SOIL CARBON, NITROGEN, AND PHYSICAL PROPERTIES IN CROPPING SYSTEMS OF OKLAHOMA

By

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in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
July, 2011

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ACKNOWLEDGMENTS

This dissertation could not have been written without the support and friendship of professors and colleagues of Oklahoma State University. The support and love of my son, relatives, and friends was my driving force. I could not have come this far without the assistance of many individuals and I want to express my deepest appreciation.

First, I would like to thank the Oklahoma State University and the Plant and Soil Sciences Department for the opportunity to achieve my academic goals, support, friendship, and guidance. Special thanks also to the Oklahoma Conservation Commission for the financial support that made the study possible.

My advisers, mentors, and friends Drs. Jeff Edwards and Chad Godsey. The mentorship, support, and friendship that I found in you will never be forgotten. Thank you so much for all you have done and for supporting me so much.

I am very grateful to the remaining members of my dissertation committee, Dr. Jason Warren and Dr. Avdhesh Tyagi. Their academic support and input and personal cheering are greatly appreciated. Thank you.

The personnel of Plant and Soil Sciences Department for all the help, support, and family environment in the Department, thank you very much. Especially Wendall Vaughan, Robert Heister, Janet Rich, Jackie Nidiffer, Angela Leas, Deanna Titus, Richard Austin, Jay Ladd, and Debbie Porter.

All the farmers and OSU Research Station personnel for giving us the opportunity to develop the studies in their fields. Always supportive and friendly.

Mr. Gary Stricklands, Jackson Co. Extension Specialist for allowing us to use his study plots and contributions in the study.

All the graduate students, colleagues that spent several hours of study and fun time. The mutual help and support made life much better and easier.

All the Brazilian Students, professors, pos-docs at Oklahoma State University and other friends in Stillwater, OK that make this community so great. Keep the good spirit guys!

To all my friends in Brazil and US that give me all the support and strength.

To my parents Leovegildo Pedroso de Abreu and Wilma Candida de Oliveira, my siblings Cleber de Oliveira Abreu and Vania Leticia Abreu, my partner and friend Selma Ramos da Silva Souza. You are the power and support in every single moment of my life. I love you so much.

However, the most important person in this process is only 4 years of age. My son Caio Abreu, the main reason for each day's battle. He has been the driving force in my life, since I heard his first heart beat. He has followed me in all

the trails and obstacles, and believe me or not, in several of them, he is the one that holds me in his arms. Son, I love you so much, thank you.

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CHAPTER I

SOIL ORGANIC CARBON AND TOTAL NITROGEN UNDER NO-TILL AND CONVENTIONAL TILL IN FARM FIELDS IN OKLAHOMA

INTRODUCTION

Intensive tillage practices have caused dramatic declines in soil quality (the ability of the soil to sustain biological processes) during the 20th century (Lal and Kimble, 1997). Removal of natural vegetation and use of tillage implements that led to a highly disturbed environment are the main causes of soil degradation. Tillage has been used for centuries as a method to alter the soil structure to prepare the seedbed, incorporate organic material into the soil, accelerate soil warming, and increase soil aeration. The physical act of tillage disrupts the soil and often causes increased decomposition of previously-stable soil organic matter (SOM). However, some believe that tillage incorporates organic material that could eventually form SOM (Balesdent et al., 2000), so no loss of SOM would occur. Soil organic matter is simply redistributed in the soil profile.

The most common types of tillage practices that have been studied in agricultural systems include: moldboard plow, chisel plow or reduced tillage like strip tillage, and no-till (NT) (Martens, 2001). Evaluating two long-term (18 and 20 years old) tillage sites in Michigan, Senthilkumar et al. (2009) found a decrease in soil C when conventional till (CT) was used, while NT increased soil C. Conservation tillage has many benefits and among them is the positive effect of immobilizing (sequestering) C from the atmosphere. Several authors (i.e. Allmaras et al., 2000; Follet, 2001; West and Post, 2002; Lal, 2004; Carter, 2005; Lal, 2009) have pointed to NT as a sink of C, based on the increase of SOM content in the topsoil (upper 20 cm). At this depth, the absence of plowing, deposition of residues on the soil surface, and slower turnover of the SOM, are among the reasons for sequestering C.

Tillage and agriculture have significantly reduced SOM content in soils of Oklahoma. A report from the Oklahoma Conservation Commission (2003) estimates losses of over 113 million tons of soil organic carbon (SOC) in the state of Oklahoma since the settlement initiated in the 1890's. Approximately 74% of the SOC (84.4 million tons) is believed to be lost from tillage. Likewise, a long term experiment in Stillwater, OK, the Magruder Plots, that was initiated in 1892, report losses from 55 to 67% of the SOM due to continuous winter wheat (*Triticum aestivum*) and CT (Davis, et al., 2003; Girma et al., 2007). Another study by Boman et al. (1996), in the same experiment, found a decrease from 4 to 1 % in the SOM content in the topsoil of the soil layer in the check plots that received no nutrient source. They estimated an annual reduction rate of 0.0151 to 0.0168 % in plots treated with beef manure and the check plots, respectively.

One limitation in the existing literature is that most studies have only evaluated the increase of SOC associated with NT to a depth of 20 to 30 cm. Recently, some authors (including VandenBygaart et al., 2003; Qin et al., 2004; Carter, 2005; Dolan et al., 2006; Baker et al., 2007) have questioned the higher capacity of no-till to sequester carbon based on the shallow sampling depth. Their arguments are based on the following reasons: 1) the absence of soil mobilization causes the formation of a compacted layer below the topsoil that restricts root growth at deeper portions of the soil; 2) the high concentration of nutrients and SOM in the upper part of the soil promotes a higher concentration of roots in the most fertile zone of the soil, and also inhibits deep root growth; 3) higher SOM content in the upper part increases the soil moisture holding capacity and more water would be available for plants so that root systems do not have to grow deep in order to absorb water; and 4) maintaining the soil covered by crop residues increases the soil's capacity of reflecting light, defined as albedo, and decreases soil temperature. Therefore, at greater depths, the soils do not warm enough to promote root growing. This last reason is probably the most important according to Baker et al. (2007). These observations are supported by Christopher, et al. (2009) that evaluated C sequestration at a depth of 60 cm under CT and NT studies in 12 locations of Indiana, Ohio and Pennsylvania. They found higher soil organic carbon (OC) stock under CT in seven locations. According to those authors, 10 years of NT is not sufficient to increase OC in soils under NT; also, the incorporation of crop residue in areas of CT promote the increase of SOM in the deeper layers of soil in the mentioned zone.

Most C sequestration studies have been concentrated in the upper US, Canada and Europe. A few studies have been conducted in warmer climatic conditions, like the southern Great Plains, in which they compare tillage systems at greater depths. Studies carried out in warmer climates, such as those in Brazil (Bayer et al., 2000; Amado et al., 2004), have shown higher SOM in NT compared to CT in tropical and subtropical conditions up to a 100 cm depth. In that climate, the albedo effect is positive for the no-till because soil temperature is more favorable for microbial activity and root growth. A more intensive cropping system promotes the degradation of compacted layers and reduces soil resistance to root growth due to the diversity of rooting systems (Dwyer et al., 1996). Additionally, mulch on the soil surface reduces the compaction effect caused by machinery traffic (Metay et al., 2007).

The amount of C sequestration by conservation tillage has been calculated by different authors (West and Post, 2002) and there is considerable variation in the estimates. Variations in climate, crops, tillage, agricultural inputs are among the reasons for the variation in the potential of sequestering C (Follet, 2001; Lal, 2004). Estimations vary from 20 to 50 g C m^{-2}. This variation has low precision in local calculations since SOC has high potential to vary within a soil, along the landscape, and especially across soil types and climate conditions. Experiments that count for local C sequestration could reduce the variation and allow a more precise estimation of C sequestration rates on a smaller scale. West and Post (2002) present a worldwide overview of 276 experiments that evaluated the input of SOM due to the adoption of no-till. Only one study in Oklahoma is presented in their review. In the mentioned study, Dao (1998) evaluated an 11 yr NT treatment and observed an increase of 65, 16.6, and 7.2% of the OC concentration in the depths of 0-0.05, 0.05-0.10, and 0.10-0.20 m respectively compared to moldboard plow.

The absence of studies that compare NT and CT in climate conditions similar to Oklahoma lead to the necessity for evaluating NT capacity to sequester C in soils of Oklahoma. The objective of this study was to evaluate the OC and total nitrogen (TN) content of soils under no-till and conventional till in Oklahoma.

MATERIAL AND METHODS

Soil sampling

Crop production fields in Oklahoma that have more than 5 yr history of NT production were identified and sampled in Oklahoma. Conventional tilled fields, adjacent to the NT fields and under the same soil series, were also sampled. No-till is defined by having more than 35% of soil coverage (CTIC, 2010) and, for this study, at least 5 yr with no soil mechanical disturbance other than planting. A total of eight NT and eight CT fields throughout six different counties were identified and sampled (Table 1.1) between March and July, 2009. Average monthly precipitation and temperature for each site is shown in Figure 1.1. Also total annual precipitation by location is presented in the figure 1.2.

In each field, soil samples were collected at four points along a linear transect in the field. Sampled points were taken approximately 30 m in distance from each other. All soil samples were taken within the same soil series. Since fields were adjacent to each other, transects were lined up parallel to each other, so samples were obtained at similar positions in the landscape. At each point, two soil cores of 3.8 cm diameter and one core of 7.5 cm diameter were collected to a depth of 110 cm using a tractor mounted hydraulic driven probe. Each core was divided into 0 to 10, 10 to 20, 20 to 40, 40 to 70, and 70 to 110 cm depths. Soil samples from the 3.8 cm cores were combined in one composite sample for each depth and sample point within the transect, dried in a forced-air oven at 50˚C, and ground to pass a 2-mm sieve. The 7.5 cm cores were divided at the same depths and a subsample of 10.0 cm long was obtained from each depth to evaluate bulk density. Samples were oven dried at 105˚C and soil dry mass was obtained to determine bulk density. Bulk density was determined using the Core Method (Grossman and Reinsch, 2002).

Soil Analysis

Soil samples were analyzed for total carbon (TC) and TN using dry combustion with a LECO FP-2000 CNS analyzer (Howard and Howard, 1990; Dokin, 1991; ISO/DIS, 1994; Westman et al., 2006). In order to account for organic carbon (OC), inorganic carbon (IC) content was determined for all soil samples using a modified pressure-calcimeter method (Sherrod et al, 2002). With TC and IC results, OC was calculated using equation 1.1.

$$OC = TC - IC \tag{1.1}$$

Data Analysis

The experimental design was a randomized complete block design with 2 treatments (NT and CT) and seven replicates (sites). Each site was treated as a block; the main effects were treatment and depth. Sampling points and sites were treated as random variables. Data was analyzed in a proc mixed model using SAS (SAS Institute, Cary, NC).

Table 1.1. Soil series, classification, crop rotation characteristics, and time under NT management for each sampled site.

Town	**County**	**Tillage**	**Soil Series**	**Soil classification**	**Rotation**	**Yrs of NT**
Miami	Ottawa	NT	Taloka silt loam	Fine, mixed, active, thermic Mollic Albaqualfs	soybean / corn / wheat / soybean / corn	5
		CT			wheat / soybean / corn / wheat / soybean / corn	-
Perry 1	Noble	NT	Port silt loam	Fine-silty, mixed, superactive, thermic Cumulic Haplustolls	wheat, soybean, corn, wheat	7
		CT			wheat, soybean, corn, wheat	-
Perry 2	Noble	NT	Kirkland silt loam	Fine, mixed, superactive, thermic Udertic Paleustolls	corn / wheat	5
		CT			corn / wheat	-
Lahoma 1	Garfield	NT	Grant silt loam	Fine-silty, mixed, superactive, thermic Udic Argiustolls	wheat / soybean /grain sorghum	12
		CT			continuous wheat	-
Lahoma 2	Garfield	NT	Pond creek	Fine-silty, mixed, superactive, thermic Pachic Argiustolls	continuous wheat	5
		CT			continuous wheat	-
Goodwell	Texas	NT	Gruver	Fine, mixed, super active, mesic Aridic Paleustoll	wheat / sorghum / fallow	5
		CT			wheat / sorghum / fallow	-
Canute	Washita	NT	Grandfield	Fine loamy, mixed, super active, thermic, Typic Haplustalfs	Cotton	18
		CT			Cotton	-
Walters	Cotton	NT	Tillman	Fine, mixed, superactive, thermic Vertic Paleustolls	continuous wheat	12
		CT			continuous wheat	-

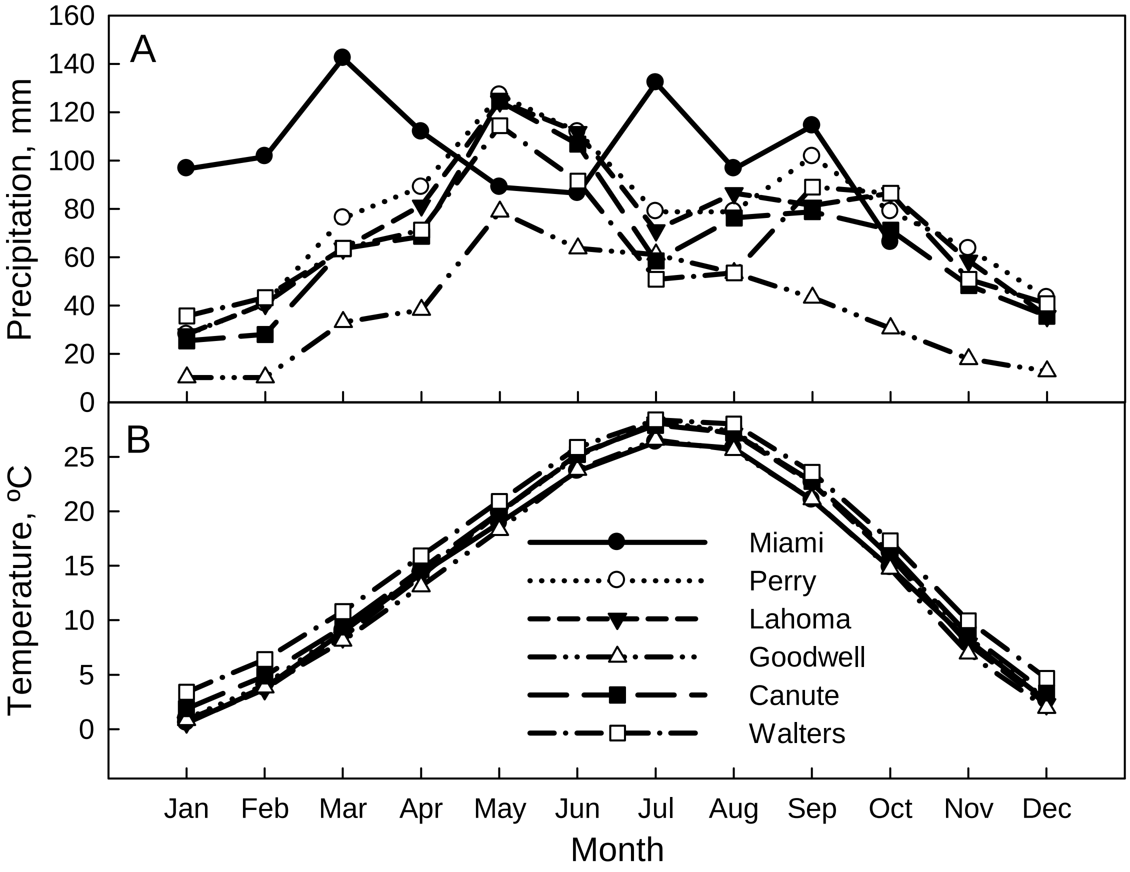

Figure 1.1. Monthly (30 yr average) precipitation (A) and temperature (B) for studied sites in Oklahoma (http://agweather.mesonet.org/index.php/data/section/climate, 2010).

