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THE EFFECT OF CONSERVATION TILLAGE AND TOPOGRAPHIC POSITION ON SOIL PROPERTIES IN CENTRAL ILLINOIS

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By

Andrew Mellinger

B.S., Cornell University, 2012

A Thesis Submitted in Partial
Fulfillment of the Requirements
For the Degree of
Master of Science

Department of Forestry
in the Graduate School
Southern Illinois University Carbondale
December, 2015

THESIS APPROVAL

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Approved by:
Dr. Jon E. Schoonover, Chair
Dr. Rachel L. Cook
Dr. John W. Groninger

Department of Forestry
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December, 2015

AN ABSTRACT OF THE THESIS OF

Andrew Mellinger, for the Master of Science degree in Forestry, presented on July 30, 2015, at Southern Illinois University Carbondale.

Title: THE EFFECT OF CONSERVATION TILLAGE AND TOPOGRAPHIC POSITION ON SOIL PROPERTIES IN CENTRAL ILLINOIS

Major Professor: Dr. Jon E. Schoonover

Since agriculture began, field management has been at the forefront of expanding food production beyond previous limitations. Agricultural productivity is closely related to the physical, chemical, and biological properties of the soil. Landscape position and field management are among primary factors affecting these soil properties. Delineation of topographic positions of the field surface by shape (i.e., convex, concave, and linear) characterizes areas that may accumulate or lose soil and nutrients either during a discrete event or cumulatively over several growing seasons. Increased soil compaction, degradation of soil structure, and erosion have all been attributed to declining agricultural production. In addition to the physical disturbance from cultivation, erosion and deposition of soil components in different landscape positions explain a large part of the heterogeneity of soil properties across an agriculture field. In response to this, conservation tillage techniques, precision agriculture, and other novel management strategies have been developed to reduce negative impacts conventional row crop production such as nutrient pollution and compaction while optimizing farmer inputs. The objective of this project was to evaluate effects of topographic position and conservation tillage techniques on soil physical, chemical, and biological properties on the field scale as well as correlate certain soil attributes with suspended soil runoff collected during the sprinkle infiltration test. Soil fertility sampling was completed every fall from 2011 to 2014 and additional sampling of soil physical properties was taken in the spring between 2013 and 2014. Differences between fall conservation tillage treatments, no-till (NT), AerWay® aerator (AA), and Great Plains Turbo-Till® (GP), and topographic positions, concave, convex and linear were analyzed. Sediment runoff and earthworm biomass were also collected in the fall in 2014. Results indicated a significant increase of soil organic matter (12%-24%), water stable aggregates (78%-98%), phosphorus (43%-76%), and cation exchange capacity (28%-35%) within concave over the convex landscape positions. Soil strength was significantly lower in the field managed with the GP vertical tillage disk compared with the AA field to a depth of 27.5 cm and the NT field to depth of 17.5 cm. Crop residue coverage (percent covered) was more complete in the NT field (12%) and the GP field (3%) compared with the AA field. Suspended sediment runoff was negatively correlated with water-stable aggregates, Ca, and Mg, but positively correlated with earthworm biomass. Extractable nutrients and soil physical properties were also strongly affected by air temperature and precipitation throughout the study period. Characterizing soil properties within topographic positions has potential applications in precision agriculture management, such as reducing excessive fertilization, and identifying areas of increased pollution potential. Evaluation of the tandem effects of conservation tillage tools and topographic position within central Illinois is important in order for the optimization of production and conservation of resources. Physical disturbance from tillage and the transport of sediment from eroded areas to depositional topographic positions are key factors influencing the variability of soil properties, crop productivity, and potential sediment-borne nutrient pollution within individual agricultural fields.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Background

The beginnings of agriculture, which included cultivation and domestication of species around 10,000 years ago, fundamentally changed the relationship between humans and our natural environment (Brown et al., 2009). Continuing intensification of agriculture has allowed our culture and population to grow. Recently, we have become increasingly aware of consequences associated with our agricultural intensification and disturbance of more of the landscape. In order to reduce the financial and ecological costs of agriculture production, conservation agriculture techniques, specifically reduced tillage and no- till, were developed to conserve and increase the efficiency of agricultural resources (Hobbs et al., 2008). These management techniques retain more crop residue on the soil surface and optimize physical disturbance; conditions associated with reduced compaction and erosion which are primary determinants of soil function and stability.

