12-2017

LONG-TERM IMPACT OF TILLAGE AND CROPPING MANAGEMENTS ON SOIL HYDRO-PHYSICAL PROPERTIES AND YIELD

Amin Nouri Gharahassanlou
University of Tennessee, anourigh@vols.utk.edu

To the Graduate Council:

I am submitting herewith a dissertation written by Amin Nouri Gharahassanlou entitled "LONG-TERM IMPACT OF TILLAGE AND CROPPING MANAGEMENTS ON SOIL HYDRO-PHYSICAL PROPERTIES AND YIELD." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant, Soil and Environmental Sciences.

Jaehoon Lee, Major Professor

We have read this dissertation and recommend its acceptance:

Neal S. Eash, Hubert J. Savoy, Xinhua Yin

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

LONG-TERM IMPACT OF TILLAGE AND CROPPING MANAGEMENTS ON SOIL HYDRO-PHYSICAL PROPERTIES AND YIELD

A Dissertation Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Amin Nouri Gharahassanlou
December 2017

DEDICATION

I dedicate my work to

My beloved wife, Maryam Akhlaghi for her endless love and support

And

to our kind-hearted little boy, Adrian Nouri

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my major advisor Dr. Jaehoon Lee for his constant supports and guidance throughout my Ph.D studies. I appreciate my graduate advisory committee members; Dr. Hubert J. Savoy, Dr. Neal S. Eash and Dr. Frank Yin for their generous helps and valuable comments on my work.

Special thanks to Dr. Arnold M. Saxton for all I learned from him as a student and for many hours of guidance and consultation he provided on my dissertation work.

Many thanks to my best friend Anidan Soleiman for his friendship, support and encouragement before and throughout my Ph. D studies. I also appreciate all my friends in BESS department and specially Farzaneh Khorsandi and Amir Haghverdi who kindly guided me through the steps during my studies.

Finally, I would like to thank the faculty and staff of Biosystems Engineering and Soil Science department; Dr. Daniel C. Yoder, Dr. Michaele E. Essington, Dr. Sindhu Jagadamma, Dr. Nourredine Abdoulmoumine, Artan Xhaferaj, and Sandra Marine who contributed to my work, knowledge and information in various ways.

ABSTRACT

Soil physical and hydraulic properties control the major soil functions related to the imbibition, transmission and retention of water, air, heat and nutrients. Adoption of no-tillage in Tennessee through the last decades has considerably decreased the fluvial soil losses. However, the long-term effect of no-tillage on soil hydro-physical properties and its interaction with companion practices such as cover crops and crop sequence has not been fully discovered.

In this project, three long-term experiments located in West Tennessee Research and Education Center in Milan and Jackson, TN were studied in 2015 and 2016 for soil hydro-physical properties. The effect of 34 years of tillage, fertilization and cover crop, 15 years of crop rotation on no-tillage with winter fallow and 37 years of a range of tillage intensities and no-tillage with and without cover crop on soil physical properties were assessed. Relationship between soil physical properties were determined and by relating the soil physical properties to corn, cotton and soybean yield and long-term yield stability, the most effective cropping and tillage managements were identified.

Long-term no-tillage substantially improved soil aggregation, water infiltration and transmission and cotton yield than conventional tillage. Effect of cover crops on measured soil physical properties were less evident than the effect of no-tillage. However, planting hairy vetch and wheat cover crops improved the soil aggregation and increased the water infiltration and transmission significantly compared with no cover crop. No-tillage planted with hairy vetch cover crop experienced significantly higher quasi-steady and cumulative infiltration compared with the other treatment combinations in both years. Cropping corn, cotton and soybean in double cropping sequences did not favor soil in improved physical quality than monoculture while existence of corn in cropping system either as continuous cropping or in sequence improved soil physical quality. Corn rotated with soybean and cotton increased yield and decreased the long-term variance in soybean yield. Under sub-humid climate of Tennessee with relatively high decomposition rate of organic matter, the magnitude of residue turnover and below-ground root activity was found to be key factors increasing the no-tillage potential for additional improvement in soil quality and yield.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

GENERAL INTRODUCTION

Expansion of farmlands worldwide, increase in irrigated land area, development in farm machinery and new technologies and production of synthetic chemicals has increased the agricultural production by 2.5 to 3 times over the last 50 years (SOLAW, 2011). However, the high level of dependency to the exterior inputs and the narrow farming goals of maximum yield and short-term response has been associated with degradation of land and water resources and diminished the agroecosystem goods and services.

In 2009, 25 percent of arable land resources worldwide was categorized as “highly degraded lands” majority of which is located in “high poverty rate” regions of the world (SOLAW, 2011). The major challenge today is developing farm managements systems with potential to recover soil quality, water and carbon storage, biodiversity and environmental health while safeguarding the food production for rising world population.

No-tillage is the central component of conservation agriculture that has grown in popularity since 1960s mainly due to its considerable effect on the conservation of soil and water resources. As of 2012, roughly 35 percent of cropland acres in the US and almost 40 percent of Tennessee farmlands were no-till planted (NASS, 2012). Despite all economically and environmentally beneficial aspects of no-tillage, the success of system in creating a quality soil for increased productivity highly depends on the soil organic carbon accumulation and biological enrichment which may vary considerably with length of no-till adoption, antecedent soil condition, soil texture, climatic factors and specific cropping managements (Rhoton, 2000; Hazarika et al., 2009).

Insufficient residue production by main crops, the lack of additional biomass input, large row spacing, extremely light or heavy textured soils, poor drainage, moderate and humid fallow periods, undiversified cropping systems, low biological activities, near surface densification among other factors may diminish the benefits and reduce the productivity of no-till system (Liang et al., 1998; Boquet et al., 2004; Calonego and Rosolem., 2010)

Incorporation of regionally adaptable companion practices such as cover crops and crop rotation can improve the potential of no-tillage to increase the soil quality while alleviating the adverse no-till effects (Blanco-Canqui et al., 2011). A wide range of plant species is available to be incorporated with no-tillage as cover crops or rotated with other species. However, the selection of most appropriate management systems is a region-specific decision which is made based on socio-economic, climatic and terrestrial considerations and requires a prior knowledge on the effectiveness of the farming management.

Effect of the farming practices on soil quality, environmental sustainability and production economy may not be evident until the long-term adoption of these managements due to the slow alterations in certain soil properties (Reynolds et al., 2014). In this context, the long-term controlled experiments are valuable assets for framers, researchers and policy makers to reveal the true effect of management practices on soil, yield and environment.

Cropping and tillage managements has been shown to considerably influence the long-term production economy by affecting the yield stability (Gaudin et al., 2015). Improved soil quality is associated with a greater soil resilience in progressing climatic perturbation (Blanco-Canqui and Francis, 2016). A resilient soil can maintain its vital functions under unfavorable internal and external forces to decrease the risk of crop failure and economic losses.

Maintenance of good soil physical quality is fundamental for environmental sustainability and yield stability as it controls the attraction, percolation and retention of water, nutrients air and heat for appropriate plant growth. Physically resilient soil should be able to imbibe and percolate water quickly in wet condition, retain and provide crop-essential water in dry periods and regulate the soil heat in temperature anomalies. Understanding the long-term impact of cover crops and cropping sequences combined with no-tillage on soil physical quality and yield is of particular interest in Tennessee where almost 80 percent of soybean, 70 percent of corn and 65 percent of cotton is no-till seeded (NASS, 2012). However, the long-term interactive effect of no-tillage, cover crops and crop rotation on soil physical properties along the contrasting soil, climate and plant species has not been adequately documented (Martins et al., 2009).

Accordingly, we measured a suite of soil physical and hydraulic properties under different tillage, cover crops, fertilization and cropping sequences on three long-term experiments located in West Tennessee Research and Education Center in Jackson and Milan, TN. First long-term experiment was initiated in 1981on a continuous cotton. The experimental design was a randomized complete block design with split plot. The main plot cover crops were randomly assigned at hairy vetch (*Vicia villosa*) cover crop with 34 kg N ha^{-1}, winter wheat (*Triticum aestivum. L*) and no-cover crops with 101 kg N ha^{-1} which split into no-till and conventional tillage. The entire design was replicated four times. Second long-term experiment was initiated in 2002. The experiment was a randomized complete block design with three replicates. Cropping systems were all double-crop permutations of corn (*Zea mays L.*), cotton (*Gossypium hirsutum L.*) and soybean [*Glycine max (L.) Merr*.] comprising six cropping systems on a no-till system with winter fallow management. Third experiment was stablished on a continuous soybean in 1979. Five tillage managements were replicated randomly in four complete blocks thereby creating a randomized complete block design.

Treatments were: moldboard plowing to 25 cm deep followed by disk and roller harrow; disk plow to 10 cm deep followed by roller harrow; chisel plow to 20 cm deep, followed by roller harrow; no-tillage on soybean stubble and no-tillage with winter wheat *[Triticum aestivum (L.) em. Thell. 'Arthur']* cover crop.

Selected soil physical and hydraulic properties measured in 2015 and 2016 were: particle size distribution, bulk density and total porosity, cone penetration resistance, in-situ gravimetric water content, soil water retention characteristics, pore size distribution, water infiltration and field-saturated hydraulic conductivity, wet aggregate stability and dry aggregate size distribution. Using model selection procedure and regression analysis relationship between management practices and associated soil hydro-physical properties and yield production was determined. Using covariate analysis, the long-term yield data were adjusted for weather parameters and management practices with greater yield stability in weather anomalies were determined.

The general objective of this project was to demonstrate and quantify the long-term impacts of cover crops, crop rotations, and no-tillage and their interactions on soil physical properties and their relationships with soil water availability, and cotton, soybean, and corn productivity. The specific objectives for the first experiment was to quantify: 1) the long-term effect of no-till and cover crop managements on soil physical and hydraulic properties and cotton yield relative to conventional tillage and no cover crop managements. 2) the effect of the addition of cover crops on soil hydro-physical properties and cotton yield under no-tillage. 3) the relationship between soil hydro-physical properties and cotton yield. The specific objectives for the second experiment was to: 1) quantify the long-term impact of six double-crop managements of corn, cotton and soybean on soil hydro-physical properties. 2) determine the effect of cropping system on yield production and stability in weather anomalies. 3) identify the soil hydro-physical properties governing the crop yield and yield stability of corn, cotton and soybean. The main objective for the third experiment was to investigate the long-term effect of a range of tillage intensities and no-tillage with and without winter wheat cover crop on soil hydro-physical properties.

REFERENCES

Blanco-Canqui, H., Mikha, M.M., Presley, D.R., Claassen, M.M., 2011. Addition of cover crops enhances no-till potential for improving soil physical properties. Soil Science Society of America Journal 75, 1471-1482.

Blanco-Canqui, Humberto, and Charles A. Francis. "Building resilient soils through agroecosystem redesign under fluctuating climatic regimes." Journal of Soil and Water Conservation 71.6 (2016): 127A-133A.

Boquet, D.J., Hutchinson, R.L., Breitenbeck, G.A., 2004. Long-term tillage, cover crop, and nitrogen rate effects on cotton. Agronomy Journal 96, 1443-1452.

Calonego, J.C., Rosolem, C.A., 2010. Soybean root growth and yield in rotation with cover crops under chiseling and no-till. European Journal of Agronomy 33, 242-249.

FAO, Food. "The State of the World'S Land and Water Resources for Food and Agriculture (SOLAW)—Managing Systems at Risk." (2011).

Gaudin, A.C., Tolhurst, T.N., Ker, A.P., Janovicek, K., Tortora, C., Martin, R.C., Deen, W., 2015. Increasing crop diversity mitigates weather variations and improves yield stability. PloS One 10, e0113261.

Hazarika, S., Parkinson, R., Bol, R., Dixon, L., Russell, P., Donovan, S., Allen, D., 2009. Effect of tillage system and straw management on organic matter dynamics. Agronomy for Sustainable Development 29, 525-533.

Liang, B., Gregorich, E., Schnitzer, M., Monreal, C., MacKenzie, A., Voroney, R., Beyaert, R., 1998. Retention and turnover of corn residue carbon in some eastern Canadian soils. Soil Science Society of America Journal 62, 1361-1366.

Martins, Márcio, et al. "Crop type influences soil aggregation and organic matter under no-tillage." Soil and Tillage Research 104.1 (2009): 22-29.

Reynolds, W. D., et al. "Impacts of 48 years of consistent cropping, fertilization and land management on the physical quality of a clay loam soil." Canadian Journal of Soil Science 94.3 (2014): 403-419.

Rhoton, F., 2000. Influence of time on soil response to no-till practices. Soil Science Society of America Journal 64, 700-709.

USDA NASS, 2012 Census of Agriculture, Ag Census Web Maps. Available at: www.agcensus.usda.gov/Publications/2012/Online_Resources/Ag_Census_Web_Maps/Overview/.

CHAPTER I
THIRTY-FOUR YEARS OF NO-TILLAGE AND COVER CROPS, IMPROVE SOIL PHYSICAL QUALITY AND COTTON YIELD

1.1 ABSTRACT

In the sub-humid, mid-south US, a substantial amount of cotton residue decomposes shortly after harvest. Cropping systems with insufficient residue production increase the risk of soil erosion and carbon and nutrient losses and reduces the soil organic carbon (SOC) storage which is central in long-term improvement of many soil properties. Inclusion of cover crops (CCs) can be an effective approach to increase the potential of NT to improve the soil physical quality. We examined 34 years of interactive effect of two tillage; (CT: conventional tillage), (NT: no-tillage) and three cover crop managements; (NCC; no cover crop) with 101 kg N ha^{-1}, hairy vetch (VCC; *Vicia villosa*) with 34 kg N ha^{-1}, and winter wheat (WCC; *Triticum aestivum. L*) with 101 kg N ha^{-1}, on soil physical properties and cotton yield on a Lexington silt loam in 2015 and 2016. Bulk density (BD) and cone penetration resistance (PR) measured before annual tillage on CT did not differ significantly among CCs and tillage managements. NT and VCC significantly increased the wet aggregate stability (WAS), soil moisture content at low matric potentials, aggregate mean weight diameter (MWD), field capacity (FC), initial infiltration rate (i_i) and field-saturated hydraulic conductivity (K_{fs}) compared with CT and NCC at 0-15 cm soil depth. WCC presented intermediate values among CCs and was not significantly different from NCC in most of the measured soil physical properties. Soil water retention characteristics (SWRC) and pore size distribution (PSD) were affected by tillage management. PSD showed a hierarchical and multi modal structure of pore space with separated structural and matrix domains. 0-7.5 and 7.5-15 cm in NT had lower structural and higher matrix porosity compared to CT which resulted in lower air capacity (AC) and higher plant available water content (PAWC) on NT compared to CT. Upper-optimal relative field capacity (RFC) also indicated the probability of aeration deficiency under NT. However, >100% greater K_{fs} under NT compared with CT affirms the existence of soil cracks and biological pores under NT. Response surface analysis shows that variations in cotton yield among tillage and CC managements were considerably controlled by water infiltration, transmission and retention and aggregation properties as well as the soil textural characteristics.

1.2 INTRODUCTION

In recent years, many efforts have been made toward establishing regionally adaptable farming strategies to maintain a balance between yield profitability, soil quality, and environmental sustainability. Good soil physical quality is a fundamental feature of resilient soils. Soil resilience is defined as the ability of soil environment to retain its key functions under internal and climatic stresses (Blanco-Canqui and Francis, 2016). Physically resilient soils should be able to imbibe and percolate water quickly in intense rainfalls, retain and provide water in dry periods and regulate the soil heat in temperature anomalies to prevent the economic losses due to progressing climatic perturbations. The concept of soil physical resilience is tied with the management-induced modifications in soil structural characteristics such as the size, morphology and arrangement of peds, stability and size distribution of aggregates and continuity, orientation and size distribution of pores and voids (Lal, 1991). Changes in mentioned properties and many other consequent incidents related to the soil physical quality, production economy and agricultural sustainability may not be clear and evident until years after management initiation. It underlines the significance of long-term studies exposing the true outcome of agricultural management practices (Reynolds et al., 2014).

The use of no-tillage has been recognized as a key component of conservation agriculture that increases soil resilience as well as offering several other agroecosystem services. However, the structural improvement of soil under NT is highly dependent on the rate of soil organic carbon (SOC) input and biological enrichment which may considerably be reduced in pace under low-residue cropping systems such as cotton (Wang and Shao, 2013; Derpsch et al., 2014). In the sub-humid, mid-south US, a substantial amount of the cotton residue decomposes between harvest and planting (Boquet et al., 2004). Thus, the lack of proper residue production makes the cotton fields less responsive to long-term no-till and thereafter, prone to compaction, sheet and rill erosion, and reduced yield (Hutchinson 1993; Pettigrew and Jones 2001). Incorporating cover crops with cotton when the water budget is not a limiting factor may decrease the time needed for the amendments in soil quality to be detectable and alleviate some adverse effects of long-term no-tillage (Blanco-Canqui et al., 2011).

Densification of top soil is the most common issue associated with NT which can undergo an accelerated recovery process by additional biomass input and increased biological activities due to incorporation of cover crops (Calonego and Rosolem., 2010). Above and below ground biomass production under NT system is the main source of organic matter input into the soil environment (Blanco-Canqui et al., 2011). Residue cover protects the soil against the erosive forces (Potter et al., 1995; Uzun et al., 2017), and increases the SOC which is associated with the majority of persistent amendments in soil physical, chemical and biological soil properties (Reeves, 1994; Blanco-Canqui et al., 2011).

While in the long-term, interactions between tillage and cover crops can completely change the agroecosystem response to cropping system, effects of these integrated systems on soil physical properties on the contrasting soil, climate and plant species has not been adequately documented (Martins et al., 2009). On a silt loam soil, planting hairy vetch (*Visia villosa Roth*) and rye (*Secale cereale L.*) in a 5-year no-till system reduced the bulk density and penetration resistance and increased the total porosity, plant available water content, and aggregate stability (Villamil et al., 2006). Blanco-Canqui et al. (2011) has reported that the addition of cover crops and particularly sun hemp (*SH; Crotalaria juncea L.*) to a 15-year continuous no-till on a silt loam increased the near surface SOC accumulation, cumulative infiltration, wet aggregate stability, and reduced the no-till-induced near surface soil compaction. On a silt loam, 17 years of NT- winter rye, hairy vetch, and crimson clover (*Trifolium incarnatum L.*) CCs increased hydraulic conductivity, water retention, total porosity and macroporosity compared to no-till / no cover crop management (Keisling et al., 1994). However, on three years of no-till, Kaspar et al. (2001) observed no influence of cover crops on soil physical attributes. On a clayey soil, Alburquerque et al. (2015) found that 21 years of rotational cropping of alfalfa (Medicago sativa)–corn cover crops on NT yielded a substantially higher C and N accumulation and lower bulk density compared to legume and grass-based cover crop rotations. This study reveals the potential of alfalfa root adding below ground biomass, C and N which is crucial in NT where the lack of soil disturbance will concentrate the SOC mainly at surface layer. Fortuna et al. (2008) reported that in 17 years of NT on a silt loam, hairy vetch CC increased the soil-available N, SOC and corn yield significantly compared to no cover crop. Moreover, conservation tillage with cover crops such as hairy vetch and wheat generally increased cotton yield (Hutchinson et al., 1991; Schwenke et al., 2001). Stevens et al. (1992) showed that hairy vetch cover crop on short-term no-tillage resulted in higher cotton yield compared to wheat (*Triticum aestivum L.*). On a silt loam, effect of no-till-cover crop combination became significant on cotton yield in year 5 of the 11 years of no-till-cover crop study compared to surface tillage (Boquet et al., 2004).

Depending on the quality and quantity of retained residue, cover crops can also regulate the soil temperature under extreme climatic condition (Kahimba et al., 2008) and decrease the evaporation during the dry periods. Symbiotic fixation of atmospheric N_2 by legume cover crops can reduce the dependency of N fertilizer (Schwenke et al., 2001; Brown et al., 1985; Ebelhar et al., 1984). The University of Tennessee Extension Service recommends 69 to 90 kg N ha^{-1} less fertilizer application when cotton under NT is covered by crimson clover or hairy vetch over winter (Savoy and Joines, 2009). This function is specifically important in no-till management because of the increased risk of preferential transport of Nitrate-N through bio-pores. Therefore, our objective for this study was to examine the following hypothesis: 1) Long-term no-till and cover crop management would improve soil physical and hydraulic properties and crop yield relative to CT and no cover crop managements. 2) No-till planted with cover crops would result in improved soil physical quality and cotton yield compared to NT without cover crops. 3) Changes in cotton yield would be associated with changes in soil hydro-physical properties.

1.3 MATERIALS AND METHODS

1.3.1 SITE DISCRIPTION AND STATISTICAL DESIGN

The long-term study plot was situated on a Lexington silt loam (fine-silty, mixed, thermic Ultic Hapludalf) at The University of Tennessee, West Tennessee Research and Education Center in Jackson, TN in a continuous cotton. The soil surface has a slope between 0-2% and formed over marine deposit. The mean annual temperature for the region is 15.6 °C and mean annual rainfall is 1350 mm. This long-term experiment was initiated in 1981 with all possible permutations of four levels of N fertilizer (0, 34, 67, and 101 kg N ha^{-1}), four levels of cover crops; no-cover crop, hairy vetch (*Vicia villosa*), winter wheat (*Triticum aestivum. L*), and crimson clover (*Trifolium incarnatum*) and two levels of tillage: no-till (NT) and conventional tillage (CT). The entire design was replicated four times. Hairy vetch cover crop (VCC) with 34 kg N ha^{-1} and wheat (WCC) and no-cover crops (NCC) with 101 kg N ha^{-1} under both tillage managements were examined for the current study (Table 1.1). The experimental design is a randomized complete block design (RCBD) with split plot. The main plot cover crops were randomly assigned at NCC, VCC and WCC which split into NT and CT. Each resulting sub plot measures 12 by 8 m in size including 8 rows of cotton. Cover crops were suppressed by applying Gramoxone® SL at the rate of 3.51 L ha^{-1} and ammonium nitrate with mentioned rates were surface-applied. After the N application, disk tillage was performed twice in CT sub plots into 10 cm deep and followed by harrow leveling process during April and May in each year. Thereafter, cotton was uniformly seeded on the entire plot targeting about 86500 plants ha^{-1}. Cotton was harvested mechanically in October and ginned for determination of lint production.

In May 2015 and April 2016, soil samples in each sub-plot were collected randomly at two depths (0-15 and 15-30 cm) with four replicates and about 1 meter from the boundaries of subplots. Intact soil cores were collected for bulk density (BD), gravimetric water content (GWC) and soil water retention characteristics (SWRC). Four samples within 0-30 cm depth with 7.5 cm depth increments were collected for SWRC analysis. Additional samplings for GWC measurement throughout the growing seasons were performed using a 2.5 cm diameter soil probe.

Table 1.1. Mean soil particle size distribution measured by hydrometer method (Gee and Or, 2002) and summary of managements.

Treatments	Depth (cm)	Sand[a] (g kg^{-1})	Silt[b] (g kg^{-1})	Clay[c] (g kg^{-1})	management
CT-VCC	0-15	179	693	127	Hairy vetch CC was killed, and two times disc-harrow was applied before planting. N (34 kg N ha^{-1}), P and K were applied uniformly. Hairy vetch was reseeded after cotton harvest
	15-30	102	618	280	
NT-VCC	0-15	142	661	196	No-tillage since 1981. Hairy vetch CC was killed before planting. N (34 kg N ha^{-1}), P and K were applied uniformly. Hairy vetch was reseeded after harvest
	15-30	116	606	279	
CT-WCC	0-15	169	684	147	Winter wheat CC was killed, and Disc-harrow was applied twice before planting. N (101 kg N ha^{-1}), P and K were applied uniformly. Winter wheat was reseeded after cotton harvest
	15-30	147	650	203	
NT-WCC	0-15	139	699	161	No-tillage since 1981. Winter wheat CC was killed before planting. N (101 kg N ha^{-1}), P and K were applied uniformly. Winter wheat was reseeded after harvest
	15-30	161	614	225	
CT-NCC	0-15	158	688	154	Disc-harrow was applied twice before planting. N (101 kg N ha^{-1}), P and K were applied uniformly. Fallow through the winter
	15-30	125	623	252	
NT-NCC	0-15	175	660	165	No-tillage and no cover crop since 1981.cotton was planted. N (101 kg N ha^{-1}), P and K were applied uniformly after planting and left fallow in winter
	15-30	128	662	210	

[a]50–2000 µm , [b]2–50 µm, [c]<2 µm
CT-VCC: chisel plow with hairy vetch cover crop; NT-VCC: no-tillage with hairy vetch cover crop; CT-WCC: chisel plow with winter wheat cover crop; NT-WCC: no-tillage with winter wheat cover crop; CT-NCC: chisel plow without cover crop; NT-NCC: no-tillage without cover crop.

1.3.2 BULK DENSITY, POROSITY, PENETRATION RESISTANCE AND WATER CONTENT

Bulk density was measured in May 2015 and April 2016 immediately before the disk plow was applied to CT managements. Additionally, in 2016, BD values were obtained from the intact soil cores collected in July 2016 after disk plow application on CT managements. Intact cores (diameter of 5.0 cm and height of 7.5 cm) were collected in four depth increments within 0-30 cm. Samples were emptied in two metal tins and mixed thoroughly to obtain samples representative for 0-15 and 15-30 cm depths. Metal tins were capped to avoid the moisture losses. BD was measured following the standard procedure for core method explained by Grossman and Reinsch (2002). Relationship between BD and particle density (PD) was used for measuring the total soil porosity (TP). The mass of soil water in field condition to the mass of oven-dried sample in 105 °C for 24 hours yielded the soil GWC which was multiplied by BD to obtain the VWC. In addition to the soil water content acquired from the intact cores, GWC was measured multiple times throughout the growing season. Cone penetration resistance (PR) was measured in 2015 and 2016 immediately before and two months after tillage, by means of a hand-held digital cone-tipped penetrometer with a cone angle of 30 ° and 1cm^2 area (Field Scout, SC 900 Soil Compaction Meter; Spectrum Technologies, Inc., Plainfield, IL, USA). Four measurements were recorded at each sub-plot applying the penetrometer on a straight line transect down to 30 cm soil depth with 2.5 cm vertical increments.

1.3.3 SOIL AGGREGATION MEASUREMENTS

Soil aggregation was characterized by dry aggregate size distribution (DASD) and wet aggregate stability (WAS) analyses. For DASD, soil samples were collected in two depths and four replicates for each treatment using a spade. Samples were located in a solid container with minimum disturbance. 100 g of air-dried soil samples, previously sieved through an 8-mm screen, were placed on top of the set of sieves with openings of 4.75, 2, 1, 0.85, 0.5, 0.25 and 0.05 mm and shaken with a vertical sieve apparatus (Model 18480, CSC Scientific, Fairfax, VA, USA) for 5 minutes with the amplitude of 0.1 mm. The soil fraction remaining on screens were collected and weighted. Geometric mean diameter (GMD) was calculated by applying probit transform to the percent oversize values. Plotting the probit transformed cumulative fraction oversize (x) and $\log_{10}$ sieve size (y) and fitting a least squares linear regression, a simple linear equation was obtained. Substituting the 0.5 for x in resulted equation, the log diameter of 50% over size or GMD was obtained (Larney, 2007). Mean weight diameter (MWD) was calculated following the procedure explained by Youker and McGuinness (1957).

$$\mathrm{MWD}=\sum_{i=1}^{n}\bar{\bar{X}}_i\,W_i \qquad (1.1)$$

Where Xi is the mean diameter (mm) of size fraction and Wi, is the fraction retained on the sieve.

Wet aggregate stability (WAS) were determined by a commercial wet sieving apparatus (08.13, Eijkelkamp Agrisearch Equipment, Giesbeek, the Netherlands). 4 g of air-dried soil sample (>1 and <2 mm) was uniformly spread in a 0.26 mm sieve and allowed for capillary wetting from the bottom (Fig. 1.1). Sample was sieved in distilled water for 3 min with the rate of 35 times per minute (Kemper and Rosenau, 1986). Thereafter, the unstable fraction was oven-dried and weighed and stable fraction was corrected for sand fraction using 2 g L^{-1} of Sodium Hydroxide as a dispersant agent. Then the fraction of water stable aggregates was calculated as:

$$\text{WAS\%}=\frac{\text{Remained on sieve-Sand}}{\text{Total sample-Sand}}\times 100 \qquad (1.2)$$

Figure 1.1. Soil samples were allowed for a gradual capillary absorbance of water from the bottom of sieve to avoid the air entrapment.

1.3.4 WATER INFILTRATION AND FIELD-SATURATED HYDRAULIC CONDUCTIVITY

Field water infiltration was measured in June of both 2015 and 2016 using a double ring infiltrometer (Reynolds et al., 2002) with 305 mm and 153 mm of outer and inner ring diameter respectively and 102 mm high (IN7-W - Turf-Tec international, Tallahassee, FL). Double ring infiltrometer was inserted into the soil depth for approximately 4 cm and to vouch for one-dimensional water flow, constant head of water was maintained in both rings about 5 cm above the soil surface. Water infiltration rate was measured in inner ring. All measurements were conducted in initial soil water status corresponding to FC for over 200 min or until steady infiltration rate was observed. Using the least squares method, infiltration data were fitted to Green and Ampt (1911) and Philip (1957) models. Philip's model is well-known for the simplicity and clear theoretical background which provides a suitable description for sorptivity (S, $LT^{-0.5}$) and the empirical constant related to K_{sat}, so-called transmissivity (A, LT^{-1}) parameter.

$$i=\frac{1}{2}St^{-0.5}+A \quad (1.3)$$

$$I=St^{0.5}+At \quad (1.4)$$

Where I (mm) is the cumulative infiltration, i is the infiltration rate (LT^{-1}), t is time passed (T). The field-saturated one-dimensional hydraulic conductivity (K_{fs}) (LT^{-1}) was measured based on the methodology explained by Reynolds et al. (2002).

$$K_{fs}=\frac{q_s}{\left[\frac{H}{C_1d+C_2a}\right]+\left\{\frac{1}{[\alpha^*(C_1d+C_2a)]}\right\}+1} \quad (1.5)$$

Where, qs (LT^{-1}) is quasi-steady infiltration rate, a (L) is the ring radius, H (L) is depth of ponded water, d (L) is the depth of ring insertion into the soil, $C_1=0.316\pi$ and $C_2=0.184\pi$ are quasi-empirical constants. α^* (L^{-1}) is the soil macroscopic capillary length which was assumed to be 0.012 mm h-1 for the textural and structural condition of the study soil.

1.3.5 WATER RETENTION AND PORE SIZE DISTRIBUTION

Soil water retention characteristics were obtained from undistributed soil cores collected at 0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm soil depths with 2 replicates per treatment and depth. Samples were collected in July 2016 between row spaces after the sowing of cotton seeds. Soil samples were saturated slowly by capillary rise and subjected to the matric pressures of: 0, -1, -3, -10 kPa on a tension table and -33, -100, -300, -500 and -1200 kPa in pressure plate extractors (Soil Moisture Equipment Corp., Santa Barbara, CA) as described by Dirksen (1999). Equilibrated samples were oven-dried at 105 °C for 48 h to determine the BD. VWC at each matric potential was calculated using BD and GWC. The soil water characteristics curve and estimated parameters were obtained by fitting the measured desorption data to the van Genuchten equation (van Genuchten, 1980):

$$\theta=\theta_r+\frac{\theta_s-\theta_r}{[1+(\alpha.h)^n]^{(1-\frac{1}{n})}} \quad (1.6)$$

Where θ_s and θ_r are the saturated and residual water content respectively ($m^3\ m^{-3}$), h is the soil water tension, α and n are fitting parameters related to the air entry potential.

Plant available water content (PAWC: $m^3\ m^{-3}$) was calculated as the difference between VWC retained at field capacity (FC: -33kPa) and the tension head of -1200kPa. Changes in soil water content beyond this tension head were not significant. Air capacity (AC: $cm^3\ cm^{-3}$) defined as the difference between saturated and FC soil moisture content was measured as an indicator of soil aeration. Relative field capacity (RFC) was calculated as the fraction of FC soil moisture content to the total porosity. Assuming the TP is almost equal to θ_s, RFC is:

$$RFC= \left(\frac{\theta_{FC}}{\theta_s}\right)=\left[1-\left(\frac{AC}{\theta_s}\right)\right] \tag{1.7}$$

RFC indicates that whether the aeration-deficiency or water-deficiency condition constitute a limitation for certain type of soil under a specific management (Olness et al., 1998; Reynolds et al., 2014).

The pore-size distribution (PSD) was derived from the soil water retention curve. Using the relationship, S=(θ-θr)/(θs-θr), θ(h) values were first converted to relative saturation S(h). Soil water content at -1200 kPa was taken as θr. Afterward, a cubic spline interpolation function was fitted to experimental data, S versus ln(h) resulting a smooth curve (Kastanek and Nielsen, 2001). Finally, the equivalent pore radius (r: µm) at a given pressure head (h: cm) was estimated using the relation r=1490/h Kutilek and Nielsen (1994). Having plotted the smooth curve, dS/d(lnh) vs r represented the pore size distribution.

1.3.6 DATA ANALYSIS

Analysis of variance was conducted using mixed model (SAS v9.3, SAS Institute, Inc., Cary, NC), and least squares means were separated using the protected Fisher's least significant difference (LSD) test. A model selection procedure was run between soil physical parameters as explanatory variables and cotton yield as response variable and parameters were selected based on the coefficient of variation, Mallow's Cp and Akaike Information Criterion (AIC). Using selected parameters, a second-order response surface model was used to explore the impact of measured soil hydro-physical properties on cotton yield. Prediction performance was validated by additional experimental data. Cubic spline function fitting procedure and related mathematical process for

PSD analysis was conducted in MATLAB (MathWorks Inc., Natick, MA).

1.4 RESULTS

1.4.1 BULK DENSITY, CONE PENETRATION RESISTANCE AND SOIL WATER CONTENT

Bulk density measured in the two years before disk plow on CT did not differ significantly (ANOVA $p<0.05$) between tillage and among CC managements (Tables 1.2 & 1.3) except for the 15-30 cm depth in 2015, with NT having significantly higher BD than CT. Differences among CC managements were non-significant either across the years or depths. Nevertheless, a general non-significant reduction in BD under VCC and WCC compared to NCC was evident at 0-15 cm (Tables 1.2 & 1.3). However, differences in depth was significant in both years ($p<0.05$) having a considerably higher BD at 15-30 compared to 0-15 cm. Non-significant differences in measurement year between 2015 and 2016 also indicated the consistency of mentioned effects. BD measurements after tillage in July 2016, however, showed a considerable reduction in BD under CT compared to NT ($p<0.01$) at the plow depth. Effect of cover crops on BD averaged over 0-15 and 15-30 cm after tillage was similar to the pre-tillage condition, revealing a non-significant ($p>0.05$) difference among treatments in neither depth.

Disregarding the magnitude of PR, cone penetration resistance measured before tillage on CT in both years and depths did not significantly differ among the cover crops and between tillage managements. Depth differences were significant in both years resulting in significantly ($p<0.01$) lower PR at 0-15 cm than 15-30 cm (Tables 1.2 & 1.3). Tillage application, decreased mean PR of CT by 25% at 0-15 cm relative to NT (Fig. 1.2). However, the differences between cover crops were not significant at any of depths.

Volumetric water content associated with the field-measured near FC moisture content showed no significant difference between tillage managements and among cover crops. However, significantly higher moisture content ($p<0.05$) was observed at 15-30 cm compared to 0-15 cm in both years. VWC measured in drier periods of the growing season in 2015 resulted in 57% and 30% ($p<0.01$) higher moisture content in NT than in CT within 0-15 cm and 15-30 cm depth, respectively. However, in 2016 soil moisture content in drier soil condition was significantly greater under CT than NT only at 0-15 cm while in 15-30 cm despite a greater moisture content under NT difference were not significant ($p=0.05$). In 2015, VCC and WCC contained in average 21% and 29% higher VWC compared to NCC at the first and second depth, respectively. Irrespective of the statistical significance, VWC measured in lower water potential in both depths and years showed the consistent trends of VCC>WCC>NCC and NT>CT among treatments (Table 1.2).