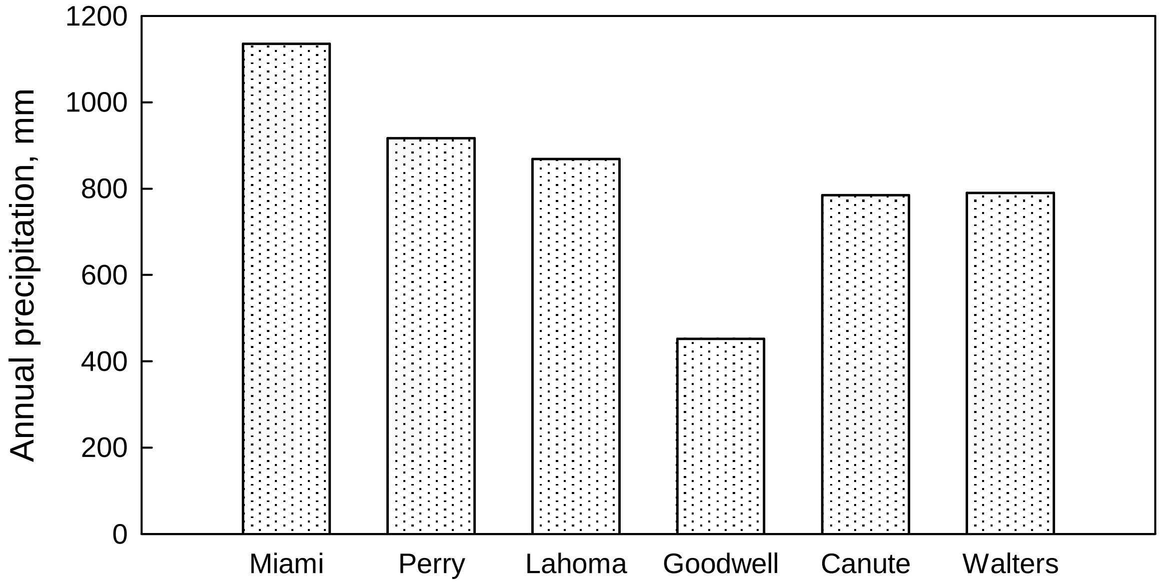

Figure 1.2. Annual (30 yr average) precipitation for studied sites in Oklahoma (http://agweather.mesonet.org/index.php/data/section/climate, 2010)

RESULTS

Organic carbon concentration

No-till fields had higher OC concentrations ($p = 0.06$) compared to CT fields. When locations were combined, concentration of OC was 0.7 g kg^{-1} greater in NT when arranged across depths. Comparing each depth (Figure 1.3), NT was superior to CT in the 0-10 and 20-40 cm depths for OC. No differences were observed in the other studied depths in OC concentrations. At individual locations, NT had numerically higher OC concentrations in the soil profile in six out of eight studied locations (Figure 1.3).

Two factors can be identified to correlate with the buildup of OC in NT sites in Oklahoma: precipitation and time under NT management. Soils located at sites where precipitation is higher seemed to have a faster buildup of OC concentration under NT. Miami (1135 mm yr^{-1} and 5 years under NT) located in eastern Oklahoma, Perry 1 and Perry 2 (917 mm yr^{-1}, 7 and 5 years under NT, respectively), both located in the North-central part of the State had numerically higher OC concentration in the soil surface and throughout the soil profile under NT compared to CT. For example, Miami NT (Figure 1.3.A) had numerically higher concentrations of OC in the surface 70 cm compared to CT. In comparison, sites located in drier areas of the state, such as Goodwell (452 mm yr^{-1}and 5 years under NT) located in the western part of Oklahoma, was not able to increase OC content under NT in a 5 year period. The other factor influencing OC concentration was the age of NT. Older NT sites, such as Lahoma 1 (12 years of NT), Walters (12 years NT), and Canute (18 years NT) had numerically higher OC concentration in soils under NT, especially in the soil surface.

Total nitrogen concentration

Following the same trend as OC, TN was higher in soils under NT compared to CT. When locations were combined, concentration of TN was 0.07 g kg^{-1} greater in NT when averaged across depth. An overall evaluation of TN concentration (Figure 1.3) showed that differences were observed only in the depths 0-10 and 20-40 cm similarly to OC. In these depths NT had higher TN compared to CT treatment. Also similar to the results of OC, the higher the annual precipitation and the longer NT management, the higher TN concentration in soil. For example, Miami (Figure 1.4.A), five years under NT, has lead the soil to have higher numerical value of TN under NT compared to CT. In Miami, the wettest location, all the depths up to 70 cm had higher TN under NT. In comparison, in Goodwell, the driest location (Figure 1.4.F), a lower amount of TN was observed in the NT.

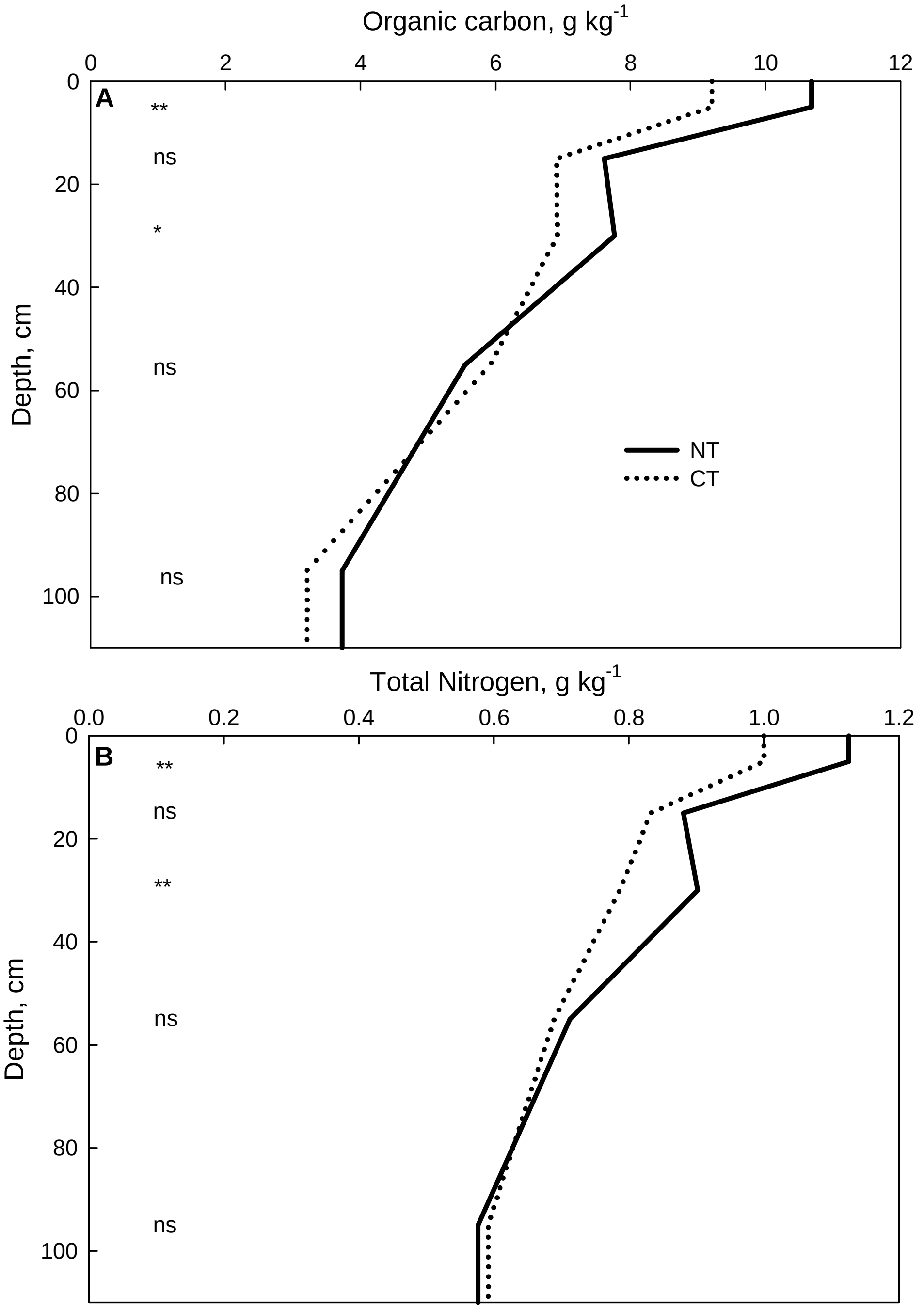

Figure 1.3. Organic carbon (A) and total nitrogen (TN) for soils under no-till (NT) and conventional till (CT) in Oklahoma. ns= nonsignificant at α=0.05. *,, **, ***,and **** indicated significance at α = 0.1, 0.05, 0.01, and 0.0001.

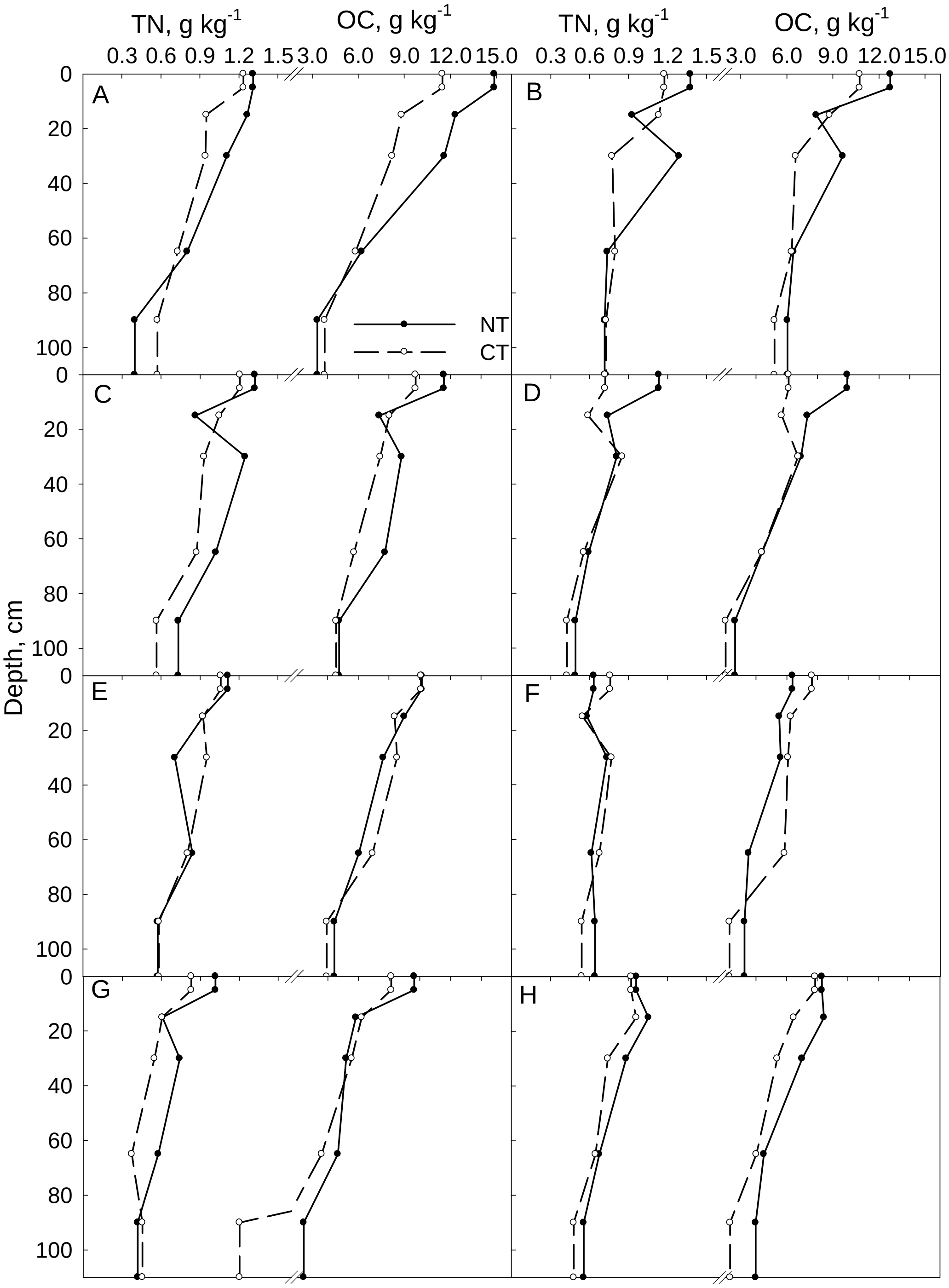

Figure 1.4. Total nitrogen (TN) and organic carbon (OC) for soils under no-till and conventional till in Miami (A), Perry 1 (B), Perry 2 (C), Lahoma 1 (D), Lahoma 2(E), Goodwell (F), Canute (G), and Walter (H), Oklahoma.

Organic carbon pool

Calculations for the OC pool had similar results as OC concentration (Figure 1.4). The difference in OC pool between NT and CT was significant (p = 0.07) when data was average across all the sites (Figure 1.6). The difference between the NT and CT fields was 8.6 Mg ha^{-1}, with NT being 1.1 times greater than conventional till across the sites. Six sites had numerically higher OC pool in NT compared to CT, while two sites had higher OC pool under CT (Figure1. 5). Higher numerical differences were found in Walters, where the NT OC pool was 1.3 times larger than CT with a difference of 22.1 Mg ha^{-1}. Similarly, Canute had 16. 3 Mg ha^{-1} more OC in soil under NT. Lahoma 1 had 9.7 Mg ha^{-1} more OC pool than CT. All those locations have been in NT for over 12 years. In sites with less time under NT management but with higher precipitation, the situation is similar. In Miami, the difference is 17.5 Mg ha^{-1} more OC under NT, and the two sites in Perry (Perry 1 and Perry 2) had differences of 15.8 Mg ha^{-1} and 11.7 Mg ha^{-1} respectively, with NT being greater than CT. The two sites where NT had lower OC pool were Lahoma 2 , with a difference of 4.0 Mg ha^{-1}, and Goodwell were the difference between tillage is 8.5 Mg ha^{-1}. Both sites have 5 years NT management and lower rainfall, compared to the other sites.

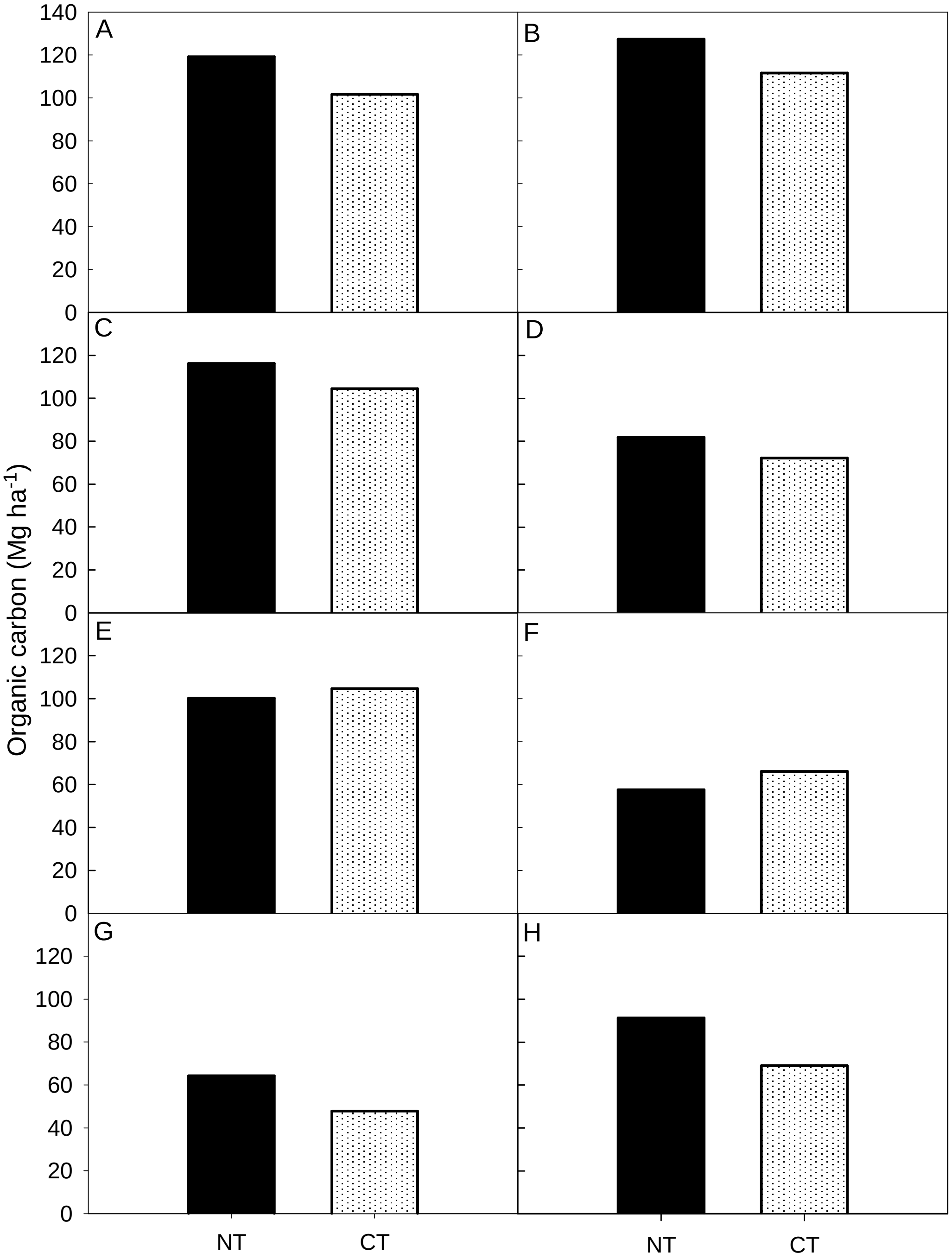

Figure 1.5. Organic carbon pool for soils (0-110 cm depth) under no-till (NT) and conventional till (CT) in Miami (A), Perry 1 (B), Perry 2 (C), Lahoma 1 (D), Lahoma 2(E), Goodwell (F), Canute (G), and Walter (H), Oklahoma.