Evaluation of no-till techniques and conservation tillage compared to conventional tillage has attracted the attention of soil scientists and agronomists for many years. However, the effects of topographic position and how topographic position interacts with tillage management to affect variation in soil properties receives much less attention. While there were a few examples of interaction between conservation tillage effects and topographic position effects in this study, topographic position was found to be an important factor affecting soil variability independently from conservation tillage treatments. Topsoil, which holds much of the nutrients necessary for agricultural productivity as well as unique physical properties, tends to be eroded from convex positions and is deposited in concave positions even in landscapes with subtle topographic positions which may affect these differences (Papiernik et al., 2009). Soil erosion from convex landscape positions and deposition in concave positions is widely understood conceptually, but it is rarely used to characterize fertility and other soil attributes within field sites with 0-2% slope. Analyzing elevation data on the field scale allows the user to delineate subtle changes in surface topography that is difficult to observe at the ground level. This classification was completed by analyzing a digital elevation map (DEM) using a topographic position index and automated using GIS software (Jenness, 2006; Wiess, 2001). Soil samples taken in each of these positions in this study indicate that these slopes independently affect soil properties or interact with other variables to affect soil properties over a single season. Characterizing soil properties within each topographic position could also be useful for precision agriculture tools as well as identifying critical source areas of nutrient loss.

Purpose

This research project comprised two parts. First, the influence of three conservation tillage practices and topographic position on soil physical and chemical properties were quantified over multiple cropping seasons in a corn-soybean rotation in central Illinois. Soil strength, soil bulk density (Bd), water-stable aggregates (WSA), volumetric water content, and crop residue coverage were quantified before and after tillage treatments were completed to determine the effects on soil properties. Differences in conservation tillage management and topographic position were considered independent fixed effects. Second, relationships between stability of soil aggregates in water (WSA), total suspended solids of runoff water, earthworm biomass, soil organic matter (SOM), and soil chemical properties were assessed. The relationship between these soil properties and total suspended solids of runoff water were evaluated to determine if WSA, earthworm biomass, SOM, compaction, and soil chemistry were useful indicators of soil erodibility. Data collected in this study provides evidence of how field management and topographic position may interact or independently affect soil attributes or relationships between soil properties within this site and their impacts on soil movement dynamics as overland flow. Few research projects attempt to quantify the joint influence of topographic position and different conservation tillage practices on soil properties in row-crop agriculture in central Illinois. A co-assessment of the suspended solids by collecting runoff water from the Cornell sprinkle infiltrometer and investigating the relationships between soil attributes and this erosion is also unique. Objectives of the study are as follows:

1. Determine the effect of soil topographic position and vertical tillage management on soil physical and chemical properties.

2. Investigate correlations between water stable aggregate percentage of soil, earthworm biomass of soil, and erodibility through the analysis of total suspended solids from runoff.
3. Assess relationships among soil properties and how they are influenced by climate topographic position, fertilization rates, and vertical tillage.

Tillage

Tillage has many applications in many farming systems. Weed control, pore space, incorporation of residue, tilth, nutrient mineralization, compaction, pest control, seedbed preparation, soil moisture, and soil temperature can be improved by tillage in the short term but are not always sustained for the long term (Hobbs et al., 2008). The advantages and disadvantages can be complicated. For example, temporary relief of compaction from tillage is accompanied by increases in compaction from the additional passes across the field and can create root-restricting “plow-pans.” (Daum, 1996). An increase of soil organic matter (SOM) mineralization due to exposure and aeration is accomplished by more effective residue incorporation from tillage (Kay et al., 2002; Frey et al., 1999). However, the losses of aggregates and SOM from physical disturbance negatively affects soil tilth in the long term which influences ease of tillage and seedling emergence. (Soil Science Society of America, 2008) which is a primary justification for tillage (Beare et al., 1994). Evidence from many studies suggest short-term benefits of physical and chemical function of soils from tillage are typically undermine long-term productivity with continual, and/or excessive disturbance.

No-till and conservation tillage strategies are alternatives to conventional tillage which reduce the amount of soil disturbance. Conservation tillage is defined as more than 30 percent crop residue left on the soil surface after all fieldwork has been completed (Soil Science Society of America, 2008). Conversely, conventional tillage is defined as any practice that retains less than 30 percent of crop residue on the soil surface and employs both primary and secondary tillage operations (CTIC, 2002; Soil Science Society of America, 2008). According to studies done by Houx et al., (2011); Logsdon (2013); Roger-Estrade et al., (2010) and many others, Excessive soil disturbance increases erosion directly through physical disturbance, and indirectly influencing chemical characteristics, and disturbing biodiversity. Tillage has also been shown to affect the stability of soil aggregates in water, potentially leading to increased erosion and instability (Barthes & Roose, 2002). For example, stable aggregates formed by macro-organisms and fungal hyphae are often more delicate than other forms and more susceptible to physical destruction by tillage (Zhang & Schrader, 1993; Tisdall, 1994). Comparisons between conventional tillage and conservation tillage were not evaluated in this study however, these comparisons were helpful when evaluating the difference between the two conservation tillage implements used in this study. Similar to differences between conservation tillage and conventional tillage, differences in soil disturbance between conservation tillage methods may also have implications for soil quality and sustainable crop production (DeLuane & Sij, 2012; Brummer et al, 1999).