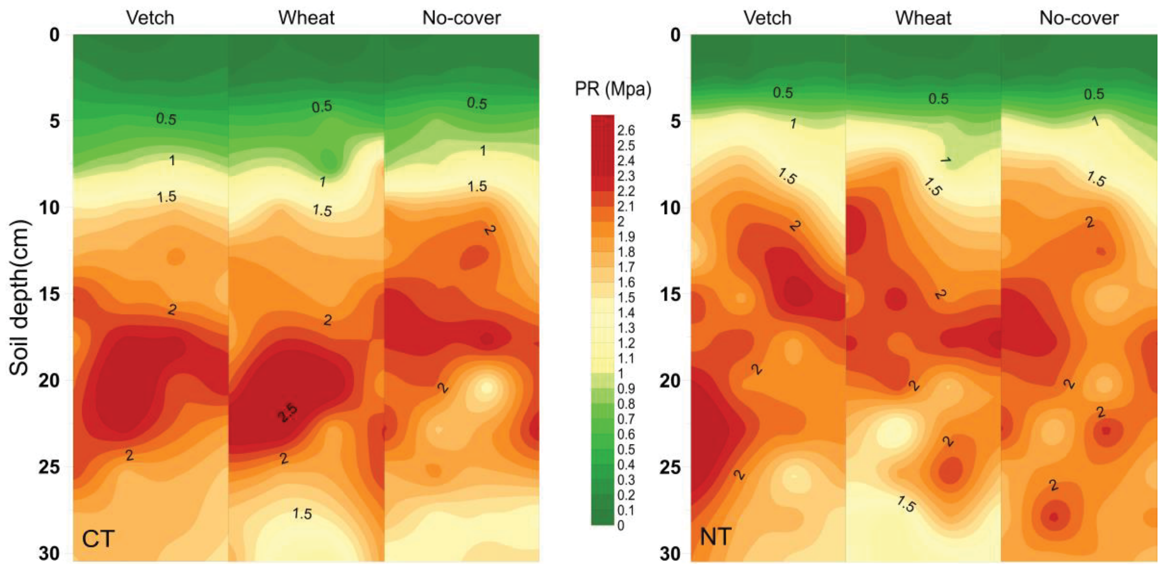

Figure 1.2. Two-dimensional representation of cone penetration resistance measured in 2016 after annual tillage on CT, averaged over tillage and cover crop managements.

Table 1.2. Wet aggregate stability, bulk density, field-measured soil moisture content, cone penetration resistance and total porosity measured in 2015 and 2016 as affected by cover crop, tillage, and sampling depth.

Treatments	WAS (%)	BD (Mg m^{-3})	θ_{vf} (cm^3 cm^{-3})	θ_{vd} (cm^3 cm^{-3})	PR (Mpa)	TP (cm^3 cm^{-3})
			2015, 0-15cm			
Cover means						
Vetch	56.4(1.67)a	1.48(0.010)a	32.2(0.82)a	22.6(1.72)a	1.57(0.07)a	44.2(0.42)a
Wheat	51.7(2.20)ab	1.50(0.016)a	34.1(0.80)a	17.4(2.21)a	1.93(0.21)a	43.4(0.60)a
No-cover	50.1(2.45)b	1.52(0.003)a	34.0(0.78)a	15.9(2.04)a	2.14(0.20)a	42.6(0.14)a
Tillage means						
CT	49.1(1.88)b	1.50(0.010)a	33.1(0.56)a	14.7(1.47)b	1.74(0.08)a	43.4(0.48)a
NT	56.4(1.07)a	1.50(0.008)a	33.7(0.79)a	22.6(1.25)a	2.01(0.20)a	43.4(0.30)a
			2015, 15-30cm			
Cover means						
Vetch	45.0(1.74)a	1.51(0.010)a	34.5(0.48)a	28.8(2.32)a	2.73(0.13)a	43.0(0.53)a
Wheat	44.9(1.50)a	1.50(0.020)a	36.0(0.63)a	21.7(1.78)b	2.62(0.20)a	43.3(0.84)a
No-cover	42.7(1.00)a	1.55(0.020)a	35.9(0.51)a	19.0(1.39)b	3.14(0.11)a	41.5(0.89)a
Tillage means						
CT	41.8(0.72)b	1.51(0.010)b	35.4(0.51)a	20.2(1.67)b	2.73(0.11)a	43.1(0.64)a
NT	46.57(1.15)a	1.56(0.010)a	35.6(0.44)a	26.2(1.77)a	2.93(0.15)a	41.0(0.45)b
			2016, 0-15cm			
Cover means						
Vetch	62.5(3.33)a	1.48(0.015)a	31.0(1.22)a	22.4(1.05)a	0.98(0.07)a	44.5(0.80)a
Wheat	58.1(3.22)a	1.48(0.009)a	29.1(0.82)a	19.5(1.89)a	110(0.15)a	44.3(0.42)a
No-cover	55.7(1.89)a	1.50(0.012)a	31.5(2.45)a	19.2(1.14)a	0.92(0.07)a	43.5(0.70)a
Tillage means						
CT	55.7(1.76)b	1.46(0.008)b	29.8(1.48)a	18.4(0.92)b	0.88(0.02)b	45.0(0.19)a
NT	61.7(2.69)a	1.52(0.010)a	31.2(1.18)a	22.4(1.16)a	1.12(0.04)a	43.0(0.19)a
			2016, 15-30cm			
Cover means						
Vetch	50.0(1.89)a	1.50(0.005)a	32.9(1.71)a	24.1(1.35)a	1.72(0.05)a	43.3(0.39)a
Wheat	49.2(2.18)a	1.52(0.016)a	33.2(1.06)a	20.9(1.15)a	1.58(0.04)a	42.7(0.46)a
No-cover	47.5(1.84)a	1.50(0.012)a	34.7(3.18)a	21.7(1.62)a	1.69(0.03)a	43.2(0.45)a
Tillage means						
CT	47.4(1.63)a	1.49(0.011)b	33.0(0.79)a	20.7(0.83)a	1.41(0.03)b	43.8(0.11)a
NT	49.4(1.55)a	1.53(0.008)a	34.1(2.33)a	23.7(1.33)a	1.91(0.05)a	42.4(0.26)a

WAS: wet aggregate stability, (BD): Bulk density measured before annual disk plow, θ_{vf}: in-situ volumetric water content at near FC water content, θ_{vd}: in-situ volumetric water content measured at drier periods of growing season, PR: cone penetration resistance measured before tillage in 2015 and after tillage in 2016, TP: total soil porosity. Values in parenthesis are standard errors. Means within a factor followed by different letters are significantly different according to LSD at $P<0.05$.

Table 1.3. Analysis of variance for wet aggregate stability, bulk density, field-measured soil moisture content, cone penetration resistance and total porosity measured in 2015 and 2016 as affected by cover crop, tillage, and sampling depth

Treatments	WAS (%)	BD (Mg m^{-3})	θ_{vf} (cm^3 cm^{-3})	θ_{vd} (cm^3 cm^{-3})	PR (Mpa)	TP (cm^3 cm^{-3})
			2015, 0-15cm			
ANOVA p-values						
Cover crops	0.0477	0.2604	0.0911	0.0514	0.0612	0.2604
Tillage	0.0017	0.3791	0.4222	<.0001	0.1574	0.3791
C×T	0.6174	0.3751	0.1625	0.5015	0.09	0.3751
			2015, 15-30cm			
ANOVA p-values						
Cover crops	0.286	0.31	0.197	0.012	0.054	0.31
Tillage	0.002	0.019	0.777	0.003	0.256	0.02
C×T	0.787	0.776	0.267	0.72	0.737	0.776
Depth	<.0001	0.013	0.001	<.0001	<.0001	0.013
C×D	0.26	0.799	0.95	0.245	0.21	0.799
T×D	0.309	0.077	0.689	0.208	0.735	0.077
C×T×D	0.682	0.703	0.802	0.308	0.347	0.703
			2016, 0-15cm			
ANOVA p-values						
Cover crops	0.105	0.10	0.536	0.208	0.595	0.10
Tillage	0.027	<.0001	0.475	0.014	<.0001	<.0001
C×T	0.202	0.0463	0.158	0.421	0.7262	0.046
			2016, 15-30cm			
ANOVA p-values						
Cover crops	0.718	0.17	0.837	0.20	0.42	0.17
Tillage	0.08	0.003	0.69	0.05	<.0001	0.003
C×T	0.86	0.69	0.936	0.20	0.56	0.69
Depth	<.0001	<.0001	0.043	0.116	<.0001	<.0001
C×D	0.867	0.968	0.818	0.787	0.221	0.97
T×D	0.399	0.53	0.927	0.493	0.011	0.53
C×T×D	0.678	0.877	0.292	0.054	0.321	0.88
Year	<.0001	0.114	0.005	0.705	<.0001	0.114
C×Y	0.999	0.262	0.404	0.01	0.007	0.262
T×Y	0.257	0.459	0.613	0.005	0.307	0.459
C×T×Y	0.48	0.612	0.27	0.251	0.146	0.613

WAS: wet aggregate stability, (BD): Bulk density measured before annual disk plow, θ_{vf}: in-situ volumetric water content at near FC, θ_{vd}: in-situ volumetric water content measured at drier periods of growing season, PR: cone penetration resistance measured before tillage in 2015 and after tillage in 2016, TP: total soil porosity.

1.4.2 *WET AGGREGATE STABILITY AND DRY AGGREGATE SIZE DISTRIBUTION*

In 2015, wet aggregate stability at the size of 1-2 mm found to be 14% and 12% ($p<0.01$) greater under NT than CT at 0-15 and 15-30 cm, respectively (Tables 1.2 & 1.3). VCC yielded 10% ($p<0.05$) higher values at surface depth compared to WCC and NCC in both measurement years. WAS varied considerably based on sampling depth, having significantly ($p<0.01$) higher values at the first depth compared to the second depth in both years.

As expected GMD and MWD were highly correlated ($r=0.95$) and resulted in 40% and 18% ($p<0.01$) greater values under NT than CT at 0-15 cm respectively. At the same soil depth, VCC and WCC revealed significantly greater values for both indicators compared to NCC. However, at 15-30cm CT had significantly greater GMD and MWD values compared to NT. NT management at 0-15cm were primarily dominated by macro-aggregates (>2 mm) and considerably less fraction of small macro-aggregates (0.25-2 mm) and microaggregates (<0.053 mm) (Fig. 1.3) whereas in 15-30 cm this order was true for CT management (Fig. 1.4). DASD was significantly affected by depth, having considerably greater GMD and MWD at surface layer compared to 15-30cm (Table 1.4).

Table 1.4. Dry aggregate size distribution parameters and fractional abundance of aggregate size classes influenced by tillage and cover crop managements and sampling depth.

Treatments	GMD (mm)	MWD (mm)	MA (%)	SMA (%)	MIA (%)
			0-15cm		
Cover means					
Vetch	2.25(0.19)a	3.01(0.12)a	55.08(3.20)a	39.94(2.70)b	2.52(0.37)b
Wheat	2.35(0.16)a	3.03(0.11)a	56.48(2.42)a	41.12(1.96)ab	1.57(0.45)b
No-cover	1.43(0.15)b	2.48(0.12)b	43.69(2.60)b	44.84(1.41)a	6.83(0.70)a
Tillage means					
CT	1.67(0.14)b	2.61(0.10)b	45.94(2.24)b	46.18(1.31)a	4.43(0.88)a
NT	2.34(0.16)a	3.08(0.09)a	57.56(2.13)a	37.75(1.18)b	2.85(0.64)b
ANOVA p-values					
Cover crops	<.0001	0.0001	0.0001	0.047	0.0002
Tillage	0.0001	<.0001	<.0001	<.0001	0.004
C×T	0.708	0.927	0.656	0.321	0.182
			15-30cm		
Cover means					
Vetch	1.38(0.08)a	2.28(0.07)a	41.55(1.86)ab	52.16(1.63)a	4.04(0.67)b
Wheat	1.36(0.15)a	2.39(0.13)a	44.85(2.93)a	42.60(1.64)b	6.53(1.00)a

Table 1.4. Continued

Treatments	GMD (mm)	MWD (mm)	MA (%)	SMA (%)	MIA (%)
No-cover	1.28(0.12)a	2.14(0.13)a	38.45(2.87)b	49.15(1.73)a	7.90(1.19)a
Tillage means					
CT	1.46(0.11)a	2.39(0.11)a	44.12(2.55)a	46.18(1.80)b	5.38(0.81)b
NT	1.22(0.05)b	2.15(0.06)b	39.11(1.47)b	49.76(1.61)a	6.93(0.96)a
ANOVA p-values					
Cover crops	0.732	0.099	0.042	<.0001	0.001
Tillage	0.029	0.014	0.017	0.008	0.033
C×T	0.418	0.577	0.389	0.035	0.006
Depth	<.0001	<.0001	<.0001	<.0001	<.0001
C×D	<.0001	0.028	0.027	0.002	0.001
T×D	<.0001	<.0001	<.0001	<.0001	<.0001
C×T×D	0.875	0.86	0.775	0.018	0.001

GMD: geometric mean diameter, MWD: mean weight diameter, MA: fraction of macro-aggregates (>2mm), SMA: fraction of small macro-aggregates (0.25-2mm), MIA: fraction of microaggregates (0.53-0.25mm). Values in parenthesis are standard errors. Means within a factor followed by different letters are significantly different according to LSD at P<0.05.

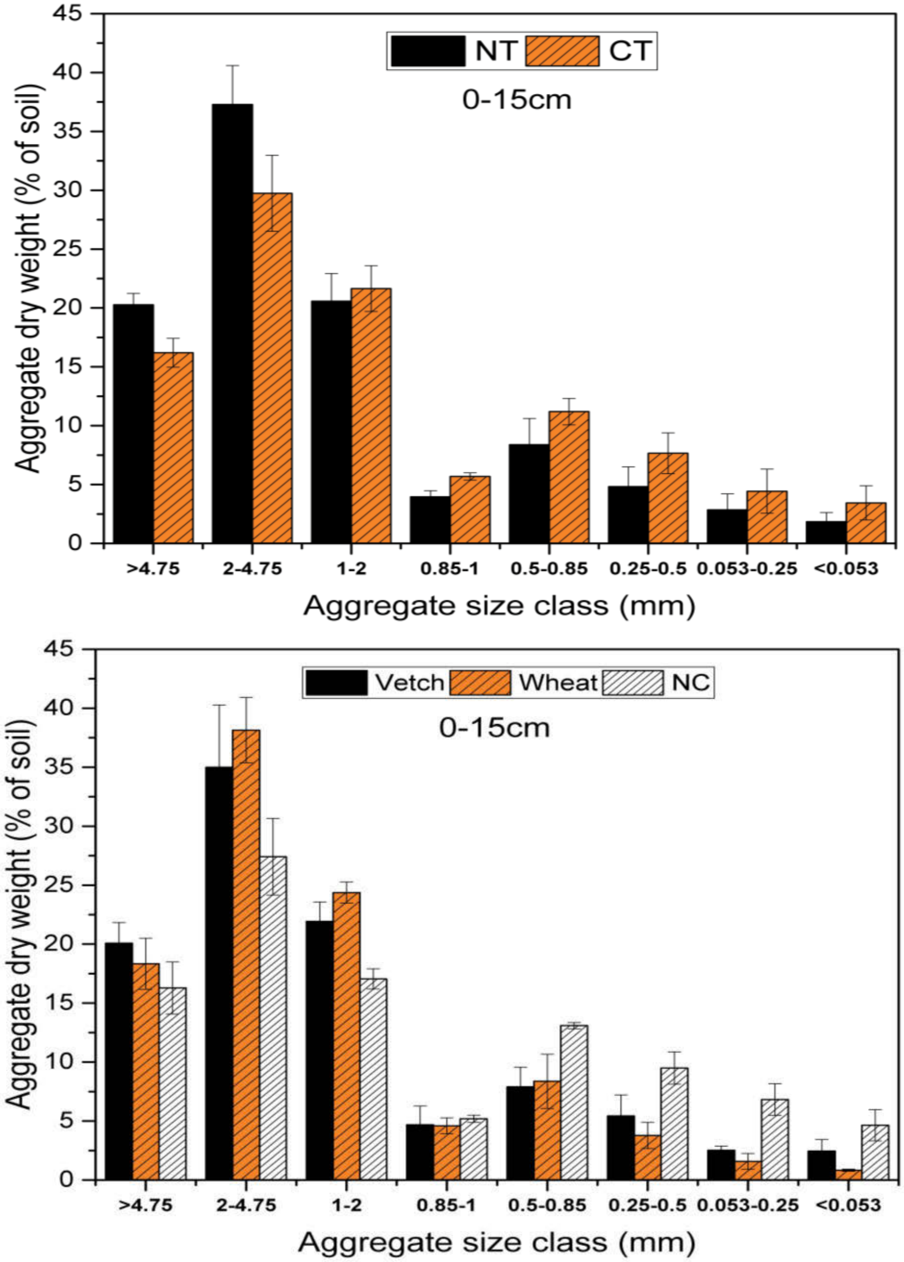

Figure 1.3. Dry aggregate size distribution at 0-15 cm soil depth averaged over tillage and cover crop managements. Error bars are standard error associated with each tillage and cover crop treatment.

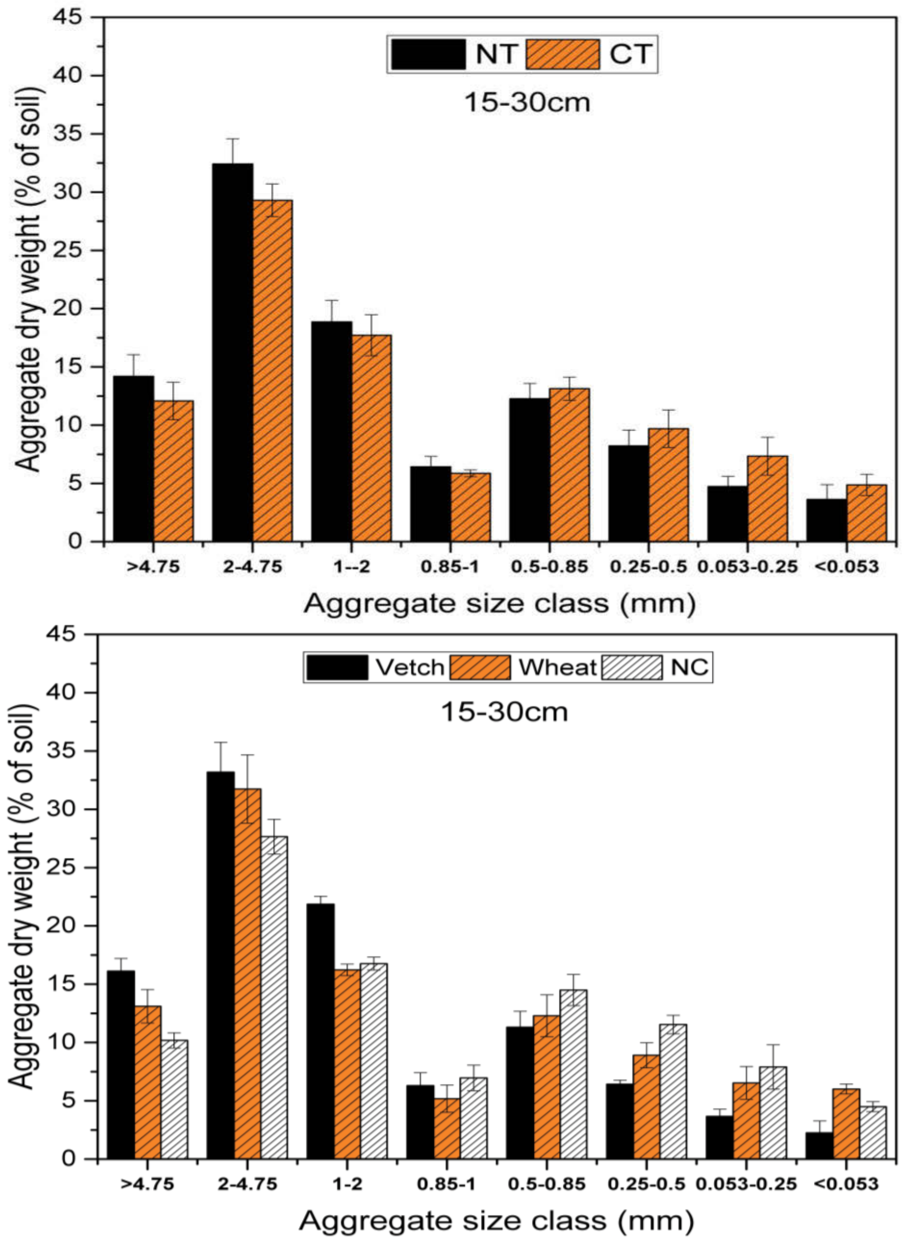

Figure 1.4. Dry aggregate size distribution at 15-30 cm soil depths averaged over tillage and cover crop managements. Error bars are standard error associated with each tillage and cover crop treatment.

1.4.3 WATER INFILTRATION AND FIELD-SATURATED HYDRAULIC CONDUCTIVITY

Field-saturated hydraulic conductivity and infiltration both significantly varied between tillage managements and among the cover crop treatments. In both years, initial (i_i) and steady state infiltration rate (ic) and field-saturated hydraulic conductivity (K_{fs}) were 45%, 100% and 133% in 2015 and 50%, 121% and 83% in 2016 ($p<0.01$) higher in NT than CT (Fig. 1.5-1.8). Initial infiltration rate was non-significantly higher under VCC than NCC, having an intermediate value for WCC. VCC and WCC showed significantly higher steady state and cumulative infiltration than NCC in both years (Table 1.5). Sorptivity parameters derived from the Philip's model was 33% and 25% greater under NT than CT in 2015 and 2016 respectively. However, due to the high standard error of measurements, sorptivity differences among cover crops were not significant in any year. Tillage differences was only significant at 2016 with NT having 25% higher mean S value than CT. Similarly, transmissivity in both years was greater under NT than CT and cover crop managements in general yielded higher transmissivity than NCC management (Table 1.5).

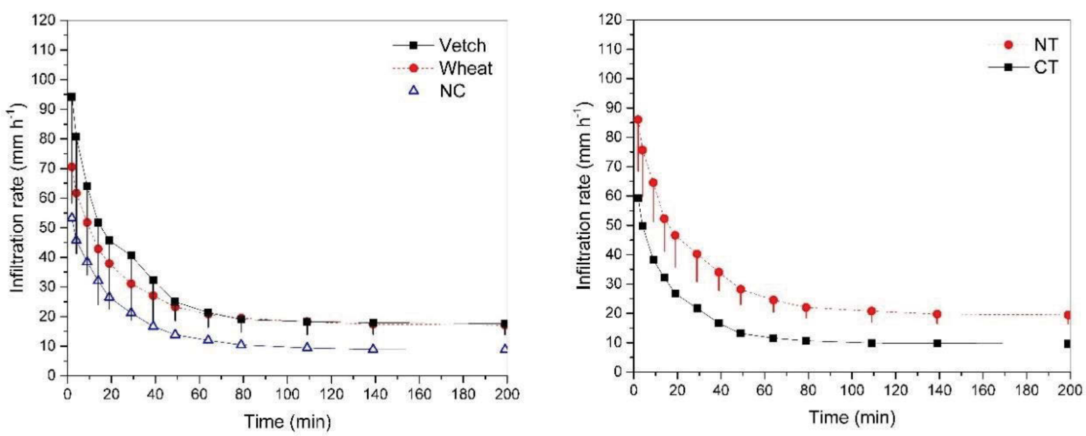

Figure 1.5. Infiltration rate as affected by no-tillage (NT) and conventional tillage (CT) and hairy vetch (Vetch), winter wheat (Wheat) and No-cover crop (NC) treatments in 2015. Vertical bars are LSD values (p <0.05).

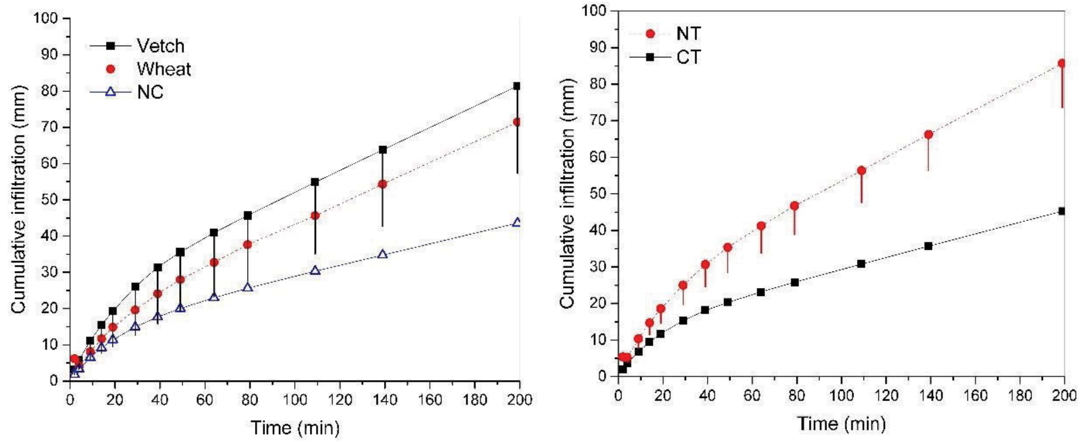

Figure 1.6. Cumulative infiltration as affected by no-tillage (NT) and conventional tillage (CT) and hairy vetch (Vetch), winter wheat (Wheat) and No-cover crop (NC) treatments in 2015. Vertical bars are LSD values (p <0.05).

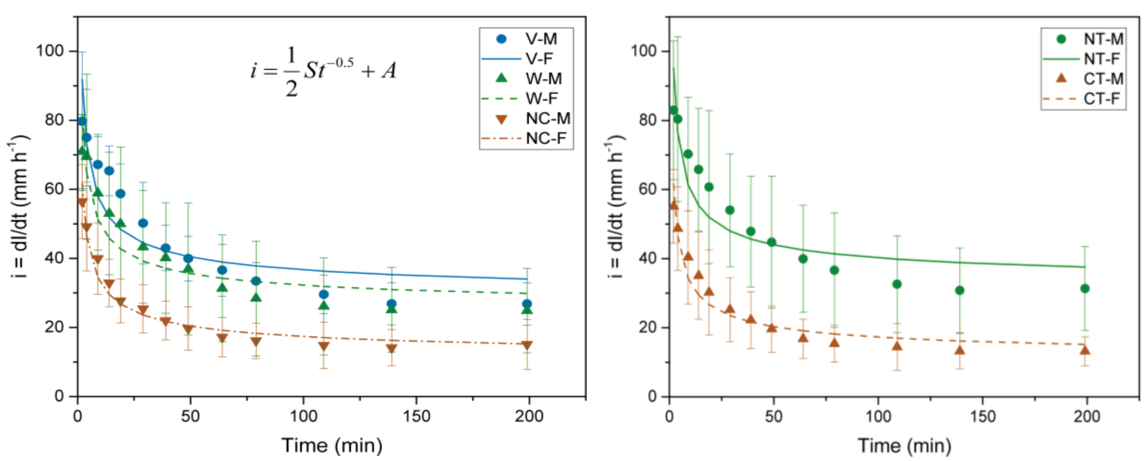

Figure 1.7. Infiltration rate as affected by no-tillage (NT) and conventional tillage (CT) and hairy vetch (V), winter wheat (W) and No-cover crop (NC) treatments in 2016. Dotted curves are measured values (M) and continuous curves represent the Philip's model estimation.

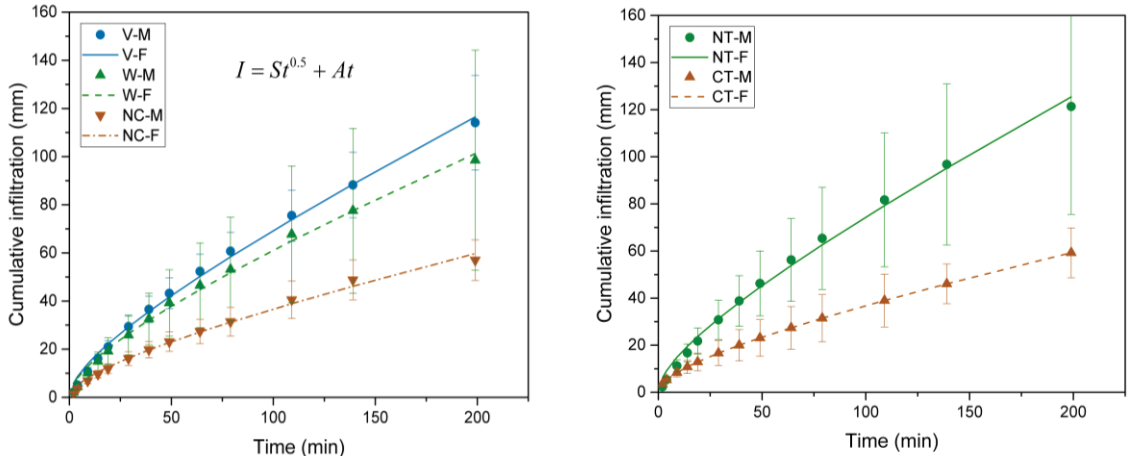

Figure 1.8. Cumulative infiltration as affected by hairy vetch (V), winter wheat (W) and No-cover crop (NC) and no-tillage (NT) and conventional tillage (CT) in 2016. Dotted curves are measured values (M) and continuous curves represent the Philip's model estimation.

Table 1.5. Effect of 34 years of tillage and cover crop managements on water infiltration and transmission measured in 2015 and 2016 and estimated by Philip's model.

Treatments	S (mm $h^{-0.5}$)	A (mm h^{-1})	i_i (mm h^{-1})	i_c (mm h^{-1})	I (mm)	K_{fs} (mm h^{-1})	Cotton lint yield (kg ha^{-1})
2015							
Cover means							
Vetch	267(49.13)a	9.6(3.30)a	94.1(15.07)a	17.6(2.77)a	81.4(20.35)a	6.88(1.09)a	1648(103.2)a
Wheat	187(26.84)a	11.4(3.48)a	70.6(9.10)a	17.1(2.98)a	71.4(25.18)a	6.40(0.52)a	1565(93.60)a
No-cover	156(22.35)a	4.70(1.97)a	53.2(6.75)a	8.8(1.30)b	43.6(7.05)b	2.56(1.19)b	1512(107.9)a
Tillage means							
CT	174(21.53)a	3.6(1.39)b	59.3(6.41)b	9.6(1.21)b	45.3(4.26)b	3.35(0.48)b	1442(68.25)b
NT	233(35.94)a	14.1(2.51)a	86.0(11.30)a	19.4(2.51)a	85.7(17.85)a	7.21(0.99)a	1708(76.60)a
ANOVA p-values							
Cover crops	0.207	0.059	0.082	<.0001	0.021	0.002	0.5203
Tillage	0.066	0.0004	0.008	<.0001	<.0001	0.0002	0.0142
C ×T	0.486	0.312	0.225	0.018	0.03	0.075	0.2965
2016							
Cover means							
Vetch	176(13.97)a	28.6(6.33)a	79.7(8.72)a	29.6(5.03)a	119.5a19.71)a	10.26(0.46)a	1695(65.4)a
Wheat	163(10.13)a	24.1(5.62)a	70.9(6.34)a	24.7(4.25)a	103.2(17.42)a	9.73(0.34)a	1691(30.6)a
No-cover	146(9.84)a	10.1(1.91)b	56.5(3.29)b	14.7(1.91)b	58.9(7.81)b	5.50(0.21b	1696(48.5)a
Tillage means							
CT	143.(5.51)b	10.6(1.46)b	55.1(2.12)b	14.6(1.35)b	59.4(5.56)b	5.76(0.51)b	1641(34.3)a
NT	180(10.25)a	31.4a(4.62)a	82.9(5.55)a	31.(3.48)a	128.3(13.87)a	11.24(1.49)a	1748(38.9)a
ANOVA p-values							
Cover crops	0.164	0.006	0.009	<.0001	0.005	0.005	0.997
Tillage	0.005	<.0001	<.0001	<.0001	<.0001	<.0001	0.07
C ×T	0.618	0.007	0.009	0.034	0.046	0.26	0.287
Year	0.044	<.0001	0.489	<.0001	0.005	<.0001	0.041

S: sorptivity, A: transmissivity, i_i: initial infiltration rate, i_c: steady-state infiltration rate, I: cumulative infiltration, K_{fs}: field-saturated hydraulic conductivity. Values in parenthesis are standard errors. Means within a factor followed by different letters are significantly different according to Fisher's protected LSD at P<0.05.

1.4.4 WATER RETENTION AND PORE SIZE DISTRIBUTION

Soil water retention analysis showed a general reduction in (VWC) at the entire range of pressure heads with increase in soil depth. CT contained greater moisture content at pressure heads between zero to -0.01Mpa while NT retained greater volume of water at matric potentials ≤-0.033Mpa at 22.5 cm of topsoil (Tables 1.6 & 1.7). At surface layer (0-7.5 cm), wherever the difference among the cover crop managements were significantly different, managements with cover crops contained significantly greater moisture content than no cover crop.

PSD was derived through fitting a cubic spline function to the experimentally measured soil water retention data (Fig. 1.9). The derivative of curve at inflection points yielded multi-modal PSD curves with distinct matrix and structural domains in most managements separated by minima point at equivalent pore radius of 1.5 µm at first layer and between 1.5 to 4.9 µm at deeper layers. Based on the assumption of Tuller and Or (2002) matrix porosity contain small pore size between 10-0.1 µm. The differences in PSD among tillage and cover crop managements were only significant at 0-15 cm of top layer. The fractional abundance of "rapid drainage macro-pores" (Reynolds et al., 2014) (i.e. equivalent pore radius >250 µm, corresponding to -0.6 m pressure head) was found to be considerably greater at 0-7.5 and 7.5-15 cm soil layers in CT than NT. At the same soil layers, NT generated a higher matrix porosity and lower structural porosity than CT. However, this effect was not evident at deeper soil layers. Differences in PSD based on CC managements were not evident at any of the investigated depths. Influence of cover crops on the fractional abundance of macro and micro-pores was found to be only significant at 0-7.5 cm, having higher macro-porosity in WCC than VCC and no cover crop.

Table 1.6. Soil water retention parameters derived from the measured soil moisture content at the range of applied tension heads.

Treatments	FC ($cm^3\ cm^{-3}$),	PWP ($cm^3\ cm^{-3}$)	PAWC ($cm^3\ cm^{-3}$)	AC ($cm^3\ cm^{-3}$)	RFC*	DS (%)	BD ($Mg\ m^{-3}$)
			Depth				
			0-7.5cm				
Cover means							
Vetch	0.34(0.012)a	0.15(0.003)a	0.19(0.011)a	0.09(0.018)a	0.78(0.04)a	97(0.24)a	1.47(0.025)a
Wheat	0.33(0.017)a	0.16(0.007)a	0.18(0.015)a	0.10(0.014)a	0.76(0.03)a	96(1.55)a	1.44(0.015)b
No-cover	0.31(0.010)a	0.14(0.005)a	0.17(0.010)a	0.11(0.014)a	0.74(0.03)a	95(1.98)a	1.48(0.02)a
Tillage means							
CT	0.31(0.007)b	0.15(0.005)a	0.16(0.008)a	0.12(0.004)a	0.71(0.01)b	94(1.27)b	1.43(0.005)b

Table 1.6. (Continued)

Treatments	FC (cm^3 cm^{-3}),	PWP (cm^3 cm^{-3})	PAWC (cm^3 cm^{-3})	AC (cm^3 cm^{-3})	RFC*	DS (%)	BD (Mg m^{-3})
NT	0.34(0.011)a	0.15(0.005)a	0.19(0.007)b	0.08(0.009)b	0.81(0.02)a	97(0.58)a	1.50(0.01)a
7.5-15cm							
Cover means							
Vetch	0.30(0.009)a	0.13(0.011)a	0.16(0.007)a	0.12(0.018)a	0.71(0.03)a	96(0.48)a	1.49(0.018)a
Wheat	0.30(0.011)a	0.14(0.006)a	0.17(0.008)a	0.10(0.015)a	0.75(0.03)a	96(0.83)a	1.52(0.008)a
No-cover	0.29(0.019)a	0.12(0.008)a	0.17(0.013)a	0.11(0.033)a	0.73(0.08)a	92(3.04)a	1.51b(0.019)a
Tillage means							
CT	0.27(0.006)b	0.12(0.006)b	0.16(0.006)b	0.15(0.008)a	0.65(0.02)b	96(0.47)a	1.48(0.010)b
NT	0.32(0.005)a	0.14(0.003)a	0.17(0.007)a	0.08(0.008)b	0.81(0.02)a	93(1.98)a	1.53(0.003)a
15-22.5cm							
Cover							
Vetch	0.31(0.009)a	0.15(0.010)a	0.17(0.005)a	0.11(0.004)a	0.72(0.01)a	95(0.01)a	1.48(0.014)b
Wheat	0.32(0.011)a	0.16(0.004)a	0.16(0.007)a	0.09(0.016)a	0.73(0.04)a	96(1.34)a	1.50(0.013)a
No-cover	0.32(0.013)a	0.16(0.009)a	0.16(0.012)a	0.11(0.013)a	0.74(0.03)a	94(1.14)a	1.46(0.010)b
Tillage means							
CT	0.30(0.006)b	0.15(0.003)a	0.15(0.006)b	0.13(0.006)a	0.66(0.01)b	95(1.12)a	1.46(0.006)b
NT	0.33(0.008)a	0.16(0.009)a	0.17(0.004)a	0.09(0.007)b	0.79(0.02)a	95(0.96)a	1.50(0.011)a
22.5-30cm							
Cover means							
Vetch	0.30(0.006)a	0.15(0.007)b	0.15(0.010)a	0.10(0.004)a	0.74(0.006)ab	93(1.26)a	1.52(0.008)a
Wheat	0.30(0.007)a	0.17(0.006)a	0.14(0.009)a	0.08(0.006)a	0.78(0.02)a	92(1.87)a	1.53(0.011)a
No-cover	0.27(0.006)b	0.14(0.006)b	0.13(0.005)a	0.11(0.007)a	0.72(0.02)b	92(0.50)a	1.55(0.013)a
Tillage means							
CT	0.29(0.006)a	0.16(0.007)a	0.14(0.003)a	0.10(0.007)a	0.74(0.02)a	91(0.95)a	1.52(0.004)b
NT	0.29(0.009)a	0.15(0.007)a	0.14(0.009)a	0.09(0.005)a	0.75(0.01)a	93(1.05)a	1.55(0.008)a

FC: field capacity moisture content, PWP: permanent wilting point soil moisture content, PAWC: plant available water content, AC: air capacity, *RFC: relative field capacity (dimensionless), DS: degree of saturation relative to the total porosity, BD: bulk density. Values in parenthesis are standard errors. Means within a factor followed by different letters are significantly different according to Fisher's protected LSD at $P<0.05$.