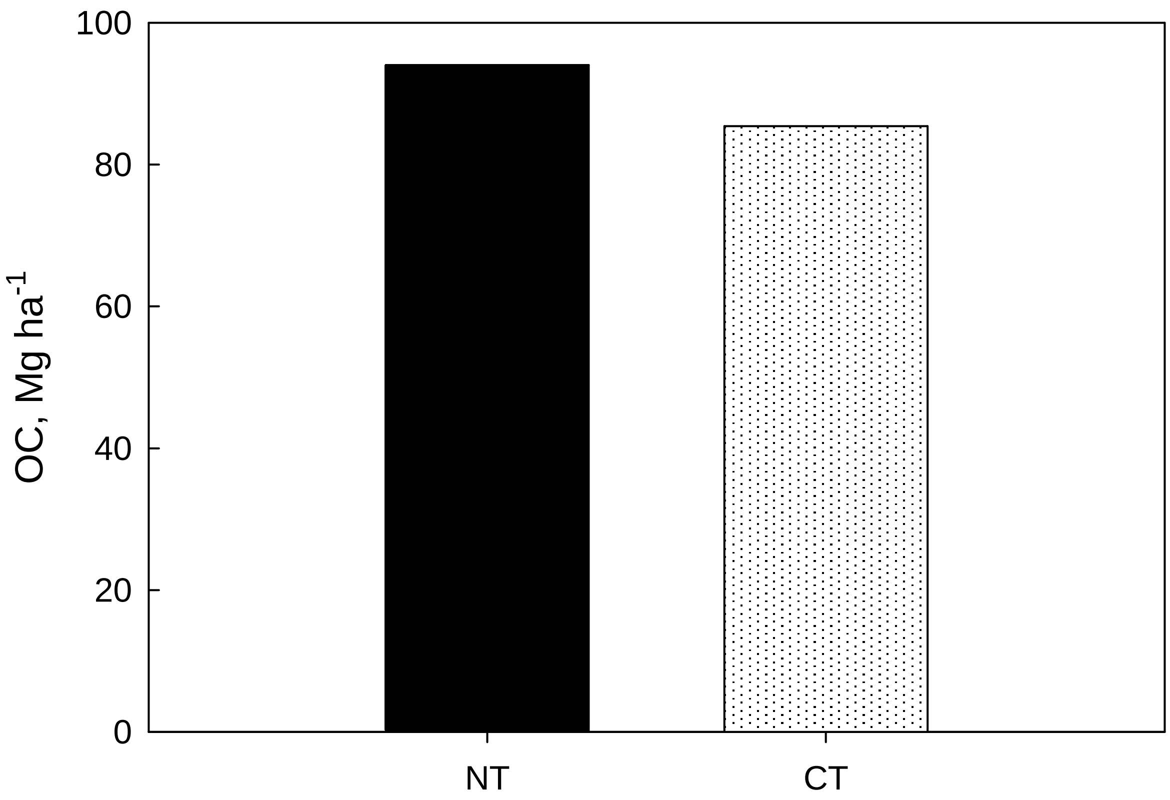

Figure 1.6. Organic carbon pool in the soils (0-110 cm depth) under No-till (NT) and conventional till (CT) in Oklahoma.

Organic carbon variability

Since NT and CT fields were sampled in parallel transects, a visual comparison was used to determine the consistency of OC along the transect in each field and between the parallel sampling points for Miami, Perry (1 and 2), Lahoma 1 and Walters sites for the 0-10 and 10-20 cm depths (Figure 1.7). For all sites a similar variation of OC content can be observed along the transect between NT and CT.

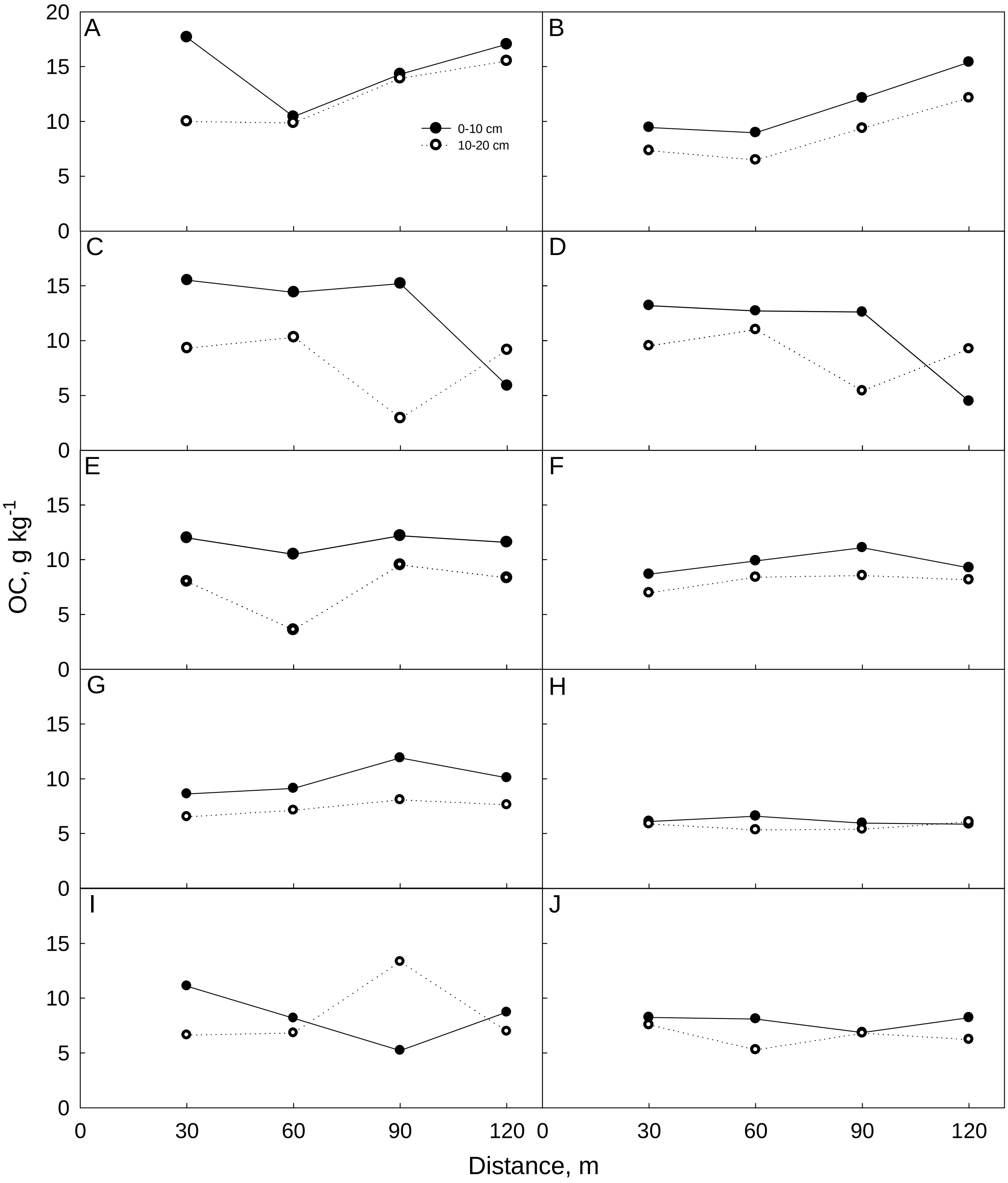

Figure1. 7. Organic carbon variability along the sample transect at Miami NT (A), Miami CT (B), Perry 1 NT (C), Perry 1 CT (D), Perry 2 NT (E), Perry 2 CT (F), Lahoma 1 NT (G), Lahoma 1 CT (H), Walters NT (I), and Walters CT (J).

DISCUSSION

Organic carbon concentration

The results from this state-wide study indicate that long-term (≥5 yr) NT cropping systems in Oklahoma increase OC (Figure 1.3 and 1.4). From the sites studied, two factors are important in increasing OC concentration in these soils: 1) time under NT management and 2) amount of annual precipitation. Sites that are over 10 year of NT, such as Canute, Walters, and Lahoma 2 had higher numerical OC concentration in soils under NT compared to CT. Also, areas where precipitation is higher (above 900 mm yr^{-1}), even if the NT adoption time is less than 10 years (5 years in Miami, 5 and 7 years in Perry), had higher numerical concentration of OC under NT compared to CT.

Observations in our study agree with other long-term studies comparing OC sequestration rates, such as Paustian et al. (1997) who affirm that lower sequestration rates are often observed in the first 5 years following NT adoption. Ussiri and Lal (2009) reported twice as much OC in the surface 30 cm in NT after 43 years of management compared to CT and molboard plow management. Additionally, studies carried out in areas of high precipitation (above 1,000 mm yr^{-1}) had reported higher OC sequestration rate compared to lower precipitation zones. Franzluebbers (2010) reports higher OC sequestration rates under NT in higher precipitations states such as Alabama (1391 mm yr^{-1}) and Georgia (1146 mm yr^{-1}) compared to Welasco, Texas (625 mm yr^{-1}). Climate dependent OC sequestration rates have been reported by Havlin et al. (1990) and Franzluebbers and Steiner (2002). Those authors found a positive relationship between crop residue production and OC accumulation, especially in the rooting zone. Our study has found similar results, where areas of higher precipitation (above 900 mm yr^{-1}) have accumulated more OC under NT regardless of time under NT management.

Another important aspect observed at some sites, such as Perry 1 and 2 was a decrease in the OC content occur in the layer 10-20 cm in NT, however in CT the same decreased was not observed. Similar observations were found by Boodey et al. (2010) in Brazil and Christopher et al. (2009). This may be explained by the incorporation of residue in the plowed layer that could promote the increasing of OC at this specific depth.

Total nitrogen

Results of total nitrogen were similar to OC content. Due to the high correlation of nitrogen and soil OC content (Spargo et al., 2008) TN results are very closely related with OC. Results from our study agree with Spargo et al. (2008). They observed an increase in TN after 14 years of NT in West Virginia. Similar results were also found by Franzluebbers et al. (1994) in Texas, NT had 45% more mineralizable N under NT compared to CT treatments. Other US states, such as Michigan (Pierce and Fortin, 1997) and Colorado (Follet and Schimel, 1989) have also observed an increase in TN with NT.

Organic carbon pool

There was greater pool of OC under NT in Oklahoma compared to CT. Sites located in eastern and central Oklahoma where precipitation is higher have greater accumulation of OC even with <10 yr in NT management. Organic carbon pools are probably larger because the potential to produce biomass is greater due to higher rainfall amounts. Franzluebbers and Steiner (2002), West and Post (2002), and Franzluebbers (2010) have presented data that agree with our observations. Greater differences in the OC pool were observed in the higher rainfall areas (Miami) and in the oldest sites (Waltes and Canute).

The use of continuous wheat and low rainfall had not been able to improve OC pool under NT in short period (5 yr). The site Lahoma 2 is under those characteristics; continuous wheat and low rainfall, consequently lower OC under NT than CT. Our results are in accordance to West and Post (2002) who indicated that continuous wheat NT is not effective in increasing soil OC concentration, those authors suggest that incorporating cover crop, and especially legumes in a continuous wheat system would help to increase OC accumulation in the soil.

CONCLUSION

No-till management has increased OC in Oklahoma soils. Time under NT management and precipitation regime plays important role in the OC sequestration. Areas of higher precipitation and longer NT management have been able to accumulate higher amount of OC compared to CT management. While short term NT in dry areas of the state had lower OC compared to CT.

Total nitrogen also had increased concentration under NT in most areas of the state. Higher numerical differences of TN were found where higher differences in OC were identified.

Studies in sequential yr in the same areas to evaluate the behavior and tendency of OC sequestration, as well as a more detailed study of depth change in the OC content using closer depths range should be consider in follow up studies. A component of characterizing OM by using isotope C fractions could be incorporated in the study to evaluate the contribution of different OM origin in the OM pool. Likewise, more studies of OC are needed in order to generate more information and data in the OC sequestration rate/dynamics in soils of Oklahoma.

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CHAPTER II

SOIL PHYSICAL PROPERTIES, ORGANIC CARBON, AND TOTAL NITROGEN AS AFFECTED BY TILLAGE AND CROP ROTATION IN OKLAHOMA

INTRODUCTION

Soil physical properties are severely affected by agriculture. Due to physical disturbance and severe alteration of natural characteristics, soils under agricultural management are susceptible to degradation. Among the most affected soil physical properties are soil aggregate characteristics and soil compaction.

Tillage prepares a crop seedbed by incorporating organic material into the soil and altering soil structure eases planting operations and ensures adequate seed to soil contact. The most common types of tillage practices studied in agricultural systems include the moldboard plow, chisel plow or some other model of reduced tillage, and no-till (Martens, 2001). The physical act of tillage disrupts the soil and often causes increased decomposition of previously-stable SOM (Balesdent et al., 2000). Incorporation of residue promotes higher organic matter mineralization and consequently higher nutrient availability for plant uptake (Hubbard and Jordan, 1996).

Conservation tillage, especially NT, has also been shown to have many effects on soil structure and quality. These effects include lower soil temperatures, greater water content, more even distribution of soil compaction through the soil profile, more stable aggregates, and higher SOM content (Karlen and Cambardella, 1996). Surface residue associated with NT is more efficient in reducing soil water losses by evaporation and is more favorable to nitrogen cycling due to lower mineralization rate and nutrient release compared to incorporated residue (Soon et al., 2001).

Soil structure refers to the size, shape, and arrangement of the soil particles and pores, and is highly variable and associated with a complex set of interactions among mineralogical, chemical, biological, and management factors (Letey, 1991). Aggregates are part of the soil structure and play important roles in soil quality. More stable aggregates enhance soil resistance to water and wind erosion, improve soil hydrological properties (Amezketa, 1999; Carminati et al., 2008), and help to increase soil resistance to compaction (Veiga et al., 2009). Mechanical disturbance of soil tends to reduce aggregate size and stability and results in a more unstable soil structure (Yang and Wander, 1998). Mechanical disturbance also makes soil more susceptible rain and wind erosion (Balesdent et al., 2000; López et al., 2000). Tillage practices can negatively impact soil structure by reducing soil organic matter (SOM). The relationship between SOM and soil structure has been studied by several authors (Tisdall and Oades, 1982; Lal and Fausey, 1994; Puget et al., 1995; Six et al., 2002; Abid and Lal, 2008; Veiga et al., 2009). Organic matter acts as a binding agent for aggregate formation and is known as a cementing agent of soil particles due to its chemical charges and capacity of forming strong bonds with soil particles. Soil aggregates formed around organic matter particles protect them against biological mineralization increasing their stability and resistance (Yang and Wander, 1998; McCarthy et al., 2008).

Soil compaction is defined as the process by which soil grains are rearranged to decrease void space, thereby increasing bulk density (SSSA, 1997). Soil will compact when the strength of the soil is less than the load being applied to the soil, and soil compaction can result from many common field operations. Several parameters, such as soil bulk density, total porosity, and penetration resistance can be used as indicators of soil compaction (Hakansson and Petelkau, 1991). The issue of soil compaction became more and more important with the use of heavy agricultural machinery to operate farmlands (Soane and Ouwerkerk, 1998) and more intensive tillage practices (Corsini and Ferraudo, 1999). The use of tillage at a constant depth over time causes the formation of a compacted layer just below the tillage depth that limits water movement within the soil, reduces root growth, and can causes reduction in crop growth and productivity. This layer is normally known as the plow pan and is located between 10 and 20 cm depth in tilled soils (Larson et al., 1980; Bengough and Mullins, 1990; Coelho et al, 2000).