Conservation tillage retains some of the benefits from tillage while limiting the costs of excessive soil disturbance from conventional practices. Specifically evaluated in this research, vertical tillage is a conservation tillage strategy that is primarily used for soil aeration, seedbed levelling and residue management in the spring or fall. This is different from disc harrows, a secondary tillage tool used in conventional tillage, which angles each disk bank in order to turn the soil more aggressively covering more residue (Thilges, 2010; Figure 2). No-tillage, effectively removes tillage activities and is sometimes completed in conjunction with occasional subsoiling in the Midwest (Soil Science Society of America, 2008).

Soil Organic Matter

Wander et al. (2000) suggested SOM as an index of soil quality because it is a factor in most soil physical and chemical characteristics. Nichols et al. (2011) also suggested that SOM is strongly correlated to aggregate stability content of the soil. Soil quality monitoring of changes in key parameters over time is important for the formation of sustainable farming practices (Baldock et al., 2009). Soil pH and SOM were determined to be the greatest indicators of soil health by Baldock et al., (2009). Additionally, SOM was found to be useful in determining the extent of soil erosion as well as being indicative of general soil productivity (Papiernick et al., 2009; Wang et al., 2014). Nutrient dynamics and soil physical structure vary widely depending on the area and climate, but tracking changes in some indicators such as SOM, is useful for all areas (Cotching et al., 2010).

Crop Residue

Surface residue was found by many studies to be an important factor in decreasing erosion. Truman et al. (2005) found that no-tillage practices in the southeast United States increased water stable aggregates by 21 percent, infiltration soil strength by 3.5 times and decreased sediment yield compared to conventional practices. They also found that 38 percent of erosion in the first 60 minutes of a simulated rainfall and 76 percent of erosion after 120 minutes was due to the presence of surface residue in both conventionally tilled and no-tillage sites. The amount of surface residue and sediment yield from the no-tillage sites were also positively correlated (Truman et al., 2005). Mulumba and Lal (2008) found that 8 Mg/ha residues in central Ohio increased porosity up to 46 percent and available water capacity up 35 percent. They also determined water stable aggregates had a strong correlation to amounts of residue. In a long term study by McVay et al. (2006) aggregate stability increased with less tillage but water holding capacity was not affected. Most of the differences observed in many tillage studies occur in the first five cm of soil (McVay et al. 2006; Mulumba & Lal 2008). Also, many tillage studies stress the importance of precipitation and temperature at the research site (McVay et al., 2006; Houx et al., 2011).

Earthworms

There are few terrestrial ecosystems, with the exception of deserts, that do not have earthworms as part of the ecosystem (Blakemore, 2007). Groups of worms can be separated into epigeic and endogenic species. Epigeic worms are small and t can tolerate a highly variable environment and thrive in high levels of organic matter like compost piles. Endogenic species live slightly deeper, derive nutrition from soil while burrowing horizontally and leaving extensive casts; and anecic species which are large worms that feed on litter they pull into deep, semi-permanent burrows (Haynes et al, 2003). These groups have distinct functions in soil and affect soil conditions in different ways (Lavelle et al, 1998). For example, Zhang and Schader (1993) found the earthworm ingestion reduced water stability of aggregates and aggregate tensile strength after drying than natural soil with the exception of *Lumbricus terrestris* casts and while the tensile strength of the burrow was higher its stability in water was lower. *Aporrectodea caliginosa* casts, an endogeic species and common in the study area, exhibited similar water stability to natural soil like *Lumbricus terrestris*, but the burrow walls were less stable in water. The authors suggested that the selection of higher quality food of these species caused the slightly higher water stability of the cast due to an increase in organic carbon. Furthermore, that casts of both these species decreased WSA particularly in clay and silt soils like the soil textures found at this study site (Zhang and Schader 1997). Despite disturbing stability of aggregates in water, earthworms have been found to be useful as reliable indicators of soil quality, productivity, and potential toxicity (Bartz et al., 2013; Stork et al., 1991; Birkas et al., 2004).