Table 1.7. Analysis of variance for soil water retention parameters derived from the measured soil moisture content at the range of applied tension heads.

Treatments	FC (cm^3 cm^{-3}),	PWP (cm^3 cm^{-3})	PAWC (cm^3 cm^{-3})	AC (cm^3 cm^{-3})	RFC*	DS (%)	BD (Mg m^{-3})
			Depth				
			0-7.5cm				
ANOVA p-values							
Cover crops	0.166	0.149	0.545	0.603	0.459	0.341	0.002
Tillage	0.021	0.404	0.043	0.008	0.007	0.035	<.0001
C ×T	0.632	0.488	0.883	0.603	0.573	0.283	0.075
			7.5-15cm				
ANOVA p-values							
Cover crops	0.124	0.264	0.519	0.279	0.164	0.194	0.121
Tillage	0.001	0.011	0.004	0.001	<.0001	0.09	0.003
C ×T	0.116	0.626	0.007	0.024	0.008	0.221	0.26
			15-22.5cm				
ANOVA ($p \leq 0.05$)							
Cover crops	0.597	0.476	0.508	0.672	0.793	0.403	0.01
Tillage	0.046	0.596	0.008	0.004	0.002	0.64	0.002
C ×T	0.386	0.932	0.216	0.061	0.294	0.655	0.671
			22.5-30cm				
ANOVA p-values							
Cover crops	0.02	0.028	0.296	0.13	0.057	0.78	0.09
Tillage	0.68	0.447	0.383	0.32	0.056	0.24	0.004
C ×T	0.5	0.149	0.204	0.72	0.08	0.31	0.29
Depth	0.002	<.0001	<.0001	0.08	0.172	0.02	<.0001
C ×D	0.35	0.02	0.846	0.45	0.275	0.76	<.0001
T × D	0.01	0.016	0.379	<.0001	<.0001	0.02	0.01
C ×T ×D	0.36	0.028	0.225	0.08	0.057	0.2	0.13

FC: field capacity moisture content, PWP: permanent wilting point soil moisture content, PAWC: plant available water content, AC: air capacity, *RFC: relative field capacity (dimensionless), DS: degree of saturation relative to the total porosity, BD: bulk density.

‘

Figure 1.9. Soil water retention data θ(h) fitted to van Genuchten model (A), soil water retention curves S(h) and associated derivative curves dS/d (ln h) against h, averaged over cover crops (B), and tillage managements (C) at four sampling depths.

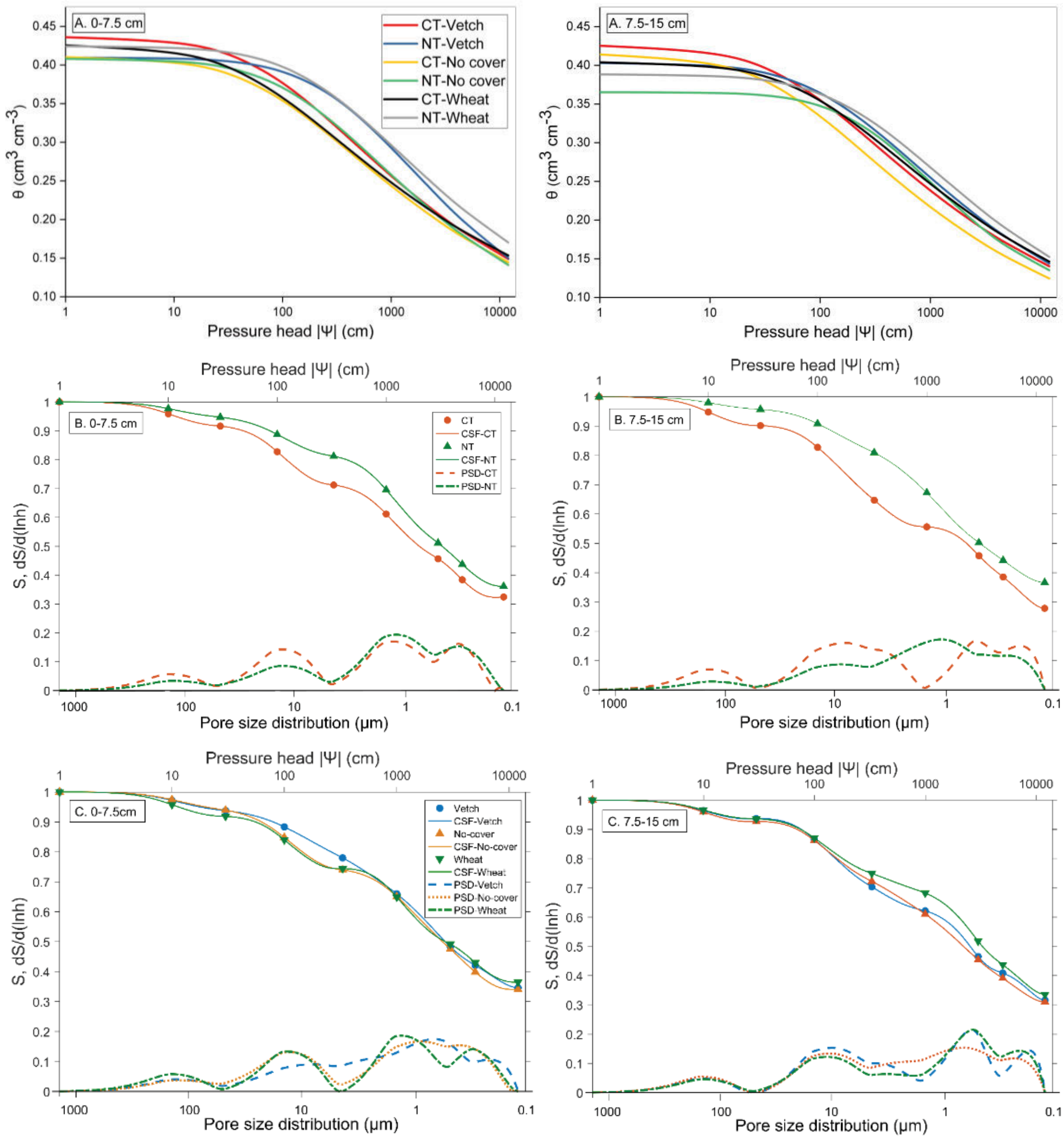

Fig. 1.9. Continued

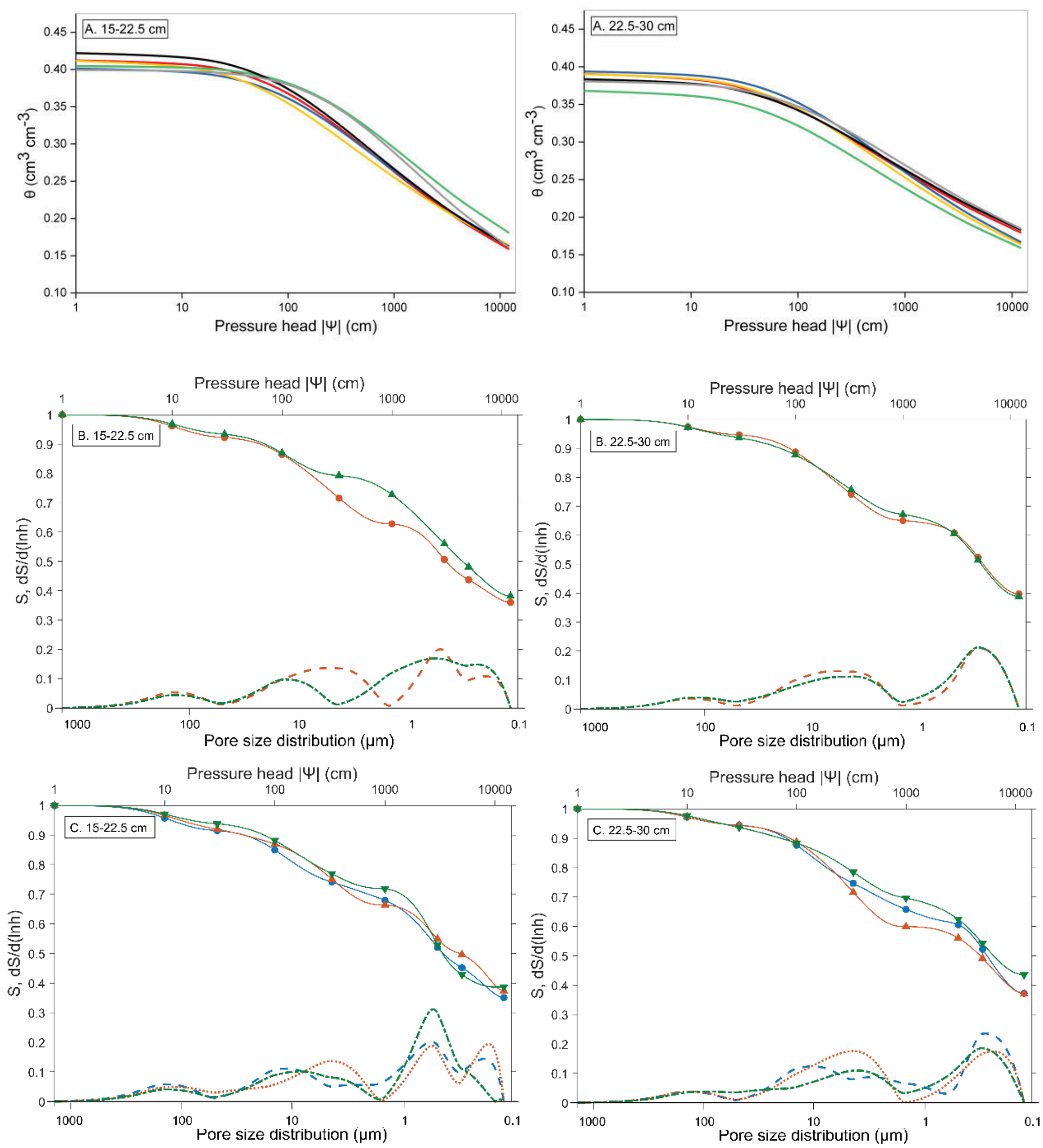

Fig. 1.9. Continued

1.5 DISCUSSION

1.5.1 BULK DENSITY, PENETRATION RESISTANCE AND MOISTURE CONTENT

Conventional tillage at the maximum state of annual bulk denity (measured before annual plowing) did not significantly differ from NT. This result implies that under 34 years of NT management, with a long-term exposure to machinery traffic and climatic factors (i.e., rainfall induced consolidation and sealing), the soil compaction is comparable with the maximum compaction which is observed after a year of tillage application at CT. This result is significant since short-term NT management, has frequently been reported to significantly increase BD under NT relative to CT (Bruce et al., 1990; Gantzer and Blake, 1978; Lampurlanés and Cantero-Martinez, 2003; Wander and Bollero, 1999). Reasonably long-term adoption of NT and subsequent increase in biological activities and soil aggregation improves soil potential to resist against the excessive soil compaction (Blanco-Canqui and Lal, 2007; Thomas et al., 1996). However, it is worthwhile to note that despite the non-significant BD differences between CT and NT in our study, no tillage consistently yielded slightly higher values than CT in both years and depths. This effect was significant ($p<0.01$) at 15-30 cm in 2015. Effect of CCs on BD is in accordance with Blanco-Canqui et al. (2011), who reported a lower state of compaction under NT planted with cover crops relative to NCC management. Similarly, we observed a non-significant reduction in BD at 0-15 cm when NT was accompanied by VCC or WCC compared to NCC. As expected, disk plow decreased the BD at plow layer and resulted in 4% ($p<0.01$) lower BD under CT than NT while two cover crop managements did not show a clear advantage over NCC.

Cone penetration resistance (PR) measured either before or after application of disk plow on CT in both years demonstrated the same trend of variations among treatments. However, the magnitude of PR values was substantially affected by temporal variations in soil water content (Unger and Jones, 1998) with increasing the PR approximately 1Mpa per 45% decrease in average soil VWC. PR measured before annual disk plow and averaged over the sampling depths showed no significant difference among tillage and CC managements. However, NCC showed 36% and 10% ($p<0.05$) higher PR than VCC and WCC at first and second depths respectively. It can be explained by greater accumulation of organic matter at surface of CC managements and also the loosening effect of stimulated biological activities. In accord with Fernández-Ugalde et al. (2009), upon disk plow, averaged PR over CT was 25% and significantly ($p<0.01$) lower than NT at 0-15 cm, while the effect of CCs was non-significant at both sampling depths (Tables 1.2 & 1.3).

Measuring four consecutive PRs on a line transect at each sub-plot provided a better insight into two dimensional variations of PR among treatments. As illustrated in (Fig. 1.2), application of disk extended the depth of minimally resistant top layer (0-1 Mpa) from about 4cm under NT to approximately 8 cm under CT. The maximum PR range (>2Mpa) was distributed from nearly 10cm to 25 cm of soil profile under NT. However, this maximally resistant layer in CT occupied a narrower range of the soil profile, approximately 15 to 25 cm. The zones with maximum range of PR showed a higher continuity in horizontal direction under CT while the distribution of same range of PR at NT followed an irregular distribution pattern which may have resulted by decreased machinery traffic under NT and rupture of soil peds due to the long-term root activity.

Variations in soil moisture content among treatments measured in-situ at near FC moisture content (2-3 days after rainfall) in neither of years matched the VWC measured at -3.30 m of pressure head in laboratory as will be explained later in this report. In-situ VWC revealed no significant difference between NT and CT while NT had greater moisture content in 0-22.5 cm soil depth measured in laboratory. This result can be attributed to the fact that convoluted network of pore system under CT has a limited structural connectivity with underlying unplowed soil layer (Roseberg and McCoy, 1992; Shipitalo et al., 2000). Hence at higher in-situ water potentials, CT tends to transmit water slower than in short laboratory cores with free drainage. This inference is supported by lower infiltration properties under CT. Field measured VWC in drier periods of the growing season in both years revealed significantly ($p<0.01$) greater soil moisture content under NT than CT in 0-15 and 15-30 cm in 2015 and 0-15 cm in 2016. This result was supported by SWRC results. Fernandez-Ugalde et al. (2009) also reported that higher moisture content under NT relative to CT was more evident in lower water potential which reveals the significance of NT management in dry regions and water limited periods of non-irrigated farming system.

Wet aggregate stability explained 44% and 50% of the variability in soil moisture content at first and second sampling depths in 2015 and 23% and 50% in 2016 respectively (Fig. 1.10, A-B). Soil moisture content with smaller coefficient of determination was also found to be related to soil clay content (Fig. 1.10, C-D). Higher water retention by more wet aggregate stability can be explained by the role of SOC in improvement of aggregate stability which in turn increases the water holding capacity of aggregates. In 2015, particularly at surface depth (0-15 cm) VCC and WCC contained greater VWC than NCC. The greatest difference was observed between NT-VCC and CT-NCC managements with 136% greater VWC under NT-VCC. In humid regions, the contribution of cover crops to the soil water storage has been recognized to be greater than their consumption during the growing season (Dabney, 1998; Joyce et al., 2002).

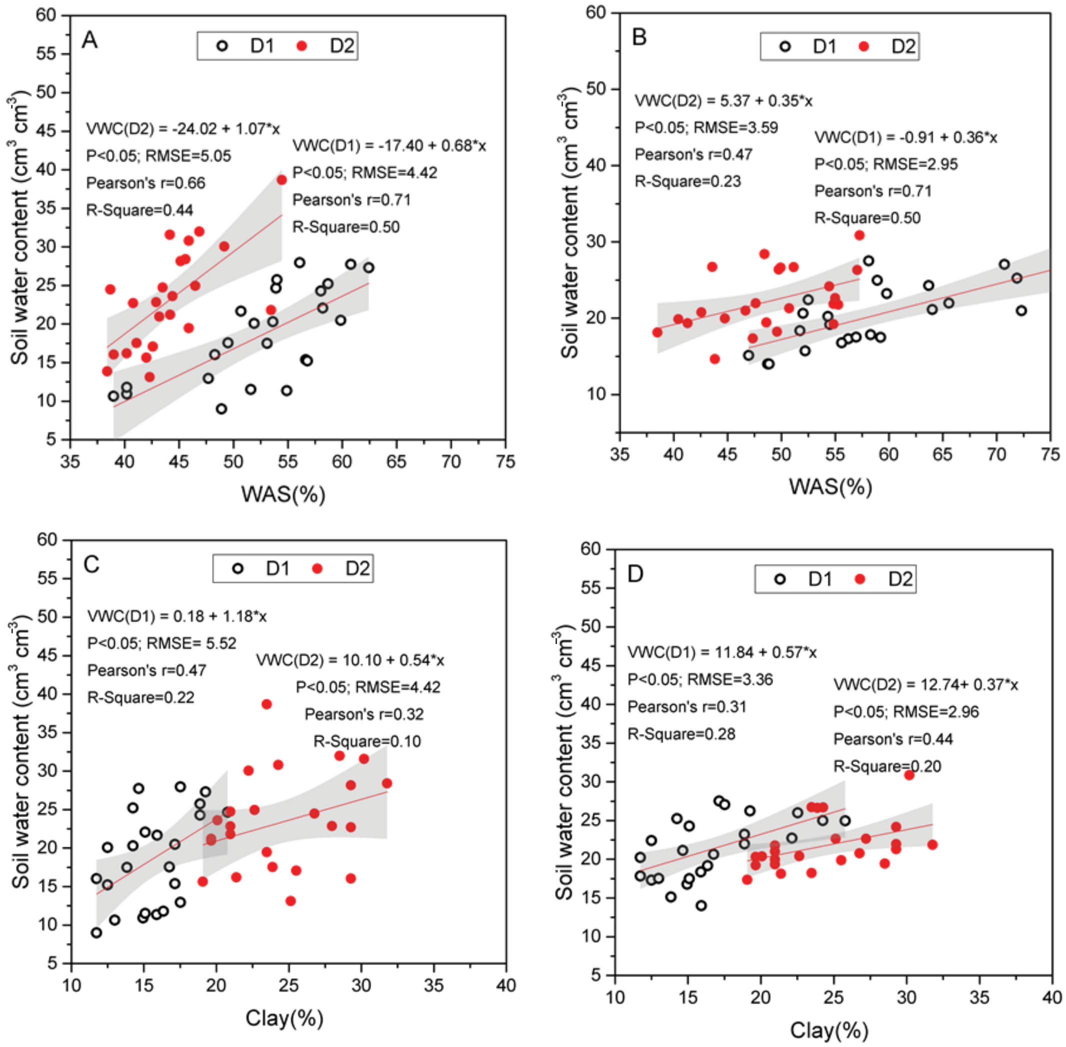

Figure 1.10. Simple linear regression represents relationship between wet aggregate stability (WAS) and volumetric soil moisture content (VWC) measured within 0-15 (D1) and 15-30 cm (D2) of soil depth in 2015 (A) and 2016 (B) and relationship between soil clay content at the same sampling depths and volumetric soil water content measured in 2015 (C) and in 2016 (D). Shaded area around the fitted lines show 95% confidence band of prediction.

1.5.2 WET AGGREGATE STABILITY AND DRY AGGREGATE SIZE DISTRIBUTION

Long-term absence of the soil disturbance under NT resulted in a significantly higher WAS than CT and under cover crops relative to NCC at mainly 0-15 cm. Higher stability of aggregates against slacking under NT and cover crop managements has been well documented by several authors (Eynard et al., 2004; Smettem et al., 1992; Cambardella and Elliot ,1993; Arshad, 1996). The reason can be related to the higher input of organic matter under NT management with reduced mineralization of SOM due to the lack of mechanical disturbance (Barreto et al., 2009; Álvaro-Fuentes et al., 2009). NT-VCC resulted in 9% and 16% greater WAS than NT-NCC at 0-15 cm in 2015 and 2016 respectively. This result indicates the significance of additional residue production by cover crops on aggregates stability. Increase in SOM improves the activity of soil biota. These organisms in turn release polysaccharides and other compounds which can serve as binding agents between soil particles and improve soil aggregation. Cover crops can reinforce this effect by inputting additional above and below ground organic matter (Unger et al., 1998). Considering all management combinations, we also found a positive correlation between WAS and clay content at 0-15 cm of soil depth resulting in $r=0.26$ and $r=0.17$ in 2015 and 2016 respectively. Similar result was also reported by Kemper et al. (1987). Clay flocculation is known as a necessity for soil aggregation (Dexter, 1988) and higher clay content has been shown to increase the aggregate stability through enhancing the cohesion of larger particles (Kemper & Koch, 1966).

Dry aggregate size distribution (DASD) was affected significantly by both tillage and cover crop managements. MWD under NT was 18% and 11% higher than CT at first and second depth respectively. Our results are in line with those of (Fernández et al., 2010) who indicated that in log-term, effect of NT on DASD can extend beyond the few centimeters of topsoil. However, cover crops were only effective at first depth having significantly (≈20%) higher MWD with VCC and WCC than NCC management. We found 23% greater fraction of macro-aggregates (MA; >2 mm) under NT than CT. Macroaggregate fraction was also 27% higher when VCC or WCC were incorporated. These results are in agreement with Mrabet et al. (2001) and Singh and Malhi (2006) who observed a higher MWD and greater fraction of macroaggregates under NT than CT. NT and cover crop contribution to the formation or maintenance of macroaggregates can be related to the fact that tillage tends to dissipate the large aggregates into the smaller ones and expose the entrapped SOC to microbial attack while the increased residue turn over by cover crops improves the aggregation further than those that depend on the main crop as the only source of organic matter. The fractional abundance of small macroaggregates (SMA; 0.25-2 mm) was significantly higher under CT than NT at surface depth while NT had greater percentage of this class size aggregates at the second depth. Microaggregates (MIA; 0.53-0.25 mm) followed the similar trend as SMA. Incorporation of VCC and WCC with both tillage managements significantly lowered the MIA values than NT-NCC and CT-NCC. Higher structural stability under NT can be partly explained by the improved aggregate size distribution which is in a direct relation with pore size distribution (Hillel, 1998). Intra-aggregate cohesive forces benefit soil resistance against compaction and provide a better medium for water and nutrient transmission.

1.5.3 WATER INFILTRATION AND FIELD-SATURATED HYDRAULIC CONDUCTIVITY

Water infiltration appeared to be highly variable in space and time showing inconsistent order of magnitudes among different tillage and cover crop treatments through four replications primarily due to the spatial heterogeneity in soil pore characteristics (Reynolds et al., 2002b). Initial infiltration rate of WCC planted under CT management did not differ significantly from NCC while WCC planted with NT had significantly higher i_i than NCC. VCC under both tillage managements had greater i_i than NCC. NT-VCC and CT-NCC managements revealed highest and lowest initial infiltration rates respectively. Lower i_i under NCC-CT can be ascribed to the soil surface properties (Suwardji and Eberbach, 1998). Accumulation of plant residue and debris at soil surface under NT, provides a protective cover that prevents the surface sealing and thereby maintains the pore connectivity in soil-atmosphere interface (Gangwar et al., 2006). Steady state infiltration rate (Ic) in both years were significantly higher under NT than CT and also was higher under both cover crops than NCC. Steady state infiltration did not differ between tillage managements under NCC system. However, NT planted with cover crops and particularly VCC showed greater i_c han CT in both years. Cumulative infiltration was trivially affected by tillage management in absence of cover crops while VCC and WCC on NT resulted in significantly higher I value than CT in both years. All these results suggest that long-term NT significantly improved water infiltration due to formation of channels, cracks and bio-pores associated with the increased biological activities and the long-term lack of disturbance (Reynolds et al., 2002b). Incorporation of cover crops with NT improves the formation of continuous pore network which has a significant influence on soil hydraulic behavior (Mikha and Rice, 2004; Strudley et al., 2008). Hydraulic conductivity (K_{fs}) also varied significantly between tillage and among cover crops. NT management resulted in significantly higher K_{fs} than CT in both years. Kahlon et al. (2013) reported that the increased K_{fs} in a silt-loam soil under NT is related to the higher porosity, lower tortuosity of pore space and more connected pores under NT than CT.

Among all measured soil physical properties differences between CCs and NCC were most evident in infiltration properties. Sorptivity is an indicator of ponded water infiltrability of the soil matrix disregarding the effect of gravity. Despite the consistently higher values under NT and cover crop managements, sorptivity did not differ significantly among cover crop managements and was only significantly higher under NT than CT in 2016. It can be related to the high variability in S values. S is known to be highly affected by initial moisture content (Philip, 1957). Shaver et al. (2002) also reported that S parameter remained unchanged among different cropping systems. Transmissivity is a gravity parameter closely related to the hydraulic conductivity. Transmissivity with correlation coefficients of r=0.86 and r=0.90 in two experimental years were highly correlated with K_{fs} calculated by Reynolds equation. Similar to the findings of Alvarez and Steinbach. (2009) and Franzluebbers. (2002), despite the higher bulk density, K_{fs}, i_i and I parameters were significantly higher under NT than CT which is related to the lower structural stability as well as the lack of continuous pore network formation under CT compared to NT.

1.5.4 SOIL WATER RETENTION, PORE SIZE DISTRIBUTION

Greater saturated water content in CT is directly related to the higher total porosity induced by tillage management (Osunbitan et al., 2005; McCoy, 1992). However, the degree of saturation (DS) defined as the ratio of the saturated porosity at atmospheric pressure to TP was found to be significantly higher under NT at surface depth (0-7.5 cm) while no significant differences were found in deeper soil layers (Tables 1.6 & 1.7). This result indicates that despite the increased TP and lowered BD by tillage, there is relatively higher abundance of occluded pores in CT that do not contribute to soil water storage or transmission. DS however was not affected significantly by cover crop management. Soil water content at 0-15 cm within the pressure head of 0-0.3 m or the equivalent pore radius of ≥50 μm was generally greater under CT than NT primarily due to the higher TP under CT. This pore size corresponds to the “drainage and aeration” pores (Reynolds et al., 2014). Within the available water range of PSD (≤4.5 μm), NT contained significantly higher moisture content than CT. However, it was limited to the upper 0-15 cm soil depth below which differences in SWRC between tillage and among CC treatments start to diminish. Across the range of applied matric tensions, whenever the water content differed significantly among cover crops, WCC and VCC contained greater water content than NCC. Plant available water content (PAWC) at the entire sampling depth (0-30 cm) was higher under NT than CT but the difference was statistically significant only at 0-15 cm soil depth. PAWC did not differ significantly among cover crop managements. For adequate soil aeration, near surface air-filled porosity (AC) should be at least 0.10-0.15 m^3 m^{-3} (Reynolds et al., 2002a; Grable and Siemer, 1968; Cockroft and Olsson, 1997). In this study, AC at 0-15 cm with average value of 0.14 m^3 m^{-3} for CT, falls within the specified optimal range whereas NT with 0.08 m^3 m^{-3} falls below the range. Based on Reynolds et al. (2014) and Drewry (2006), this condition may cause periodic anaeorbiosis on account of low oxygen diffusion rate. However, according to Hillel (2003) the air diffusion which has a greater contribution to soil aeration, unlike the convective flow is not affected by PSD but it is mainly related to the total volume and tortuosity of continuous pores. NT management is generally characterized by higher connected and oriented pore space due to the long-term biological activities and climatic factors. Relative field capacity (RFC) indicates that the aeration is more likely of concern than dryness (Tables 1.6 & 1.7). Several studies have reported an optimal range of 0.6-0.7 m^3 m^{-3} for RFC. Lower values likely result in a water-limited condition while higher values are associated with aeration-limited soil condition (Olness et al., 1998). Except for 7.5-22.5 cm soil depth in which the mean RFC for CT was 0.65 m^3 m^{-3} in remaining depths and among cover crops and NT management RFC was >0.7 m^3 m^{-3}.

Derivative curve derived from the SWRC revealed a hierarchical structure of the soil porosity with separated structural (inter-aggregate) and matrix domains (intra-aggregates). Number of peaks in sub-domains decreased with depth, having a bimodal structure for each domain at 0-7 cm and mono to di-modal structure in each domain in deeper layers. Number of domains or peaks corresponds to the number of inflection points of SWRC and multi-modality of PSD is and indicator of structured soil (Durner, 1992). We observed a more pronounced difference in PSD of tillage managements than those for cover crops. At the surface layers (0-7.5 and 7.5-15 cm), Higher fraction of larger pores in CT is the consequence of soil loosening by tillage operation that have also been inferred by some other authors (Lipiec et al., 2006; Hill et al., 1985). Tillage-induced differences in PSD, observed dominantly at the range of pore size corresponding to the structural porosity (>4.9 μm). Effect of cover crops on PSD however was not distinguishable at any depth. PSD analysis resulted in higher fraction of larger pores under CT than NT at surface layer which contrasts our measured hydraulic properties which was substantially higher under NT (i.e. K_{fs}, i_i, I and A). This contradiction can be explained by three possible reasons: first, size of intact soil cores collected from field for SWRC analysis is considerably smaller than the area covered by double ring infiltrometer which was utilized for infiltration measurements. Therefore, the probability that infiltrometer has included greater number of biological pores and/or cracks under NT is much higher. Second, besides the volume of macropores, shape and orientation of pores are also important parameters in water percolation. Third, soil surface sealing due to raindrop impact which is a field specific phenomenon can considerably reduce the water infiltration at the non-protected surface of CT management.

1.5.5 PRINCIPAL COMPONENT ANALYSIS

Principal component analysis for selected soil physical properties is presented in Fig. 1.12. First and second PCs explained 34% and 19% of variability in measured parameters respectively, differentiating CT from NT and cover crops from NCC management. Data points under NT were associated with higher infiltration properties, bulk density, penetration resistance, macroaggregates, available water content, hydraulic conductivity and yield. while CT was associated with lower values of mentioned parameters but higher microaggregates, sand fraction and total porosity. The effect of tillage management on standing biomass was visually evident at the field (Fig. 1.11)

Figure 1.11. Standing cotton biomass dramatically declines at the transition point from no-tillage (right) to conventional tillage (left) without winter cover and 101 kg ha^{-1} ammonium nitrate fertilization.

Figure 1.12. Principal component analysis (PCA) for selected measured soil physical and hydraulic properties across years and depths. The PCA differentiates the measured parameters based on tillage (A), cover crops (B) and tillage*cover crop (C). BD: bulk density; PR: penetration resistance; M1: field-measured near FC moisture content; M2: field-measured moisture content within the range of available water; MA: macroaggregates; SMA: small macroaggregates; MIA: microaggregates; GMD: geometric mean diameter; MWD: mean weight diameter; FC: field capacity moisture content; AWC: available water content; WAS: wet aggregate stability; K_{fs}: field-saturated hydraulic conductivity; I: cumulative infiltration.

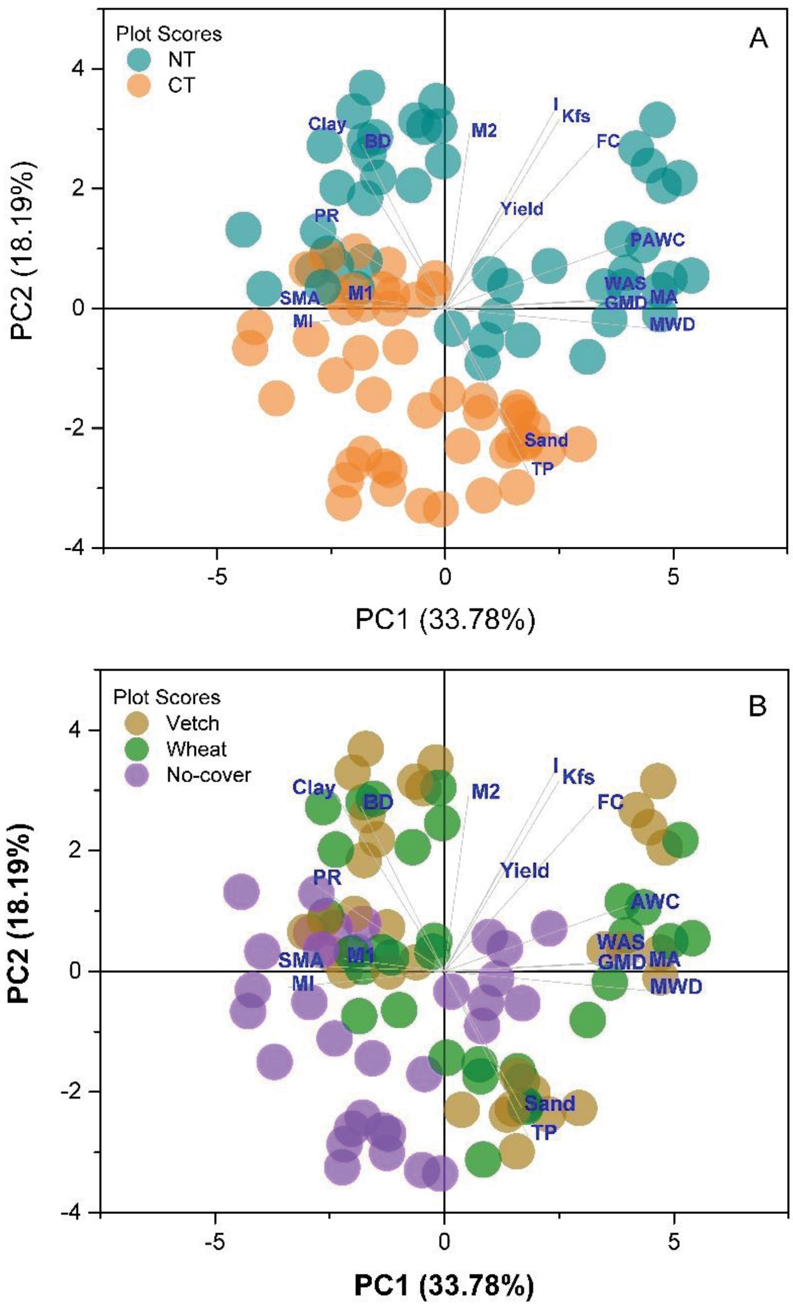

Fig. 1.12. Continued

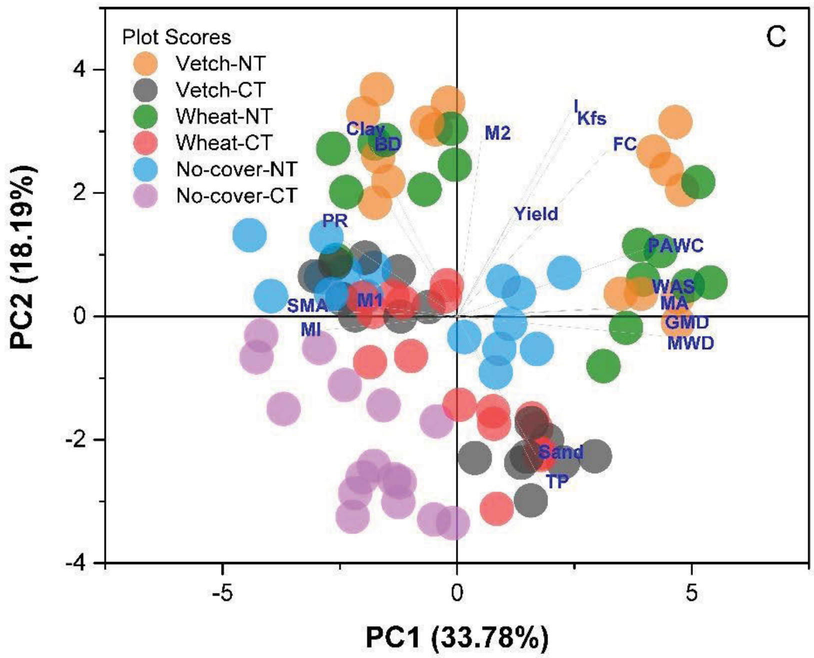

Fig. 1.12. Continued

Principal component analysis on the effect of cover crop managements, successfully differentiated the cover crops from no cover crop management. However, no obvious distinction was observed between two cover crops. Most apparent properties associated with no cover crop management is higher percentage of micro and small macroaggregates, while higher values in the other properties are related to cover crop managements. These results are in accordance with those derived from the ANOVA test.