Responses of various perennial and annual crops to soil compaction have been studied and documented. Laboski et al. (1998) found that the plowpan reduced soil drainage in the rooting zone causing limited oxygen availability for root respiration. Corsini and Ferraudo (1999) evaluated the effect of tillage practices during 8 years in subtropical soils of Brazil and reported that conventional till (CT) decreased bulk density in the surface layer but increased bulk density every year in the layer just below tillage operations. They also reported that no-till (NT) agriculture increased soil bulk density and decreased porosity during the first three years of no till, but soil bulk density decreased after three years due to the recovery of soil structure under NT. Likewise increasing in moisture retention and distribution, and reduction soil penetration resistance promote higher root distribution throughout the soil profile under NT compared to CT cropping system (Dwyer et al., 1996).

The effect of crop rotation on soil properties has been well studied and crop rotation has generally shown a positive impact on soil properties (Buchholtz, 1944; Karlen et al., 1994; Pauli, 1968; Villamil et al., 2006) and different crop species have different impacts on soil properties. These impacts are related to plant properties of nutrient uptake, root system pattern, and the quantity and quality of residue left on the soil after harvest (Martens, 2000). Kim and Dale (2005), for example, state that the use of winter cover crop following a corn/soybean rotation increased soil organic carbon (OC) content and yield of summer crops. Moreover this rotation reduced nitrous oxide emission as compared to continuous corn. Rotating corn and soybean increases the yield of both crops compared to monocropping (Karlen et at., 1994) and reduces long-term energy input. According to Kim and Dale (2005), the use of a corn/soybean rotation requires an input of 461 GJ ha^{-1} in a 40-year period. In the same time, the input required to produce continuous corn would be 718 GJ ha^{-1}. The lesser nitrogen requirement when producing a leguminous crop is the primary reason for the differential between the two systems. Lindwall et al. (1994) reported that CT and absence of rotation have decreased winter wheat yield in Canadian soils after nine years of study. Similar trends were reported by Lund et al. (1993), where rotation of corn, soybean, and wheat were compared. Reduced yield was observed for all the crops when a monocrop system was used compared to rotation, regardless of the rotational crop or sequence.

When combined, no-till and crop rotation can have a positive effect on SOC. West and Post (2002) have estimated that by changing from CT to NT an increasing on the soil C sequestration of 57±14 g of C m^{-2} year^{-1} is expected to occur and increasing rotational diversity would add another 20±12 g of C m^{-2} year^{-1} in the 0-30 cm depth layer No-till and crop rotation can result in greater biomass production in wheat production, especially when crop intensity is increased and cover crops are included (Lindwall et al. 1994). When combined with an absence of residue incorporation this greater biomass production results in greater soil coverage, greater moisture retention, lower soil bulk density, higher soil organic carbon, higher total nitrogen (TN) and eventually, higher yield, especially in years of water deficiency (Aese and Pikul Jr., 1995)

Two important advantages of intensification of crop rotation are the higher biomass yield compared to monocropping systems and diversity of biomass characteristics such as carbon:nitrogen (C:N) ratio. Carbon:nitrogen ratio is a property that is highly influencial on biomass susceptibility to decomposition (Mitchell et al., 1991; Bullock, 1992). High C:N ratio is more characteristic of grasses, which are more resistant to decomposition, while low C:N ratio is common in legume residues and their low resistance to decomposition. Due to these characteristics, a mixture of different species generally produces biomass more resistant to decomposition that will protect soil from erosion and accelerate nutrient cycling.

The objective of this study was to evaluate OC, TN, soil penetration resistance and soil aggregate stability of soils under NT, CT and different crop rotations in Oklahoma. The hypothesis was that no-till would increase soil organic carbon and nitrogen in the soil profile when compared to conventional till. Also, when rotations were compared, more diverse and intense rotations were expected to increase soil organic carbon and total nitrogen, as well as increase aggregate stability and alleviate soil compaction.

MATERIAL AND METHODS

Study Sites

Two crop rotation and tillage study sites in western Oklahoma were evaluated in 2010 to determine the effects of tillage and rotation on SOC, TN, and soil physical characteristics. Average monthly precipitation and mean temperature for both sites are provided in Figure 2.1. The first tillage/rotation study site was established in 2002 near Altus, OK (34°38′38″N 99°19’36″W) on a Hollister silty clay loam (0 to 1 percent slope, Fine, smectitic, thermic, Typic Haplusterststs). Experimental design was split-plot arrangement of a randomized complete block with three replications. Main plots were tillage treatment (NT and CT) and subplots were seven rotation sequences that included cotton (*Gossypium hirsutum* L), wheat (*Triticum aestivum* L.), and grain sorghum (*Sorghum bicolor* L*)* (Table 2.1).

The second tillage/rotation site was established in 2005 near Lahoma, OK (36°23′17″N 98°5′20″W) on a Pond Creek silt loam (0 to 1 percent slope, Fine-silty, mixed, superactive, thermic Pachic Argiustolls). Experimental design was a randomized complete block with four replications. Five cropping systems were evaluated including CT continuous wheat, NT continuous wheat, and three rotational systems including combinations of grain sorghum, soybean (*Glycine max* L.), and sunflower (*Helianthus annuus* L.) (Table 2.2).

Soil Analysis

Organic carbon, total nitrogen, and bulk density

A tractor-mounted, hydraulic-driven probe was used to collect two 3.8 cm diameter soil cores to a depth of 110 cm in each plot. Samples were divided into 0 to 10, 10 to 20, 20 to 40, 40 to 70, and 70 to 110-cm depth subsamples. Soil samples were dried in a forced-air oven at 50˚C and ground to pass through a 2-mm sieve. Air dried, sieved samples were used to determine soil total carbon (TC) and total nitrogen (TN) analyzed using loss on ignition method (Howard and Howard, 1990; Dokin, 1991; ISO/DIS, 1994; Westman et al., 2006). Additionally, inorganic carbon (IC) content was analyzed using a modified pressure-calcimeter method (Sherrod et al, 2002).Soil Organic carbon (OC) was calculated as the difference between and total carbon (TC) and inorganic carbon (IC).

Bulk density samples were determined by the core method (Grossman and Reinsch, 2002) using a 7.5 cm diameter core collected from each plot. Bulk density cores were sub-divided using the same depths as reported for OC samples. A 10-cm long subsample was taken in the center 10 cm of each depth was for evaluation of bulk density. Samples were oven dried at 105˚C, and soil dry mass was obtained to determine bulk density.

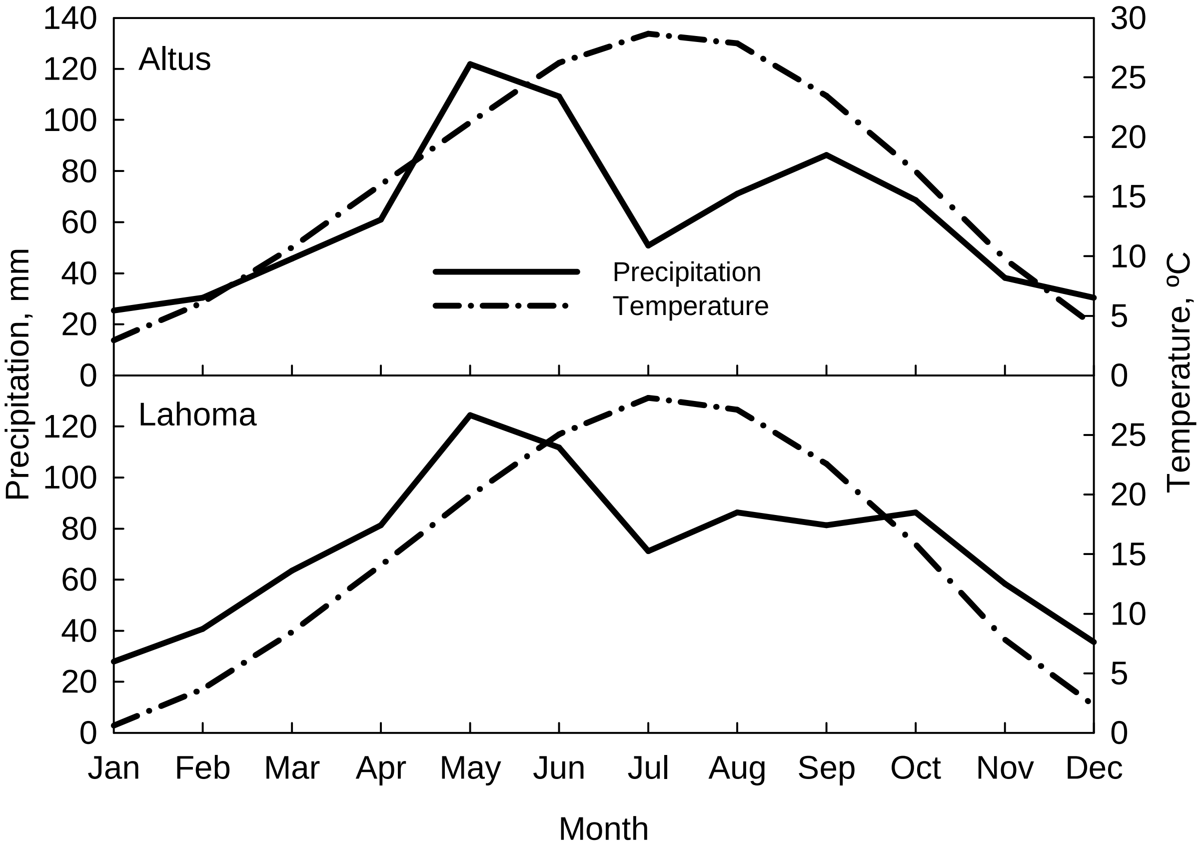

Figure 2.1. Monthly (30 yr average) precipitation and temperature for Altus and Lahoma, OK

(http://agweather.mesonet.org/index.php/data/section/climate verified 30 March 2011).

Table 2.1. Rotation subplots in Altus, OK. Tillage (NT and CT) was the whole plot.

Treatment	Rotation
1	Cotton / wheat / grain sorghum (C-W-GS)
2	Wheat / cotton (W-C)
3	Cotton / grain sorghum (C-GS)
4	Wheat / double crop grain sorghum / cotton (W-DCGS-C)
5	Cotton (C)
6	Wheat (W)
7	Grain sorghum (GS)

Table 2.2. Tillage and rotation treatments in Lahoma, OK.

Treatment	Tillage	Rotation
1	Conventional till	Wheat (W – CT)
2	No-till	Wheat (W – NT)
3	No-till	Grain sorghum/soybean/wheat (GS-S-S –NT)
4	No-till	Soybean/soybean/wheat/cowpea /soybean / wheat (S-S-W – NT)
5	No-till	Sunflower/soybean/wheat (SF-S-W – NT)

Soil aggregate stability

Approximately 500 g of aggregated soil was collected in each plot with a shovel inserted to a 10-cm depth and stored in plastic bags. Soil samples were ground to pass through an 8-mm sieve and moisture content was determined. Samples were air dried and residual moisture content was determined prior to analysis. Wet aggregate stability was determined according to aggregate stability methodology described by Yoder (1936) and Low (1954). Soil samples were placed in the top of a series 4, 2, 1, 0.5, and 0.25-mm of sieves for ten minutes and then shaken in water for 10 minutes at a speed of 30 rotations per minute. Aggregate size was estimated by geometric mean diameter (GMD), which is the average size of the aggregates in mm. Soil aggregate stability was calculated by equation 2.1 described by Mazurak (1950)

$$GMD = \exp\left[\sum_{i-1}^{n} w_i log\bar{x}_i / \sum_{i-1}^{n} w_i\right]. \qquad [2.1]$$

Where: *GMD* is the geometric mean diameter (mm), w_i is the weight of aggregates in a given size class of a specific average diameter x_i, and $\sum_{i-1}^{n} w_i$ is the total weight of the sample.

Soil penetration resistance

Penetration resistance was measured in March 2010 from the soil surface to 35 cm depth using a tractor-mounted hydraulic probe with a soil cone penetrometer with a 20 mm tip and inclination angle of 29.85˚. The probe was inserted into the soil at a constant speed of 30 mm sec^{-1} with penetration resistance measurements taken every 0.5 seconds. Cone penetrometer characteristics and methodology were in accordance to requirements of ASAE (1999). At the same time soil penetration resistance measurements were take, soil gravimetric water at 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, and 30-35-cm depths was measured using the gravimetric method (Black, 1965).

Data Analysis

Data were analyzed using the PROC GLM procedure of SAS (SAS Institute, Cary, NC) and means were separated using least significant difference (LSD) at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Organic carbon

Soils under NT at Altus had 2.2 g kg^{-1} more OC than CT in the soil surface (0-10 cm), but equal amount of OC at depths greater than 10 cm (Table 2.3). More OC was present in C-GS, continuous C and continuous W rotations from 0 to 10 cm under NT as compared to all CT treatments except GS at the same depth. No differences between treatments were found between 10 to 40 cm. At the depth of 40 to 70 cm GS under CT management had the least OC content. At 70 to 110 cm depth, W-DCGS-C under NT had lower OC than NT C-W-GS, NT W, CT C-W and CT W.

At Lahoma no significant difference was found among treatments at any depth after 5 years of study (Table 2.3). Lahoma is under similar climatic conditions as Altus (Figure 2.1), so a similar response of NT increasing OC in the top 10 cm of soil was expected but not observed. At 0 to 10 cm an average of 10.6 g OC kg^{-1} of soil was measured among NT treatments compared to 10.1 g OC kg^{-1} in the W-CT treatment at 10 to 20 cm. The average of NT treatments was 8.5 g OC kg^{-1} and the average of the W-CT treatment was 8.4 g OC kg^{-1}.

No till management and crop rotation increased OC concentration in the top 10 cm of soil in Altus; however, no effect on subsurface OC was observed and neither tillage nor crop rotation affected OC at Lahoma. Other researchers have noted greater OC content associated with soils under NT or under intense crop rotation (Havlin et al., 1990). Increasing OC accumulation due to NT and crop rotation in the top 20 cm of soil has also been frequently reported in the literature

(Lal et al., 1994; Dao, 1998; West and Post, 2002; Baker et al., 2007; Olson et al., 2010); however, similar results were not obtained in this study. Two possible causes for the lack of difference in OC concentration at depths greater than 10 cm or among rotations are the short period under NT management and inadequate precipitation. In areas of higher precipitation (above 1,000 mm yr^{-1}) a period of “adaptation” of approximately 3 years is expected to occur (Olness et al., 2002). During this period, problems related to absence of tillage occur and a decrease in grain yield and biomass production is expected to occur (Lund et al., 1993; Lindwall, et al., 1994; West and Post, 2002). After the adaptation period, OC accumulation in the topsoil is expected to start, but in areas of water deficit and/or insufficient crop rotation, positive effects of NT could take longer to occur (Campbell and Zentner, 1993; Baker et al., 2007). Differences in the OC concentration where observed only in the soil surface (0-10 cm), so when bulk soil (0 to 110 cm) were computed, no differences were observed. By using the whole soil profile, differences are less likely to occur because differences in the top layer are “diluted” in the bulk soil. Baker et al (2007) state that physical conditions, especially soil temperature and soil compaction can limit root growth below the vadose zone (20 cm) and consequently effect organic matter content at deep layer of the soil.

Total nitrogen

Response of TN to tillage and rotation at Altus was similar to that of OC (Table 2.4). Soil surface TN content was greater under NT compared to CT (p=0.0008). Total nitrogen content was 0.21 kg ha^{-1} greater under NT than CT at the 0 to 10-cm depth. Total nitrogen content in continuous W under NT was higher than C-W, C-GS, W-DCGS-C rotations and continuous C under CT at the 0 to 10-cm depth. The C-GS rotation under NT was also superior to C-W, C-GS, W-DCGS-C rotations under CT in terms of TN. Similar results were also observed by Lindwall et al. (1994)

where increasing OC content in the soil resulted in increased N content and consequently increased protein content in wheat. Likewise, Havlin et al. (1990) found increased organic N in soils under NT in two long-term studies in Kansas. At the depth of 10 to 20 cm no significant differences in TN between tillage regimens was observed; however, comparison among treatments showed that the rotations C-W-GS, C-W, and C-GS under CT were superior to C under both NT and CT. At the depth of 20 to 40 cm the only difference of TN content was observed between W and C-GS rotations under CT. At Lahoma, no differences in TN were found among treatments down to 20 -cm. At the 20 to 40-cm sampling depth W under NT and GS-S-S rotation under NT had lower TN compared to the S-S-W treatment under NT. Similar to OC at these two sites, as depth increased TN content decreased in all treatments in both locations.

Soil penetration resistance

Soil penetration resistance in Altus (Figures 2.2 and 2.3) was greater in NT compared to CT for rotations and monocrop systems at three surface evaluated depths (5, 10, and 15 cm). With the exception of the 5-cm depth under CT, decreased soil resistance was associated crop rotation regardless of tillage system. The C-W rotation had greater soil resistance compared to W-DCGS-C at the depths of 5, 10, 15, 20, 30, and 35 cm, and greater than C-W-GS at the depths of 5 and 10 cm. The C-W rotation had higher penetration resistance than W at 5 cm, but lower penetration resistance at greater depths.