Soil Aggregate Formation

A soil aggregate is a collection of soil particles/materials that agglomerate more strongly compared to the surrounding material (Kemper & Rosenau, 1986). There are two general size classifications of soil aggregates, microaggregates, classified as less than 250 μm, and macroaggregates, classified as larger than 250 μm. Macroaggregates are typically more loosely associated conglomerates of microaggregates and other materials (Edwards et al., 1967; Oades et al., 1991). The strength of coherence and size of aggregates is determined by chemical and physical properties of the materials and is mediated by moisture content (Tisdall et al., 1982; Tisdall, 1994; Kemper & Rosenau, 1986). Inorganic chemical processes are more common in the formation of smaller aggregates and are typically stronger than macroaggregates (Tisdall et al., 1982). Plants and fungal organism interactions such as vesicular arbuscular mycorrhizal associations also facilitate formation of soil aggregates by physically connecting smaller aggregates and establishing a macroaggregate structure. Polysaccharides released by roots, macrofauna (earthworms) and hyphae also chemically contribute to binding particles and microaggregates into larger structures (Tisdall, 1994; Fonte et al., 2012).

Destruction of Soil Aggregates

Physical soil disturbance and aggregate destruction by physical disturbance provides a good example of how properties that form aggregates are interrelated. Destruction of loosely associated macroaggregates through a disturbance, such as tillage, destabilizes the natural soil structure and may decrease water infiltration and aeration (Bronick et al., 2005). Macropores stabilized by delicate root and fungal hyphae networks are easily destroyed by tillage (Tisdall, 1994). Besides the destruction of existing macroaggregate structure, soil disturbance by tillage increases aeration and exposed particle surface area and subsequently bacterial mineralization of SOM as well as rapidly changing soil moisture (Beare et al., 1994; Bronick et al., 2005).

Loss of SOM is particularly important because many cultivated soil series are found to have macroaggregates stabilized by SOM and biological activity (Tisdall, 1994; Six et al, 2000). The formation of soil aggregates helps preserve SOM and protect it from mineralization (Bronick et al., 2005; Beare et al., 1994). The movement and concentration of organisms, organic structures, and inorganic crystalline bonds in an aggregate is controlled by moisture content and pH. These tend also to be variable in a cultivated landscape because of chemical inputs and, of course, physical disturbance.

Finally, moisture content may be the most critical variable mediating all of these processes, but moisture content disturbs aggregates directly in two ways. First, since neither wetting nor clay mineral structure is homogenous in the soils found at this site, interspersed 2:1 clay minerals and/or aggregates swell while 1:1 illite clay minerals do not, causing larger aggregates to shear into smaller aggregates (Kemper & Rosenau, 1986). Rapid wetting also causes gases within the aggregate to be trapped, leading to physical rupturing of the aggregate (Kemper et al., 1985). Second, soluble bonding agents holding aggregates together also dissolve 6and move as moisture contents rise. As moisture leaves soil aggregates, particles begin to contract and solutes concentrate cementing adjacent particles together. Further drying causes the aggregates to become brittle and if they are broken, moisture must be reintroduced to remobilize cementing agents to reform them (Kemper & Rosenau, 1986).

Soil Moisture and Infiltration

Soil moisture content is important in determining the variability of water aggregate stability, and has a considerable influence on soil compaction, plant productivity, and erosion. Likewise, soil temperature and water infiltration are critical determinants of soil moisture and thus are important for most soil processes and are among s the primary factors influencing erosion (Ben-Hur et al., 1992; Wang et al., 2014). Soil physical attributes, such as soil texture and structure also determine base soil infiltration and, ultimately moisture. Fine textured, mineral soils have increased surface area which increases water holding capacity and decreases conductivity. The mineral portions have high initial absorption, but slow adsorption once saturation is attained (Rawls et al., 2004). Similar to fine textured mineral fraction, soils with high SOM levels also have high surface area and high initial absorption; however, since organic materials are not symmetrical, macropores are conserved allowing for greater infiltration rates even after saturation (Reeves, 1997). These carbon-based structures also encourage increased formation of macroaggregates (Tisdall, 1994; Beven et al., 1982). Plants and macrofauna also help create large macropores that act as conduits for water flow (Shipitalo et al., 2004; Beven et al., 1982).

Disrupted aggregates slake into fine particles, which when mobilized clog pore space, causing surface sealing. (Yan et al., 2008; Lado et al., 2004) As more particles are exposed to chemical and physical dispersion, they continue to become finer which allows them to move further and more effectively clog pore space (Wakindiki &Ben-Hur., 2002). The decrease in infiltration rates increases potential for surface runoff and subsequent sediment transport. Lado and others (2004) observed strong evidence that soil aggregates are both stabilized by SOM and are highly related to the extent of erosion. This was due mainly to lower surface sealing and less chemical dispersion of clay particles within soil aggregates. Plants and macrofauna also help create large macropores that act as conduits for water flow (Shipitalo et al., 2004).