1.5.6 EFFECT OF SOIL PHYSICAL PROPERTIES ON AVAILABLE WATER CONTENT AND COTTON LINT YIELD

Tillage and cropping management considerably affected the growth and yield of cotton. Cotton yield was significantly higher under NT compared to CT in 2015 and non-significantly greater in 2016 (Table 1.5). Although differences between cover crops were not significant in either of year, VCC resulted in higher cotton yield in 2016. The central composite second-order regression, revealed the effect of soil physical properties and interaction between those parameters on PAWC and cotton yield (Fig. 1.13). Test of lack of fit and coefficient of determination, confirmed the adequacy of predicted models. Response surface model explained 69% of PAWC primarily due to the linear effect of K_{fs} and MWD (Table 1.8). PAWC was predicted to be maximum when K_{fs} and MWD both are on top of the measured range for these parameters. It implies that increase in MWD favors PAWC when the K_{fs} is not a limiting factor. Linear effect of soil clay content and quadratic cumulative infiltration resulted in maximum PAWC which indicates that when the soil clay content is low, increased cumulative infiltration does not increase the PAWC. The third response surface relates the linear effect of clay content and linear and quadratic effect of K_{fs} to the PAWC. A significant twist at the lower rates of clay indicates that the lowest rate of PAWC occur when the K_{fs} is high at the lower percentage of clay content. Non-significant linear effect of PAWC and significant linear effect of steady state infiltration explained 67% of response in cotton yield. High PAWC when the steady state infiltration is low, probably due to the lower aeration resulted in yield reduction while the maximum cotton yield is obtained when the both parameters increase simultaneously. Variations in WAS and FC explained 78% of variations in cotton yield. According to the yield response surface, increase in aggregate stability favors the cotton yield whenever the stable aggregates also retain higher water content in FC. WAS up to 60% increase the yield response along the entire range of FC. However, aggregates with water stability index greater than 0.60 % that do not retain at least 32 $cm^3\ cm^{-3}$ water at FC lead to decrease the cotton yield. Model parameters and of selected RS analysis has been shown in Table 1.8.

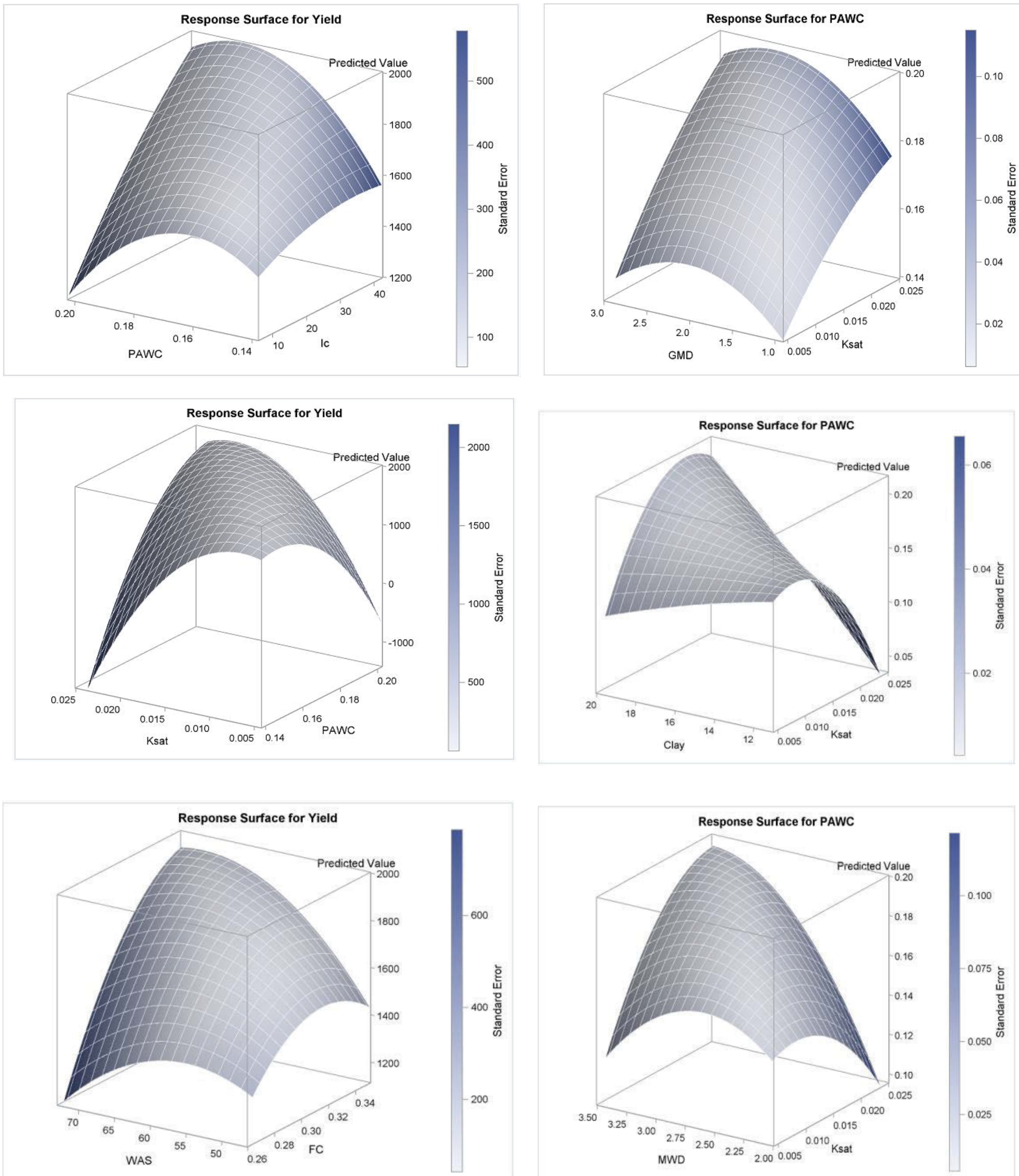

Figure 1.13. Selected response surface illustrations for cotton yield (left) and plant available water content as a function of measured soil hydro-physical properties. Explanatory variables were selected based on the coefficient of determination and lack of fit test.

Table 1.8. Central composite response surface regression parameters estimating the optimum values of soil physical properties for the maximum response of cotton yield (kg ha^{-1}) and plant available water content (%).

Response Variable	Explanatory Variables	R^2	a	b	Predicted response*
Yield	$PAWC^a$-Ic^b	0.67	0.23	117.53	2377
Yield	$Ksat^a$-$PAWC^b$	0.54	0.017	0.18	1945
Yield	WAS^a-FC^b	0.78	71.34	0.36	1947
PAWC	$Clay^a$-$Ksat^b$	0.82	10	0.007	0.16
PAWC	$Clay^a$-I^b	0.75	18	130.6	0.19
PAWC	GMD^a-$Ksat^b$	0.65	2.47	0.039	0.21
PAWC	MWD^a-$Ksat^b$	0.69	3.52	0.025	0.20

Stationary point is maximum
*Is the maximum cotton lint yield (kg ha^{-1}) and available water content (cm^3 cm^{-3})

1.6 CONCLUSION

34 years of no-tillage and cover crop management considerably influenced the soil hydro-physical properties and cotton yield in west Tennessee.

- Our first hypothesis that NT and CCs would improve NT soil physical quality greater than CT and NCC is supported by our findings. NT showed a significantly higher WAS, VWC, GMD, MWD, MA, FC moisture content, PAWC, RFC, initial and cumulative infiltration and K_{fs} and cotton yield than CT. Cover crops with smaller effect than tillage, significantly the mean weight diameter and geometric mean diameter of aggregates, water infiltration and field-saturated hydraulic conductivity than no cover crop
- In accordance with our second hypothesis, incorporation of cover crops with NT, generally increased the NT potential on improving soil hydro-physical properties. This effect were mainly limited to 0-15 cm of soil surface. Hairy vetch CC with 67 kg ha^{-1} and less N-fertilizer, contributed much greater to WAS, initial infiltration rate and soil moisture content than winter wheat CC. VCC incorporated with NT significantly increased the quasi-steady and cumulative infiltration in both years than other cover crop/tillage combinations.
- Effect of management practices on PSD was more evident in tillage managements. NT decreased the structural porosity which is mainly responsible for water drainage and transmission and consequently decreased the air capacity in favor of increase in matrix porosity. Increased matrix porosity resulted in higher PAWC under NT than CT. Based on the field-measured infiltration properties, lower structural porosity in bulk of NT soil was effectively compensated by fissures and bio-pores formed under long-term NT.
- Response surface analysis showed that the variations in cotton lint yield were considerably

related to the changes in soil physical and hydraulic properties under management practices. Maximum cotton yield was attained at the optimum range of WAS, K_{fs} and steady state infiltration rate, FC water content, and PAWC. PAWC was found to be significantly related to the aggregate size distribution, infiltration properties and soil clay content.

1.7 REFERENCES

Addiscott, T., 1995. Entropy and sustainability. European Journal of Soil Science 46, 161-168.

Alburquerque, M., Dieckow, J., Sordi, A., Piva, J., Bayer, C., Molin, R., Pergher, M., Ribeiro-Junior, P., 2015. Carbon and nitrogen in a Ferralsol under zero-tillage rotations based on cover, cash or hay crops. Soil Use and Management 31, 1-9.

Alvarez, R., Steinbach, H., 2009. A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yield in the Argentine Pampas. Soil and Tillage Research 104, 1-15.

Álvaro-Fuentes, J., Cantero-Martinez, C., López, M., Paustian, K., Denef, K., Stewart, C., Arrúe, J., 2009. Soil aggregation and soil organic carbon stabilization: effects of management in semiarid Mediterranean agroecosystems. Soil Science Society of America Journal 73, 1519-1529.

Barreto, R.C., Madari, B.E., Maddock, J.E., Machado, P.L., Torres, E., Franchini, J., Costa, A.R., 2009. The impact of soil management on aggregation, carbon stabilization and carbon loss as CO 2 in the surface layer of a Rhodic Ferralsol in Southern Brazil. Agriculture, Ecosystems & Environment 132, 243-251.

Blanco-Canqui, H., Francis, C.A., 2016. Building resilient soils through agroecosystem redesign under fluctuating climatic regimes. Journal of Soil and Water Conservation 71, 127A-133A.

Blanco-Canqui, H., Mikha, M.M., Presley, D.R., Claassen, M.M., 2011. Addition of cover crops enhances no-till potential for improving soil physical properties. Soil Science Society of America Journal 75, 1471-1482.

Boquet, D.J., Hutchinson, R.L., Breitenbeck, G.A., 2004. Long-term tillage, cover crop, and nitrogen rate effects on cotton. Agronomy Journal 96, 1443-1452.

Brown, S., Whitwell, T., Touchton, J., Burmester, C., 1985. Conservation tillage systems for cotton production. Soil Science Society of America Journal 49, 1256-1260.

Bruce, R., Langdale, G., Dillard, A., 1990. Tillage and crop rotation effect on characteristics of a sandy surface soil. Soil Science Society of America Journal 54, 1744-1747.

Calonego, J.C., Rosolem, C.A., 2010. Soybean root growth and yield in rotation with cover crops under chiseling and no-till. European Journal of Agronomy 33, 242-249.

Cockroft, B., Olsson, K., 1997. Case study of soil quality in south-eastern Australia: management of structure for roots in duplex soils. Developments in Soil Science 25, 339-350.

Dabney, S.M., 1998. Cover crop impacts on watershed hydrology. Journal of Soil and Water Conservation 53, 207-213.

Derpsch, R., Franzluebbers, A., Duiker, S., Reicosky, D., Koeller, K., Friedrich, T., Sturny, W., Sá, J., Weiss, K., 2014. Why do we need to standardize no-tillage research? Soil and Tillage Research 137, 16-22.

Dexter, A., 1988. Strength of soil aggregates and of aggregate beds, Impact of water and external forces on soil structure: selected papers of the 1st Workshop on Soilphysics [sic] and Soilmechanics [sic], Hannover 1986/J. Drescher, R. Horn and M. de Boodt (Editors). Cremlingen-Destedt: Catena, c1988.

Dirksen, C., 1998. Soil physics measurements.

dos Reis Martins, M., Cora, J.E., Jorge, R.F., Marcelo, A.V., 2009. Crop type influences soil

aggregation and organic matter under no-tillage. Soil and Tillage Research 104, 22-29.
Drewry, J., 2006. Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: a review. Agriculture, Ecosystems & Environment 114, 159-169.
Durner, W., 1992. Predicting the unsaturated hydraulic conductivity using multi-porosity water retention curves. Indirect methods for estimating the hydraulic properties of unsaturated soils, 185-202.
Ebelhar, S., Frye, W., Blevins, R., 1984. Nitrogen from legume cover crops for no-tillage corn. Agronomy Journal 76, 51-55.
Eynard, A., Schumacher, T., Lindstrom, M., Malo, D., 2004. Aggregate sizes and stability in cultivated South Dakota prairie Ustolls and Usterts. Soil Science Society of America Journal 68, 1360-1365.
Fernández-Ugalde, O., Virto, I., Bescansa, P., Imaz, M., Enrique, A., Karlen, D., 2009. No-tillage improvement of soil physical quality in calcareous, degradation-prone, semiarid soils. Soil and Tillage Research 106, 29-35.
Fernández, R., Quiroga, A., Zorati, C., Noellemeyer, E., 2010. Carbon contents and respiration rates of aggregate size fractions under no-till and conventional tillage. Soil and Tillage Research 109, 103-109.
Fortuna, A., Blevins, R., Frye, W., Grove, J., Cornelius, P., 2008. Sustaining soil quality with legumes in no-tillage systems. Communications in Soil Science and Plant Analysis 39, 1680-1699.
Franzluebbers, A., 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil and Tillage Research 66, 197-205.
Gangwar, K., Singh, K., Sharma, S., Tomar, O., 2006. Alternative tillage and crop residue management in wheat after rice in sandy loam soils of Indo-Gangetic plains. Soil and Tillage Research 88, 242-252.
Gantzer, C., Blake, G., 1978. Physical characteristics of Le Sueur clay loam soil following no-till and conventional tillage. Agronomy Journal 70, 853-857.
Gee, G.W., Or, D., 2002. 2.4 Particle-size analysis. Methods of Soil Analysis. Part 4, 255-293.
Grable, A.R., Siemer, E., 1968. Effects of bulk density, aggregate size, and soil water suction on oxygen diffusion, redox potentials, and elongation of corn roots. Soil Science Society of America Journal 32, 180-186.
Green, W.H., Ampt, G., 1911. Studies on Soil Phyics. The Journal of Agricultural Science 4, 1-24.
Grossman, R., Reinsch, T., 2002. 2.1 Bulk density and linear extensibility. Methods of Soil Analysis: Part 4 Physical Methods, 201-228.
Hill, R., Horton, R., Cruse, R., 1985. Tillage effects on soil water retention and pore size distribution of two Mollisols. Soil Science Society of America Journal 49, 1264-1270.
Hillel, D., 1998. Environmental soil physics: Fundamentals, applications, and environmental considerations. Academic press.
Hutchinson, R., Breitenbeck, G., Brown, R., Thomas, W., 1991. Requirements of Cotton. System 1992, 1993.
Hutchinson, R., Brown, R., Leonard, B., Kennedy, C., 1993. Effects of tillage systems and winter cover crops on yield and maturity of cotton on a loess soil in northeast Louisiana, Proceedings of the 1993 Southern Conservation Tillage Conference for Sustainable Agriculture, Monroe, LA, pp. 85-91.

Joyce, B., Wallender, W., Mitchell, J., Huyck, L., Temple, S., Brostrom, P., Hsiao, T., 2002. Infiltration and soil water storage under winter cover cropping in California's Sacramento Valley. Transactions of the ASAE 45, 315.

Kahimba, F., Ranjan, R.S., Froese, J., Entz, M., Nason, R., 2008. Cover crop effects on infiltration, soil temperature, and soil moisture distribution in the Canadian Prairies. Applied Engineering in Agriculture 24, 321-333.

Kahlon, M.S., Lal, R., Ann-Varughese, M., 2013. Twenty-two years of tillage and mulching impacts on soil physical characteristics and carbon sequestration in Central Ohio. Soil and Tillage Research 126, 151-158.

Kaspar, T., Radke, J., Laflen, J., 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. Journal of Soil and Water Conservation 56, 160-164.

Kastanek, F.J., Nielsen, D.R., 2001. Description of soil water characteristics using cubic spline interpolation. Soil Science Society of America Journal 65, 279-283.

Keisling, T., Scott, H., Waddle, B., Williams, W., Frans, R., 1994. Winter cover crops influence on cotton yield and selected soil properties 1. Communications in Soil Science & Plant Analysis 25, 3087-3100.

Kemper, W., Rosenau, R., 1986. Aggregate stability and size distribution.

Kemper, W., Rosenau, R., Dexter, A., 1987. Cohesion development in disrupted soils as affected by clay and organic matter content and temperature. Soil Science Society of America Journal 51, 860-867.

Kemper, W.D., Koch, E.J., 1966. Aggregate stability of soils from western United States and Canada: measurement procedure, correlations with soil constituents. Agricultural Research Service, US Department of Agriculture.

Kutílek, M., Nielsen, D.R., 1994. Soil hydrology: texbook for students of soil science, agriculture, forestry, geoecology, hydrology, geomorphology and other related disciplines. Catena Verlag.

Lal, R., 1991. Soil structure and sustainability. Journal of Sustainable Agriculture 1, 67-92.

Lampurlanés, J., Cantero-Martinez, C., 2003. Soil bulk density and penetration resistance under different tillage and crop management systems and their relationship with barley root growth. Agronomy Journal 95, 526-536.

Larney, F.J., Lindwall, C.W., Bullock, M.S., 1994. Fallow management and overwinter effects on wind erodibility in southern Alberta. Soil Science Society of America Journal 58, 1788-1794.

Lipiec, J., Kuś, J., Słowińska-Jurkiewicz, A., Nosalewicz, A., 2006. Soil porosity and water infiltration as influenced by tillage methods. Soil and Tillage research 89, 210-220.

McCoy, B.J., Rolston, D.E., 1992. Convective transport of gases in moist porous media: Effect of absorption, adsorption, and diffusion in soil aggregates. Environmental Science & Technology 26, 2468-2476.

Mikha, M.M., Rice, C.W., 2004. Tillage and manure effects on soil and aggregate-associated carbon and nitrogen. Soil Science Society of America Journal 68, 809-816.

Mrabet, R., Saber, N., El-Brahli, A., Lahlou, S., Bessam, F., 2001. Total, particulate organic matter and structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. Soil and Tillage Research 57, 225-235.

Olness, A., Clapp, C., Liu, R., Palazzo, A.J., 1998. Biosolids and their effects on soil properties. Handbook of Soil Conditioners. Marcel Dekker, New York, NY, 141-165.

Osunbitan, J., Oyedele, D., Adekalu, K., 2005. Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. Soil and Tillage Research 82, 57-64.

Peoples, M., Bowman, A., Gault, R., Herridge, D., McCallum, M., McCormick, K., Norton, R., Rochester, I., Scammell, G., Schwenke, G., 2001. Factors regulating the contributions of fixed nitrogen by pasture and crop legumes to different farming systems of eastern Australia. Plant and Soil 228, 29-41.

Pettigrew, W.T., Jones, M.A., 2001. Cotton growth under no-till production in the lower Mississippi river valley alluvial flood plain. Agronomy Journal 93, 1398-1404.

Philip, J.R., 1957. The theory of infiltration: 4. Sorptivity and algebraic infiltration equations. Soil Science 84, 257-264.

Potter, K., Torbert, H., Morrison Jr, J., 1995. Tillage and residue effects on infiltration and sediment losses on vertisols. Transactions of the ASAE 38, 1413-1419.

Reeves, D., 1994. Cover crops and rotations. Advances in Soil Science: Crops Residue Management, 125-172.

Reynolds, W., Bowman, B., Drury, C., Tan, C., Lu, X., 2002a. Indicators of good soil physical quality: density and storage parameters. Geoderma 110, 131-146.

Reynolds, W., Drury, C., Yang, X., Tan, C., Yang, J., 2014. Impacts of 48 years of consistent cropping, fertilization and land management on the physical quality of a clay loam soil. Canadian Journal of Soil Science 94, 403-419.

Reynolds, W., Elrick, D., Youngs, E., Amoozegar, A., Booltink, H., Bouma, J., 2002b. 3.4 Saturated and field-saturated water flow parameters. Methods of Soil Analysis, Part 4, 797-801.

Rhoton, F., Bruce, R., Buehring, N., Elkins, G., Langdale, C., Tyler, D., 1993. Chemical and physical characteristics of four soil types under conventional and no-tillage systems. Soil and Tillage Research 28, 51-61.

Roseberg, R., McCoy, E., 1992. Tillage-and traffic-induced changes in macroporosity and macropore continuity: air permeability assessment. Soil Science Society of America Journal 56, 1261-1267.

Savoy, H., Joines, D., 2009. Lime and fertilizer recommendations for the various crops of Tennessee. Chapter II. Agronomic crops. BEES Info 100.

Shaver, T., Peterson, G., Ahuja, L., Westfall, D., Sherrod, L., Dunn, G., 2002. Surface soil physical properties after twelve years of dryland no-till management. Soil Science Society of America Journal 66, 1296-1303.

Shipitalo, M., Dick, W., Edwards, W., 2000. Conservation tillage and macropore factors that affect water movement and the fate of chemicals. Soil and Tillage Research 53, 167-183.

Singh, B., Malhi, S., 2006. Response of soil physical properties to tillage and residue management on two soils in a cool temperate environment. Soil and Tillage Research 85, 143-153.

Smettem, K., Rovira, A., Wace, S., Wilson, B., Simon, A., 1992. Effect of tillage and crop rotation on the surface stability and chemical properties of a red-brown earth (Alfisol) under wheat. Soil and Tillage Research 22, 27-40.

Stevens, W., Johnson, J., Varco, J., Parkman, J., 1992. Tillage and winter cover management effects on fruiting and yield of cotton. Journal of Production Agriculture 5, 570-575.

Strudley, M.W., Green, T.R., Ascough, J.C., 2008. Tillage effects on soil hydraulic properties in space and time: State of the science. Soil and Tillage Research 99, 4-48.

Suwardji, P., Eberbach, P., 1998. Seasonal changes of physical properties of an Oxic Paleustalf (Red

Kandosol) after 16 years of direct drilling or conventional cultivation. Soil and Tillage Research 49, 65-77.
Thomas, G., Haszler, G., Blevins, R., 1996. The effects of organic matter and tillage on maximum compactability of soils using the proctor test1. Soil Science 161, 502-508.
Tuller, M., Or, D., 2002. Unsaturated hydraulic conductivity of structured porous media. Vadose Zone Journal 1, 14-37.
Unger, P.W., Jones, O.R., 1998. Long-term tillage and cropping systems affect bulk density and penetration resistance of soil cropped to dryland wheat and grain sorghum. Soil and Tillage Research 45, 39-57.
Unger, P.W., Vigil, M.F., 1998. Cover crop effects on soil water relationships. Journal of Soil and Water Conservation 53, 200-207.
Uzun, O., Kaplan, S., Basaran, M., Deviren Saygın, S., Youssef, F., Nouri, A., Ozcan, A.U., Erpul, G., 2017. Spatial distribution of wind-driven sediment transport rate in a fallow plot in Central Anatolia, Turkey. Arid Land Research and Management 31, 125-139.
Van Genuchten, M.T., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Science Society of America Journal 44, 892-898.
Villamil, M., Bollero, G., Darmody, R., Simmons, F., Bullock, D., 2006. No-till corn/soybean systems including winter cover crops. Soil Science Society of America Journal 70, 1936-1944.
Wander, M., Bollero, G., 1999. Soil quality assessment of tillage impacts in Illinois. Soil Science Society of America Journal 63, 961-971.
Wang, Y., Shao, M., 2013. Spatial variability of soil physical properties in a region of the Loess Plateau of PR China subject to wind and water erosion. Land Degradation & Development 24, 296-304.
Youker, R., McGuinness, J., 1957. A short method of obtaining mean weight-diameter values of aggregate analyses of soils. Soil Science 83, 291-294.

CHAPTER II
EFFECT OF LONG-TERM CROP ROTATION UNDER NO-TILLAGE ON SOIL HYDRO-PHYSICAL PROPERTIES, YIELD AND YIELD STABILITY

2.1 ABSTRACT

The effect of cropping system and tillage management on soil quality is best acquired when managements have been stablished for a reasonably long period of time and is most legitimate when it has been related to yield. Accordingly, (i) soil hydro-physical properties of a 15-year, non-tilled Loring silt loam under winter fallow was assessed among six crop management of corn (C) (Zea mays L.), cotton (T) (Gossypium hirsutum L.) and soybean (S) [Glycine max (L.) Merr.], (ii) yield stabilities of three crops in weather perturbations were evaluated and (iii) measured soil hydro-physical properties under each management was related to the mean yield production of corresponding crop. Among all cropping systems, corn incorporated cropping systems, especially CC (continuous corn) and CS (corn-soybean), resulted in greater wet aggregate stability, soil water content, cumulative infiltration, geometric mean diameter, mean weight diameter and plant available water content mainly at 15 cm of surface layer. Corn included managements also exhibited the greatest yield stability in weather perturbation. Corn rotated with soybean (CS) increased mean yield production and yield stability of both corn and soybean. Rotating corn with cotton (TC) resulted in greatest mean cotton yield and yield stability and intermediate soil physical condition among cotton cropping systems. TC also increased the yield stability of corn but produced lower corn yield than CS. Although total porosity at each depth did not vary significantly among cropping managements, pore size distribution and in particular water "transmission and drainage" pore volume was considerably affected by crop types in the rotation. On the other hand, matrix porosity and plant available water content were found to be significantly limited by increased bulk density through the entire measurement depth. Results indicate that under sub-humid mid-south US climatic condition, inclusion of corn with greater potential of residue production and more resistant structure of residue in rotation with soybean and cotton improves the soil physical quality and consequently the mean cotton and soybean yield production and stability.

2.2 INTRODUCTION

Long-term field experiments are known to be the most effective approach revealing the true effect of cropping system and tillage management on soil quality, environmental sustainability and crop yield (Verhulst et al., 2011; Reynolds et al., 2014). Understanding the long-term impact of no-tillage (NT) cropping systems on soil physical quality is of particular interest in Tennessee where almost 80% of soybean, 70% of corn and 65% of cotton is no-till seeded (NASS, 2012). No-tillage improves soil hydro-physical quality (Blanco-Canqui et al., 2004), by reducing the aggregate disintegration and preserving the soil organic carbon (SOC) (Thomas et al., 2007, Uzun et al., 2017). The direction and rate of changes under NT, however, has been shown to be significantly affected by antecedent soil condition (i.e., soil texture, drainage), climate and cropping system (Liang et al., 1998; Rhoton, 2000; Hazarika et al., 2009). These factors dictate the time required for the agroecosystem to reach the equilibrium state.

Crop rotation with increased and more diverse above and below ground residue has been shown to increase the NT potential to further improve the soil physical quality. Accelerated rate of C-sequestration and increased biological activities associated with crop rotation is directly related to the aggregate stability, water retention capacity and water transmission (Reeves, 1994; Drinkwater et al., 1998; Franzluebbers, 2005). Management-induced additional SOC build up has also been reported to alleviate some detrimental effects on NT such as the excessive soil surface compaction (Blanco-Canqui and Lal, 2004). Cropping systems with diverse plant species, varying in biochemical characteristics have different effects on soil properties and SOC sequestration (Martens, 2000). The C/N ratio of the plant tissue is a crucial factor determining the N availability and decomposition rate of plant residue which should be considered in climate-specific strategies of cropping systems. For example, soybean residue tends to decompose much faster than those of corn in humid and mild months between the harvest and planting in mid-south US. Corn on the other hand, produces the highest quantity of residue among the annual crops (Huggins et al., 2007) over 1.5 times greater than those of legumes (Buyanovsky and Wagner, 1986).

Incorporation of crops with different rooting patterns and plant-specific managements (e.g. row spacing) may also change the soil condition differently due to the contrasting effects on soil structure and the rate of residue input (Benjamin et al., 2010). No-till has been shown to increase the cropping system's potential to improve soil quality since planting species with low C/N ratios on plowed farm can lead to the oxidative loss of the pre-existing SOC (Sisti et al, 2004). NT has been shown to minimize this effect and it can be the reason why management-induced variations in SOC and SOC-related soil properties are higher under conventional tillage than under NT (Wright and Hons, 2004). After 30 years of crop rotation management on a Canadian silt loam, Munkholm et al. (2013) concluded that the cropping diversification had a greater positive effect on soil physical quality when planted on no-tillage than on conventional tillage. There are many studies in the literature regarding the effect of crop rotation and tillage management on soil hydro-physical properties, the results however have generally been reported as mean values across tillage and cropping systems which makes it arduous to retrieve the effect of crop rotation on soil quality under a specific tillage management.

Crop rotation under NT in interaction with crop, soil, climate and length of study has been shown to change the soil hydro-physical properties differently (Paustian et al., 1997; Haynes, 2000). In a study conducted on a silt loam in western Illinois, Zuber et al. (2015) reported a greater wet aggregate stability under continuous corn compared to corn (*Zea mays L.*) /soybean (*Glycine max (L.) Merr.*) /wheat (*Triticum aestivum L.*), corn/soybean and continuous soybean cropping systems. Similarly, on a 28 year NT on a Wooster silt loam Lal et al. (1994) reported that continuous corn had 10% lower bulk density and 83% higher SOC and better aggregation than corn/soybean rotation. Conversely, on a clay loam soil in central Mexico, 14 years of corn/wheat rotation under NT increased the soil water content and bulk density and reduced wet aggregate stability compared to the continuous corn and wheat (Fuentes et al., 2009). Likewise, in a corn-based cropping system on a silt loam, Parihar et al. (2016) reported that increasing the corn frequency on NT management decreased the SOC and aggregate stability significantly at 0-15 cm. Nonetheless, there are several cases that soil physical properties even on long-term NT may remain nonresponsive to cropping management (Filho et al., 2002).

Cropping system affects not only the yield production but also influences the potential of the soil environment to retain the crop yield in climatic perturbations thereby reducing the economic losses (Gaudin et al., 2015). Munkholm et al. (2013) found a meaningful correlation between the rotation-induced changes in soil quality and corn yield. They reported that corn rotated with soybean increased the corn yield by 10-23% relative to the continuous corn. Furthermore, Pedersen and Lauer (2002) reported that on a NT silt loam, corn/soybean rotation increased the corn yield by 12% compared to continuous corn. Corn rotated with cotton also increased corn yield by 1-13% compared to continuous corn (Reddy et al., 2006). In contrast, after 8 years of cropping management on a silt loam soil, Hussain et al, (1999) did not observe any difference between corn yield under no-till continuous cropping and those rotated with soybean. This conflicting result may be due to the greater and immediate effect of tillage management than the cropping system on soil properties (Kumar et al., 2012).

In spite of increased acres of NT management throughout the US, there is limited information and conflicting reports regarding the independent effect of no-till cropping management, especially those incorporating cotton, on soil quality and crop yield (Blanco-Canqui et al., 2010). Our objective was to: (i) quantify the long-term impact of six double-crop managements of corn, cotton and soybean on soil hydro-physical properties. (ii) determine the effect of cropping system on yield and yield stability in weather anomalies. (iii) identify the soil hydro-physical properties governing the crop yield and yield stability of corn, cotton and soybean.

2.3 MATERIALS AND METHODS

2.3.1 SITE DESCRIPTION AND EXPERIMENTAL DESIGN

A long-term experiment was initiated in 2002 at the University of Tennessee, Research and Education Center at Milan, Tennessee (35.54° N, -88.44° W) on a Loring silt loam (Fine-silty, mixed, active, thermic Oxyaquic Fragiudalf, according to the USDA classification system) (Table 2.1). Mean annual precipitation at the experimental site is 107 cm and the mean annual temperature is 14.7°C. This experiment had been managed as a long-term no-tillage since 1986. All the cropping managements were double-crop permutations of corn (*Zea mays L.*), cotton (*Gossypium hirsutum L.*) and soybean [*Glycine max (L.) Merr*.] comprising six cropping systems on a winter fallow management. In April of each year, fallow weeds were terminated before sowing. Corn, cotton and soybean were planted between 12 April and 9 May, 7 and 12 May, and 29 April and 30 May, respectively, on sub-plots sizing 6.1 by 12.2 m each year. Corn and soybean were seeded on 76 cm row spacing while cotton rows were 102 cm apart resulting 8 rows in corn and soybean and six rows on cotton per plot. Nitrogen fertilizer were applied as sidedress at the rates of 128.5 kg N ha^{-1} on corn and 33.4 kg N ha^{-1} on cotton between May and June of each year. In April of each year, all treatments received 112 kg K ha^{-1} of muriate potash (KCl). Two center rows of corn, cotton and soybean plots were harvested within dates ranging between 29 August-27 September, 10 September-25 October, and 23 September-16 October respectively. A complete explanation of planting systems and maintenance methods can be found in Ashworth et al. (2014).

Table 2.1. Cropping managements and associated particle size distribution measured by hydrometer method (Gee and Or, 2002) in 2015.

Cropping system	Year		Particle size distribution (g kg^{-1})					
	Y1	Y2	Sand[a]	Silt[b]	Clay[c]	Sand[a]	Silt[b]	Clay[c]
			0-15 cm			15-30 cm		
TT	Cotton	Cotton	140±12	740±28	120±36	120±27	643±40	236±15
TC	Cotton	Corn	160±39	690±30	150±47	101±22	662±27	236±39
CC	Corn	Corn	130±33	680±16	190±24	121±18	651±48	228±64
CS	Corn	Soybean	150±10	690±44	160±48	130±43	724±62	146±105
SS	Soybean	Soybean	120±16	790±24	90±38	117±20	687±30	197±48
ST	Soybean	Cotton	110±10	710±32	180±37	139±37	709±21	152±53

[a] 50–2000 μm (g kg^{-1}), [b] 2–50 μm (g kg^{-1}), [c] <2 μm (g kg^{-1})
± represents the standard deviation of three replicates

2.3.2 SOIL SAMPLING

Soil samples were collected for dry bulk density (ρ_b), total porosity (ϕ), and gravimetric water content (θ_m) in May 2015 and 2016 at near field capacity (FC) moisture content before planting. Intact soil cores were collected using stainless steel cores with volume of 147 cm^3 using a hammer-driven core sampler. Sampling performed at two soil depths (0-15cm and 15-30 cm) and with three replicates for each cropping system. Thereafter, soil samples were emptied into metal containers and were capped to avoid moisture losses. For assessing the management-based temporal dynamics in θ_m throughout the growing season, additional samplings were also conducted at the same depths. Herein, using a 2.5 cm diameter soil probe, three samples were collected randomly from the inner area of each plot, about one meter apart from the plot boundaries and were bulked per management into a composite sample. For soil water retention characteristics (SWRC) analysis, in May 2016 intact cores were collected in two replicates for each cropping management at four equal depth increments between 0 to 30 cm soil profile. Soil sampling for wet aggregate stability (WAS) analysis was conducted using a flat, square-cornered spade in early June, 2015 and early May, 2016 when the soil was slightly drier than θ_{FC}. Thus, clods could be collected from 0-15 cm and 15-30 cm soil depths and broken apart manually to obtain the maximum of natural aggregates (Le Bissonnais, 1996). For dry aggregate size distribution (DASD) however, relatively dry samples were collected to minimize the aggregate susceptibility to disturbance (Nimmo and Perkins, 2003). DASD samples were also collected in 2016 at 0-15 cm and 15-30 cm soil depths using a spade and were located in rigid containers to avoid the disruption of aggregates while handling.

