6	47.6	50.9	45.9
SLA ($cm^2\ g^{-1}$)	156.25	159.88	165.19	173.54
$\delta\ ^{13}C$ (‰)	-27.63	-27.73	-28.25	-28.05
Leaf C (%)	40.2	40.0	41.8	40.5
Leaf N (%)	3.1	3.1	3.6	3.3

†Values proceeded by a different lowercase letter are significantly different for a given response variable within a crop (α=0.05).

Figure 3-1. Average yield of peanut under the sod-based rotation with strip tillage (SBR/ST), sod-based rotation with moldboard plow tillage (SBR/MP), traditional rotation with strip tillage (TR/ST), and traditional rotation with moldboard plow tillage (TR/MP). Wiregrass Research and Extension Center, Headland, AL, 2013.



†Values with different lowercase letters are significantly different (α=0.05).

Figure 3-2. Comparison of total monthly precipitation and monthly precipitation frequency (days with at least one precipitation event) in 2013 and 11 year average for 2002 through 2012 (January through December). Wiregrass Research and Extension Center, Headland, AL (AWIS Weather Services, 2014; NOAA, 2014).

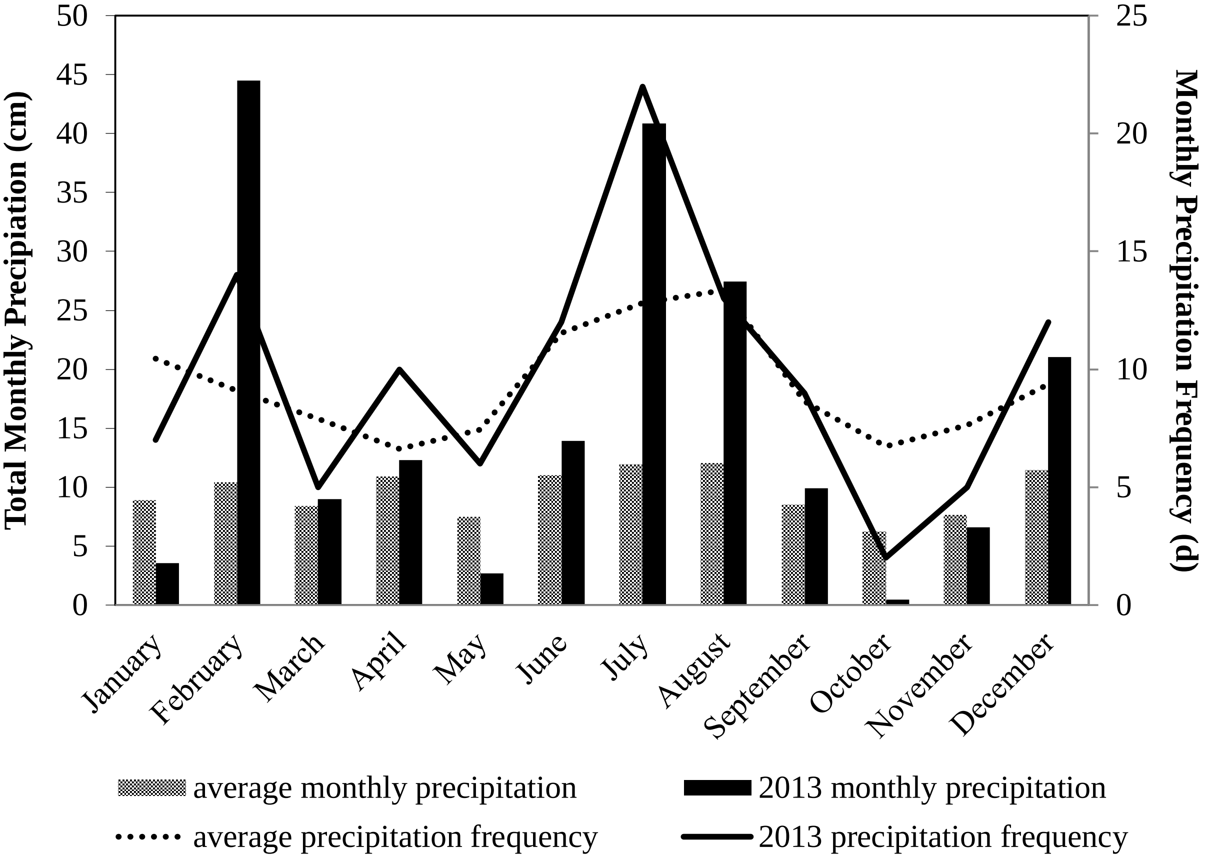
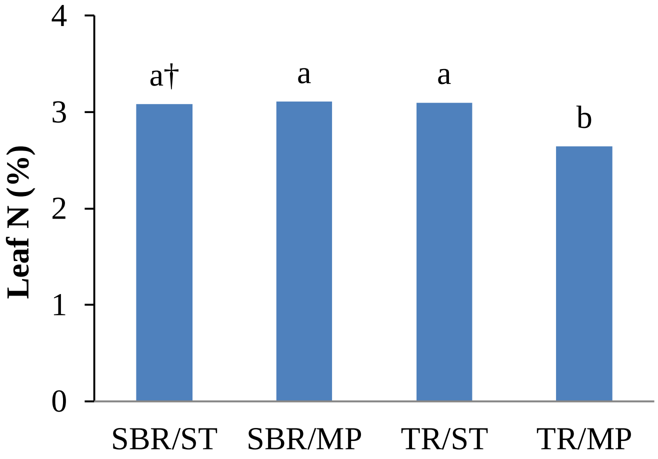


Figure 3-3. Average leaf N of cotton under the sod-based rotation with strip tillage (SBR/ST), sod-based rotation with moldboard plow tillage (SBR/MP), traditional rotation with strip tillage (TR/ST), and traditional rotation with moldboard plow tillage (TR/MP). Wiregrass Research and Extension Center, Headland, AL, 2013.



†Mean values with different lowercase letters are significantly different (α=0.05).