Tillage had no effect on soil penetration resistance at Lahoma but there were differences among rotations (Figure 2.4). The W - NT and S-S-W treatments had lower penetration resistance throughout the soil profile than W – CT and GS-S-S - NT. There was lower soil water content at Lahoma (average of 0.17 g g^{-1}) at the time of soil penetration resistance measurement than Altus

(Figure 2, 3, and 4). The treatments W – CT between 12 and 24 cm, GS-S-S – NT between 11 and 27 cm, and SF-S-S – NT between 16 and 22 cm exceeded the 2000 kPa threshold for root growth restriction. At both locations treatments with lower soil moisture content at analysis had higher penetration resistance, especially W - CT. Increased penetration resistance in the layer between 15 and 20 cm was observed in all treatments at Lahoma. This is probably a plow pan layer resulting from several years of tillage in these soils.

Using crop rotation and cover crops in NT systems have alleviated soil compaction in other experiments (Hill and Cruse, 1985; Dwyer et al., 1996) and diversified rooting systems are believed to decrease compaction. Likewise, some tap rooted crops, such as cotton have stronger root systems capable of penetrating compacted layers better than fibrous-rooted crops such as wheat. The use of crop rotation at Altus reduced soil compaction under both tillage systems. The limit soil resistance for root growth and plant development is 2000 kPa (Hakansson and Petelkau, 1991). At the studied moisture content, NT W and CT W reached this 2000 kPa soil resistance threshold at 25 and 33 cm, respectively (Figure and 2.3).

Soil aggregate stability

Soil aggregate GMD at Altus was greater under NT ($p<0.0001$) than CT (Table 2.5). Significant differences were also observed among rotations and between tillage regimens within the same rotation. The rotation C-W-GS had 0.03 mm greater GMD under NT than CT. Similarly, C and W treatments had 0.04 mm greater GMD under NT than CT. At Lahoma, aggregate stability analysis (Figure 5), showed that S-S-W – NT (0.178 mm), had greater GMD than GS-S-S – NT (0.167 mm) and W – NT (0.156 mm). Similar results were reported by Martins et al. (2009) and Veiga et al. (2009) who found effect of crop rotation and tillage in the size of soil aggregates. The reduction of breakdown of aggregates by avoiding tillage associated to the diverse rooting systems that press the soil particles against each other to buildup aggregates are among the reason for higher aggregate stability under NT and intense crop rotation.

Table 2.3. Organic carbon from crop rotation and tillage plots at Altus and Lahoma, OK.

		Depth, cm					
	Rotation	0-10	10-20	20-40	40-70	70-110	Total
				g kg^{-1}			Mg ha^{-1}
Altus							
No-till							
	C-W-GS	13.4 abc	8.4 a	5.8 a	3.8 b	3.9 a	94.4 a
	C-W[†]	12.9 abc[‡]	8.4 a	6.7 a	4.0 ab	3.2 ab	88.3 a
	C-GS	14.6 a	8.9 a	7.2 a	4.7 ab	2.2 ab	89.8 a
	W-DCGS-C	11.9 bc	8.4 a	6.5 a	4.4 ab	1.3 b	76.4 a
	C	14.3 ab	9.4 a	7.3 a	5.2 ab	3.5 ab	98.1 a
	W	14.7 a	9.4 a	7.6 a	5.3 ab	4.6 a	103.6 a
	GS	13.8 abc	8.6 a	7.1 a	6.3 a	3.2 ab	105.7 a
	Average	13.6 A[§]	8.8 A	6.9 A	4.8 A	3.1 A	93.8 A
Conventional till							
	C-W-GS	11.4 c	8.7 a	5.9 a	6.1 a	3.2 ab	94.1 a
	C-W	10.9 c	9.3 a	7.6 a	4.9 ab	4.3 a	100.4 a
	C-GS	11.5 c	8.9 a	6.4 a	5.7 ab	2.1 ab	86.6 a
	W-DCGS-C	10. 9 c	8.9 a	7.0 a	5.9 ab	2.8 ab	103.2 a
	C	11.0 c	8.7 a	6.8 a	4.2 ab	3.5 ab	93.4 a
	W	11.7 c	9.7 a	7.9 a	5.7 ab	4.5 a	106.5 a
	GS	12.2 abc	8.8 a	7.3 a	3.6 c	3.3 ab	87.8 a
	Average	11.4 B	9.0 A	7.0 A	5.2 A	3.4 A	96.8 A
Lahoma							
	W – CT	10.1 a	8.4 a	8.5 a	6.9 a	3.9 a	104.8
	W – NT	10.2 a	9.0 a	7.6 a	6.1 a	3.5 a	94.2
	GS-S-S – NT	10.8 a	8.5 a	8.9 a	7.1 a	3.7 a	108.4
	S-S-W – NT	11.1 a	8.4 a	8.6 a	6.8 a	3.8 a	102.7
	SF-S-S – NT	10.2 a	8.2 a	8.5 a	6.7 a	3.6 a	98.3

[†] Cotton (C), wheat (W), grain sorghum (GS), soybean (S), and sunflower (SF), under no-till (NT) and conventional till (CT)

[‡] Means followed by same lowercase letter do not differ from each other at the same depth and location at α = 0.05

[§] Mean values within a location followed by the same uppercase letter are not significantly different at α = 0.05

Table 2.4. Total nitrogen from crop rotation and tillage plots at Altus and Lahoma, OK.

Rotation	Tillage	Depth, cm 0-10	 10-20	 20-40	 40-70	 70-110
		g kg^{-1}				
Altus						
No-till						
C-W-GS[†]		1.21 abc[‡]	0.76 ab	0.72 ab	0.60 a	0.27 c
C-W		1.09 abc	0.83 ab	0.55 ab	0.46 a	0.44 abc
C-GS		1.27 ab	0.87 ab	0.66 ab	0.54 a	0.45 abc
W-DCGS-C		1.18 abc	0.75 ab	0.60 ab	0.55 a	0.38 bc
C		1.21 abc	0.58 b	0.72 ab	0.57 a	0.36 bc
W		1.40 a	0.76 ab	0.58 ab	0.49 a	0.42 abc
GS		1.16 abc	0.74 ab	0.71 ab	0.43 a	0.20 c
Average		1.22 A	0.63 A	0.65 A	0.52 A	0.36 B
Conventional-till						
C-W-GS		1.06 abc	0.92 a	0.70 ab	0.48 a	0.52 ab
C-W		1.01 c	0.92 a	0.70 ab	0.45 a	0.52 ab
C-GS		0.97 c	0.99 a	0.54 b	0.52 a	0.63 ab
W-DCGS-C		0.78 c	0.88 ab	0.69 ab	0.36 a	0.64 a
C		1.03 bc	0.66 b	0.58 ab	0.48 a	0.39 abc
W		1.14 abc	0.77 ab	0.79 a	0.56 a	0.40 abc
GS		1.08 abc	0.78 ab	0.56 ab	0.60 a	0.44 abc
Average		1.01 B	0.73 A	0.65 A	0.49 A	0.51 A
Lahoma						
W – CT		1.06 a	0.92 a	0.95 ab	0.80 a	0.58 a
W – NT		1.12 a	0.92 a	0.83 b	0.84 a	0.57 a
GS-S-S – NT		1.31 a	0.92 a	0.84 b	0.73 a	0.51 a
S-S-W – NT		1.08 a	1.16 a	1.13 a	0.76 a	0.58 a
SF-S-S – NT		1.06 a	1.04 a	0.97 ab	0.86 a	0.61 a

† Cotton (C), wheat (W), grain sorghum (GS), soybean (S), and sunflower (SF), under no-till (NT) and conventional till (CT)

‡Means followed by same lowercase letter do not differ from each other at the same depth and location at α = 0.05

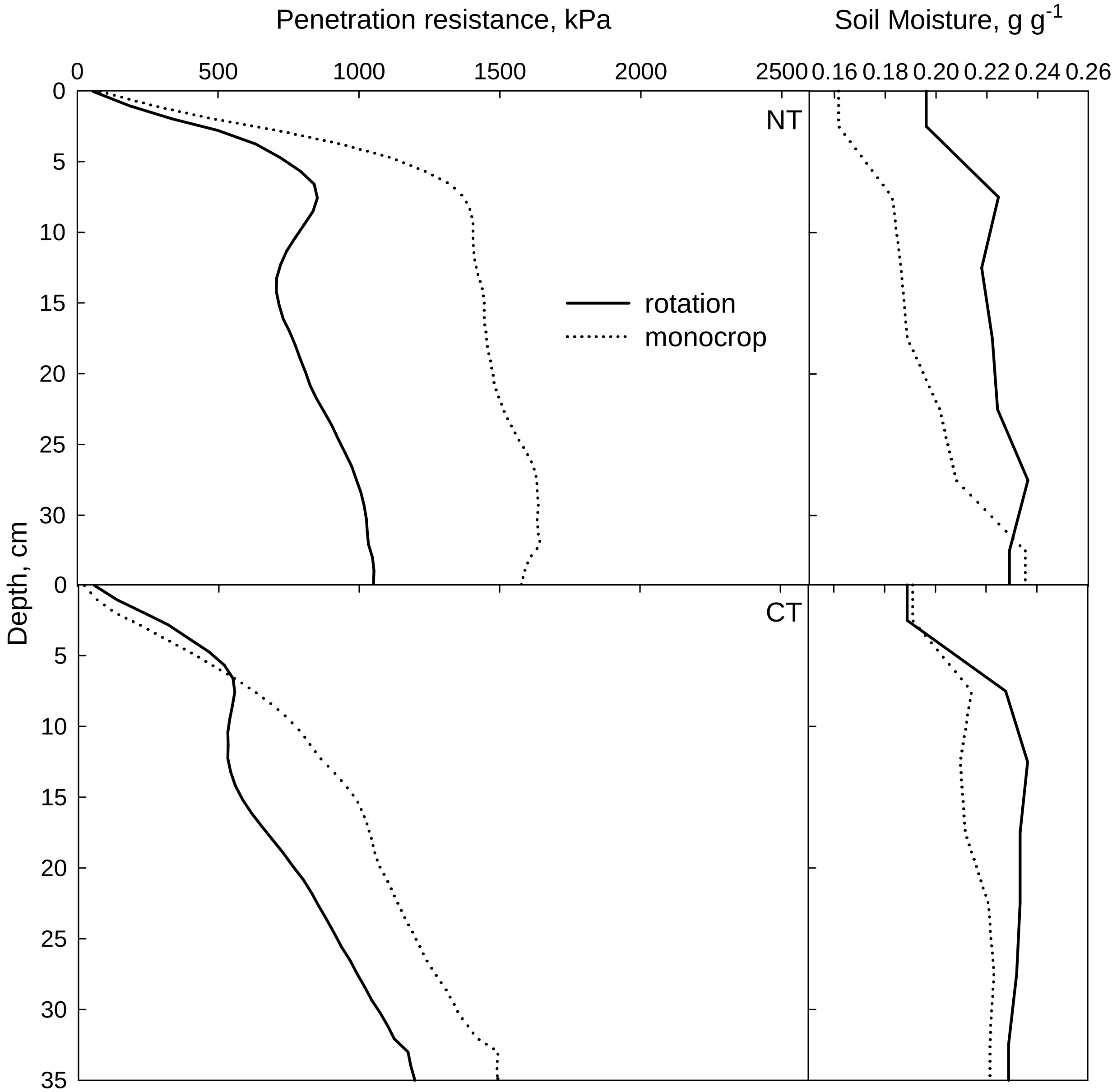

Figure 2.2. Soil penetration resistance under crop rotation and monocrop systems under no-till (NT) and conventional-till (CT) management at Altus, Oklahoma. Data was collected on March, 19, 2010.

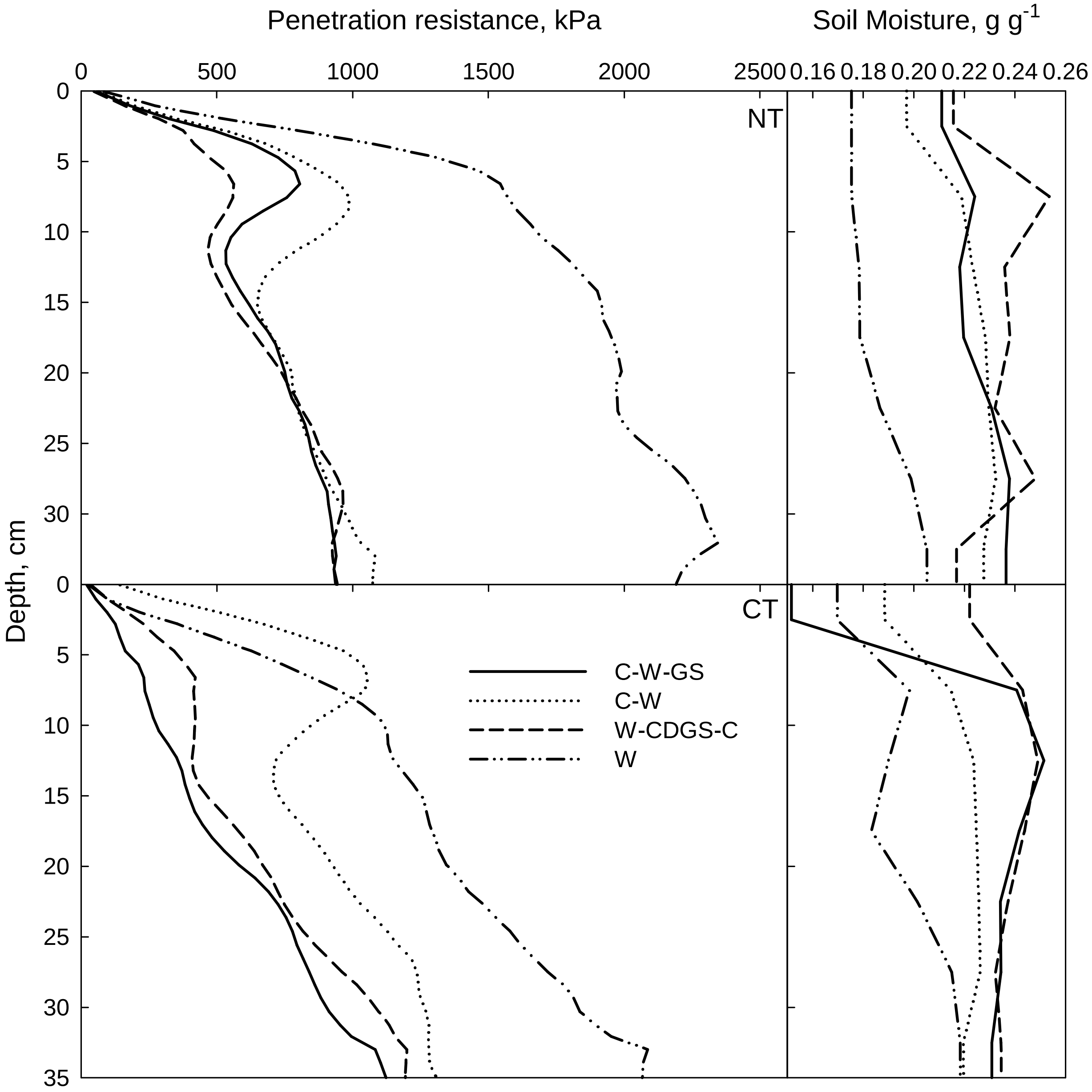

Figure 2.3. Soil penetration resistance under crop rotation (Cotton (C), wheat (W), grain sorghum (GS)) and monocrop wheat under no-till (NT) and conventional-till (CT) management at Altus, Oklahoma. Data was collected on March, 19, 2010.