2.3.3 DRY BULK DENSITY, CONE PENETRATION RESISTANCE AND SOIL WATER CONTENT

Dry bulk density was determined following the standard procedure explained for the core method by Grossman and Reinsch (2002). Total porosity was calculated as one minus the solid volume fraction of samples defined as the ratio of ρ_b to the particle density (ρ_p) which was assumed to be 2.65 g cm^{-3}. Soil moisture content of intact cores collected for ρ_b measurements was measured gravimetrically at the beginning of the growing season. Furthermore, θ_m was measured multiple times at each crop rotation management throughout the growing season in different time steps after the latest rainfall. Using ρ_b data, θ_m values were eventually converted to volumetric water content (θ_v). Cone penetration resistance (PR) was measured in both experimental years using a hand-held digital cone-tipped penetrometer with a cone angle of 30° and 1 cm^2 area (Field Scout, SC 900 Soil compaction Meter; Spectrum Technologies, Inc., Plainfield, IL, USA). Four measurements per treatment/replicate were recorded on a line transect down to 30 cm with 2.5 cm depth increments.

2.3.4 SOIL AGGREGATION MEASUREMENTS

Soil aggregation was characterized by wet aggregate stability (WAS) and dry aggregate size distribution (DASD). Wet aggregate stability was determined using (08.13, Eijkelkamp Agrisearch Equipment, Giesbeek, the Netherlands) wet sieving apparatus. 4 gr of air-dried soil samples previously fractioned between 1 and 2 mm, was evenly spread on a 0.26 mm sieve and allowed for slow capillary wetting from the bottom by placing on a relatively wet piece of cloth. Sieve containing aggregates then placed on sieve holder and oscillated in distilled water for 3 minutes at the rate of 35 times per minute (Kemper and Rosenau, 1986). Afterwards, unstable fraction was collected, over-dried and weighted. Stable fraction retained on sieve was lowered and raised again in distilled water containing 2 g L^{-1} of Sodium Hydroxide dispersant agent to separate the sand fraction. Sand-free, stable fraction was also oven dried and weighted. Then, using the following relationship, the stable fraction of aggregates was calculated:

$$\text{WAS\%}=\frac{\text{Remained on sieve-Sand}}{\text{Total sample-Sand}}\times 100 \qquad (2.1)$$

Dry aggregate size distribution was determined by placing 100 g of air-dried soil samples previously passed through 8 mm sieve on the top of a sieve column including seven sieves with openings of 4.75, 2, 1, 0.85, 0.5, 0.25 and 0.05 mm and shaking by a vertical sieve apparatus (Catalogue no. 18480, CSC Scientific, Fairfax, VA) for 5 min with the amplitude of 0.1 mm. Afterwards, the oversize fraction retained on each sieve was collected and weighed. Geometric mean diameter (GMD) was calculated according to the procedure explained by Larney et al. (1994) and Mean weight diameter (MWD) was calculated using the following equation (Youker and McGuinness. 1957).

$$\text{MWD}=\sum_{i=1}^{n}\overline{\overline{X}}_i\, W_i \qquad (2.2)$$

Where X_i is the mean diameter (mm) of size class and W_i, is the fraction retained on each sieve.

2.3.5 WATER INFILTRATION AND FIELD-SATURATED HYDRAULIC CONDUCTIVITY

The differences in water infiltration and transmission characteristics among six cropping systems were measured in June and July 2015 and 2016 using double ring infiltrometer (IN7-W - Turf-Tec international, Tallahassee, FL) (Reynolds et al., 2002). Infiltrometer had two concentric outer and inner rings with diameters of 305 mm and 153 mm respectively. The height of the infiltrometer was 102 mm. Measurements were attempted to be conducted at near FC moisture content by inserting the infiltrometer into nearly 4 cm of soil depth and maintaining approximately 5 cm of constant water head at both rings. Infiltration rate was recorded in inner ring at specified time intervals up to 200 min or until the quasi-steady-state of infiltration was attained. Experimental infiltration data were fitted to Green and Ampt (1911), and Philip (1957) models using the least square method. Philip model is simple to use and provides a clear description of sorptivity (S, $LT^{-0.5}$) and the empirical transmissivity (A, LT^{-1}) constant which is associated with the saturated hydraulic conductivity.

$$i=\frac{1}{2}St^{-0.5}+A \tag{2.3}$$

$$I=St^{0.5}+At \tag{2.4}$$

Where I (mm) is the cumulative infiltration, i is the infiltration rate (LT^{-1}), and t is the time elapsed (T).

The field-saturated one-dimensional hydraulic conductivity (K_{fs}) (LT^{-1}) was measured using the approach explained by Reynolds et al, (2002) for double ring infiltrometer.

$$K_{fs}=\frac{q_s}{\left[\frac{H}{C_1d+C_2a}\right]+\left\{\frac{1}{[\alpha^*(C_1d+C_2a)]}\right\}+1} \tag{2.5}$$

Where, qs (LT^{-1}) is quasi-steady infiltration rate, (L) is the ring radius, d (L) is the depth of ring insertion into the soil, H (L) is depth of ponded water, $C_1=0.316\pi$ and $C_2=0.184\pi$ are quasi-empirical constants. α^* (L^{-1}) is the soil macroscopic capillary length which was assumed here to be 0.012 mm h^{-1} according to the textural and structural characteristics of the study soil.

2.3.6 *WATER RETENTION CHARACTERISTICS AND PORE SIZE DISTRIBUTION*

Intact core samples collected in 2016 at 0-7.5, 7.5-15, 15-22.5 and 22.5-30 cm soil depths with 2 replicates per treatment and depth, were examined for SWRC analysis. First, samples were saturated slowly by capillary rise and then subjected to the matric potentials (ψ): 0, -1, -3, -10 kPa on a tension table and -33, -100, -300, -500 and -1200 kPa in pressure plate extractors (Soil Moisture Equipment Corp., Santa Barbara, CA) as described by Dirksen (1998). ρ_b and ϕ were obtained by oven-drying the equilibrated soil samples at 105°C for 48 h. θ_v at each matric potential was calculated as the product of ρ_b and θ_m. Experimental data were fitted to the van Genuchten (VG) equation (van Genuchten, 1980) to obtain the VG parameters:

$$\theta=\theta_r+\frac{\theta_s-\theta_r}{[1+(\alpha.h)^n]^{(1-\frac{1}{n})}} \tag{2.6}$$

Where θ_s and θ_r are the saturated and residual water content respectively ($m^3\ m^{-3}$), *h* is the tension head, α is a fitting parameter associated with the inverse of air entry potential and *n* and $m=(1-1/n)$ are shape parameters.

Since the θ_v changes beyond the - ψ=1200k Pa pressure head were not significant, the plant available water content (PAWC: $m^3\ m^{-3}$) was calculated as the difference in θ_v retained in soil at field capacity (ΨFC: -33kPa) and (Ψ=-1200kPa) corresponding to permanent wilting point (PWP). State of management based soil aeration was quantified by air capacity (AC: $cm^3\ cm^{-3}$) index which is defined as the difference between θs and θ_{FC}. In root zone of medium to fine-textured soils, AC>0.12 to 0.17 $m^3\ m^{-3}$ has been proposed to be appropriate for the maximum crop yield (Drewry and Paton, 2005; Drewry et al., 2008). Relative field capacity (RFC) is another index that shows if the functioning of a particular soil is more limited by “aeration-limited” or “water-limited” conditions (Olness et al, 1998; Reynolds et al., 2014). RFC is expressed as the ratio of FC moisture content to the total porosity.

$$RFC=\left(\frac{\theta_{FC}}{\phi}\right)=\left[1-\left(\frac{AC}{\phi}\right)\right] \tag{2.7}$$

The proposed optimal range for RFC is 0.6≤RFC≤0.7 (Skopp et al, 1990; Reynolds et al, 2002). RFC<0.6 results in "droughty" condition which leads to reduction in microbial activity and consequently nitrate availability while RFC>0.7 may result in decreased microbial activity due to the aeration deficiency (Reynolds et al., 2008).

To obtain the pore size distribution (PSD) from the soil water retention data, θ(ψ) was first transformed into the relative saturation (S(ψ): $cm^3\ cm^{-3}$), according to the equation:

$$S(\psi) = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{2.8}$$

A cubic spline function with a natural end condition was fitted to the experimentally obtained S vs lnψ resulting in a smooth curve (Kutilek et al., 2006). Then lnψ values were converted to pore radii (r) following the relation r=1490/ψ, with ψ and r given in μm and cm respectively. Finally, the derivative curve of dS(ln(ψ)/dln(ψ) (Kutilek and Nielsen., 1994) was calculated and plotted as the pore size distribution. The minimum point between two major peaks on the generally tri-modal PSD curve was taken as the boundary between the structural and matrix porosity and the volume of each domain was calculated accordingly (Kutilek et al., 2006).

2.3.7 YIELD ANALYSIS

Yield analysis was performed on data collected from 2002 to 2016 by grouping the six cropping managements under corn, cotton and soybean crops. Yield production of each crop was studied in three cropping managements, one monoculture and two double-crop rotations. Fluctuations in yield as influenced by weather perturbations (Fig. 2.1) dissemble the effect of cropping system and soil quality on yield. To minimize the effect of weather, and to reduce the variance of the yield across the years, weather parameters including the average and cumulative precipitation, maximum, average and minimum temperature through the growing season (April to September inclusively) of 13 years of study period were clustered into 14 single, double and triple month/s and seasonal groups. Thereafter, yield data were related to each climatic cluster separately using canonical correlation. Covariate analysis was performed to adjust the yield to the covariates of climatic factors in cluster with greatest overall positive correlation with precipitation and greatest negative correlation with temperature parameters. Adjusted yield data averaged from 2010 to 2016 (assuming the maximum agroecosystem equilibrium) were related to the soil hydro-physical properties through multiple regression analysis. Due to the excessive drought and crop failure in 2012, the yield data associated with this year was excluded from the analysis.

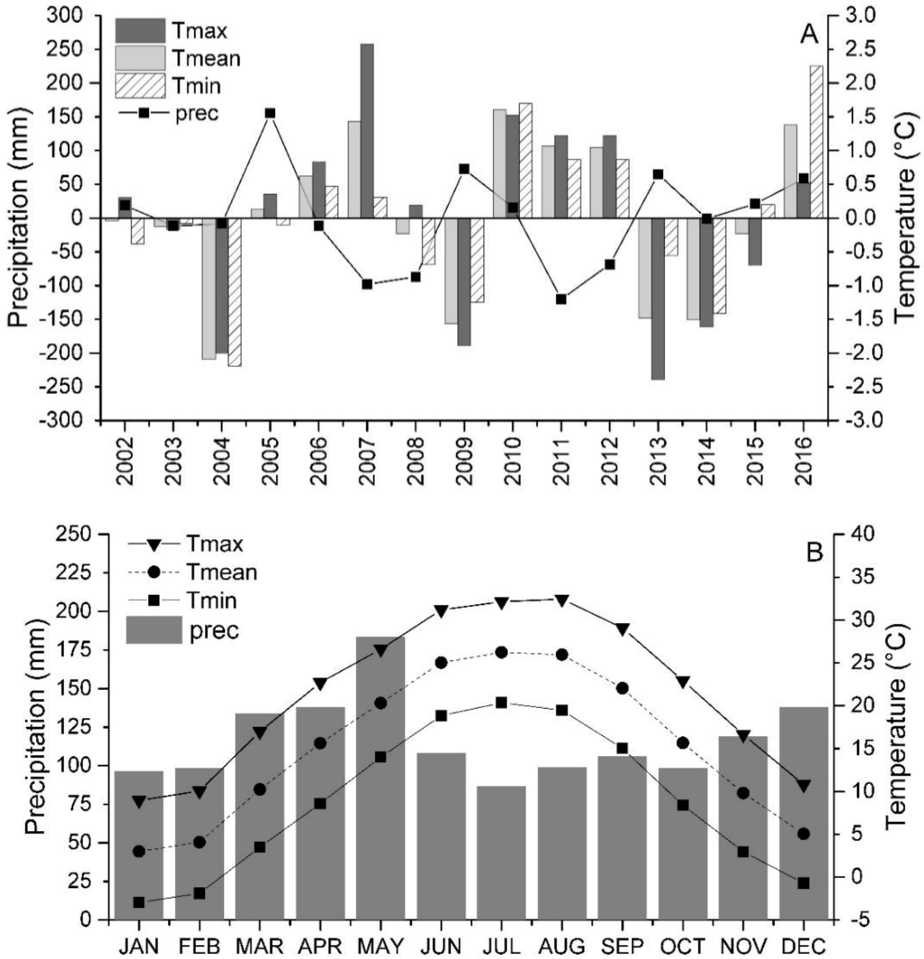

Figure 2.1. Deviation of cumulative precipitation (prec), maximum (Tmax), mean (Tmean) and minimum (Tmin) air temperature from the corresponding mean values, recorded at the experimental site through the course of study in July and August of each year (A) and monthly averaged precipitation and air temperature across the study period (B).

2.3.8 DATA ANALYSIS AND MODEL DEVELOPMENT

The experiment was a randomized complete block design (RCBD) with three replicates. Mixed ANOVA (SAS V9.3; SAS Inst., Cary, NC) was used to compare six cropping managements and orthogonal contrasts were run to compare the pair-wise means as affected by crop types, as well as the monoculture versus crop rotation. For the 2-yr soil hydro-physical properties in each sampling depth, cropping management was considered fixed effect and replicates were considered as random effect. Significance of sampling depth was assessed separately considering it as sub-plot fixed effect. Variable selection procedure was run to obtain the effect of soil hydro-physical properties on adjusted corn, cotton and soybean yield between 2010 to 2016. Variables were selected based on the Mallow's cp, AIC (Akaike information criterion) and coefficient of determination. Model fittings for soil hydro-physical properties were conducted in SAS. MATLAB (MathWorks Inc., Natick, MA) was used for PSD analysis. All statistical procedures were conducted using "DandA.sas" macro (http://dawg.utk.edu).

2.4 RESULTS

2.4.1 DRY BULK DENSITY, CONE PENETRATION RESISTANCE AND SOIL WATER CONTENT

Cropping system did not affect the bulk density significantly at any sampling depth of any year (Tables 2.2 & 2.3). Orthogonal contrast also revealed no significant clue of ρ_b alterations due to the inclusion of any specific crop in management. The smallest and the greatest values of ρ_b were observed in CS and TT, respectively, which differed by 3.5% in 2015. Despite the generally greater ρ_b in deeper soil profile, the depth differences were also not significant in any year. In-situ volumetric water content measured 2-3 days after the latest rainfall (near-FC moisture content) did not significantly vary among cropping systems ($p>0.05$) (Tables 2.2 & 2.3). Corn either as continuous cropping or in rotation with cotton and soybean resulted in lower moisture content at higher field matric potential in both years compared with the other managements. Conversely, soil moisture content at 0-15 cm in drier periods was greater under CS, CC and ST in both years. Cropping in sequence also resulted in higher moisture content at surface depth in drier periods compared with the monoculture systems ($p < 0.01$ in 2015). Cone penetration resistance averaged across sampling depths did not vary significantly ($p>0.05$) among cropping managements in any year and depth. However, PR was significantly higher at 15-30 in both years.

2.4.2 SOIL AGGREGATION PARAMETERS

At 0-15 cm soil depth, water stable fraction of aggregates varied significantly ($p<0.05$) among the cropping systems in both years (Tables 2.2 & 2.3). CC and CS resulted in the greatest WAS, while in both years while TC and SS in 2015 and TC and TT in 2016 displayed the lowest values. Cropping managements with corn, showed 5.8% and 5.2% ($p<0.05$) higher WAS compared to the ones without corn whereas managements with cotton decreased the WAS by 6.4% and 6.2% ($p<0.05$) compared with corn and soybean managements in 2015 and 2016 respectively. At 15-30 cm soil depth, results on WAS were non-significant and highly inconsistent. Dry aggregate size distribution revealed a significant difference in GMD and MWD among the cropping systems at both sampling depths (Table 2.4).

GMD and MWD of CC and CS were significantly higher than ST and SS at the first depth while TC and ST resulted in the lowest values at the second depth. The greatest fraction of macroaggregates (> 2 mm) were observed under CC and CS at both depths while a highest fraction of microaggregates (0.053-0.25 mm) was observed in ST and SS at the both depths.

2.4.3 WATER INFILTRATION AND FIELD-SATURATED HYDRAULIC CONDUCTIVITY

Initial infiltration rate differed significantly among cropping systems in 2016 (Table 2.5). CS in both years showed highest i_i among cropping systems while lowest values were observed in TT. However, the i_i differences were only significant at 2016. Inclusion of soybean increased initial infiltration rate significantly ($p<0.05$) in both years while cotton considerably reduced i_i compared to managements without cotton in both years. TT and TC in both years resulted in the lowest cumulative and steady state infiltration while the highest values were associated with CS management. K_{fs} varied significantly among treatments in both years. Similar to the other hydraulic parameters, CS demonstrated the greatest K_{fs} while TT and TC had the lowest values. S parameter did not vary significantly among managements in either year and differences in transmissivity was only significant in 2016 (Table 2.5).

2.4.4 SOIL WATER RETENTION CHARACTERISTICS

Field capacity moisture content was significantly ($p = 0.01$) affected by cropping management at 0-15 cm soil depth (Table 2.6). CS and CC managements resulted in significantly higher θ_{FC} compared with TT, TC and ST. Corn managements had significantly ($p<0.05$) higher θ_{FC} compared with other managements while cotton reduced the θ_{FC} significantly ($p<0.01$) relative to

Table 2.2. Wet aggregate stability (WAS), bulk density (ρb), moisture content at near-FC field moisture (θ_{va}), moisture content at lower field matric potential (θ_{vb}), cone penetration resistance (PR) and total porosity (ϕ) measured in 2015 in two sampling depths.

	0-15 cm soil depth						15-30 cm soil depth					
Cropping system	WAS (%)	ρb (Mg m^{-3})	θ_{va} (cm^3 cm^{-3})	θ_{vb} (cm^3 cm^{-3})	PR (Mpa)	ϕ (%)	WAS (%)	ρb (Mg m^{-3})	θ_{va} (cm^3 cm^{-3})	θ_{vb} (cm^3 cm^{-3})	PR (Mpa)	ϕ (%)
TT	41 c	1.54 a	30.2 a	17.9 c	1.9 a	42 a	43.4 a	1.54 a	29.5 a	24 a	2.34 a	41.9 a
TC	39.8 c	1.51 a	32.2 a	20.1 c	1.84 a	42.9 a	31.8 a	1.55 a	32.2 a	28 a	2.65 a	41.5 a
CC	52.3 a	1.52 a	28.1 a	23.6 b	1.45 a	42.6 a	29.3 a	1.55 a	33.7 a	20.4 a	2.38 a	41.5 a
CS	49.1 ab	1.49 a	30.1 a	26.9 a	1.56 a	43.8 a	30.8 a	1.49 a	30.8 a	25.1a	2.36 a	43.8 a
SS	40.8 c	1.52 a	33.1 a	20.4 c	1.68 a	42.6 a	37.8 a	1.52 a	34.0 a	28 a	2.52 a	42.6 a
ST	42.2 bc	1.52 a	33.2 a	24.2 ab	1.74 a	42.6 a	28.6 a	1.56 a	32.8 a	22.1a	2.58 a	41.2 a
ANOVA ($p \leq 0.05$)												
Rotation	0.012	0.6001	0.0781	0.0004	0.3782	0.6002	0.2106	0.6481	0.9017	0.753	0.4849	0.6481
Contrasts												
Sequence vs Monoculture	-1	-0.020	1.36	3.06**	0.04	0.67	-6.4	0.000	-0.48	0.92	0.11	0.04
Corn vs Others	5.8*	-0.020	-2.01*	2.71**	-0.15	0.59	-6.0	-0.010	0.12	-0.22	-0.02	0.3
Cotton vs Others	-6.4*	0.010	1.51	-2.94**	0.26*	-0.5	2.0	0.030	-1.32	0.21	0.1	-1.15
Soybean vs Others	-0.4	0.020	1.86	3.29**	-0.07	0.59	-2.4	-0.020	0.73	0.93	0.03	0.9
Corn vs Soybean	4.6	0.000	-2.9*	-0.44	-0.06	0	-2.7	0.010	-0.46	-0.86	-0.04	-0.45
Corn vs Cotton	9.1**	-0.020	-2.64*	4.24**	-0.31*	0.82	-6.0	-0.030	1.08	-0.32	-0.09	1.09
Cotton vs Soybean	-4.5	0.020	-0.26	-4.68**	0.25	-0.82	3.3	0.040	-1.54	-0.54	0.06	-1.54
Depth							<.0001	0.1925	0.2045	0.0542	<.0001	0.1926

§ Means followed by different letters are significantly different based on the protected LSD ($p < 0.05$) within cropping systems.

*Means are significantly different at $p < 0.05$.

** Means are significantly different at $p < 0.01$.

† Minus sign represents the lower mean value of the first contrast group.

‡ Lack of minus sign represents the greater mean value of the first contrast group.

Table 2.3. Wet aggregate stability (WAS), bulk density (ρb), moisture content at near-FC field moisture (θ_{va}), moisture content at lower field matric potential (θ_{vb}), cone penetration resistance (PR) and total porosity (ϕ) measured in 2016 in two sampling depths.

	0-15 cm soil depth						15-30 cm soil depth					
Cropping system	WAS (%)	ρb (Mg m^{-3})	θ_{va} (cm^3 cm^{-3})	θ_{vb} (cm^3 cm^{-3})	PR (Mpa)	ϕ (cm^3 cm^{-3})	WAS (%)	ρb (Mg m^{-3})	θ_{va} (cm^3 cm^{-3})	θ_{vb} (cm^3 cm^{-3})	PR (Mpa)	ϕ (cm^3 cm^{-3})
TT	45.7 c§	1.53 a	37 a	20.4 a	1.00 a	42.3 a	46.7 a	1.54 a	35.2 a	24.8 a	1.15 a	42 a
TC	51.7 bc	1.53 a	36 a	20.1 a	0.98 a	42.2 a	50.9 a	1.54 a	36.0 a	25.4 a	1.34 a	42 a
CC	56.9 ab	1.51 a	36.4 a	24.8 a	0.80 a	42.8 a	55.5 a	1.52 a	32.7 a	24.6 a	1.34 a	42.5 a
CS	58.2 a	1.52 a	30.5 a	23.3 a	0.88 a	42.8 a	56.8 a	1.51 a	34.3 a	25.3 a	1.29 a	43 a
SS	53.3 ab	1.52 a	32.5 a	20.8 a	0.86 a	42.5 a	51.3 a	1.51 a	34.2 a	22.9 a	1.30 a	42.9 a
ST	52.3 ab	1.51 a	35.7 a	22.9 a	1.02 a	43.1 a	48.4 a	1.53 a	35.7 a	26.4 a	1.33 a	42.2 a
ANOVA (p≤ 0.05)												
Rotation	0.0148	0.23	0.2019	0.2574	0.6029	0.23	0.074	0.07	0.5919	0.8097	0.882	0.07
Contrasts												
Sequence vs Monoculture	2.1‡	0	-1.22	0.13	0.07	0.16	0.9	0	1.29	1.61	0.06	-0.09
Corn vs Others	5.2*	0	-0.7	1.39	-0.08	-0.06	5.6*	0	-0.7	0.42	0.06	0.1
Cotton vs Others	-6.2**†	0	3.08	-1.85	0.15	-0.12	-5.8*	0.02*	1.88	1.26	-0.03	-0.71**
Soybean vs Others	3.1	-0.01	-3.59*	0.59	-0.001	0.34	1.1	-0.01	0.11	-0.07	0.03	0.51
Corn vs Soybean	1.5	0.01	2.17	0.6	-0.06	-0.3	3.4	0.01	-0.61	0.37	0.02	-0.31
Corn vs Cotton	8.5**	0	-2.84	2.43	-0.17	0.05	8.6**	-0.02*	-1.94	-0.63	0.07	0.61*
Cotton vs Soybean	-7*	0.01	5.01*	-1.83	0.11	-0.35	-5.2*	0.02**	1.33	1	-0.05	-0.92**
Depth							0.29	0.27	0.001	0.01	<.0001	0.27

§ Means followed by different letters are significantly different based on protected LSD (p < 0.05) within cropping systems.
*Means are significantly different at p < 0.05.
** Means are significantly different at p < 0.01.
† Minus sign represents the lower mean value of the first contrast group.
‡ Lack of minus sign represents the greater mean value of the first contrast group.

Table 2.4. Geometric mean diameter (GMD), mean weight diameter (MWD), fraction of macroaggregates (MA > 2mm), small macroaggregates (0.25 > SMA < 2mm) and microaggregates (0.0.53 > MIA < 0.25) measured in two sampling depth in 2016.

Cropping system	0-15 cm soil depth				
	GMD	MWD	MA (%)	SMA (%)	MIA (%)
TT	2.0bc	2.9bc	54.8bc	39.1a	3.0a
TC	2.2bc	3.0bc	56.3abc	39.3a	2.8a
CC	2.9a	3.4a	63.4a	33.8a	1.8a
CS	2.5ab	3.2ab	58.4ab	36.4a	2.6a
SS	1.8c	2.8c	52.7bc	40.1a	4.1a
ST	1.7c	2.7c	50.0c	42.3a	4.6a
ANOVA (p≤ 0.05)					
Cropping system	0.008	0.02	0.04	0.26	0.17
Contrasts					
Sequence vs Monoculture	-0.09	-0.03	-2.03	1.63	0.31
Corn vs Others	0.70**	0.40**	6.87**	-4.02	-1.5*
Cotton vs Others	-0.43*	-0.24*	-4.45	3.49	0.59
Soybean vs Others	-0.36*	-0.19	-4.46	2.16	1.23
Corn vs Soybean	0.81**	0.44**	8.50**	-4.64	-2.05*
Corn vs Cotton	0.81**	0.48**	8.49**	-5.63*	-1.58
Cotton vs Soybean	-0.05	-0.03	0.01	0.99	-0.47
	15-30 cm soil depth				
TT	1.5abc§	2.5bc	45.7abc	43.7ab	5.9bc
TC	1.3c	2.3c	40.5bc	47.9a	7.4ab
CC	1.7ab	2.6ab	46.3ab	47.0a	4.0c
CS	1.8a	2.8a	49.3a	40.8b	6.7ab
SS	1.3bc	2.4bc	42.4bc	46.4a	7.4ab
ST	1.2c	2.2c	39.9c	47.2a	8.5a
ANOVA (p≤ 0.05)					
Cropping system	0.02	0.01	0.03	0.03	0.01
Contrasts					
Sequence vs Monoculture	-0.06†	-0.04	-1.64	-0.36	1.68**
Corn vs Others	0.25*‡	0.22*	2.73	-0.49	-1.27*
Cotton vs Others	-0.28*	-0.25**	-3.99*	1.56	1.23*
Soybean vs Others	-0.04	-0.02	-0.37	-1.43	1.71*
Corn vs Soybean	0.22	0.18	2.32	0.71	-2.24**
Corn vs Cotton	0.40**	0.35**	5.04*	-1.53	-1.87*
Cotton vs Soybean	-0.18	-0.17	-2.72	2.24	-0.36
Depth	<.0001	<.0001	<.0001	<.0001	<.0001

§ Means followed by different letters are significantly different based on the protected LSD ($p < 0.05$) within cropping systems.
*Means are significantly different at $p < 0.05$.
** Means are significantly different at $p < 0.01$.
† Minus sign represents the lower mean value of the first contrast group.
‡ Lack of minus sign represents the greater mean value of the first contrast group.

corn and soybean managements. Permanent wilting point however did not vary considerably among cropping managements in any depth. Differences in PAWC was only significant at surface depth ($p = 0.04$), with significantly higher values in CS compared with the other managements while the SS exhibited an intermediate value.

Differences in RFC and AC were not significant at any sampling depth. RFC of all managements was consistently greater than 0.7 which has often been denoted as the upper limit for this index. The greatest RFC value was associated with the CS at the surface depth while TC which showed the lowest value at the first depth revealed the highest RFC value at the second depth. Except for TC and SS, AC at the first depth were generally smaller than 0.11 cm3 cm-3 which has been mentioned as the lower limit of this index for appropriate aeration in medium and fine textured soils.

2.4.5 PORE SIZE DISTRIBUTION

PSD derived from SWRC demonstrated the hierarchical distribution of porous media with a distinction between the matrix and structural porosity. The separation ("minima point") between two domains occurred similarly among the depths, at the equivalent pore radius corresponding to 4.2-4.4 μm. Matrix domain exhibited a bi-modal structure which tended to diminish with increase in soil depth. Minima point separated two structural sub-domains at the pore radius of about 47 μm. All cropping managements demonstrated a bi-modal organization of structural domain at 0-7.5 cm while at 7.5-15 cm only one peak was observed in TT and CC managements. At 15-22.5 cm, bi-modality in structural domain was not observed in any of the management and finally at the lowest depth (22.5-30 cm), among six cropping systems only SS and ST displayed a bi-modal arrangement of the structural domain (Fig. 2.2). In matrix domain, uni-modal structure in PSD curve was pronounced in three of four depths. In depth three (15-22.5 cm), two matrix sub-domains were separated at minimum point corresponding to the pore radius of approximately 0.55 μm.

2.4.6 EFFECT OF CROPPING SYSTEM ON YIELD STABILITY IN WEATHER PERTURBATIONS

Corn, cotton and soybean yield were affected by variations in rainfall and air temperature through the growing seasons. Among the time clusterings, yield was positively correlated with cumulative rainfall and negatively correlated (minimum $\pm r > 0.5$) with the maximum and mean temperature in July and August of each year. Corn yield declined into the first quantile across the managements and years (< 8424 kg ha-1) in 2002, 2007, 2011 and 20016, all years have

Table 2.5. Soil hydraulic parameters including sorptivity (S), transmissivity (A), Initial infiltration rate (i_i), steady state infiltration rate (i_c), cumulative infiltration (I) and field-saturated hydraulic conductivity (K_{fs}) measured in growing season of 2015 and 2016.

	S (mm $h^{-0.5}$)	A (mm h^{-1})	i_i (mm h^{-1})	i_c (mm h^{-1})	I (mm)	K_{fs} (cm day^{-1})
Treatments			2015			
TT	164 a§	6.8 a	59 a	12.3 b	54 a	11.7 c
TC	168 a	12.4 a	65 a	16.8 ab	71 a	16 bc
CC	186 a	13 a	72 a	19 a	78 a	18.1 ab
CS	214 a	15.1 a	85 a	21.9 a	91 a	21 ab
SS	186 a	14.7 a	75 a	20.3 a	84 a	19.3 ab
ST	207 a	14.2 a	84 a	22 a	83 a	22.4 a
ANOVA ($p \leq 0.05$)						
Rotation	0.31	0.09	0.08	0.03	0.06	0.01
Contrasts						
Sequence vs Monoculture	17.7‡	2.4	9.3	3.04	9.7	3.4*
Corn vs Others	3.6	1.6	1.7	1.02	6.3	0.6
Cotton vs Others	-15.7†	-3.1	-8.5	-3.38*	-14.8*	-2.8
Soybean vs Others	29.9*	3.9*	16.1*	5.4**	18.2*	5.6**
Corn vs Soybean	-19.7	-1.7	-10.8	-3.28	-8.9	-3.8*
Corn vs Cotton	14.5	3.6	7.7	3.3	15.8*	2.5
Cotton vs Soybean	-34.2	-5.3*	-18.5*	-6.58**	-24.7**	-6.3**
Treatments			2016			
TT	188 a	13.4 bc	72 b	18.2 b	78 c	17.4 b
TC	213 a	8.9 c	76 b	16.2 b	70 c	15.5 b
CC	272 a	19.2 b	106 a	28.1 a	115 ab	27.9 a
CS	250 a	28.8 a	111 a	30.8 a	137 a	29.4 a
SS	269 a	18.5 b	109 a	28.8 a	108 b	27.5 a
ST	242 a	19 b	98 ab	26.3 a	109 b	25.1 a
ANOVA ($p \leq 0.05$)						
Rotation	0.23	0.01	0.03	0.0006	0.0035	0.0006
Contrasts						
Sequence vs Monoculture	-7.8	1.9	-0.8	-0.61	5.1	-0.6
Corn vs Others	12.1	2	4.7	0.63	9.3	0.6
Cotton vs Others	-49.6*	-8.4**	-26.4**	-9.01**	-34.7**	-8.6*
Soybean vs Others	29.7	8.3**	20.9*	7.75**	30.4**	7.4**
Corn vs Soybean	-13.2	-4.7	-12.1	-5.33*	-15.8	-5.1*
Corn vs Cotton	46.3	7.8*	23.4*	7.23**	33**	6.9**
Cotton vs Soybean	-59.5*	-12.5**	-35.5**	-12.57**	-48.9**	-12**

§ Means followed by different letters are significantly different based on the protected LSD ($p < 0.05$) within cropping systems.
*Means are significantly different at $p < 0.05$.
** Means are significantly different at $p < 0.01$.
† Minus sign represents the lower mean value of the first contrast group.
‡ Lack of minus sign represents the greater mean value of the first contrast group.

Table 2.6. Characteristics of the water retention curve measured in 2016. Parameters are: field capacity moisture content (FC), permanent wilting point (PWP), plant available water content (PAWC), relative field capacity (RFC, dimensionless) and air capacity (AC).

Treatment-Depth	0-15 cm soil depth					15-30 cm soil depth				
	FC	PWP	PAWC	RFC	AC	FC	PWP	PAWC	RFC	AC
Cropping system	(cm^3 cm^{-3})	(cm^3 cm^{-3})	(cm^3 cm^{-3})	Unitless	(cm^3 cm^{-3})	(cm^3 cm^{-3})	(cm^3 cm^{-3})	(cm^3 cm^{-3})	Unitless	(cm^3 cm^{-3})
TT	0.3c§	0.14a	0.16b	0.73abc	0.11abc	0.3a	0.13a	0.16a	0.75a	0.1a
TC	0.3c	0.14a	0.16b	0.71c	0.12a	0.29a	0.14a	0.15a	0.76a	0.09a
CC	0.32ab	0.15a	0.17b	0.75ab	0.10bc	0.30a	0.14a	0.15a	0.73a	0.11a
CS	0.33a	0.14a	0.19a	0.76a	0.10c	0.29a	0.15a	0.14a	0.72a	0.11a
SS	0.31bc	0.14a	0.17ab	0.72bc	0.12ab	0.29a	0.14a	0.15a	0.74a	0.1a
ST	0.3bc	0.15a	0.16b	0.73abc	0.11abc	0.28a	0.13a	0.15a	0.73a	0.1a
ANOVA (p≤ 0.05)										
Rotation	0.0123	0.3681	0.041	0.0705	0.1082	0.7378	0.2831	0.698	0.8777	0.8278
Contrasts										
Sequence vs Monoculture	0.005‡	0.003	0.003	0.002	0.001	-0.006	0	-0.007	0	-0.001
Corn vs Others	0.012*	0.003	0.009	0.015	-0.005	0.002	0.009	-0.007	0	0.001
Cotton vs Others	-0.017**†	0	-0.017**	-0.020*	0.006	-0.002	-0.008	0.007	0.014	-0.008
Soybean vs Others	0.010*	0	0.011*	0.006	0	-0.007	0	-0.006	-0.014	0.005
Corn vs Soybean	0.001	0.002	-0.001	0.006	-0.003	0.007	0.007	0	0.010	-0.003
Corn vs Cotton	0.022**	0.002	0.019**	0.026*	-0.008	0.003	0.013	-0.01	-0.011	0.007
Cotton vs Soybean	-0.020**	0	-0.021**	-0.020	0.004	0.004	-0.006	0.01	0.021	-0.01
Depth						<.0001	0.3115	0.0105	0.8543	0.0824

FC, field capacity moisture content; PWP, permanent wilting point; PAWC, plant available water content, RFC, relative field capacity; AC, air capacity.
§ Means followed by different letters are significantly different based on $p < 0.05$ within cropping systems.
*Means are significantly different at $p < 0.05$.
** Means are significantly different at $p < 0.01$.
† Minus sign represents the lower mean value of the first contrast group.
‡ Lack of minus sign represents the greater mean value of the first contrast group

been marked with dry and/or hot mid-growing season (Fig. 2.1). Except for 2002, both CS and TC went through lower corn yield losses in these years compared to CC (Fig. 2.3). Cotton yield was more affected by temperature extremes than those of precipitation.The greatest over mean and under mean maximum temperature occurred in 2007 and 2013 where ST and TT experienced the most serious yield penalties, dropping down into the first quartile (< 2068 kg ha-1). However, yield reduction was not significantly different between these two managements.Major soybean yield reductions occurred (< 2427 kg ha-1) due to the lowest recorded precipitation through the course of study and extraordinary high temperature in 2007 and 2011 and extremely low temperature in 2014. CS showed lower decline in yield compared to SS while ST yield in 2014 was not significantly different from SS.

2.4.7 MEAN YIELD PRODUCTION AS AFFECTED BY MANAGEMENT INDUCED SOIL PHYSICAL CONDITION

Based on variable selection procedure, variation in mean yield production among three crops was controlled by different soil hydro-physical properties. Corn and soybean yield declined mainly due to the lower clay content, θ_{FC}, PAWC, θ_{vb}, K_{fs}, GMD and wet aggregate stability at upper 15 cm of soil layer. Multiple regression analysis revealed an increased mean soybean yield by increase in PAWC and clay content (R^2 = 0.96). Likewise, greater volumetric water content during drier periods of growing season together with higher GMD values resulted in improved soybean productivity (R^2 = 0.65). On the other hand, 76% of variability in corn yield was explained by PAWC and GMD and up to 70% by K_{fs} and WAS. Nonetheless, reduction in cotton yield was mainly related to the limitations in soil aeration thereby explaining 84% of decline in cotton yield as influenced by increase in RFC and decrease in AC.

2.5 DISCUSSION

2.5.1 CROPPING MANAGEMENT AFFECTS THE SOIL HYDRO-PHYSICAL QUALITY

Bulk density did not differ significantly between 0-15cm (1.52 Mg m^{-3}) and 15-30cm (1.53 Mg m^{-3}). These values are not significantly different from the lower limit of critical range for this factor (1.50-160 Mg cm^{-3}) which may restrict appropriate root growth in medium textured soils (Daddow and Warrington. 1983). ρ_b is a soil property that is primarily altered through the mechanical manipulation

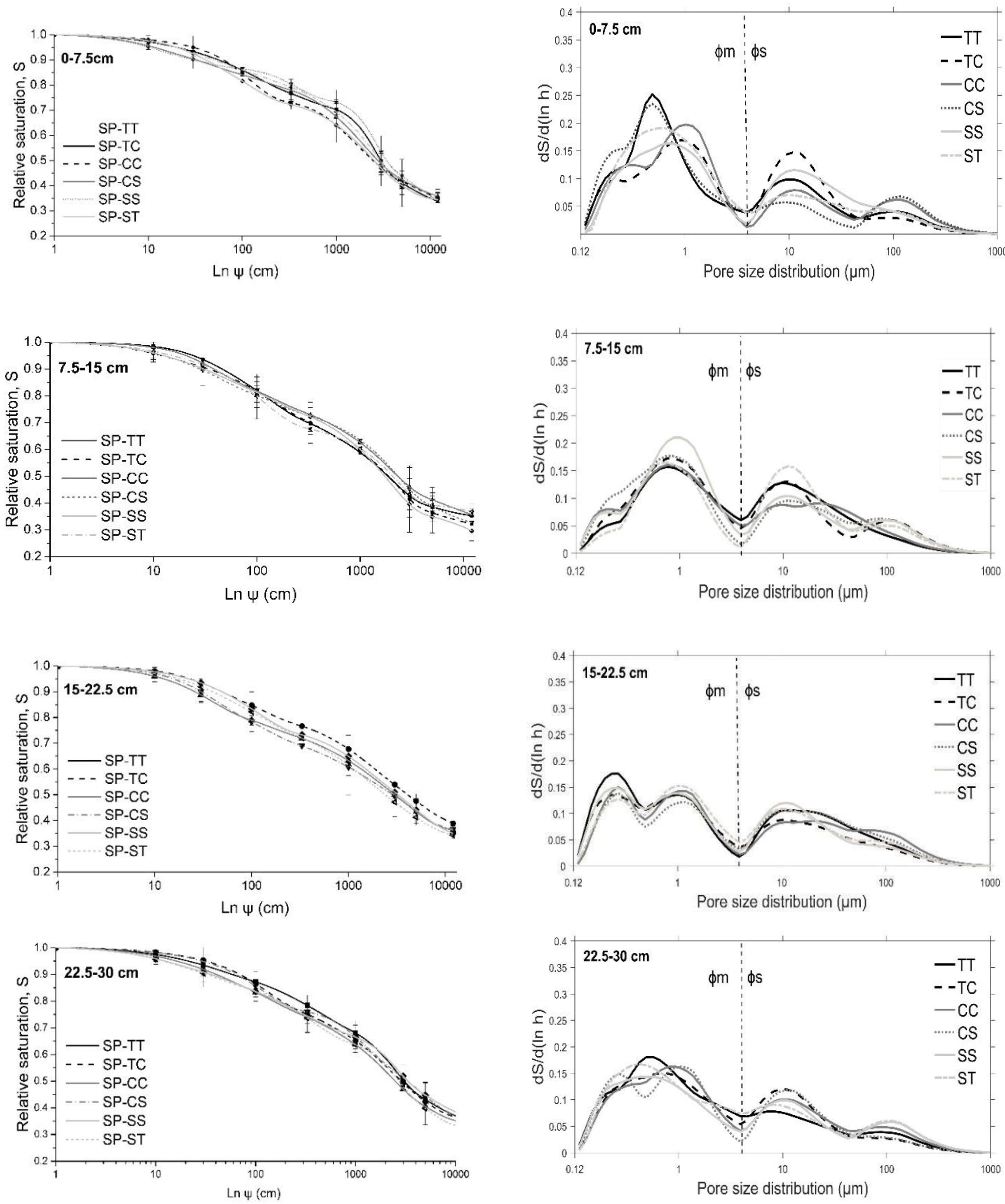

Figure 2.2. Soil water retention curve, represented as curves with fitted cubic spline function to the experimentally measured volumetric water content θv, versus pressure head (Ln ψ) (graphs on the left) and corresponding derivative curve, pore size distribution, versus equivalent pore radii (graphs on the right). Vertical dashed lines between two major peaks on PSD curve separate the structural domain (ϕ_s) from the matrix domain (ϕ_m) (Kutilek et al., 2006).

of soil. Thus, NT systems, in which the changes in soil compaction relies on biological amendments and residue accumulation, ρ_b may require an extended time to decrease. Despite the non-significant differences in ρ_b among cropping managements, cropping in rotation and corn managements at 0-15 cm had slightly lower ρ_b than monoculture managements and cotton managements respectively. Bulk density at 15-30 cm was significantly greater in cotton versus soybean management and cotton versus other managements. Lower rate of residue turnover due to the larger row spacing is probably the reason for poor performance of cotton included cropping managements to lower the bulk density. Additionally, large row spacing in cotton cropping system leads to reduced residue production.

Cone penetration resistance differed significantly in two experimental years due to the difference in soil moisture content at the measurement time. Approximately 30% reduction in volumetric water content (from 33 to 23 m^3 m^{-3}) averaged across 0-30 cm soil depth, resulted in 1 Mpa increase in mean PR value. Based on the SWRC, θ_v = 23.4 cm^3 cm^{-3} corresponds to the pressure head of almost -3000 cm-H_2O (average $\theta_v \approx$ 20 cm^{-3} cm^{-3}). Considering the average θ_{pwp}= 14 cm^3 cm^{-3}, the proper utilization of nearly 37% of plant available water might be restricted by excessive PR, particularly at 15-30 cm where the mean PR was above the upper optimal limit (2.47 Mpa) at mean θ_v = 23.4 cm^3 cm^{-3}. PR greater than 2 Mpa has frequently been reported as a threshold beyond which the root functioning and crop yield may substantially be restrained (Atwell, 1993; Carter, 2002). However, biological pores and cracks formed under long-term NT has been shown to be appropriate pathways for root extension (Ehlers et al., 1983).

Despite the non-significant effect of cropping systems on PR, CC and CS in 2015 and CC and SS in 2016 resulted in the lowest PR values at 0-15 cm. Inclusion of corn in cropping system lowered the PR value at both depths of two years although this effect was significant only at surface depth measured in 2015. Besides the considerably greater above ground residue turn over, fibrous and extensive corn root has also been reported with the soil loosening potential compared to the concentrated tap root system of cotton and soybean (Coulter et al., 2009) which can be related to the lower PR which was observed at both depths under corn incorporated cropping managements. Volumetric moisture content measured 2-3 days after rainfall (near FC moisture content) were variable among managements in two years. Orthogonal contrast shows that corn and cotton included managements with exception of second depth in 2015, had consistently lower and greater moisture content than other managements respectively. It can be related to lower water infiltration and transmission under cotton managements which may increase soil water content for a while after rainfall.

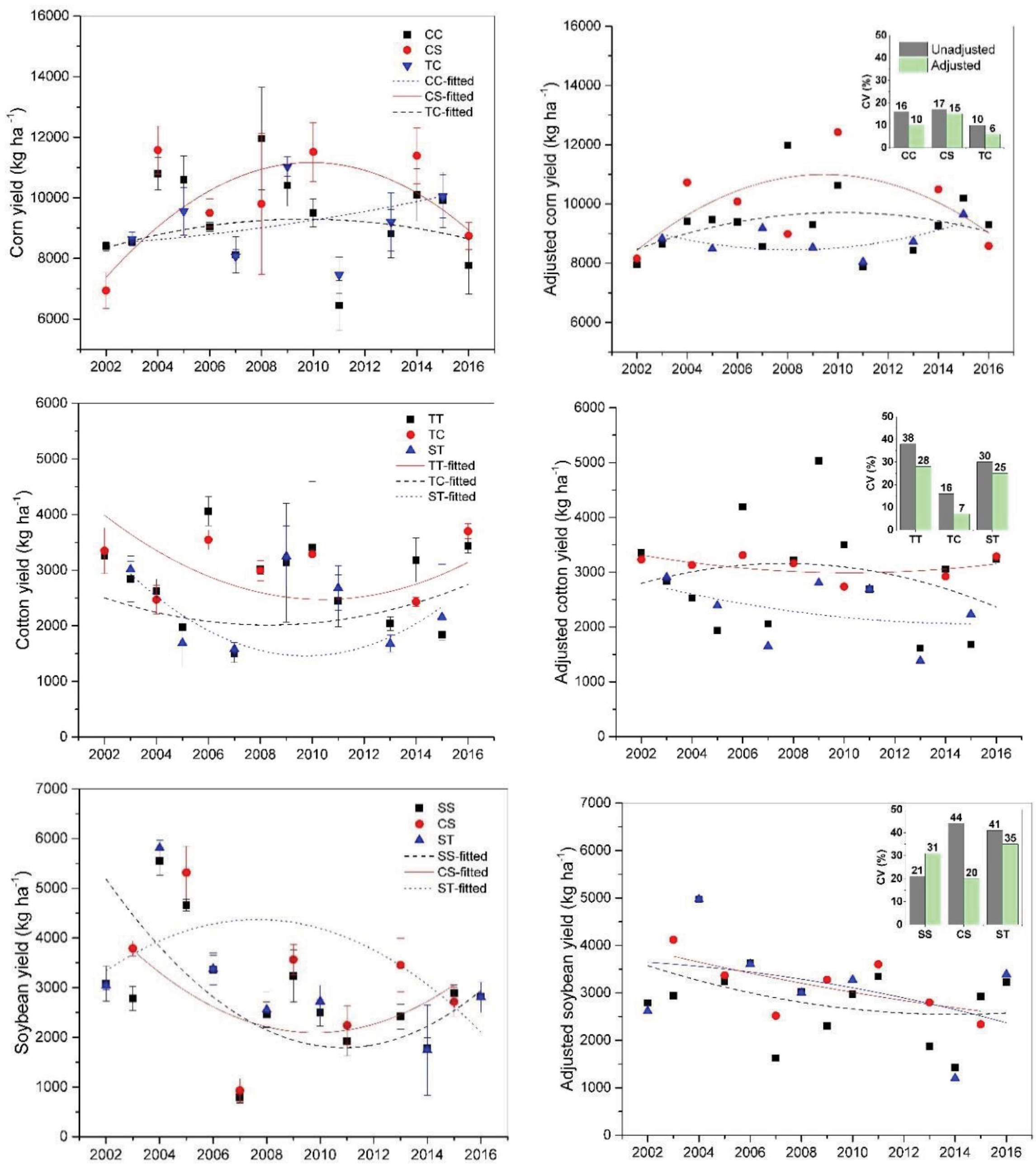

Figure 2.3. Long-term corn, cotton and soybean yield and polynomial regression curves illustrating the trend of variations under cropping systems (Left) and corresponding yield data adjusted to the covariates of precipitation and air temperature in July and August of each year (Right). Vertical error bars are standard deviation of yield among three replicates and bar graphs are the coefficient of variation (CV) before (gray) and after (green) the adjustments were applied.

Moreover, insufficient residue production under cotton cropping systems may reduce the water drainage by affecting soil surface characteristics. Activity of soil biota may also affect the water transmission and water availability by modifying the pore structure. According to another study conducted at the same experiment by Ashworth et al. (2017), the smallest total population of three earthworm species was observed under continuous cotton and cotton-corn management measured in cotton cycle of management. They concluded that the earthworm population decreases and increases significantly with inclusion of cotton and soybean respectively.

In-situ moisture content measured at drier periods of the growing season was significantly different among cropping systems only at 0-15 cm in 2015. Non-significant results in 2016 is probably due to the relatively high standard error while the mean values remained almost constant. TT, TC and SS at surface depth in both years resulted in a lower moisture content than the other three managements which is in agreement with SWRC analysis. Cropping in sequence resulted in consistently higher moisture content compared to the monoculture.

Cropping systems varied in WAS significantly at only 0-15cm in both years. CC and CS had consistently greater fraction of water stable aggregates than TT. Contrast results indicate that the existence of corn significantly ($p<0.05$) increased the WAS compared to the other crops. Greatest difference occurred between corn and cotton managements with an average of 8.8% greater WAS in corn than cotton. As discussed earlier, cropping managements with greater residue turn over has been shown to further increase the SOC storage which in turn, has been found to be meaningfully related to the greater water stability of aggregates (Jagadamma et al., 2008; Coulter et al., 2009). SOC in our experiment has previously been quantified by Ashworth et al. (2014) after three time phases (4, 8 and 12 yr) since 2002. They included more extensive cropping managements (including our managements) and evaluated them on four cover crop managements. After 4 years, a general reduction in SOC in all managements was evident at 0-15 cm. After 8 years, surprisingly greater SOC increase occurred in TT than CC and SS and in more frequent soybean occurrences although initial rates of SOC could not be fully recovered under winter fallow. However, in 2012 (Ashworth et al., 2017), C and N content averaged across fallow managements, at 0-15 cm was greatest under CC and CS relative to the other managements. They concluded that corn included managements after 12 years of continuous cropping had greater contribution to SOM build up than either cotton or soybean and it is probably the reason for significantly greater WAS under CC and CS and lowest rates under TT at surface depth in both years.

The same trend of variation was also observed in DASD analysis in which managements differed significantly ($p = 0.02$) at both depths, producing the greatest GMD and MWD values for

CC, CS and TC at 0-15cm, all having the corn included. Therefore, increased SOC under corn incorporated managements also favored the formation of larger aggregates especially at 0-15 cm soil depth. Corn managements extended their effects on GMD and MWD to the second depth but in a different manner. Cropping systems differed in fraction of macroaggregates (>2 mm) at 0-15, whereas at 15-30 cm cropping systems differed in small-macro (0.25-2 mm) and microaggregates (0.053-0.25 mm).

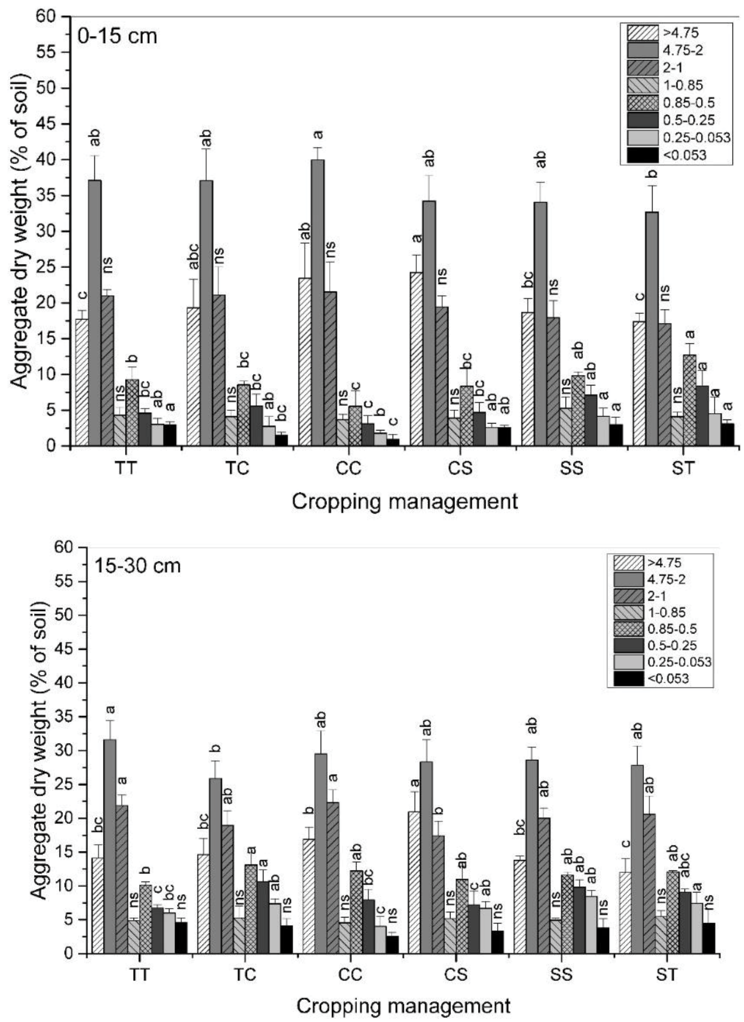

Figure 2.4. Aggregate size distribution at two sampling depths under six cropping systems (TT, continuous cotton; TC, cotton-corn; CC, continuous corn; CS, corn-soybean; SS, continuous soybean; ST, soybean-cotton) on no-tillage management. Letters on the vertical STD error bars indicate the significance of difference ($p < 0.05$) in the same aggregates size category across managements. ns: non-significant.

This result implies that cropping systems based on the magnitude of SOC stock may change GMD and MWD through affecting different size ranges of aggregates in different soil depths. Detailed illustration of DASD is provided in Figure (2.4).

S factor is the measure of water-ponded infiltrability of soil which similar to the observations of Shaver et al. (2002) did not vary significantly among cropping systems in either year. However, a positive correlation (r = 0.39 in 2015) was detected between S and water "transmission and fissures" pore space (r = >25 μm) (Greenland, 1981). K_{fs} correlation with S, resulted in r = 0.54 and r = 0.63 in two successive years. Dunin (1976) observed that in theoretically long time Philip's A parameter (transmissivity) approximated the field measured hydraulic conductivity. Transmissivity was found to be highly correlated with K_{fs} (r = 0.94 and r = 0.88 in 2015 and 2016 respectively). Trend of variations in i_i, i_c, I and K_{fs} was identical among the cropping systems. CS in both years had the highest initial, steady state and cumulative infiltration and field-saturated hydraulic conductivity while TT and TC interchangeably exhibited the lowest values. However, the effect of cropping system on i_c and K_{fs} was significant ($p < 0.05$) in 2015. Contrast analysis showed that in spite of positive values, in neither of years, occurrence of corn in rotation significantly improved hydraulic properties while the effect of soybean in both years was positively significant. The reason can be attributed to the greater biological enrichment and specifically the earthworm population under soybean than corn and cotton managements as reported by Ashworth et al. (2017) at the same experiment. Inclusion of cotton in management resulted in the lowest water infiltration and transmission compared to soybean and corn managements.

The effect of cropping system on water retention characteristics was significant only at 0-15cm soil depth. PAWC was significantly ($p = 0.04$) affected by the variations among managements in FC moisture content while PWP moisture content did not differ among managements significantly ($p>0.05$). All managements revealed an upper-optimal level of RFC at both depths with a greater magnitude in subsoil layer which may indicate a general "aeration limited" condition in our soil (Reynolds et al., 2002). TC and SS exposed the closest values to the optimal range (0.6 > RFC > 0.7) at surface depth. AC, another soil aeration indicator was equal or slightly greater than the lower critical limit (< 0.11 m^3 cm^{-3}) of the specified range (Kundler, 1989) for this index although the differences among the managements were not significant ($p > 0.10$). This result also indicates that in general, the appropriate aeration might be limited periodically (Reynolds et al., 2014) which may affect the vital activities of the soil biota. Changes in bulk density and total porosity under NT is generally limited to the few centimeters of topsoil with a magnitude varying based on the rate of residue production. According to Dexter (1991), activity of soil fauna or root system do not modify the bulk density as they move through reducing the porosity of the surrounding soil matrix. PSD curve derived from the SWRC showed that despite the non-significant difference among the cropping systems in structural porosity, distribution of pores within this range varied significantly. Within the structural pore space, CC and CS managements revealed a greater volume of macropores larger than approximately 43-51 μm at 0-7.5 cm soil depth. Volume fraction of larger pores within the structural porosity was also greater in SS and TC, CC and CS and SS and ST at second, third and fourth depth respectively which can be considered as the direct influence of the cropping management. In general, occurrence of corn and soybean led to a greater abundance of pores at the larger end of the structural pore space compared to the cotton managements which can be explained by the greater SOC storage, more extensive rooting pattern and higher biological activities. These results are supported by greater water transmission under these managements. Matrix porosity, PAWC and to some smaller extent the structural porosity in entire sampling depth (0-30 cm) were negatively correlated with the bulk density (Fig. 2.5). Reynolds et al. (2014) observed the similar results on a clay loam soil although the structural porosity has been generally found to be more prone than matrix porosity to decrease by increase in bulk density (Richard et al., 2001).

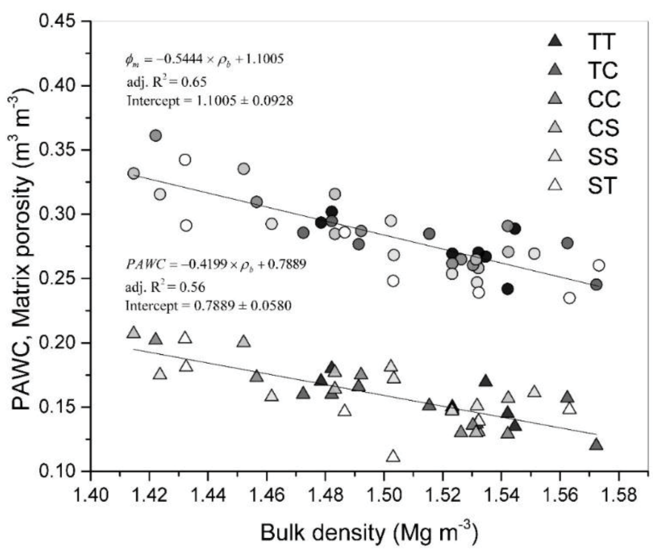

Figure 2.5. Plant available water content (PAWC) and matrix porosity (ϕm) of six cropping managements (TT, continuous cotton; TC, cotton-corn; CC, continuous corn; CS, corn-soybean; SS, continuous soybean; ST, soybean-cotton) on no-tillage management across the range of measured dry bulk density.

It seems that the clay content is an effective factor in dynamics of matrix porosity in relation with bulk density. For example, in a study conducted by Kutilek et al. (2006), among the soils from five textural groups, only the clay loam soil with the greatest clay content experienced a decrease in matrix porosity as exposed to an ascending order of compressive stress.

2.5.2 PRINCIPAL COMPONENT ANALYSIS

PCA differentiated the cropping systems based on the associated soil hydro-physical properties at 0-15 cm in two experimental years (Fig. 2.6). Two first principal components explained 54% of cumulative variability in soil physical properties among the cropping managements. Despite some exceptions, the most favorable soil physical condition consisting of a better aggregation and greater aggregate stability, higher plant available water content and field-measured moisture content was associated with corn-soybean (CS) and continuous corn (CC) managements. However, soybean included managements resulted in improved water infiltration and transmission parameters, while continuous cotton (TT) and cotton-corn (TC) were associated with the lowest hydraulic properties.

2.5.3 CROPPING SYSTEM AFFECTS CORN, COTTON AND SOYBEAN YIELD AND YIELD STABILITY

As shown in Fig. 2.1, temperature and precipitation anomalies in July and August of each year led to the considerable yield penalties with an intensity varying based on the cropping system. This early-mid productive period corresponds to the early tasseling, silking and pollination of corn, first bloom to first boll in cotton and beginning pod to full seed growth stages of soybean in which the crops are in the maximum water demand due to the longer days, higher temperature and solar radiation. When the water supply or rainfall do not meet the evapotranspiration demand of crops in this period, the yield losses become inevitable (Lamm and Abou kheira, 2009; TeKrony et al., 1981; Hake and Grimes, 2010). We observed that yield reduction in weather perturbations vary based on the cropping system. In other words, cropping systems based on the type and frequency of crops in management determine the support that soil system provides to maintain the yield in unfavorable weather condition. The yield variations due to the fluctuation in weather, especially in relatively short-term studies may mask the true effect of the cropping management and soil quality on yield production.

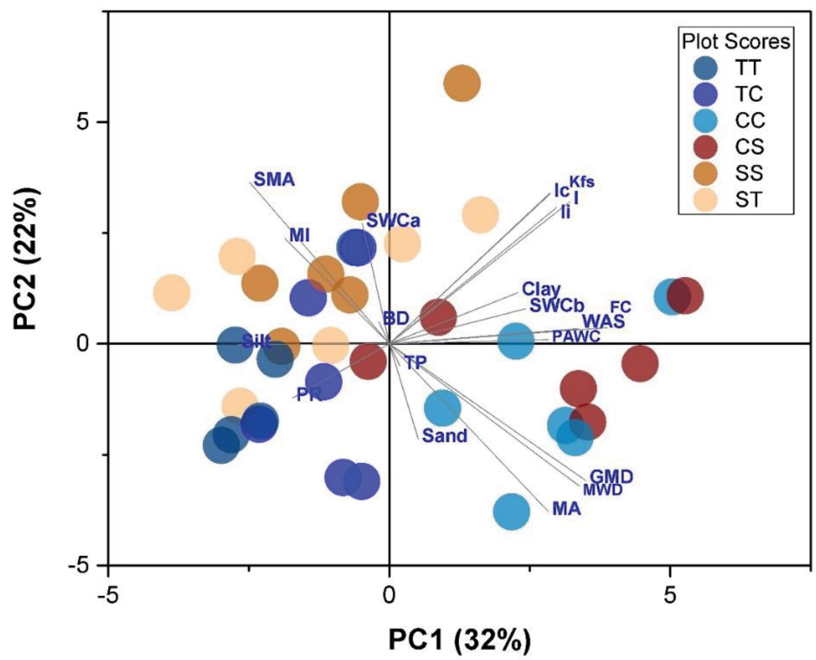

Figure 2.6. Principal component analysis of soil physical properties (SMI, small macoaggregates; MI, microaggregates; MA, macroaggregates; SWCa, near-FC in-situ soil moisture content; SWCb, in-situ soil water content in lower matric potential; BD, bulk density; TP, total porosity; K_{fs}, field-saturated hydraulic conductivity; i_i, initial infiltration; i_c, quasi-steady infiltration rate; I, cumulative infiltration; FC, field capacity moisture content; PAWC, plant available water content; WAS, wet aggregate stability; GMD, geometric mean diameter; MWD, mean weight diameter, PR, cone penetration resistance) as influenced by six cropping managements on a winter fallow no-tillage management.

Approach toward minimizing the yield variability by adjusting to the covariates of precipitation and air temperature considerably decreased the yield variance. The coefficient of variation (CV) in weather-adjusted corn yield was lowest in TC while the mean yield is comparable with CC. However, CS in spite of the greatest CV, increased mean corn yield significantly compared to CC. Similar to corn, TC increased the stability of cotton yield, but at the same time increased the mean yield compared to ST. Significant variation (CV=32%) in cotton yield under TT however makes the mean yield Comparisons deceptive. Smallest year by year variations and greatest stability in soybean yield occurred in CS management which increased the mean production of soybean yield compared to SS while SS did not differ significantly in mean yield with ST. Negative slope of the long-term yield trend in soybean is due to the extraordinary greater yield in two initial years (2004 & 2005). In summary, (i) smaller variations in corn yield was observed than cotton and soybean. (ii) TC was found to be a cropping system which provides the greatest stability for cotton and corn yield and increased the mean cotton yield. (iii) Among the monoculture cropping systems of corn, cotton and soybean, cotton resulted in the most unsecure and unstable yield production. (iv) Corn/soybean rotation increased the mean yield of corn and soybean compared to SS and CC and increased the soybean yield stability.

2.5.4 YIELD PRODUCTION AND STABILITY AS AFFECTED BY MANAGEMENT-INDUCED SOIL HYDRO-PHYSICAL QUALITY

Corn yield, regardless the type of cropping management, demonstrated significantly greater long-term stability compared with soybean and cotton. CS and TC managements increased not only the yield stability of corn, but they also decreased the variation and increased the yield production of cotton and soybean. These results can be related to the significantly greater wet aggregate stability, moisture content, GMD, MWD, PAWC, lower PR and greater SOC as reported by Ashworth et al. (2017) on corn managements, especially under CC and CS. Among the cotton managements, TC led to more positive soil physical condition than TT in most of the measured soil physical parameters; however, TC did not differ significantly from ST. Higher yield production and stability under TC than TT can be tied with the higher observed water infiltration and transmission (i_i, i_c, I, K_{fs}), improved aggregation (higher GMD, MWD, and WAS), and greater water content at drier periods (θ_{vb}). Yield averaged across three replicates between 2010 to 2016 (Fig. 2.7), showed that corn yield under CS was 18% and 20% greater than those of TC and CC, respectively. CS resulted in the best physical condition not only among corn included managements but among all cropping systems. Cotton yield in 2016 was 15% and 44% greater under TC than TT and ST respectively. CS also increased soybean yield by 16% and 17% relative to ST and SS respectively. Generally better yield performance of crop sequence versus monoculture is supported by more favorable hydraulic properties, total porosity, moisture content and PAWC under rotational cropping especially at the surface depth. Corn included managements in general and CS and TC managements in particular, found to be the best cropping systems that favored the corn, cotton and soybean yield with greater mean production and stability in weather perturbations. CS also demonstrated the most outstanding soil physical condition among cropping system while TC generally resulted in intermediate condition.

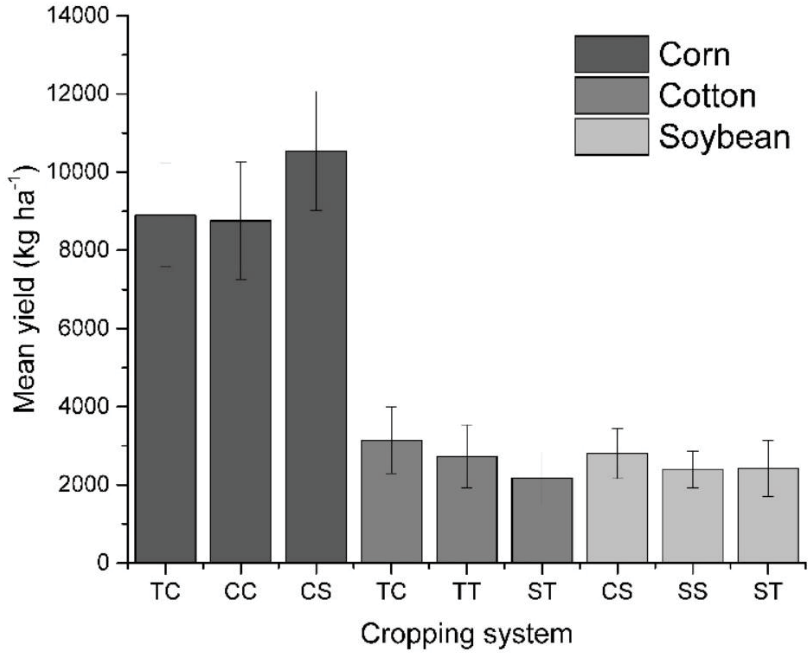

Figure 2.7. Mean corn, cotton and soybean grain yield averaged across replicates and years between 2010 to 2016

2.6 CONCLUSION

Long-term cropping management on non-tilled silt loam, resulted in significant effects on soil hydro-physical properties, yield production and stability of yield in unfavorable weather condition. Alterations in soil physical condition were found to be strongly related to the magnitude and quality of residue production. Corn with greatest potential of residue production was found to be the best counterpart for soybean and cotton in double crop rotation under sub-humid, mid-south US climatic condition. Corn/soybean rotation resulted in greatest wet aggregate stability, soil moisture content in lower matric potentials, initial and cumulative infiltration, hydraulic conductivity and plant available water content and increased mean corn and soybean yield and yield stability of soybean. Cotton/corn rotation on the other hand, displayed intermediate standing in soil physical condition among cotton included managements but significantly increased the mean yield and yield stability of cotton compared to soybean/cotton and continuous cotton managements. Overall, cropping in sequence yielded more improved soil physical condition and yield production than monoculture. Dry bulk density and total porosity did not differ significantly among cropping systems. However, differences in pore size distribution considerably affected the water infiltration, transmission and storage parameters. Higher volume of macropores (> 43-51 μm) at surface depths under continuous corn and corn soybean led to greater initial and cumulative water infiltration and field-saturated hydraulic conductivity and lower values of near-FC moisture content.

This study provided a long-term insight into soil physical attributes as affected by cropping management under no-tillage system. However, the long-term trend of yield under cropping scenarios, due to the considerable fluctuations in climatic factors (e.g. precipitation and temperature) will require a longer time to become more pronounced.

2.7 REFERENCES

Ashworth, A., Allen, F., Tyler, D., Pote, D., Shipitalo, M., 2017. Earthworm populations are affected from long-term crop sequences and bio-covers under no-tillage. Pedobiologia 60, 27-33.

Ashworth, A.J., Allen, F.L., Wight, J.P., Saxton, A.M., Tyler, D.D., Sams, C.E., 2014. Soil organic carbon sequestration rates under crop sequence diversity, bio-covers, and no-tillage. Soil Science Society of America Journal 78, 1726-1733.

Atwell, B., 1993. Response of roots to mechanical impedance. Environmental and Experimental Botany 33, 27-40.

Benjamin, J.G., Halvorson, A.D., Nielsen, D.C., Mikha, M.M., 2010. Crop management effects on crop residue production and changes in soil organic carbon in the central Great Plains. Agronomy Journal 102, 990-997.

Bissonnais, Y.l., 1996. Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. European Journal of Soil Science 47, 425-437.

Blanco-Canqui, H., Lal, R., 2004. Mechanisms of carbon sequestration in soil aggregates. Critical Reviews in Plant Sciences 23, 481-504.

Blanco-Canqui, H., Stone, L., Schlegel, A., Benjamin, J., Vigil, M., Stahlman, P., 2010. Continuous cropping systems reduce near-surface maximum compaction in no-till soils. Agronomy Journal 102, 1217-1225.

Boquet, D.J., Hutchinson, R.L., Breitenbeck, G.A., 2004. Long-term tillage, cover crop, and nitrogen rate effects on cotton. Agronomy Journal 96, 1443-1452.

Buyanovsky, G., Wagner, G., 1986. Post-harvest residue input to cropland. Plant and Soil 93, 57-65.

Carter, M.R., 2002. Soil quality for sustainable land management. Agronomy Journal 94, 38-47.

Castro Filho, C., Lourenço, A., Guimarães, M.d.F., Fonseca, I., 2002. Aggregate stability under different soil management systems in a red latosol in the state of Parana, Brazil. Soil and Tillage Research 65, 45-51.

Coulter, J.A., Nafziger, E.D., Wander, M.M., 2009. Soil organic matter response to cropping system and nitrogen fertilization. Agronomy Journal 101, 592-599.

Daddow, r.l., Warrington, g.e., 1983. Growth-limiting soil bulk densities as influenced by soil texture.

Dexter, A., 1991. Amelioration of soil by natural processes. Soil and Tillage Research 20, 87-100.

Dirksen, C., 1998. Soil physics measurements.

Drewry, J., Cameron, K., Buchan, G., 2008. Pasture yield and soil physical property responses to soil compaction from treading and grazing—a review. Soil Research 46, 237-256.