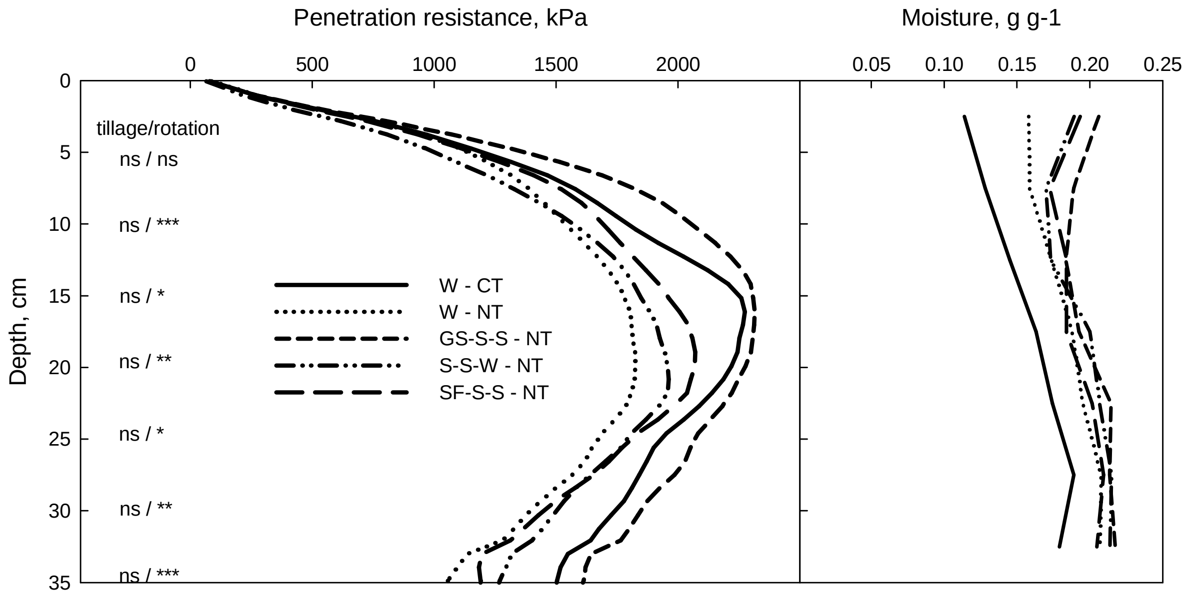

Figure 2.4. Soil penetration resistance under different crop rotation and tillage (Cotton (C), wheat (W), grain sorghum (GS) no-till (NT) and conventional-till (CT) in Lahoma, Oklahoma. ns= nonsignificant at α=0.05. *,, **, ***,and **** indicated significance at α = 0.1, 0.05, 0.01, and 0.0001. Data was collected on April, 1, 2010.

Table 2.5. Soil geometric mean diameter (GMD) under different crop rotation and tillage in Altus, OK.

Tillage	C-W-GS	C-W	C-GS	W-DCGS-C	C	W	GS	Mean
NT	0.18 Aabcd	0.17 Acde	0.18 Aabc	0.17 Abcde	0.20 Aab	0.20 Aa	0.19 Aabc	0.19 A
CT	0.15 Be	0.16 Ae	0.17 Acde	0.18 Abcde	0.16 Be	0.16 Be	0.18 Aabcd	0.16 B

* Means followed by the same upper case letter do not differ from each other within a rotation treatment, and means followed by th same lower case letter do not differ from each other with a tillage regimen at α=0.05.

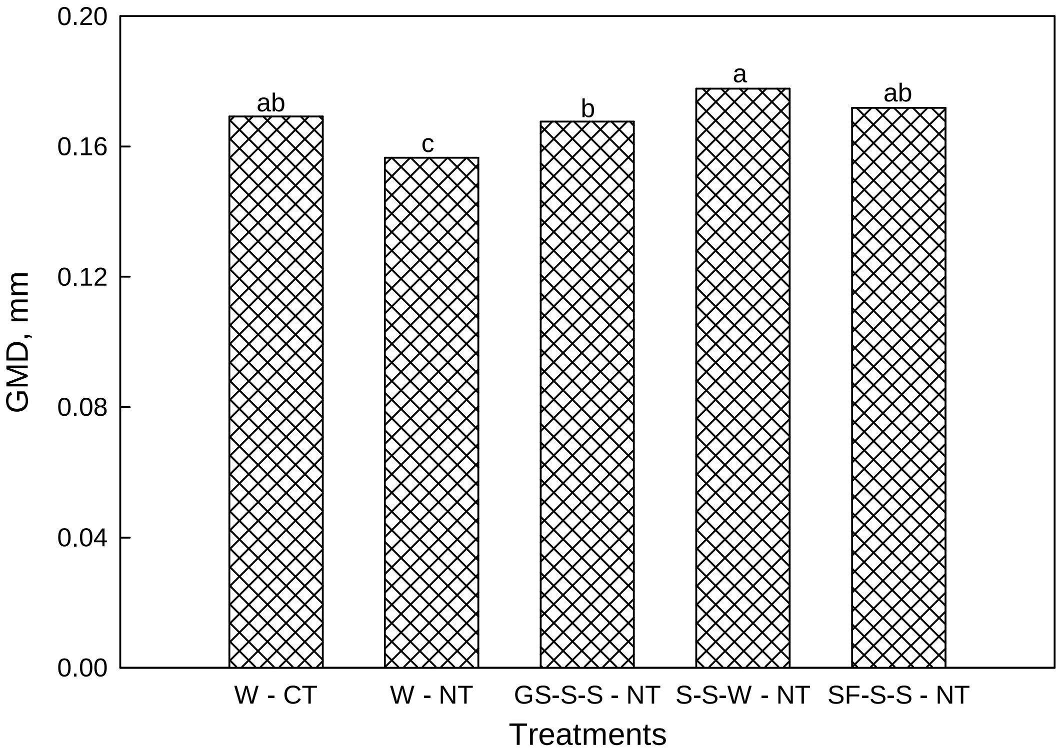

Figure 2.5. Soil geometric mean diameter (GMD) under different crop rotation and tillage in Lahoma, OK. Means followed by same letter do not differ from each other treatments (α=0.05).

CONCLUSION

Overall, the use of NT and crop rotation increased soil quality parameters at Altus and Lahoma test sites; however, the short duration (8 years in Altus and 5 years in Lahoma) under NT management has not been enough to cause an effect in all evaluated properties and depths. So far, the greatest impact has been observed at the soil surface (0 to 10 cm) but not at depths greater than 10 cm.

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CHAPTER III

INCREASING CROP ROTATION AND INTENSITY IN CENTRAL OKLAHOMA

INTRODUCTION

The advance of no-till (NT) cropping systems is closely related with the use of crop rotation and cover crops. Rotating crops is an important tool to decrease disease pressure, alleviate weed competition, increase soil quality (Derpsch, 1985) and control erosion processes (Havlin, et al., 1990; Reeves, 1994; Delgado, 1998).Crop species have different impacts on soil properties. Characteristics of root system distribution, rooting depth, nutrient uptake pattern, quality, and quantity of biomass can greatly influence soil properties (Martens, 2000).

The use of soil for long-term continuous monocrop production has several implications on soil properties (Randall, 2003) including a negative effect on soil quality. However, the use of crop rotations and cover crops have been reported to contribute in increasing soil quality in agricultural fields (Karlen, et al., 1994; Villamil, et al., 2006). Kim and Dale (2005) using modeling projections for Scott Co., IA, state that the use of a winter cover crop following a corn-soybean rotation increases soil organic carbon (OC) content and yield of summer crops, and reduced nitrous oxide emission compared to continuous corn. Reduction in CO_2 emission by the use of cover crops and tillage systems has also been studied by Dao (1998) in Oklahoma. Dao reported that tillage increased CO_2 emission by a magnitude of three fold compared to NT treatments.

Rotation of corn-soybean has been found to increase yield of both crops compared to mono-cropping (Karlen, et at., 1994). In addition, this same rotation has a reduction of energy input in a long-term system when compared to a continuous crop. According to Kim and Dale (2005) the use of acorn-soybean rotation requires an input of 461 GJ ha^{-1} in a period of 40-years. In the same time, the input required to produce continuous corn would be 718 GJ ha^{-1}. Reasons for that difference are less nitrogen fertilizer and less fuel used in the rotational system. Nelson et al. (1991) states that crop rotation produces greater cover on soil and helps to prevent against soil erosion. Russell, et al (2006) using alfalfa in a rotation system found a positive impact of this crop by increasing up to 30 mg of N in each kg of soil, and up to eight kg of soil OC ha^{-1}. At the same time, grain yield was strongly correlated with soil N content. Overall, the use of a crop rotation promotes an increase in soil quality and maintains the soil productivity capacity over time.

Including cover crops in wheat based (*Triticum aestivum* L.) rotations has been reported with positive results by several authors. West and Post (2002) indicate that continuous wheat cropping system is not effective in increasing OC in the soil, even in NT systems. However, incorporating different crops, including legumes in the wheat rotation can enhance soil OC sequestration by 8 times compared to continuous wheat system. Investigating rotation, tillage and seeding effects in winter wheat in Canada, Lindwall et al. (1994) reported that no effect of rotation was observed in the first two years of the study, however, higher wheat yields were observed in the following two years compared to continuous wheat. Continuous wheat treatment had to be terminated after four years under NT due to high weed competition, while weed pressure in the rotation treatments was minimal. Lund et al. (1993) found no advantage of rotating corn, soybean, and wheat in wheat yield in Wisconsin soils, however those authors reported higher yield in corn and soybean in rotation compared to continuous crop.

Two of the most important benefits of crop rotation are the increase of biomass yield to protect the soils and the increase in the diversity of the biomass. Carbon-nitrogen relationship (C:N) for example is a property that is highly dependent on the biomass's susceptibility to decomposition (Bullock, 1992; Mitchell, et al., 1991). High C:N ratio is more characteristic of non legume plants which are more resistant to decomposition, while low C:N relationship is common in legumes residues and their resistant to decomposition is much lower. In that aspect, a combination of different species would provide greater diversity in decomposition rates.

The absence of tillage can lead the soil to high levels of soil compaction, increased penetration resistance, high concentration of fertilizers and nutrients in the top layer, among other effects. The use of crop rotation is a key component to make NT cropping systems sustainable (Fidelis, et al., 2003). Crop rotations associated with NT and intensification of cropping systems help create vertical pores in the soil that will increase water conductance, enhance soil structure and aggregate stability. Also, increased crops intensity and rotation tend to produce more biomass that serves as mulch, protecting the soil against erosion and soil compaction, decreasing the growth of weeds, increasing water infiltration and storage, and promoting biological activity (Camargo and Piza, 2007).

Crop rotation in Oklahoma is limited. Large areas of agriculture in the state are under continuous winter wheat and with limited cropping intensity. The 2009 Oklahoma Agricultural Statistics (USDA-NASS, 2009) Oklahoma's harvested areas of principal crops is 3.52 million ha. From those, 1.82 million ha are wheat, followed by soybean (145.69 thousand ha), and corn (141.64 thousand ha). Wheat is, by far, the largest grown crop in Oklahoma. The lack of crop rotation and generally low diversity cropping has threatened the sustainability of these cropping systems. Pikul Jr. et al. (2006), West and Post (2006) Havlin, et al. (1990) among other authors have stated that continuous cropping systems are of lower sustainability compared to cropping systems that include crop rotation and increase crop intensity.

Even with increasing in residue addition by the use of cover crop, West and Post (2002) did not identify an increase in soil organic C content due to cover crop use in already stabilized long-term NT systems. The authors indicate that this effect is probably due to the very close to steady state OC already reached in the long-term NT system. However, they affirm that in conventional till (CT) system, cover crops are very important in enhancing soil OC. Also, for new NT systems, they indicate that cover crops would promote the enhancement of OC in the soil due to the highest residue input.

Our objective was to evaluate crop rotations combining grain crops and cover crops to enhance crop rotation and intensity in Central Oklahoma. Also to identify crop rotation effects on soil pore size distribution, total porosity, and soil bulk density after 2-yr intensive rotation.

MATERIAL AND METHODS

Study Sites

The study was conducted in 2008 and 2009 at two sites in Central Oklahoma. Average monthly precipitation and mean temperature for Payne County, where both sites were located, is provided in Figure 3.1. The first site was at the Oklahoma State University Agronomy Research Station in Stillwater, OK (36°5’24” N, 97°3’00” W). Soil was classified as a Ashport silty clay loam, (0 to 1 percent slope, Fine-silty, mixed, superactive, thermic Fluventic Haplustolls). The second site was at the Cimarron Valley Research Station in Perkins, OK (35°58′23″N 97°1′59″W). Soil was classified as a Konawa fine sandy loam (3 to 5 percent slope, Fine-loamy, mixed, active, thermic Ultic Haplustalfs). The experimental design was randomized complete block with nine treatments and four replicates. Both sites had similar experimental design and plots randomization. Although only separated by a short distance, soil types were drastically different as indicated by the taxonomic classifications.

Rotation treatments

Nine rotations including grain crops: corn (*Zea maiz* L.), soybean (*Glicine max* L.) (maturity group IV), wheat (*Triticum aestivum* L.) and cover crops. Cover crops included: forage radish(*Raphanus sativus* L.), sunn hemp (*Crotalaria spectabilis* L.), pigeonpea (*Cajanus cajan*), cowpea (*Vigna unguiculata*), and Austrian pea (*Pisum sativus*) that were used in rotations to increase crop intensity and biomass production. The 2 years rotations for this experiment were:1-wheat (w); 2-Cowpea- sunn hemp -wheat-pigeonpea (ca-sh-w-pp); 3- cowpea-pigeonpea- wheat-sunn hemp (cp-pp-w-sh); 4- soybean-austrian pea-corn (sb-ap-co); 5- corn-radish-soybean (co-ra-sb); 6- corn-soybean (co-sb); and 7 soybean-corn (sb-co). At Stillwater, conventional tillage was performed until the installation of the experiment, while in Perkins the field was under no tillage for 2 years prior to the start of the experiment. All crops were planted no-till. Fertilizers were applied only on grain crops at the following rates: corn: 120 kg N ha^{-1} in form of urea (46% N) and 22.3 kg P ha^{-1}, in form of liquid ammonium polyphosphate at planting. Soybean: 6.56 kg ha^{-1} of N and 22.3 kg P_2O_5 ha^{-1} were applied in form of liquid ammonium polyphosphate at planting. An extra 32 kg ha^{-1} of P_2O_5 was applied broadcast in the form of super triple phosphate (0-46-0). Wheat: 25 kg ha^{-1} P_2O_5 was applied in form of liquid ammonium polyphosphate at planting, 60 kg N ha^{-1} was applied in as urea at planting and another 50 kg ha^{-1} was applied in March. For all cover crops, no fertilizer was applied. However all the legume seeds were inoculated with the correct strain of Rizhobium prior to planting. Grain yield was measured in each grain crop plot. Using the middle two rows for corn and middle 4 rows for soybean grain yield using a small plot combine (Winterstieger, Germany), wheat was harvested using a Hege plot combine model 140. Moisture content was measured in all plots to correct for 15.5% for corn and 13% for soybean and wheat. Biomass was measured in a random 0.25m^2 in the central part of the plot after flowering in the cover crops and after harvesting in the grain crops plots. Cover crops that anticipated wheat had to be terminated by application of 2 4-D at doses of 0.75 kg of active ingredient ha^{-1}.

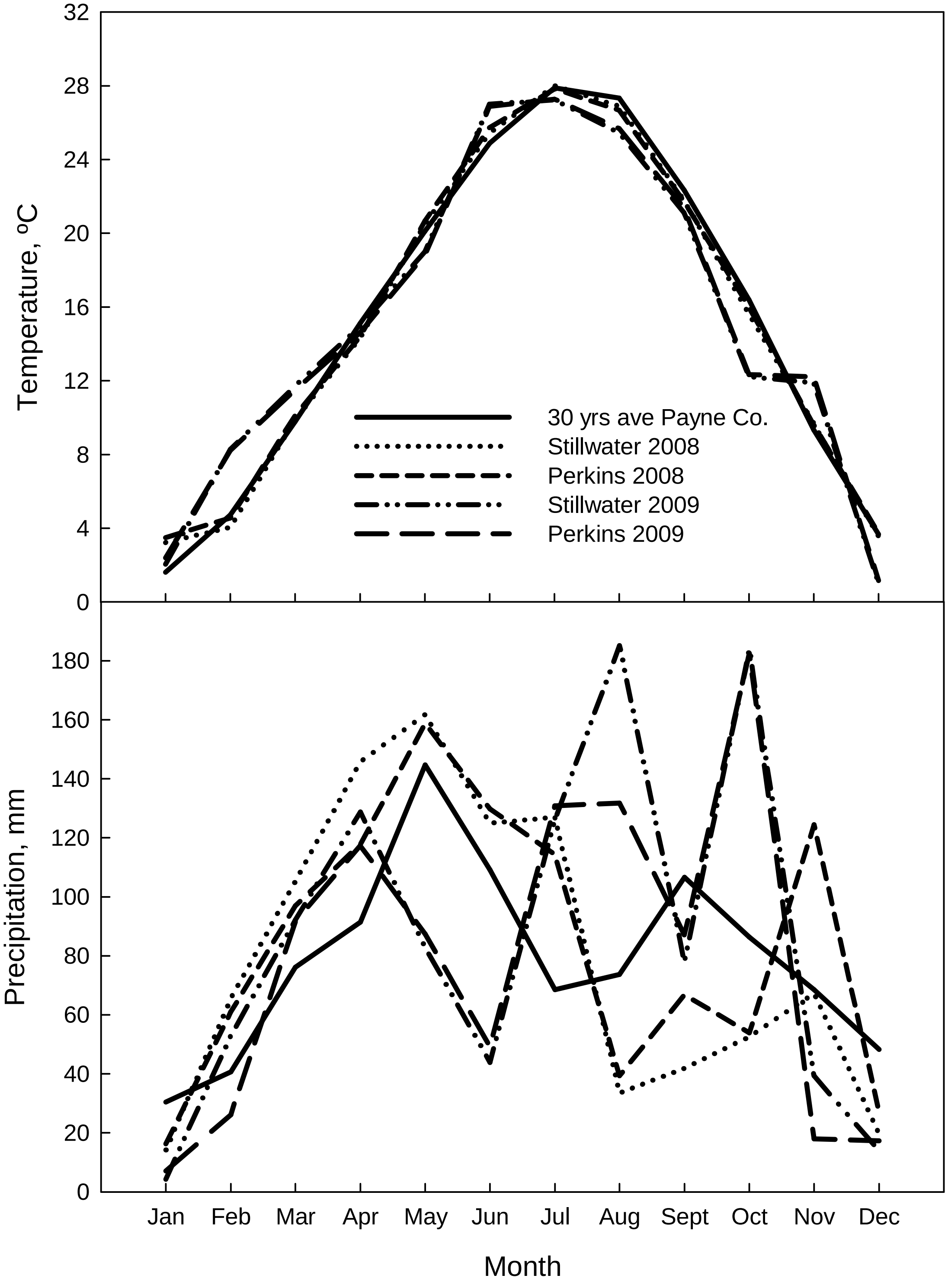

Figure 3.1. Normal average monthly precipitation and mean temperature for Payne Co., monthly precipitation and temperature for Stillwater and Perkins during 2008 and 2009 (http://agweather.mesonet.org/index.php/data/section/climate).