Drewry, J., Paton, R., 2005. Soil physical quality under cattle grazing of a winter-fed brassica crop. Soil Research 43, 525-531.

Drinkwater, L.E., Wagoner, P., Sarrantonio, M., 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396, 262.

Dunin, F.X., 1976. Infiltration: its simulation for field conditions. Facets of Hydrology.

Ehlers, W., Köpke, U., Hesse, F., Böhm, W., 1983. Penetration resistance and root growth of oats in tilled and untilled loess soil. Soil and Tillage Research 3, 261-275.

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

Fuentes, M., Govaerts, B., De León, F., Hidalgo, C., Dendooven, L., Sayre, K.D., Etchevers, J., 2009. Fourteen years of applying zero and conventional tillage, crop rotation and residue management systems and its effect on physical and chemical soil quality. European Journal of Agronomy 30, 228-237.

Gaudin, A.C., Tolhurst, T.N., Ker, A.P., Janovicek, K., Tortora, C., Martin, R.C., Deen, W., 2015. Increasing crop diversity mitigates weather variations and improves yield stability. PloS One 10, e0113261.

Gee, G., Or, D., 2002. 2.4. 3.5 Hydrometer Method. Methods of Soil Analysis, Part 4, 278-283.

Green, W.H., Ampt, G., 1911. Studies on soil physics. The Journal of Agricultural Science 4, 1-24.

Greenland, D., 1981. Soil management and soil degradation. European Journal of Soil Science 32, 301-322.

Grossman, R., Reinsch, T., 2002. 2.1 Bulk density and linear extensibility. Methods of Soil Analysis: Part 4 Physical Methods, 201-228.

Hake, K., Grimes, D., 2010. Crop water management to optimize growth and yield. Physiology of Cotton, 255-264.

Haynes, R., 2000. Interactions between soil organic matter status, cropping history, method of quantification and sample pretreatment and their effects on measured aggregate stability. Biology and Fertility of Soils 30, 270-275.

Hazarika, S., Parkinson, R., Bol, R., Dixon, L., Russell, P., Donovan, S., Allen, D., 2009. Effect of tillage system and straw management on organic matter dynamics. Agronomy for Sustainable Development 29, 525-533.

Huggins, D., Clapp, C., Lamb, J., Randall, G., 2007. Corn-soybean sequence and tillage effects on soil carbon dynamics and storage. Soil Science Society of America Journal 71, 145-154.

Hussain, I., Olson, K.R., Ebelhar, S.A., 1999. Long-term tillage effects on soil chemical properties and organic matter fractions. Soil Science Society of America Journal 63, 1335-1341.

Jagadamma, S., Lal, R., Hoeft, R.G., Nafziger, E.D., Adee, E.A., 2008. Nitrogen fertilization and cropping system impacts on soil properties and their relationship to crop yield in the central Corn Belt, USA. Soil and Tillage Research 98, 120-129.

Kemper, W. D., and R. C. Rosenau. "Aggregate stability and size distribution." (1986): 425-442.

Kumar, A., Chen, Y., Sadek, M.A.-A., Rahman, S., 2012. Soil cone index in relation to soil texture, moisture content, and bulk density for no-tillage and conventional tillage. Agricultural Engineering International: CIGR Journal 14, 26-37.

Kundler, P., 1989. Erho¨ hung der Bodenfruchtbarkeit, 1st ed. VEB Deutscher Landwirtschaftsverlag, Berlin, 452 pp.

Kutílek, M., Jendele, L., Panayiotopoulos, K.P., 2006. The influence of uniaxial compression upon pore size distribution in bi-modal soils. Soil and Tillage Research 86, 27-37.

Kutílek, M., Nielsen, D.R., 1994. Soil hydrology: textbook for students of soil science, agriculture, forestry, geoecology, hydrology, geomorphology and other related disciplines. Catena Verlag.

Lal, R., Mahboubi, A., Fausey, N., 1994. Long-term tillage and rotation effects on properties of a central Ohio soil. Soil Science Society of America Journal 58, 517-522.

Lamm, F., Aiken, R., Kheira, A.A., 2009. Corn yield and water use characteristics as affected by tillage, plant density, and irrigation. Transactions of the ASABE 52, 133-143.

Larney, F.J., Lindwall, C.W., Bullock, M.S., 1994. Fallow management and overwinter effects on wind erodibility in southern Alberta. Soil Science Society of America Journal 58, 1788-1794.

Liang, B., Gregorich, E., Schnitzer, M., Monreal, C., MacKenzie, A., Voroney, R., Beyaert, R., 1998. Retention and turnover of corn residue carbon in some eastern Canadian soils. Soil Science Society of America Journal 62, 1361-1366.

Martens, D.A., 2000. Plant residue biochemistry regulates soil carbon cycling and carbon sequestration. Soil Biology and Biochemistry 32, 361-369.

Munkholm, L.J., Heck, R.J., Deen, B., 2013. Long-term rotation and tillage effects on soil structure and crop yield. Soil and Tillage Research 127, 85-91.

NASS, National Agricultural Statistical Service. 2016. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=TENNESSEE.

Nimmo, J.R., Perkins, K.S., 2002. 2.6 Aggregate stability and size distribution. Methods of Soil Analysis: Part 4, 317-328.

Olness, A., Clapp, C., Liu, R., Palazzo, A.J., 1998. Biosolids and their effects on soil properties. Handbook of Soil Conditioners. Marcel Dekker, New York, NY, 141-165.

Parihar, C.M., Yadav, M., Jat, S., Singh, A., Kumar, B., Pradhan, S., Chakraborty, D., Jat, M., Jat, R., Saharawat, Y., 2016. Long term effect of conservation agriculture in maize rotations on total organic carbon, physical and biological properties of a sandy loam soil in north-western Indo-Gangetic Plains. Soil and Tillage Research 161, 116-128.

Paustian, K., Andrén, O., Janzen, H.H., Lal, R., Smith, P., Tian, G., Tiessen, H., Noordwijk, M.v., Woomer, P.L., 1997. Agricultural soils as a sink to mitigate CO2 emissions. Soil Use and Management 13, 230-244.

Pedersen, P., Lauer, J.G., 2002. Influence of rotation sequence on the optimum corn and soybean plant population. Agronomy Journal 94, 968-974.

Philip, J.R., 1957. The theory of infiltration: 4. Sorptivity and algebraic infiltration equations. Soil Science 84, 257-264.

Reddy, K.N., Locke, M.A., Koger, C.H., Zablotowicz, R.M., Krutz, L.J., 2006. Cotton and corn rotation under reduced tillage management: impacts on soil properties, weed control, yield, and net return. Weed Science 54, 768-774.

Reeves, D., 1994. Cover crops and rotations. Advances in Soil Science: Crops Residue Management, 125-172.

Reynolds, W., Bowman, B., Drury, C., Tan, C., Lu, X., 2002a. Indicators of good soil physical quality: density and storage parameters. Geoderma 110, 131-146.

Reynolds, W., Drury, C., Yang, X., Tan, C., 2008. Optimal soil physical quality inferred through structural regression and parameter interactions. Geoderma 146, 466-474.

Reynolds, W., Drury, C., Yang, X., Tan, C., Yang, J., 2014. Impacts of 48 years of consistent cropping, fertilization and land management on the physical quality of a clay loam soil. Canadian Journal of Soil Science 94, 403-419.

Reynolds, W., Elrick, D., Youngs, E., Amoozegar, A., Booltink, H., Bouma, J., 2002b. 3.4 Saturated and field-saturated water flow parameters. Methods of Soil Analysis, Part 4, 797-801.

Rhoton, F., 2000. Influence of time on soil response to no-till practices. Soil Science Society of America Journal 64, 700-709.

Richard, G., Cousin, I., Sillon, J., Bruand, A., Guérif, J., 2001. Effect of compaction on the porosity of a silty soil: influence on unsaturated hydraulic properties. European Journal of Soil Science 52,

49-58.
SAS Institute. 2007. SAS/STAT 9.3 User's guide. SAS Inst., Cary, NC.
Shaver, T., Peterson, G., Ahuja, L., Westfall, D., Sherrod, L., Dunn, G., 2002. Surface soil physical properties after twelve years of dryland no-till management. Soil Science Society of America Journal 66, 1296-1303.
Sisti, C.P., dos Santos, H.P., Kohhann, R., Alves, B.J., Urquiaga, S., Boddey, R.M., 2004. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. Soil and Tillage Research 76, 39-58.
Skopp, J., Jawson, M., Doran, J., 1990. Steady-state aerobic microbial activity as a function of soil water content. Soil Science Society of America Journal 54, 1619-1625.
TeKrony, D., Egli, D., Henson, G., 1981. A visual indicator of physiological maturity in soybean plants. Agronomy Journal 73, 553-556.
Thomas, G., Dalal, R., Standley, J., 2007. No-till effects on organic matter, pH, cation exchange capacity and nutrient distribution in a Luvisol in the semi-arid subtropics. Soil and Tillage Research 94, 295-304.
Uzun, O., Kaplan, S., Basaran, M., Deviren Saygın, S., Youssef, F., Nouri, A., Ozcan, A.U., Erpul, G., 2017. Spatial distribution of wind-driven sediment transport rate in a fallow plot in Central Anatolia, Turkey. Arid Land Research and Management 31, 125-139.
Van Genuchten, M.T., 1980. A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. Soil science society of America journal 44, 892-898.
Verhulst, N., Nelissen, V., Jespers, N., Haven, H., Sayre, K.D., Raes, D., Deckers, J., Govaerts, B., 2011. Soil water content, maize yield and its stability as affected by tillage and crop residue management in rainfed semi-arid highlands. Plant and Soil 344, 73-85.
Wright, A.L., Hons, F.M., 2004. Soil aggregation and carbon and nitrogen storage under soybean cropping sequences. Soil science society of America journal 68, 507.
Youker, R., McGuinness, J., 1957. A short method of obtaining mean weight-diameter values of aggregate analyses of soils. Soil Science 83, 291-294.
Zuber, S.M., Behnke, G.D., Nafziger, E.D., Villamil, M.B., 2015. Crop rotation and tillage effects on soil physical and chemical properties in Illinois. Agronomy Journal 107, 971-978.

CHAPTER III
LONG-TERM IMPACT OF TILLAGE INTENSITY AND WINTER WHEAT COVER CROP ON SOIL HYDRO-PHYSICAL PROPERTIES IN THE MID-SOUTH US

3.1 ABSTRACT

Environmental sustainability and a positive economic outcome of a farm management system is more evident and reliable after a long-term institution. Accordingly, impact of 36 years of tillage and cropping managements on soil physical and hydraulic properties including: bulk density, total porosity, moisture content, wet aggregate stability, cone penetration resistance, geometric mean diameter, mean weight diameter, initial and cumulative infiltration, field-saturated hydraulic conductivity was measured on a Lexington silt loam in Jackson, TN. Five tillage-cropping management systems were examined: moldboard plow (MP); disk plow (DP); chisel plow (CP); no-tillage (NT) and no-tillage with winter wheat [Triticum aestivum (L.) em. Thell. 'Arthur'] cover crop (NT-W). Soil physical properties were assessed by collecting soil samples at 0-15 and 15-30 cm and hydraulic properties were measured in field. Statistical analyses were conducted as a randomized complete block design with four replicates. NT managements and CP resulted in significantly higher bulk density than MP and CP while the highest penetration resistance was observed under NT and DP. NT considerably increased the wet aggregate stability at both depths than CP, DP and MP but did not differ with NT-W. WAS differences were significant at 15-30 cm. Field-measured near FC moisture contents did not vary significantly among treatments while CP and MP resulted in greater moisture content at drier periods. NT and NT-W showed significantly higher geometric mean and mean weight diameter at 0-15cm which was related to a greater macroaggregation (> 2 mm) under these managements. Hydraulic properties did not differ significantly among managements. However, NT-W and NT resulted in greater initial infiltration and sorptivity than other managements while DP resulted in comparable hydraulic conductivity and cumulative infiltration with NT and NT-W. These results indicate that 36 years of continuous wheat cover crop on NT did not favor this management with further improvement in soil physical properties. NT and NT-W were associated with the greater aggregation and aggregate stability and higher water infiltration and percolation. A complementary yield analysis will better clarify if the yield production under no tillage managements is supported by their improved physical properties or limited by a higher bulk density and penetration resistance.

3.2 INTRODUCTION

Most Tennessee upland soils are silt-loam in texture with organic matter content that is generally less than one percent at surface of tilled soils. This condition increases the vulnerability of the top soil against erosive forces. In 1977, the average rate of soil erosion in Tennessee farmlands was 15 tons. $acre^{-1}$. $year^{-1}$ and more than 50 tons. $acre^{-1}$. $year^{-1}$ in upland farms (Denton and Tyler, 2002). Poorly aggregated surface soil could remarkably decrease the infiltrability of rainfall water and lead to crop failure due to excessive drought in sub-humid mid-south region (Denton and Tyler, 2002). Soil erosion and the loss of soil productivity was the main reason for widespread adoption of no-tillage (NT), which gradually made NT the conventional tillage in Tennessee. Despite the major role of NT system in reduction of fluvial soil losses in Tennessee, long-term effect of NT on soil hydro-physical quality compared with the other types of conservation tillage practices has not been well documented.

Tillage managements based on the intensity of soil manipulation and the rate of residue retention may affect the soil physical properties differently (Barzegar et al., 2003). Conventional tillage incorporates the almost entire or retains less than 15% of crop residue at the surface while reduced tillage (RT) maintains 15-30% of plant residue and no-tillage leaves almost all the residue at soil surface (Cassel, 1982; Kladivko, 1994). Greater burial of crop residue with increased tillage intensity is known to be associated with the greater oxidative loss of soil organic carbon (SOC) and disintegration of soil aggregates (Abiven et al., 2009). Improved soil aggregation due to the lack of mechanical soil disturbance (Bullock et al., 1988; Daraghmeh et al., 2009) and increase in soil organic carbon stock is associated with a more structured pore system that in turn improves aeration and water transmission (Jastrow and Miller, 1991; Karami et al., 2012).

No-tillage has demonstrated the ability to reduce the production cost (Van den Putte et al., 2010) improve soil aggregation (Kladivko et al., 1986; Weill et al., 1989), increase water infiltration and hydraulic conductivity (Lampurlanes and Cantero-Martinez, 2006) and availability of water (Smika 1990; Cameira et al., 2003). Structured, stable, continuous and interconnected pore network formed under NT system due to the long-term biological activities can be referred as the main source of the amendments in soil aeration and hydraulic properties (Dörner et al., 2010). Accumulation of residue cover at the surface of undisturbed soil, builds an organic coating that maintains the continuity of gas and water exchange at the soil-atmosphere interface (Lentz and Bjorneberg, 2003). However, contradictory results in the literature (Green et al., 2003; Alvarez and Steinbach, 2009) indicate that the effect of no-tillage or reduced tillage on soil hydro-physical quality is a function of antecedent soil condition, climate, length of application and the inclusion of other complementary actions such as cover crops and cropping sequence.

In spite of all beneficial aspects of NT management, relying on herbicides for weed control and excessive surface application of N-fertilizers in long-term NT has always been a concern about emissions of nitrous oxide, nitrate contamination and the environmental sustainability of this management (Mkhabela et al., 2008).

No-till management may increase soil compaction by increasing bulk density (Culley et al., 1987; Ne Smith et al., 1987; Bruce et al., 1990) and cone penetration resistance (Munoz-Romero et al., 2010) due to the lack of soil inversion and machinery traffic which may limit the zone can be explored by roots and consequently affect the proper utilization of water and nutrients by plants (Sasal et al., 2006; Wyngaard et al., 2012). However, reasonably long-term adoption of NT and RT has been shown to increase the soil resilience to bear greater pressure load (Jabro et al., 2009). Blanco-Canqui et al. (2009) suggested that reduced or strip tillage may be necessary to alleviate the excessive soil compaction and create more favorable condition in certain soils than NT. However, periodic chiseling has been shown to have only a residual impact on BD reduction of NT since within a time less than a year, BD can recover to its initial state (Veiga et al., 2007; Reichert et al., 2017).

Reduced tillage has generally been reported to create more favorable physical condition compared with intensive tillage. Barzgar et al (2003) showed that soil tilled by chisel had higher aggregate stability and moisture content in all depth increments between 0-100 cm compared to that of moldboard plow. RT, in some cases has been found to be more advantageous than NT. Liu et al. (2013) found that reduced tillage is more advantageous than CT and NT in terms of economic returns for farmers. Double disk and chisel plow has also been shown to decrease bulk density and increase water infiltration than NT but builds up less organic carbon content at the surface layer (Mendoza et al., 2008). Length of RT management has also been found to affect the rate of changes in soil hydro-physical properties. Short-term RT adoption in temperate regions has been reported with greater or comparable BD at soil surface compared with CT (Yang and Wander, 1999), while in long-term, RT has been shown with the potential to further decrease BD (Deen and Kataki, 2003). In a 17-year study in North Dakota, long-term reduced tillage with sweep plow, resulted in higher SOC and lower bulk density compared with conventional tillage (Liebig et al., 2004). Kroulík et al. (2007) showed that disk plow leads to a reduced bulk density, cone penetration resistance and water infiltration and higher moisture content than NT. In contrast, Blanco-Canqui et al. (2010) reported lower cumulative infiltration under NT than RT. Alvarez and Steinbach (2009) reviewed 35 tillage studies in Pampas, Argentine, and reported that regardless the length of tillage management, bulk density, cone penetration, water infiltration and water content was greater for NT compared with different types of reduced tillage. However, Lindstrom and Onstad (1984) observed that the impact of tillage on soil physical properties are only significant at the Ap horizon. They observed higher bulk density and penetration resistance in no-till than chisel-disk plow and moldboard-disk plow while saturated hydraulic conductivity was considerably higher in moldboard-disk management. Except for the first years of adoption, NT or RT managements have generally been reported with comparable or greater yield production compared to CT (Hodgson et al., 1989; Lal et al., 1989).

The rate of changes in soil hydro-physical properties under conservation tillage is generally tied with the rate of SOC build up (Dexter, 1991). In a 13-year study of no-tillage, reduced tillage and conventional tillage application on a loam textured soil, changes in aggregate stability was found to be consistent with the changes in SOM with the greater values for NT, CT and MT respectively in both continuous wheat and wheat-vetch rotation. Non-significant change in bulk density was observed between tillage types (Hernanz et al., 2002).

In low residue cropping systems or when the climatic condition is favorable for the fast decomposition of organic matter, incorporation of cover crops with additional biomass input may increase the potential of no-tillage. Blanco-Canqui et al. (2010) reported an increased aggregate stability, water retention and cumulative infiltration when NT was covered with wheat over the winter. However, in a short-term study Wagger and Denton (1989) reported no significance effect of winter wheat cover crop on improving soil physical properties of a NT soil compared to no cover crop, NT management.

The effect of farming management systems on soil physical properties may not be evident or highly variable before a long-term application of these managements. Moreover, the effect of tillage managements on soil physical properties as shown by literature may considerably differ with soil inherent properties and climatic condition. The objective of this study was to investigate the effect of thirty-six years of moldboard plow, chisel plow, disk plow, NT and NT with winter wheat cover crop system on bulk density, penetration resistance, wet aggregate stability and dry aggregate size distribution, water infiltration and percolation under mid-south US climatic condition on a Lexington silt loam.

3.3 MATERIALS AND METHODS

3.3.1 STUDY SITE AND EXPERIMENTAL SETTING

This research was conducted on a long-term soybean (Glycine max) located at West Tennessee Research and Education Center, Jackson, TN. According to the Köppen classification, the climate of the study region is humid subtropical (Cfa) with mean annual temperature of 15.6 °C and mean annual rainfall of 1350 mm. The experiment was stablished in 1979 on a one-hectare area for a continuous study of six tillage and cropping managements on a uniform Lexington silt loam (fine-silty, mixed thermic ultic Hapludalf). Five treatments were selected for this study were: moldboard plowing to 25 cm deep (MP) followed by disk and roller harrow; disk plow to 10 cm deep (DP) followed by roller harrow; chisel plow to 20 cm deep (CP), followed by roller harrow; no-tillage (NT) on soybean stubble and no-tillage with winter wheat *[Triticum aestivum (L.) em. Thell. 'Arthur']* cover crop (NT-W). Each plot had four rows of soybean 1.5 m apart. In each year since 1979, single-crop soybean was seeded in mid-May, targeting 160,000 plants per acre following the chemical suppression of the wheat bio-cover by applying 0.71 kg ha^{-1} paraquat (1, 1'-dimethyl- 4,4'-bipyridinum ion) in early May. Pre-emergence weed control was conducted applying alachlor [2- chloro-2',6'-diethyl-N-(methoxymethyl) acetanilide] at 3.36 kg ha^{-1} and metribuzin [4-amino-6-tert-butyl-3-(methylthio)-as-triazin- 5(4H)-one) at 0.42 kg ha^{-1}. Post-emergence weed was controlled applying 0.13 kg ha^{-1} clethodim. Two middle rows of soybean were harvested in early October and yield was adjusted to 130 g. kg^{-1} moisture content. Then winter wheat was reseeded in late October.

3.3.2 BULK DENSITY, TOTAL POROSITY, PENETRATION RESISTANCE AND WATER CONTENT

Dry bulk density was determined by the core method (Grossman and Reinsch. (2002) by collecting samples one month after tillage. The stainless-steel cores with approximate volume of 147 cm^3 (75 mm in height and 50 mm in diameter) were used for collecting samples at two equivlent depths between 0-30 cm. Total porosity was calculated based on the bulk density and particle density (assumed to be 2.65 g. cm^{-3}). Gravimetric moisture content for all samples was obtained and knowing the bulk density, volumetric water content was calculated. Three-time measurements of in-situ moisture content were performed through the growing season using a hand probe. Cone penetration resistance (PR) was measured by a hand-held digital cone-tipped penetrometer with a cone angle of 30° and 1cm^2 area (Field Scout, SC 900 Soil Compaction Meter; Spectrum Technologies, Inc., Plainfield, IL, USA). Four measurements per management per replicate were recorded on a line transect down to 30 cm of soil depth with 2.5 cm vertical intervals.

3.3.3 SOIL AGGREGATION MEASUREMENTS

Relative fraction pf wet aggregate stability (WAS) was determined using a wet sieving apparatus (08.13, Eijkelkamp Agrisearch Equipment, Giesbeek, the Netherlands). Soil samples were collected from each treatment within the growing season of 2015 at two sampling depths of

0-15 and 15-30 cm with four replicates. 4 g of air-died (fractioned between 1 and 2 mm) aggregates were uniformly placed on sieves with size of 0.26 mm and wetted from the bottom by capillary motion. Sieves were located on apparatus and sieved in distilled water for 3 minutes with the oscillation rate of 35 times per minute as explained by (Kemper and Rosenau, 1986). Unstable fraction of aggregates was collected, oven-dried and weighted. Stable fraction was corrected for sand content chemically ($2g.L^{-1}$ of Sodium Hydroxide) and mechanically. Stable fraction was weighted and oven-dried and 0.2 g, weight of dispersant agent was subtracted and fraction of stable aggregates was calculated as: WAS% = (Remained on sieve-Sand)/ (Total sample-Sand) ×100

Dry aggregate size distribution (DASD) analysis was conducted on bulk samples collected at 0-15 and 15-30 cm. Samples were collected using a flat head shovel and located in a metal container to avoid the disturbance of aggregates. 100 g of air-dried soil samples, previously passed through a 8 mm sieve, were placed on top of the sieve series of 4.75, 2, 1, 0.85, 0.5, 0.25 and 0.05 mm size and was sieved for 5 min with the amplitude of 0.1 mm by a vertical sieving apparatus (model 18480, CSC Scientific, Fairfax, VA, USA). The soil fraction remaining on screens were collected and weighted. Geometric mean diameter (GMD) was calculated by applying a probit transform to the percent oversize values. Plotting the probit transformed cumulative fraction oversize (x) and log10 sieve size (y) and fitting a least squares linear regression, a simple linear equation was obtained. Substituting the 0.5 for x in resulted equation, the log diameter of 50% over size or GMD was obtained (Larney, 2007). Mean weight diameter (MWD) was calculated following the procedure explained by Youker and McGuinness (1957).

$$MWD=\sum_{i=1}^{n} \bar{\bar{X}}_i W_i \quad (3.1)$$

Where Xi is the mean diameter (mm) of size fraction and Wi, is the fraction retained on the sieve.

3.3.4 WATER INFILTRATION AND FIELD-SATURATED HYDRAULIC CONDUCTIVITY

Water infiltration characteristics were measured in field (Reynolds et al., 2002) using a double ring infiltrometer (IN7-W - Turf-Tec international, Tallahassee, FL) which was 102 mm high with 305 and 153 mm of outer and inner ring diameters respectively. Infiltrometer was inserted to a depth of about 40 mm and to avoid the flow divergence in inner ring due to the difference in hydrostatic pressure constant head of water was maintained at both rings 50 mm above the soil surface. Water infiltration in inner ring continued for 230 min or until the steady state infiltration was obtained. The infiltration data were fitted to Green and Ampt (1911), and Philip (1957) models using the least square method. Philip's model is well-known for the simplicity and clear theoretical background which provides a suitable description for sorptivity (S, $LT^{-0.5}$) and the empirical constant related to Ksat, so-called transmissivity (A, LT^{-1}) parameter.

$$i=\frac{1}{2}St^{-0.5}+A \tag{3.2}$$

$$I=St^{0.5}+At \tag{3.3}$$

Where I (mm) is the cumulative infiltration, i is the infiltration rate (LT-1), t is time passed (T).

The field-saturated one-dimensional hydraulic conductivity (K_{fs}) (LT^{-1}) was measured based on the methodology explained by Reynolds et al. (2002).

$$K_{fs}=\frac{q_s}{\left[\frac{H}{C_1d+C_2a}\right]+\left\{\frac{1}{[\alpha^*(C_1d+C_2a)]}\right\}+1} \tag{3.4}$$

Where, qs (LT^{-1}) is quasi-steady infiltration rate, a (L) is the ring radius, H (L) is depth of ponded water, d (L) is the depth of ring insertion into the soil, $C_1=0.316\pi$ and $C_2=0.184\pi$ are quasi-empirical constants. α^* (L^{-1}) is the soil macroscopic capillary length which was assumed to be 0.012 mm h^{-1} for the textural and structural condition of the study soil.

3.3.5 STATISTICAL ANALYSIS

The experimental design consisted of five tillage and cropping managements that were replicated randomly in four complete blocks thereby creating a randomized complete block design (RCBD). Mixed ANOVA procedure was conducted in SAS (SAS v9.3, SAS Institute, Inc., Cary, NC) and least square means were separated by Fisher's significant difference test. For each sampling depth, tillage and cropping system was considered as fixed effect and replicates were considered as random effect. Then sampling depth was considered as sub-plot fixed effect and significance of depth was obtained. The graphs were prepared in Origin (OriginLab, Northampton, MA).

3.4 RESULTS AND DISCUSSION

3.4.1 BULK DENSITY, TOTAL POROSITY, PENETRATION RESISTANCE AND WATER CONTENT

The effect of tillage and cropping management on soil BD and TP was significant (p=0.03) at only 0-15 cm of soil depth (Table 3.1). At surface depth, DP had the lowest BD (1.43 g cm^{-3}) and greatest TP (45.9%); while NT-W had the highest BD (1.48 g cm^{-3}) and the lowest TP (44.1%). At 15-30 cm, CP and MP had greater BD than NT, NT-W and DP. In spite of consistently greater BD values among managements at second depth than first depth, BD did not differ significantly between two depths (p>0.05). Interactive effect of tillage management and depth was also not statistically significant. No-tillage has frequently been reported with increased BD compared with reduced and conventional tillage (Lal, 1999; Bhattacharyya et al., 2009). However, the significance of difference may vary considerably with time of sampling. BD has generally the lowest value immediately after tillage and gradually increases during the growing season due to the raindrop effect and machinery traffic (Leij et al., 2002). We collected our samples one month after tillage on tilled managements and observed that DP and MP had more long-lasting effect on the reduction of BD than CP which can be related to their initial soil manipulation intensity.

Cone penetration resistance was significantly affected by tillage and cropping management at 0-15 cm (p=0.001). At this depth, NT had the highest PR followed by DP; whereas MP had the lowest PR. The PR was in the order: NT > DP >NT-W > CP >MP (Fig. 3.1). NT managements (NT and NT-W) with average value of 1.97 Mpa had 12% greater PR than those of reduced tillage managements (CP and DP) with average PR of 1.76 Mpa and 47% higher PR than MP. At 15-30 cm, despite the statistically non-significant difference among managements, DP and NT likewise the surface depth had the greatest PR, while the lowest value was observed in MP. PR at 15-30 cm was 64% and significantly (p< 0.01) higher than 0-15 cm soil depth, however, management by depth interaction was not significant. Similar results on the loosening effect of tillage in tilled layer and higher PR values under NT than types of reduced and conventional tillage have been reported by several authors (Moreno et al., 1997; Lal and Ahmadi. 2000; Tabaglio et al., 2009; Schjønning and Rasmussen, 2000). Villamil et al. (2015) reported a greater PR at top 30 cm of a silt loam under NT than CP in all three levels of corn residue removal and across all experimental sites. It has been agreed by several authors that PR greater than 2.0 or 2.5 Mpa can restrict root extension Carter, 2002. It is well known that root penetration can temporally change within the growing season with changes in soil moisture content. In rain-fed cropping system of sub-humid, mid-South region, where soil water content is determined by rainfall events, PR values beyond this threshold was frequently observed in drier periods of growing season. There were times in growing season that penetrometer could not be inserted beyond a few centimeters of top soil by human force under NT management. However, considering the appropriate biomass and yield response to NT, this limitation was not the case in our study. Similar observations were also reported by Fernández-Ugalde et al. (2009) who noted that roots by physiological adaptation (increasing root thickness) to the increased PR and extending through the biological pores can deals with the issue of high PR.

Volumetric water content measured at field in a moisture condition corresponding to FC, was not significantly different among managements at any depth (Table 3.1). However, NT-W had 11% greater moisture content than the average of the other managements. VWC measured at field at drier periods of growing season significantly varied among managements at only 0-15 cm where CP and MP had significantly (p=0.03) greater VWC than the other managements. MP also had the greatest moisture content at 15-30 cm; however, the differences were not statistically significant. The lowest moisture content under NT-W was not expected. Because it is known that the additional residue cover returned by cover crops reduces the water evaporation and increases the water holding capacity of surface soil. No-tillage has generally been reported to increase the soil water content greater than reduced and conventional tillage (Govaerts et al., 2007; Bescansa et al., 2006; Martens, 2000; Nielsen et al., 2005). Salem et al. (2015) observed greater moisture content at most measured soil layers of NT than minimum and conventional tillage. Fernández-Ugalde et al. (2009) showed that greater moisture content under NT was more evident in lower matric potential which indicate a better water availability under no-tillage management. However, we did not found any significant difference among NT, CP and MP managements.

3.4.2 SOIL AGGREGATION MEASUREMENTS

Wet aggregate stability (WAS) differed considerably among treatments. However, due to high variance among replicates the differences were only significant at 15-30 cm of soil depth (p=0.03). At surface depth, NT and NT-W with average value of 44.4, resulted in 27% greater WAS than CP and DP (average WAS=34.90) and 36.7% greater WAS than MP. At 15-30 cm, NT had significantly greater fraction of water stable aggregates than CP> DP> MP, whereas NT did not differ significantly with NT-W. WAS was not affected significantly by either sampling depth or depth by management interaction (p>0.05).

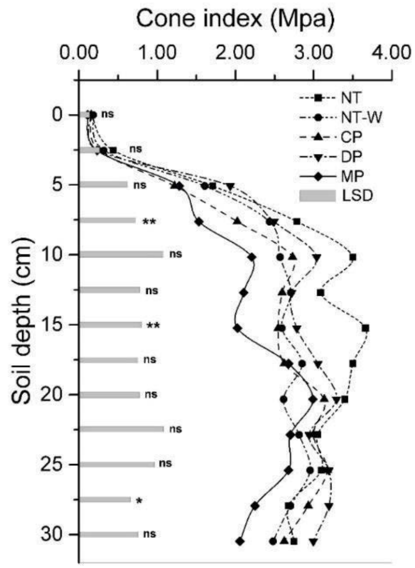

Figure 3.1. Mean soil profile penetration resistance (PR) as affected by tillage managements and wheat cover crop. CP, chisel plow; DP, disk plow; MP, moldboard plow; NT, no-tillage; NT-W, no-tillage planted with wheat cover crop. Horizontal bars on Y axis represent the LSD values (p <0.05). ns, is non-significant; *, is significant at p <0.05; **, is significant at p <0.01.

Average fraction of water stable aggregates at 0-15 cm was 17% greater than at 15-30 cm (Stone and Schlegel, 2010; Blanco-Canqui et al., 2009). Considerably higher WAS under NT and NT-W is attributed to maintenance of aggregate structure due to the lack of mechanical disruption and accumulation of below and above ground soil organic carbon under NT management. However, additional biomass input by wheat cover crop under NT-W management did not benefit the no-tillage management with higher fraction of WAS than NT. This can be related to the relatively high temperature and rainfall in fallow periods which leads to the rapid decomposition of organic matter.

Dry aggregate size distribution of both sampling depths was significantly affected by tillage and cropping management (Table 3.2). At 0-15 cm GMD and MWD were significantly higher under NT-W and NT managements; whereas the lowest value was observed in MP. Similar results were also observed by Bhattacharyya et al. (2009) and Angers et al. (1993). GMD, as an average of two NT managements was 43% greater than average of reduced tillage managements (DP and CP) and 84% greater than MP. Greater residue retention by NT system has frequently been reported to increase the biological activities specially at near surface layer which in turn accelerates the formation of larger aggregates (Six et al., 2000) by releasing the binding agents (Tisdall and Oades, 1982).

Table 3.1. Mean values and ANOVA table of soil physical properties as affected by tillage and cropping managements. Parameters are: WAS, wet aggregate stability; ρb, bulk density; θ_{va}, near FC in-situ soil moisture content; θ_{vb}, soil moisture content at lower field matric potential; PR, penetration resistance; Φ, total porosity.

	WAS (%)	ρb (Mg m^{-3})	θ_{va} (cm^3 cm^{-3})	θ_{vb} (cm^3 cm^{-3})	PR (Mpa)	Φ (%)
Management			*0-15 cm soil depth*			
CP	36.31(3.69)a	1.47(0.005)a	30.1(0.53)a	20.4(2.11)a	1.60(0.08)cd	44.6(0.18)b
DP	33.50(4.88)a	1.43(0.01)b	28.2(1.12)a	14.5(1.12)b	1.92(0.15)ab	45.9(0.49)a
MP	32.50(5.73)a	1.45(0.009)ab	31.7(0.64)a	19.5(2.47)a	1.34(0.07)d	45.2(0.33)ab
NT	46.50(3.44)a	1.46(0.01)a	30.6(1.58)a	17.2(1.38)ab	2.17(0.15)a	44.9(0.45)b
NT-W	42.37(8.38)a	1.48(0.006)a	33.5(1.31)a	13.4(1.85)b	1.77(0.11)bc	44.1(0.24)b
			15-30 cm soil depth			
CP	39.69(0.96)b	1.50(0.03)a	32.3(1.92)a	22.9(2.78)a	2.96(0.30)a	43.4(1.32)a
DP	39.19(3.72)b	1.44(0.03)a	30.9(0.91)a	20.7(3.71)a	3.11(0.09)a	45.7(1.30)a
MP	37.01(1.73)b	1.50(0.01)a	30.9(0.60)a	23.4(0.67)a	2.56(0.18)a	43.4(0.31)a
NT	47.06(3.49)a	1.46(0.03)a	28.9(2.56)a	17.7(1.74)a	3.08(0.07)a	44.9(1.19)a
NT-W	42.01(2.42)ab	1.49(0.01)a	31.4(1.39)a	14.9(2.45)a	2.74(0.26)a	43.7(0.26)a
ANOVA (p≤ 0.05)						
Depth (A)	0.09	0.03	0.05	0.03	0.001	0.03
Depth (B)	0.03	0.45	0.66	0.13	0.11	0.44
Depth	0.17	0.21	0.9	0.04	<.0001	0.21
T*D	0.84	0.74	0.21	0.71	0.53	0.74

CP, chisel plow; DP, disk plow; MP, moldboard plow; NT, no-tillage; NT-W, no-tillage planted with wheat cover crop.
§ Means followed by different letters are significantly different based on $p < 0.05$ within managements.