Soil Analysis

Undisturbed samples were taken in the depths of 2-4, 7-9, and 15-17 cm for analysis of bulk density, total porosity, water retention curve at the tensions of -0.1 and -0.3 bar, and pore size distribution. Soil bulk density and total porosity were carried out using the volumetric ring method (Grossman and Reinsch, 2002). Soil water retention curve and pore size distribution were carried out using a tension plate method (Klute, 1986).

Data Analysis

Grain yield, biomass, soil bulk density, and pore size distribution were analyzed comparing rotations that included the same grain crop separated. All the data was analyzed using the PROC GLM procedure of SAS (SAS Institute, Cary, NC) and least significant difference (LSD).

RESULTS AND DISCUSSION

Grain Yield

In general, when increasing cropping intensity grain yield was not affected (Figure 3.2). Also, the inclusion of cover crops between summer and winter grain crops did not affect grain yield (Figure 3.2). In 2008, corn grain yield was 7,015 kg ha^{-1} when averaged across the CO-RA-SB and CO-SB rotation (Figure 3.2.A). There was no difference between treatments. In 2009, corn grain yield was similar between the SB-AP-CO and SB-CO. Camargo and Piza (2007), reported that in subtropical areas in Brazil, increases in biomass yield production by inclusion of sunn hemp, black oats, and radish as cover crops did not affected grain yield in corn the following year.

Similar to corn grain yields, soybean seed yield (Figure 3.2. C and 3.2.D) was not affected by the inclusion of a late fall cover crop when compared to a SB-CO rotation. Radish was planted after corn harvest in October 2008 and was terminated by frost in mid-December, a production of 3,100 kg of above ground biomass ha^{-1} during this period was observed. The use of the radish did not affect soybean yield compared to having a fallow period during the fall and winter.

Cropping systems using continuous wheat and wheat following double cover crop were studied. The use of two combinations of summer cover crops did not affect winter wheat yield in 2009 (Figure 3.2.E). Wheat systems were continuous wheat following a summer fallow period (3 m), wheat following cowpea followed by sunn hemp or pigeon pea as a late summer cover crop in the two rotational systems. Wheat grain yields of all rotations were similar.

Increasing crop intensity by double cropping wheat/soybean and soybean/sorghum, Franzluebbers et al. (1995) reported an increase in land use efficiency and optimization of nitrogen use by wheat and sorghum in South Central Texas over an 11-yr period. The inclusion of soybean in rotation with wheat and sorghum increased nitrogen biological fixation and nitrogen content in the residue, reducing the nitrogen fertilization requirement in the cropping system. The use of a more intense cropping system associated with reduced tillage lead to a lower nitrogen requirement, lower nitrogen losses, higher nitrogen cycling, and higher yield according to those authors.

Biomass yield

Cropping systems that increased crop diversity and crop intensity, by incorporating cover crop into the crop rotation system, increased biomass production (Figure 3.3). Wheat production system that included double cover crops during the summer previous to wheat planting increased biomass production by a 865 and 878 % for CP+PP and CP+SH, respectively. The biomass contribution of those two systems were 9,494 kg ha^{-1} for the CP+ PP and 14,544 kg ha^{-1} for the CP+SH system. Summer cover crops have the potential to produce high amounts of biomass. Cowpea, pigeonpea, and sunn hemp produced an average of 4,894, 4,600, and 9,650 kg of biomass ha^{-1}, respectively, in a 45-60 d period. Mansoer et al. (1997) reported that sunn hemp had average biomass yields of 5,900 kg ha^{-1} in a 12-wk period and biological fixation of 120 kg ha^{-1} of nitrogen. Those authors attest that sunn hemp is a sustainable alternative as summer cover crop due to its high potential to produce biomass and fix nitrogen. No difference was observed in biomass yield of the corn-soybean rotation system compared to the same rotation with the inclusion of late fall or winter cover crops. Planting radish as late fall cover crop after corn contributed 3,100 kg ha^{-1} of above ground biomass. No subsurface biomass was measured; however the contribution of radish with below ground biomass is estimated to be equal or greater than above ground biomass (McMahon, et al., 2002). While Austrian winter pea planted as winter cover crop after soybean contributed 1,836 kg ha^{-1} of biomass.

Biomass production depends on water availability. Some cash and cover crops require more moisture than others, so the choice of crops used in the rotation depend on the water available during the growing season (Tanner and Sinclair, 1983). The two years of the study had fluctuations in precipitation, however annual precipitation was numerically greater compared to the 30-yr normal precipitation for Payne County (Figure 3.1). Precipitation varies on the year to year basis, so the occurrence of dryer years can influence plant growth and may result in crop failure during some years. The buildup of residue on the soil surface may reduce runoff and protect the soil against water loss by evaporation (Wagger and Mengel, 1988; Holderbaum et al., 1990)

Bulk density

No effect of rotation was observed on soil bulk density (Table 3.1). The use of cover crops, increasing crop intensity and rotation over a 2-yr period was not sufficient to promote changes in soil bulk density (Figure 3.4). However, differences between depths were observed in most treatments at both locations. When differences among depths were observed, the shallower depth (2 to 4 cm) had a lower bulk density compared to greater depths. These findings were not unexpected as higher OM content and higher root biomass typically occurs in the shallowest layer of the soil, effectively lowering bulk density in the upper part of the soil horizon. Villamil et al. (2006), studying the effect of crop rotation in soil properties in Urbana, IL, found that including winter cover crop between summer crops reduced bulk density after 5 years of study. Pikul Jr. et al. (2006), observed that changes in bulk density caused by crop rotation in long term experiments are seasonable and can change due to root effect, moisture content and clay minerals. Changes within the same treatment between different depths are easily identified over time.

To decrease bulk density, Calonego and Rosolem (2010) used cover crop rotation and deep tillage. The use of cover crops rotation with soybean promoted the decrease in bulk density and increased of soybean seed yield after four years. As reported by those authors, our study did not find significant increase of soybean yield in the first year of crop rotation on soybean grain yield. However, differences may be expected after several years under rotational system.

Evaluating two tillage treatments near Aimes, IA, Hill and Cruse (1985) did not find differences between conventional and no till in a 2-yr tillage systems study but found increased in bulk density under no-till after 8-yr of continuous tillage treatment in the depth of 6 to 12 cm. Those authors indicate that changes in bulk density and soil porosity may not be observed in short-term cropping systems. In the subtropical zone of Brazil Martins et al. (2009) found differences in aggregate sizes, bulk density and organic matter content in soils that had cover crops sunn hemp, forage radish, sunflower, and millet compared to only grain crop rotations of corn and soybean combinations after 4-yr of crop rotation. Factors such as the short time under cropping system management could have influenced results in our study. A longer period of crop rotations with different crop intensity as we had in the study, could promote differences in bulk density and pore size distribution. As reported in cited studies, 4-yr rotations have been sufficient to promote reduction of soil bulk density.

Pore size distribution

Different crop rotation did not affect pore size distribution in any studied layer of the soil (Figure 3.6 and 3.7, Table 3.1). Due to differences in soil texture, differences between locations were observed, but no differences among treatments. Using cropping systems that increase crop rotation and crop diversity is expected to influence pore size distribution. However, the short period of two years was not sufficient to build up a pore network in soils under more diverse cropping systems. Calonego and Roselem (2010) reported effects of crop rotation using sunn hemp and other cover crops in rotation with soybean after 4 years rotation period. The use of those cover crops increased root elongation and biomass, also decreased soil penetration resistance. However a longer than 2 years period has to be used under crop rotation in order to observe those differences. Tisdal and Oades (1982) report that aggregate stability, especially macroaggregates, and soil porosity are dependent on soil management. Long term conservation tillage and increased crop diversity contribute to the increase in soil aggregation and consequently macropore occurrence in soil. Mechanical disturbance of soil by plowing destroys long vertical pores formed by root decomposition (Hamblin, 1980; Carpenedo and Mielniczuk, 1990). However, even under tillage systems that promote the stability of vertical soil pores, like no-till, pore formation from root decomposition depend on root and environment characteristics (Hamblin, 1987; Lal, 1993). Also, the stability of soil aggregates and pores are dynamic properties and can vary due to intrinsic factors such as soil texture and moisture dynamics (Key et al., 1988). Comparing our study, several factors could have influenced the results. The short time for formation of stable pores could be one of the possible factors influencing pore distribution in the soil.

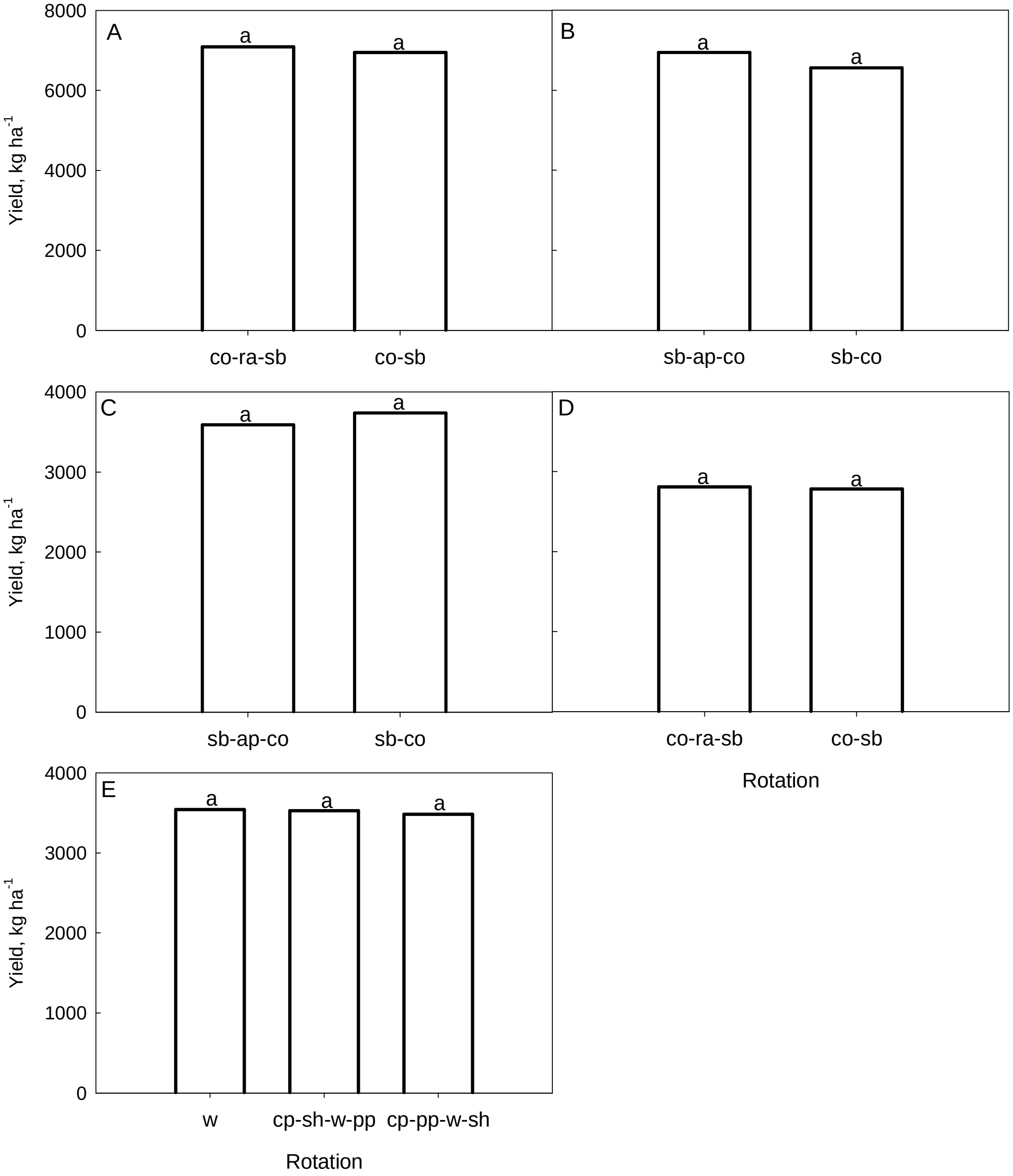

Figure 3.2. Grain yield of corn (co) 2008 (A) and 2009 (B), soybean (sb) 2008 (C) and 2009 (D), and wheat (w) 2009 (E) in cropping systems using radish (ra), Austrian winter pea (ap), cowpea (cp), sunn hemp (sh), and pigeon pea (pp) as cover crops.

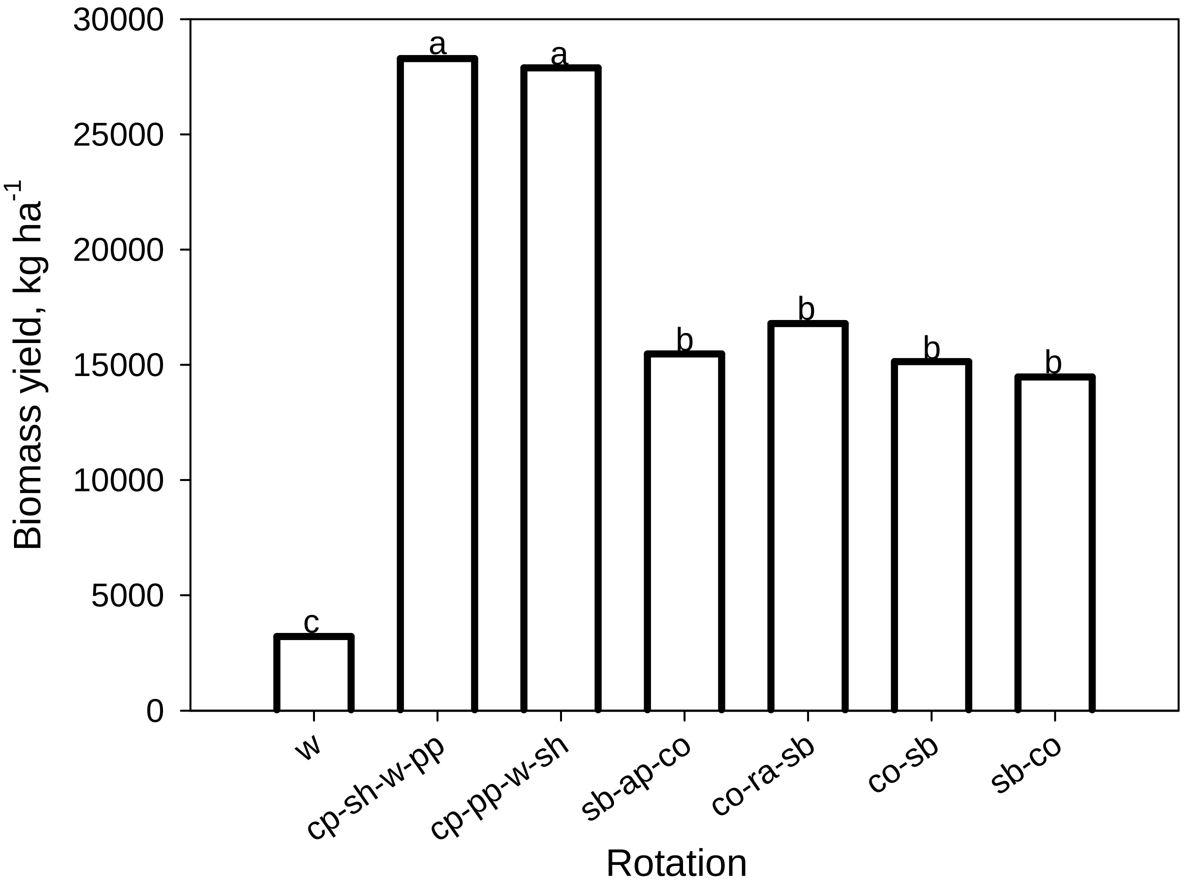

Figure 3.3. Biomass yield of different cropping systems using grain crops corn (co), soybean (sb), and wheat (w) combined with cover crops radish (ra), Austrian winter pea (ap), cowpea (cp), sunn hemp (sh), and pigeon pea (pp).

Table 3.1. Statistical significance of depth, treatment, and location for soil bulk density (BD) pore size distribution in the classes of >1.45µm, 1.45µm < 0.48µm, and <0.48µm in soils under different cropping systems at 0.10 “*”, 0.05 “**”, 0.01 “***”, and non-signficant “ns” LSD significance level.

	Depth	Treatment	Location
BD	***	ns	***
>1.45µm	*	ns	**
1.45µm < 0.48µm	ns	ns	***
<0.48µm	**	ns	***

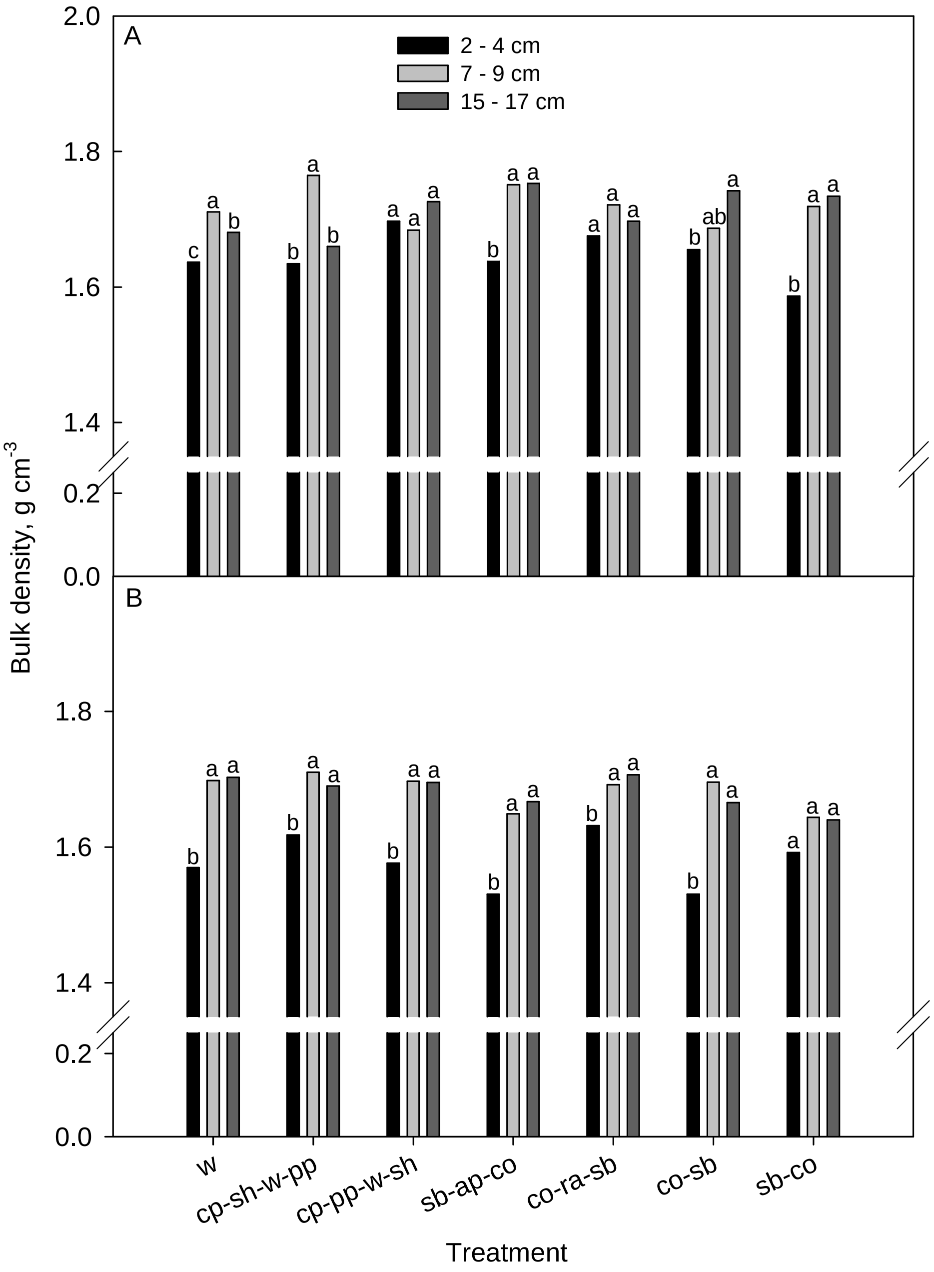

Figure 3.4. Soil bulk density under different cropping systems using grain crops corn (co), soybean (sb), and wheat (w) combined with cover crops radish (ra), Austrian winter pea (ap), cowpea (cp), sunn hemp (sh), and pigeon pea (pp) in Perkins (A) and Stillwater (B), Oklahoma. Means followed by the same lower case letter do not differ from each other within a treatment in different depths at α=0.05.

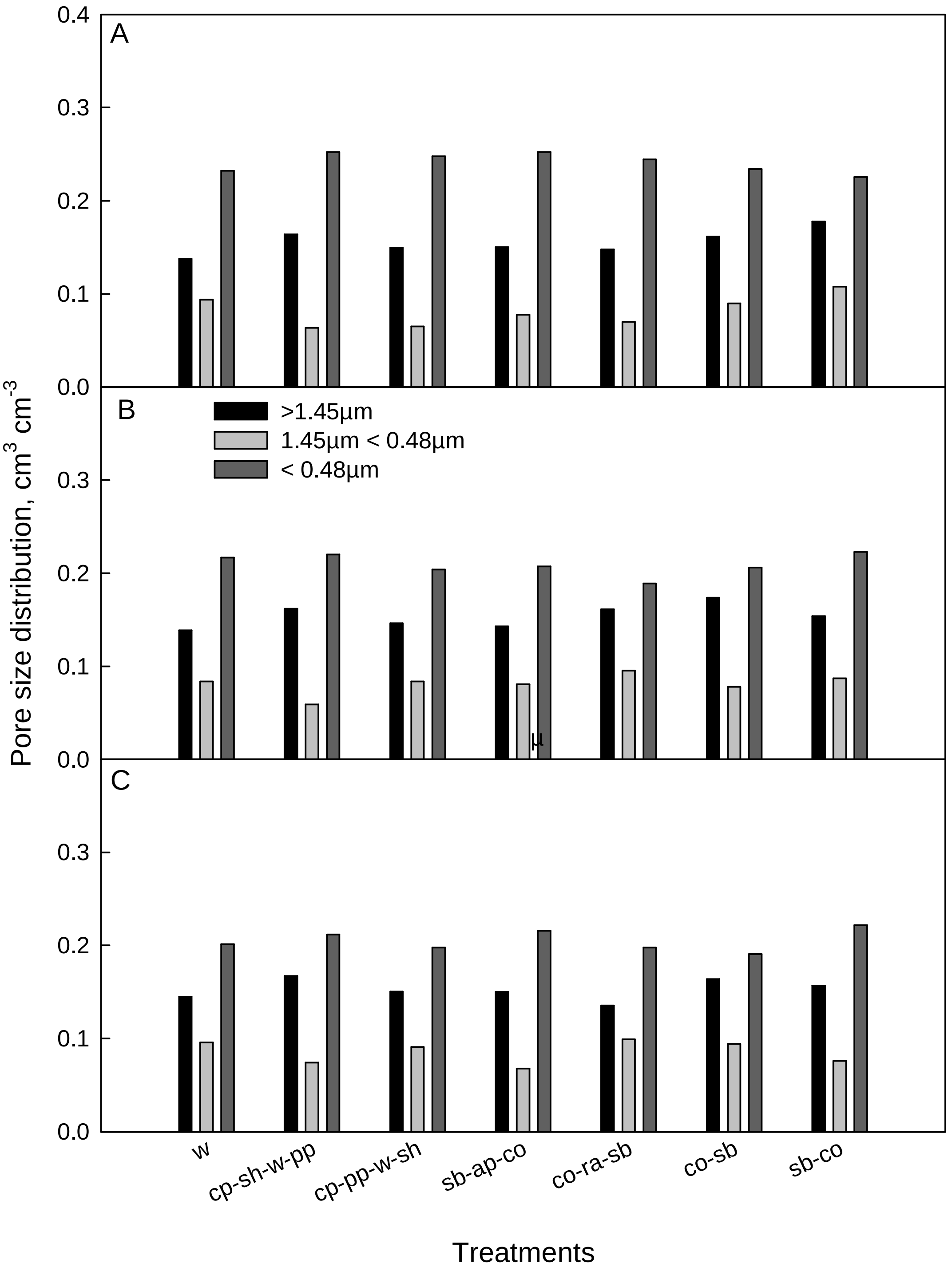

Figure 3.5. Pore size distribution at of 2-4 (A), 7-9 (B), and 15-17 (C) cm depth in soils under different cropping systems using grain crops corn (co), soybean (sb), and wheat (w) combined with cover crops radish (ra), austrian winter pea (ap), cowpea (cp), sunn hemp (sh), and pigeon pea (pp) in Perkins, OK.

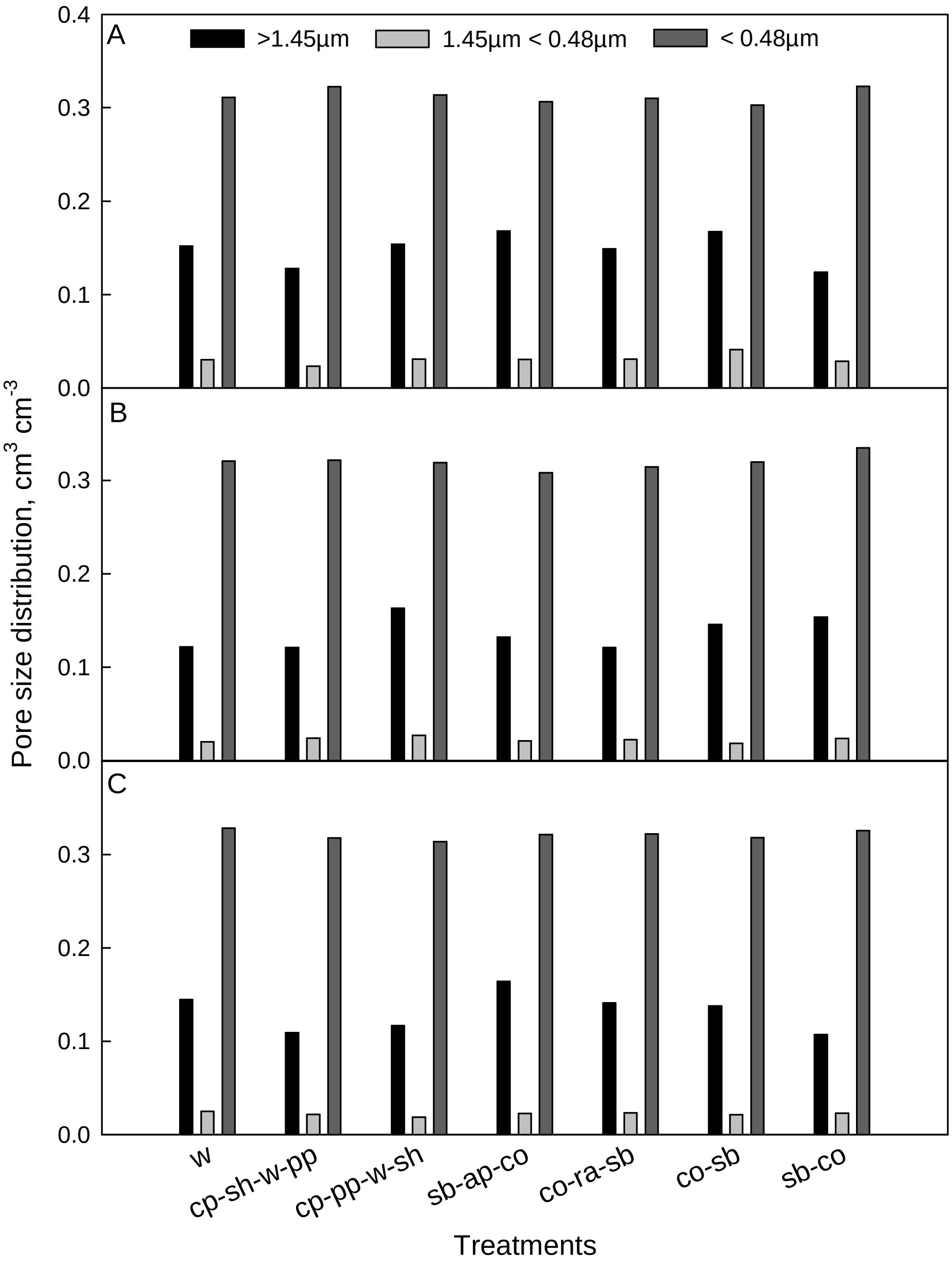

Figure 3.6. Pore size distribution at of 2-4 (A), 7-9 (B), and 15-17 (C) cm depth in soils under different cropping systems using grain crops corn (co), soybean (sb), and wheat (w) combined with cover crops radish (ra), austrian winter pea (ap), cowpea (cp), sunn hemp (sh), and pigeon pea (pp) in Stillwater, OK.

CONCLUSION

Increasing crop intensity and diversity produced higher biomass yield in a two year study in Central Oklahoma. In environments that receive over 950 mm of precipitation yr^{-1} an intensified rotation could be used.

Including cover crops in cropping systems did not affect grain yield in corn, soybean and wheat crops. Cover crops prior to cash crops had no negative effect on reducing cash crop yields neither during fall/winter cover crops on summer cash crops (soybean and corn) nor as summer cover crops affecting winter wheat.

Use of different crop rotations with and without cover crops did not affect soil bulk density, soil porosity and pore size distribution after two years of study. The short period of (2 yr) the study had no effect on soil physical properties. Longer period under the same rotation and tillage practice should be needed in order to observe effects on soil physical properties.

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VITA

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Scope and Method of Study:

Soils across the State of Oklahoma where areas of conventional and long term no-till are under similar climate conditions and soil properties (same soil series) were sampled in 4 points of a transect across the field at 110 cm depth and divided in 5 different depths (0-10; 10-20; 20-40; 40-70; and 70-110 cm). Samples were air dried and sieved at 2mm mesh. Sixteen farm fields (eight no-till and eight conventional till) were sampled in the principal agricultural areas of Oklahoma. Also, two tillage experiments that have no-till and conventional till treatments combined with different crop rotations where sampled and compared as well. Organic C and total N were analyzed. Besides, bulk density was determined at each depth and sampling point in order to account for the amount of organic carbon and nitrogen storage in the soil profile. Results were analyzed by LSD comparing tillage system. Organic carbon and total nitrogen was analyzed by LECO analyzer and carbonates were analyzed so the amount of organic carbon can be calculated. Another chapter of the study analyzed the use of cover different cover crops; including forage radish, sunn hemp, pigeon pea, cowpea, and Austrian winter pea in cash crop rotations that included soybean, corn, and wheat. Grain yield, biomass, and soil physical properties were analyzed in two locations in Central Oklahoma.

Findings and Conclusions:

For most Oklahoma studied areas, no-till soils had higher organic carbon and total nitrogen stock in the soil profile than conventional till. Top soils no-till have also more carbon stock in no-till compared to conventional till soils. The increasing of crop intensity and diversity did not affect grain yield in the cash crops, but increased biomass production. After two years of rotations no effect of crop rotation or crop intensity was observed in soil physical properties.

ADVISER’S APPROVAL: Dr. Jeffrey T. Edwards