These significant differences in GMD and MWD were initiated from the significant difference in the fraction of macroaggregates (> 2mm), small macroaggregates (0-.25-2 mm) and microaggregates (0.05-0.25 mm) at 0-15 cm and significantly different fraction of macroaggregates at 15-30 cm. In accordance with Beare et al. (1994) and Mikha and Rice. (2004), at 0-15 cm, fractional abundance of macroaggregates was significantly higher under NT and NT-W than CP and MP; whereas DP revealed intermediate value. Similarly, on a sandy loam, Fernández et al. (2010) observed significantly greater fraction of macroaggregates under NT at all depth increments down to 18 cm of the soil. However, the fraction of SMA and MIA was conversely greater under CP and MP than NT and NT-W. The differences in GMD and MWD at 15-30 cm soil depth were mainly affected by the significance of difference in MA fraction while no significant differences were observed in SMA and MIA. DASD differences among managements were significantly affected by sampling depth ($p < 0.05$). The MWD in average was 13% greater at surface depth than second depth. As illustrated in (Fig. 3.2), two size classes of aggregate (1-2 m and 0.85-1 mm) in neither of sampling depths were affected by tillage and cropping managements. MP at both depths had significantly greater fraction of aggregates in smallest size class of < 0.05. Our results on the distribution of aggregate size classes accord the findings of Singh and Malhi (2006) who concluded that the elimination of aggregate fragmentation by tillage and additional residue turn over increases the macroaggregation in a Canadian loam. We found that the effect of tillage and cropping management on soil aggregation is not limited to the few centimeters of the surface layer. The reason is probably the greater and more rapid effect of soil disturbance than aggregation process on aggregate size distribution.

3.4.3 WATER INFILTRATION AND FIELD-SATURATED HYDRAULIC CONDUCTIVITY

As shown in (Fig. 3.3), hydraulic properties including initial and cumulative infiltration and field-saturated hydraulic conductivity resulted in considerable variations among four replicates (Reynolds et al., 2000). The highest variations were observed under NT and NT-W managements. Despite the normality of replicates distribution (Shapiro-Wilk $p > 0.05$), no significant differences in any measured hydraulic parameters was observed among managements. NT-W with an average value of 144 $mm.h^{-1}$ had the highest li while MP with an average value of 86 $mm.h^{-1}$ had the lowest i_i.

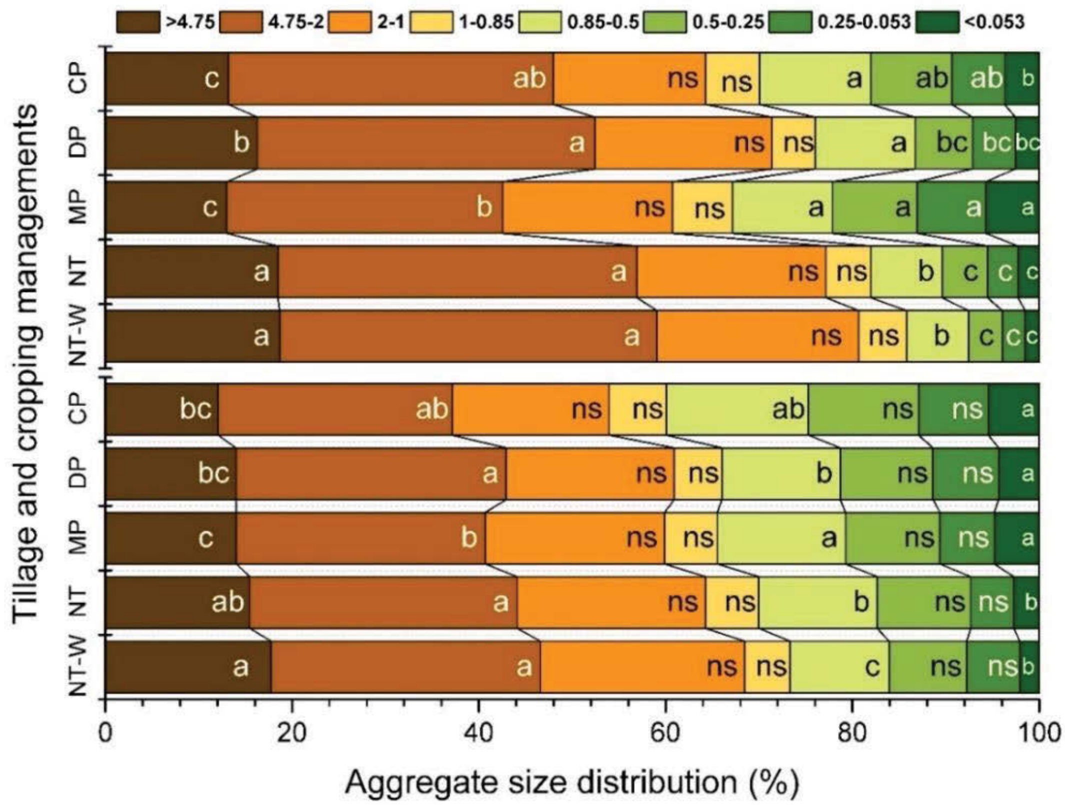

Figure 3.2. Dry aggregate size distribution at 0-15 and 15-30 cm soil depth under five management practices. CP, chisel plow; DP, disk plow; MP, moldboard plow; NT, no-tillage; NT-W, no-tillage planted with wheat cover crop. Different letters in bars indicate significant difference among treatments at each specific size class within each depth ($p < 0.05$).

Table 3.2. Mean values and ANOVA table of dry aggregate size distribution as affected by tillage and cropping managements. Parameters are: GMD, geometric mean diameter; MWD, mean weight diameter; MA, fraction of macroaggregates (> 2mm); SMA, fraction of small macroaggregates (0.25-2 mm); MIA, fraction of microaggregates (0.05-0.25 mm).

	WAS (%)	ρb (Mg m^{-3})	θ_{va} (cm^3 cm^{-3})	θ_{vb} (cm^3 cm^{-3})	PR (Mpa)	Φ (%)
Management	*0-15 cm soil depth*					
CP	36.31(3.69)a	1.47(0.005)a	30.1(0.53)a	20.4(2.11)a	1.60(0.08)cd	44.6(0.18)b
DP	33.50(4.88)a	1.43(0.01)b	28.2(1.12)a	14.5(1.12)b	1.92(0.15)ab	45.9(0.49)a
MP	32.50(5.73)a	1.45(0.009)ab	31.7(0.64)a	19.5(2.47)a	1.34(0.07)d	45.2(0.33)ab
NT	46.50(3.44)a	1.46(0.01)a	30.6(1.58)a	17.2(1.38)ab	2.17(0.15)a	44.9(0.45)b
NT-W	42.37(8.38)a	1.48(0.006)a	33.5(1.31)a	13.4(1.85)b	1.77(0.11)bc	44.1(0.24)b
	15-30 cm soil depth					
CP	39.69(0.96)b	1.50(0.03)a	32.3(1.92)a	22.9(2.78)a	2.96(0.30)a	43.4(1.32)a
DP	39.19(3.72)b	1.44(0.03)a	30.9(0.91)a	20.7(3.71)a	3.11(0.09)a	45.7(1.30)a
MP	37.01(1.73)b	1.50(0.01)a	30.9(0.60)a	23.4(0.67)a	2.56(0.18)a	43.4(0.31)a
NT	47.06(3.49)a	1.46(0.03)a	28.9(2.56)a	17.7(1.74)a	3.08(0.07)a	44.9(1.19)a
NT-W	42.01(2.42)ab	1.49(0.01)a	31.4(1.39)a	14.9(2.45)a	2.74(0.26)a	43.7(0.26)a
ANOVA (p≤ 0.05)						
Depth (A)	0.09	0.03	0.05	0.03	0.001	0.03
Depth (B)	0.03	0.45	0.66	0.13	0.11	0.44
Depth	0.17	0.21	0.9	0.04	<.0001	0.21
T*D	0.84	0.74	0.21	0.71	0.53	0.74

§ Means followed by different letters are significantly different based on $p < 0.05$ within managements.
CP, chisel plow; DP, disk plow; MP, moldboard plow; NT, no-tillage; NT-W, no-tillage planted with wheat cover crop.

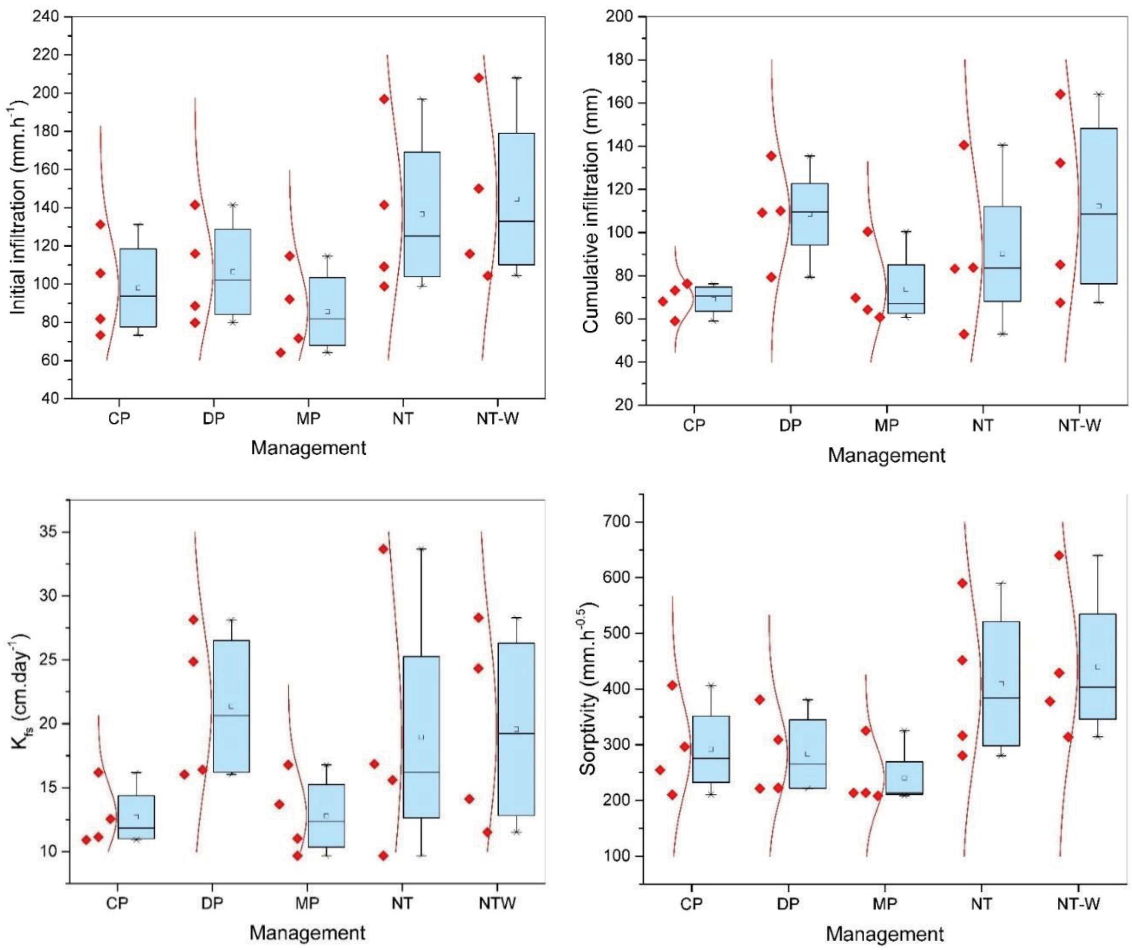

Figure 3.3. Initial and cumulative infiltration, field-saturated hydraulic conductivity and sorptivity as affected by tillage managements and wheat cover crop. CP, chisel plow; DP, disk plow; MP, moldboard plow; NT, no-tillage; NT-W, no-tillage planted with wheat cover crop. Bell curve represent the normal distribution of four replicates. Normality was accepted by Shapiro-Wilk (p >0.05). Treatment means are not significantly different for any parameter based of Fisher's LSD (p>0.05).

The trend of initial infiltration followed the order of; NT-W> NT> DP> CP> MP. Residue cover retained at soil surface due to reduced or eliminated soil manipulation preserves the pore continuity at soil-atmosphere interface which leads to increase the initial water infiltration. Additionally, higher root density at near surface zone under NT (De Rouw et al., 2010) has a soil loosening effect that increases the soil porosity and consequently the water percolation.

The cumulative infiltration during 230 min of each individual experiment was highest in NT-W and lowest in CP. The order of magnitudes among managements were: NT-W> DP> NT> MP> CP. Field-saturated hydraulic conductivity however, was greatest under DP and lowest under CP and MP. Order of magnitude for K_{fs} was: DP> NT-W> NT> MP> CP. These results contrast those reported by Blanco-Canqui et al. (2017) who observed a greater water infiltration under MP than NT one year after tillage application in a long-term study on a Aksarben silty clay loam. They concluded that long-term NT has not improved the water infiltration of their study soil. The reason can be attributed to the fact that they have measured water infiltration on different tillage applications one year after all tilled managements had been converted to NT, hence the corn residue retained at the surface of previously tilled soil has formed a protective cover at soil surface that probably reduced the chance of surface sealing (Stone and Schlegel, 2010). It is important to note that soil surface condition affects all the aspect of water infiltration independent from the pore characteristics of the soil matrix. Based on our visual experience from the study site, rainfalls occur shortly after tillage at the begging of growing season, detach and splash the aggregates to smaller units which rapidly clog the inlet of pores at the transition interface and considerably decrease the water infiltration. This effect varies among the tillage intensities and residue cover associated with each tillage system. Function-based approach toward assessing the soil quality parameter requires a greater concentration on in-situ measurement in presence of other influents than laboratory analysis. Our results are in accordance with the findings of Dao (1993), Mahboubi et al. (1993) and Arshad et al. (1999) who found higher water infiltration and saturated hydraulic conductivity under NT than conventional tillage. Large and continuous pore system formed by long-term biological activities and root activity in undisturbed soils has been shown to contribute considerably to water infiltration and percolation (Strudley et al., 2008). In contrast, in other studies conventional tillage resulted in greater hydraulic conductivity than NT or reduced tillage (Datiri andLowery, 1991) or no significant difference has been found. Chang and Lindwall (1989) found no significant difference in hydraulic conductivity of a clay loam among tillage managements however, they reported greater infiltration under NT than conventional tillage.

Sorptivity is defined as the soil capacity to imbibe water (Lal and Vandoren., 1990) which is highly related to the initial infiltration rate and antecedent soil moisture content (Kumar et al., 2012). Our calculated sorptivity parameter, correlated well with initial infiltration rate (r=0.92). In accordance with findings of Huang et al. (2015) and Lal and Vandoren (1990), NT-W with 440 mm.$h^{-0.5}$ of S had the greatest capacity among all managements to absorb water in initial stages of infiltration process. This management was followed by NT system with mean S value of about 410 mm.$h^{-0.5}$. Reduced tillage managements (CP and DP) exhibited intermediate S values (292 and 283 mm $h^{-0.5}$ respectively), while MP had the lowest mean S value (240 mm $h^{-0.5}$). Greatest S under NT-W can be attributed to the organic matter retained at the soil surface by the lack of soil mixture. Organic substances when added to soil, increase the capacity of soil to absorb and retain the water. This specification of organic matter in addition to the continuity of pore system and the surface on NT soil explains the reason for higher sorptivity under NT managements than reduced or conventionally tilled soils.

3.5 CONCLUSION

Additional residue input by winter wheat bio-cover did not favor no-tillage with further improvement in soil physical properties than no-tillage. NT management systems were found to have higher bulk density, penetration resistance, in-situ near FC moisture content and lower total porosity than reduced tillage managements and conventional tillage. Differences were mostly significant at surface depth. However, the aggregation parameters significantly differed among treatments at both sampling depths. Compared with either MP or RT managements, NT managements promoted the geometric mean diameter, mean weight diameter and fraction of macroaggregates (> 2 mm) at both depths. NT also resulted in non-significantly higher wet aggregate stability at 0-15 cm and significantly higher WAS at 15-30 cm compared with MP, CP and DP. Significance of differences among treatment in hydraulic properties was affected by relatively high spatial variability among replicates. Despite the greater initial infiltration rate, cumulative infiltration, field-saturated hydraulic conductivity and sorptivity mainly under NT managements and DP than CP and MP, no statistically significant differences were observed for any measured hydraulic property.

The findings indicate that under sub-humid and temperate climate of mid-south US, additional residue and root biomass returned on NT by wheat cover crop is not sufficient to create a consistently more favorable soil physical condition than NT without cover crop. NT managements despite the increased bulk density and penetration resistance at surface layer, resulted in an improved aggregation, aggregate stability, and non-significantly better hydraulic properties than

CP, DP and MP managements. Between two reduced tillage systems, disk plow was found to be comparable with NT in certain measured properties such as cumulative infiltration and field-saturated hydraulic conductivity. Future works will concentrate on the relationship between the all reported and unreported soil physical properties, yield and yield stability to identify the properties which may promote or limit the productivity.

3.6 REFERENCES

Abiven, Samuel, Safya Menasseri, and Claire Chenu. "The effects of organic inputs over time on soil aggregate stability–A literature analysis." Soil Biology and Biochemistry 41.1 (2009): 1-12.

Alvarez, R., and H. S. Steinbach. "A review of the effects of tillage systems on some soil physical properties, water content, nitrate availability and crops yield in the Argentine Pampas." Soil and Tillage Research 104.1 (2009): 1-15.

Angers, D. A., N. Samson, and A. Legere. "Early changes in water-stable aggregation induced by rotation and tillage in a soil under barley production." Canadian journal of Soil Science 73.1 (1993): 51-59.

Barzegar, A. R., et al. "Soil physical characteristics and chickpea yield responses to tillage treatments." Soil and Tillage Research 71.1 (2003): 49-57.

Beare, M. H., et al. "Aggregate-protected and unprotected organic matter pools in conventional-and no-tillage soils." Soil Science Society of America Journal 58.3 (1994): 787-795.

Bescansa, P., et al. "Soil water retention as affected by tillage and residue management in semiarid Spain." Soil and Tillage Research 87.1 (2006): 19-27.

Bhattacharyya, R., et al. "Soil aggregation and organic matter in a sandy clay loam soil of the Indian Himalayas under different tillage and crop regimes." Agriculture, Ecosystems & Environment 132.1 (2009): 126-134.

Blanco-Canqui, Humberto, et al. "No-till induced increase in organic carbon reduces maximum bulk density of soils." Soil Science Society of America Journal 73.6 (2009): 1871-1879.

Blanco-Canqui, Humberto, L. R. Stone, and P. W. Stahlman. "Soil response to long-term cropping systems on an Argiustoll in the central Great Plains." Soil Science Society of America Journal 74.2 (2010): 602-611.

Blanco-Canquia, Humberto, et al. "Long-term tillage impact on soil hydraulic properties." Soil & Tillage Research 170 (2017): 38-42.

Bruce, R. R., G. W. Langdale, and A. L. Dillard. "Tillage and crop rotation effect on characteristics of a sandy surface soil." Soil Science Society of America Journal 54.6 (1990): 1744-1747.

Bullock, Murray Stewart, S. D. Nelson, and W. D. Kemper. "Soil cohesion as affected by freezing, water content, time and tillage." Soil Science Society of America Journal 52.3 (1988): 770-776.

Cameira, M. R., R. M. Fernando, and L. S. Pereira. "Soil macropore dynamics affected by tillage and irrigation for a silty loam alluvial soil in southern Portugal." Soil and Tillage Research 70.2 (2003): 131-140.

Carter, M. R., et al. "Influence of rotation and tillage on forage maize productivity, weed species, and soil quality of a fine sandy loam in the cool–humid climate of Atlantic Canada." Soil and Tillage Research 67.1 (2002): 85-98.

Gassel, D. K. "Tillage effects on soil bulk density and mechanical impedance." Predicting tillage effects on soil physical properties and processes predictingtilla (1982): 45-67.

Chang, C., and C. W. Lindwall. "Effect of long-term minimum tillage practices on some physical properties of a Chernozemic clay loam." Canadian Journal of Soil Science 69.3 (1989): 443-449.

Culley, J. L. B., W. E. Larson, and G. W. Randall. "Physical properties of a typic Haplaquoll under conventional and no-tillage." Soil Science Society of America Journal 51.6 (1987): 1587-1593.

Dao, Thanh H. "Tillage and winter wheat residue management effects on water infiltration and storage." Soil Science Society of America Journal 57.6 (1993): 1586-1595.

Daraghmeh, O. A., Jens Raunsø Jensen, and C. T. Petersen. "Soil structure stability under conventional and reduced tillage in a sandy loam." Geoderma 150.1 (2009): 64-71.

Datiri, Benjamin C., and Birl Lowery. "Effects of conservation tillage on hydraulic properties of a Griswold silt loam soil." Soil and Tillage Research 21.3-4 (1991): 257-271.

Da Veiga, Milton, et al. "Soil compressibility and penetrability of an Oxisol from southern Brazil, as affected by long-term tillage systems." Soil and Tillage Research 92.1 (2007): 104-113.

Deen, W., and P. K. Kataki. "Carbon sequestration in a long-term conventional versus conservation tillage experiment." Soil and Tillage Research 74.2 (2003): 143-150.

Denton, H. P., and D. D. Tyler. "Making no-till “conventional” in Tennessee." Making conservation tillage conventional: Building a future on 25 (2002): 53-58.

De Rouw, Anneke, et al. "Possibilities of carbon and nitrogen sequestration under conventional tillage and no-till cover crop farming (Mekong valley, Laos)." Agriculture, Ecosystems & Environment 136.1 (2010): 148-161.

Dexter, A. R. "Amelioration of soil by natural processes." Soil and Tillage Research 20.1 (1991): 87-100.

Dörner, J., et al. "Effect of land use change on the dynamic behaviour of structural properties of an Andisol in southern Chile under saturated and unsaturated hydraulic conditions." Geoderma 159.1 (2010): 189-197.

Fernández, Romina, et al. "Carbon contents and respiration rates of aggregate size fractions under no-till and conventional tillage." Soil and Tillage Research 109.2 (2010): 103-109.

Fernández-Ugalde, Oihane, et al. "No-tillage improvement of soil physical quality in calcareous, degradation-prone, semiarid soils." Soil and Tillage Research 106.1 (2009): 29-35.

Govaerts, Bram, et al. "Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue and crop rotation managements." Soil and Tillage Research 94.1 (2007): 209-219.

Green, Timothy R., Lajpat R. Ahuja, and Joseph G. Benjamin. "Advances and challenges in predicting agricultural management effects on soil hydraulic properties." Geoderma 116.1 (2003): 3-27.

Green, W. Heber, and G. A. Ampt. "Studies on Soil Phyics." The Journal of Agricultural Science 4.1 (1911): 1-24.

Grossman, R. B., and T. G. Reinsch. "2.1 Bulk density and linear extensibility." Methods of Soil Analysis: Part 4 Physical Methods (2002): 201-228.

Hernanz, J. L., et al. "Long-term effects of tillage systems and rotations on soil structural stability and organic carbon stratification in semiarid central Spain." Soil and Tillage Research 66.2 (2002): 129-141.

Hodgson, D. R., N. A. Hipps, and M. A. Braim. "Direct drilling compared with ploughing for winter wheat grown continuously and the effects of subsoiling." Soil Use and Management 5.4 (1989): 189-194.

Huang, Manxiang, et al. "Effects of no-tillage systems on soil physical properties and carbon sequestration under long-term wheat–maize double cropping system." Catena 128 (2015): 195-202.

Jabro, Jay D., et al. "Tillage effects on physical properties in two soils of the Northern Great Plains."

Applied Engineering in Agriculture 25.3 (2009): 377-382.

Jastrow, J. D., and R. M. Miller. "Methods for assessing the effects of biota on soil structure." Agriculture, Ecosystems & Environment 34.1-4 (1991): 279-303.

Karami, Alidad, et al. "Organic resource management: impacts on soil aggregate stability and other soil physico-chemical properties." Agriculture, Ecosystems & Environment 148 (2012): 22-28.

Kemper, W. D., and R. C. Rosenau. "Aggregate stability and size distribution." (1986): 425-442.

Kladivko, Eileen J. "Residue effects on soil physical properties." Managing agricultural residues. Lewis Publishers, Boca Raton, FL (1994): 123-141.

Kroulík, M. I. L. A. N., et al. "Water infiltration into soil related to the soil tillage intensity." Soil and Water Research 2.1 (2007): 15-24.

Kumar, Sandeep, et al. "Water infiltration influenced by agroforestry and grass buffers for a grazed pasture system." Agroforestry Systems 84.3 (2012): 325-335.

Lal, R., T. J. Logan, and N. R. Fausey. "Long-term tillage and wheel traffic effects on a poorly drained mollic ochraqualf in northwest Ohio. 1. Soil physical properties, root distribution and grain yield of corn and soybean." Soil and Tillage Research 14.4 (1989): 341-358.

Lal, R., and D. M. Vandoren. "Influence of 25 years of continuous corn production by three tillage methods on water infiltration for two soils in Ohio." Soil and Tillage Research 16.1-2 (1990): 71-84.

Lal, R. "Long-term tillage and wheel traffic effects on soil quality for two central Ohio soils." Journal of Sustainable Agriculture 14.4 (1999): 67-84.

Lal, R., and M. Ahmadi. "Axle load and tillage effects on crop yield for two soils in central Ohio." Soil and Tillage Research 54.1 (2000): 111-119.

Larney, Francis J., C. Wayne Lindwall, and Murray S. Bullock. "Fallow management and overwinter effects on wind erodibility in southern Alberta." Soil Science Society of America Journal 58.6 (1994): 1788-1794.

Lampurlanés, J., and C. Cantero-Martínez. "Hydraulic conductivity, residue cover and soil surface roughness under different tillage systems in semiarid conditions." Soil and Tillage Research 85.1 (2006): 13-26.

Leij, Feike J., Teamrat A. Ghezzehei, and Dani Or. "Modeling the dynamics of the soil pore-size distribution." Soil and Tillage Research 64.1 (2002): 61-78.

Lentz, Roderick D., and David L. Bjorneberg. "Polyacrylamide and straw residue effects on irrigation furrow erosion and infiltration." Journal of Soil and Water Conservation 58.5 (2003): 312-318.

Liebig, M. A., D. L. Tanaka, and Brian J. Wienhold. "Tillage and cropping effects on soil quality indicators in the northern Great Plains." Soil and Tillage Research 78.2 (2004): 131-141.

Lindstrom, M. J., and C. A. Onstad. "Influence of tillage systems on soil physical parameters and infiltration after planting." Journal of Soil and Water Conservation 39.2 (1984): 149-152.

Liu, Yang, et al. "The effects of conservation tillage practices on the soil water-holding capacity of a non-irrigated apple orchard in the Loess Plateau, China." Soil and Tillage Research 130 (2013): 7-12.

Mahboubi, A. A., R. Lal, and N. R. Faussey. "Twenty-eight years of tillage effects on two soils in Ohio." Soil Science Society of America Journal 57.2 (1993): 506-512.

Martens, Dean A. "Management and crop residue influence soil aggregate stability." Journal of Environmental Quality 29.3 (2000): 723-727.

Mendoza, R. B., et al. "Tillage effects on soil quality indicators and nematode abundance in Loessial soil under long-term no-till production." Communications in Soil Science and Plant Analysis 39.13-14 (2008): 2169-2190.

Moreno, F., et al. "Soil physical properties, water depletion and crop development under traditional and conservation tillage in southern Spain." Soil and Tillage Research 41.1-2 (1997): 25-42.

Mikha, Maysoon M., and Charles W. Rice. "Tillage and manure effects on soil and aggregate-associated carbon and nitrogen." Soil Science Society of America Journal 68.3 (2004): 809-816.

Mkhabela, M. S., et al. "Gaseous and leaching nitrogen losses from no-tillage and conventional tillage systems following surface application of cattle manure." Soil and Tillage Research 98.2 (2008): 187-199.

Munoz-Romero, Verónica, et al. "Monitoring wheat root development in a rainfed vertisol: Tillage effect." European Journal of Agronomy 33.3 (2010): 182-187.

NeSmith, D. S., et al. "Soil compaction in double-cropped wheat and soybeans on an Ultisol." Soil Science Society of America Journal 51.1 (1987): 183-186.

Nielsen, David C., Paul W. Unger, and Perry R. Miller. "Efficient water use in dryland cropping systems in the Great Plains." Agronomy Journal 97.2 (2005): 364-372.

Philip, J.R., 1957. The theory of infiltration: 4. Sorptivity and algebraic infiltration equations. Soil Science 84, 257-264.

Reichert, José Miguel, et al. "Is chiseling or inverting tillage required to improve mechanical and hydraulic properties of sandy clay loam soil under long-term no-tillage?" Geoderma 301 (2017): 72-79.

Reynolds, W. D., et al. "3.4 Saturated and field-saturated water flow parameters." Methods of Soil Analysis, Part 4 (2002): 797-801.

Salem, Haytham M., et al. "Short-term effects of four tillage practices on soil physical properties, soil water potential, and maize yield." Geoderma 237 (2015): 60-70.

Sasal, María Carolina, Adrián Enrique Andriulo, and Miguel Angel Taboada. "Soil porosity characteristics and water movement under zero tillage in silty soils in Argentinian Pampas." Soil and tillage Research 87.1 (2006): 9-18.

SAS Institute. 2007. SAS/STAT 9.3 User's guide. SAS Inst., Cary, NC

Schjønning, Per, and Karl J. Rasmussen. "Soil strength and soil pore characteristics for direct drilled and ploughed soils." Soil and Tillage Research 57.1 (2000): 69-82.

Singh, Baldev, and S. S. Malhi. "Response of soil physical properties to tillage and residue management on two soils in a cool temperate environment." Soil and Tillage Research 85.1 (2006): 143-153.

Six, J. A. E. T., E. T. Elliott, and Keith Paustian. "Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture." Soil Biology and Biochemistry 32.14 (2000): 2099-2103.

Smika, D. E. "Fallow management practices for wheat production in the Central Great Plains." Agronomy Journal 82.2 (1990): 319-323.

Stone, Loyd R., and Alan J. Schlegel. "Tillage and crop rotation phase effects on soil physical properties in the west-central Great Plains." Agronomy Journal 102.2 (2010): 483-491.

Strudley, Mark W., Timothy R. Green, and James C. Ascough. "Tillage effects on soil hydraulic properties in space and time: State of the science." Soil and Tillage Research 99.1 (2008): 4-48.

Tabaglio, Vincenzo, Carolina Gavazzi, and Cristina Menta. "Physico-chemical indicators and microarthropod communities as influenced by no-till, conventional tillage and nitrogen fertilisation after four years of continuous maize." Soil and Tillage Research 105.1 (2009): 135-142.

Tisdall, Judith M., and J_M Oades. "Organic matter and water-stable aggregates in soils." European Journal of Soil Science 33.2 (1982): 141-163.

Van den Putte, An, et al. "Assessing the effect of soil tillage on crop growth: A meta-regression analysis on European crop yields under conservation agriculture." European Journal of Agronomy 33.3 (2010): 231-241.

Villamil, María B., Joseph Little, and Emerson D. Nafziger. "Corn residue, tillage, and nitrogen rate effects on soil properties." Soil and Tillage Research 151 (2015): 61-66.

Wagger, M. G., and H. P. Denton. "Tillage effects on grain yields in a wheat, double-crop soybean, and corn rotation." Agronomy Journal 81.3 (1989): 493-498.

Weill, A. N., E. MCKYES, and CR DE KIMPE. "Effect of tillage reduction and fertilizer on soil macro-and microaggregation." Canadian journal of Soil Science 69.3 (1989): 489-500.

Wyngaard, Nicolás, et al. "Fertilization and tillage effects on soil properties and maize yield in a Southern Pampas Argiudoll." Soil and Tillage Research 119 (2012): 22-30.

Yang, Xue-Ming, and Michelle M. Wander. "Tillage effects on soil organic carbon distribution and storage in a silt loam soil in Illinois." Soil and Tillage Research 52.1 (1999): 1-9.

Youker, R. E., and J. L. McGuinness. "A short method of obtaining mean weight-diameter values of aggregate analyses of soils." Soil Science 83.4 (1957): 291-294.

GENERAL CONCLUSION

Thirty-four years of no-tillage and cover crop management improved soil hydro-physical quality and cotton yield than conventional tillage and no cover crop managements. No-till improved wet aggregate stability, aggregate size, water infiltration and transmission compared with conventional tillage. No-tillage increased the crop-essential water in drier period of growing season and increased the cotton yield in both experimental years relative to conventional tillage. Effect of cover crops on soil physical properties were less consistent than the effect of no-tillage and was mainly limited to 0-15 cm of soil surface layer.

Cover crops managements, particularly hairy vetch resulted in non-significantly greater wet aggregate stability, lower bulk density and higher in-situ volumetric water content in drier periods of growing season and significantly greater water infiltration, field-saturated hydraulic conductivity, mean weight diameter and geometric mean diameter than no cover crop management. However, cover crop managements did not significantly affect the cotton yield. Incorporation of hairy vetch with no-tillage significantly and consistently improved the quasi-steady and cumulative infiltration compared to the other treatment combinations. However, despite the general improvement in other soil physical properties under no-tillage with cover crop, the differences with no cover crop were not statistically significant.

Model selection procedure and response surface analysis showed that the variations in cotton lint yield among treatments were considerably related to the changes in soil physical and hydraulic properties. Cotton yield was found to be related to the soil aggregation, water transmission and available water content. Water availability was found to be significantly related to the aggregate size distribution, infiltration properties and soil clay content. These results indicate that long-term adoption of no-tillage in mid-south US resulted in improved soil hydro-physical quality. However, additional improvements in soil quality and productivity of no-tillage requires the cropping managements with greater and more diverse biomass input.

Fourteen years of continuous and double-cropping systems of corn, cotton and soybean affected the soil physical and hydraulic properties of no-tillage including the soil aggregation, water infiltration and transmission and water availability. Cropping in sequence did not significantly affect the soil physical properties than monocropping system. However, type of crop in management significantly affected certain soil physical properties. Characteristics and magnitude of residue retained at soil surface was significantly related to changes in soil physical properties. In general, cropping corn in sequence with cotton and soybean improved soil hydro-physical quality and cotton and soybean yield. Rotating corn with soybean resulted in improved wet aggregate stability, soil moisture content in drier periods, initial and cumulative infiltration, hydraulic conductivity and plant available water content and increased mean corn and soybean yield and yield stability of soybean. Rotating corn with cotton resulted in an intermediate soil physical condition among cotton managements while the mean yield and yield stability of cotton was greatest under this management. Bulk density, cone penetration resistance and total porosity were not affected by cropping managements. A significant year by year variance was observed in corn, cotton and soybean yield. Despite the notable reduction in this variance by adjusting to precipitation and temperature covariates, identification of the real trend of yield production under six cropping systems will require a longer period of yield monitoring.

Thirty-seven years of no-tillage, reduced tillage and conventional tillage on a soybean continuous resulted in significant effect on certain soil physical properties. No-tillage significantly increased the bulk density and addition of winter wheat as cover crop did not affect the bulk density of no-tillage. No-till managements despite a higher fraction of water stable aggregates did not differ significantly with chisel, disk and moldboard. However, the mean weight diameter and geometric mean diameter of aggregates were found to be significantly higher under no-tillage managements at 0-15 and 15-30 cm of soil depth. Soil hydraulic properties including initial and cumulative infiltration and field-saturated hydraulic conductivity were higher under both no-tillage managements than disk, chisel and moldboard plow. However, due to the relatively high spatial variability in hydraulic properties, no significant differences were found between managements.

The findings indicate that adoption of no-tillage in long-term can significantly preserve the aggregates and improve the aggregate stability compared with reduced and conventional tillage. However, these amendments are not strong enough to contribute significantly to the reduction of soil compaction, hydraulic properties and soil water content in drier periods of growing season. Long-term incorporation of winter wheat cover crop did not significantly improve the soil physical quality of no-tillage. These results suggest that under sub-humid climate of mid-south US with relative high decomposition rate of organic matter, cropping systems with more intensive biomass turnover should be accompanied by no-tillage to improve the physical quality of no-tillage and to decrease the soil compaction.

VITA

Amin Nouri was born in 1981, in Urmia, Iran. He received his Bachelor in Soil Science from Urmia University. He earned his Master of Science is Soil Erosion and Conservation, from Soil Science and Plant Nutrition department in Ankara University, Turkey. His Ph.D. work is a collection of three chapters that will be presented as journal publications. He has presented his work in annual assemblies of Soil Science Society of America, International Symposium on Agriculture and the Environment, European Geosciences Union, and other national, international and outreach programs.