Erosion Processes

Raindrop and sheet erosion are typically observed on a smaller scale compared to sediment transport via rills and gullies and also predominating in this study. Although secondary in volume, raindrop and wash processes still represent an important source of sediment and may predispose more advanced erosion. Soil detachment by raindrops are destabilized chemically by introducing dispersing solutes and physically by the force of impact (Planchon et al., 2000). Dispersed and separated particles may be entrained or may contribute to surface crusting (Lado et al., 2004). Deposition and erosion of fine textured material is easily observed after a storm.

Development of microtopography is also primarily influenced by sheet erosion as well. Planchon and others (2000) found that raindrop erosion explained much of the change of microtopography in agricultural watersheds over time and the progression may be represented by the diffusion equation. This microrelief also may affect the formation of larger relief formations. Planchon and Mouche (2010) were eventually successful in creating a unique physical model describing evolution of microtopography that is validated by field data and laboratory experiments. The model parameters are detachment rate, projection distance, and an anisotropy coefficient which expresses slope dependency of the other two parameters. The model accurately predicts surface roughness and size of mounds developing under shelter such as the retention of material underneath small stones and vegetation.

Rain drop erosion is best understood by analyzing the processes after impact (Planchon et al., 2010). Ghadiri (2004) observed cratering of the raindrop is dependent nearly exclusively on raindrop size while crater shape depends on the soil properties. It was determined that cratering absorbs 13 to 23 percent of the energy post impact. Additionally, the rim of entrained particles around the center of the impact is larger on the downslope side suggesting a general downward movement of soil particles. Sediment can be propelled by these impacts far distances, average of 10 cm-20cm and as far as 1 m, depending on sediment size and is also oriented downslope (Leguédois, 2005). Continuing rain drop impacts also create a thin layer of water heavily laden with entrained sediment on the surface (Planchon et al., 2010).

Surface crusting by the sorting of finer particles and submersion by this film also protects underlying materials from being transported. This promotes overland flow or sheet flow and eventually more advanced erosion structures (Lado et al, 2004). Barthes & Roose (2002) observed a relationship between the stability of aggregates and subsequent overland flow and erosion both by analyzing slaking characteristics of soil samples and in a simulated rainfall study. Runoff, soil loss, and solids discharge all had very significant negative correlations with macroaggregates while runoff intensity and solid discharge were negatively correlated with soil carbon. This agrees with other studies looking at SOM and WSA to estimate erosion potential of a landscape (Yan et al., 2008; Barthes et al., 2002; Ritchie et al., 2007; Le Bissonnais et al., 1998).

Soil Deposition

Erosion fundamentally affects the chemical, biological, and physical aspects of soil in all areas of the world (Changere & Lal, 1997; Taylor et al, 2010; Doran & Zeiss, 2000). Topographic position and slope indicate locations of deposition and erosion areas and n fundamentally affects the chemical, biological, and physical aspects of soil (Weesies et. al., 1994; Langdale et al., 1982; Ritchie et al., 2007). Characterization of the depositional areas is also completed by tracking Cesium-137 with areas of higher activity located within the depositional areas and lower activity in eroded areas (Lowrance et al., 1988; Ritchie et al., 2007). The burial of entrained fine particles within the depositional areas also may have negative effects on infiltration rate and aeration which protect SOM from mineralization. Other studies have shown that sediment transported via runoff is both easily mineralized, dispersed and no longer aggregated, therefore, SOM is not conserved within these depressions (Lal, 2003; Polyakov & Lal, 2004). Whether erosion is a sink or source of carbon is a matter of debate between soil scientists and sedimentologists (Lal, 2005; Kirkels et al., 2014).

Despite the disagreement on the final fate of soil carbon, these studies provide evidence for the preferential movement of the productive, finely textured soil materials moving downslope. In a study by Papernik and others (2009), soil organic carbon clearly eroded towards lower slope positions where it accumulated causing consistently higher amounts. Increased crop productivity was observed on the upland slopes when deposited soil was pushed back up the slope. However, more research was deemed necessary by the authors to determine the long term consequences of soil relocation. Another study by Polyakov and Lal (2004) observed similar soil carbon movement but also observed an increase in soil carbon mineralization. Depositional areas emitted 26 percent more carbon than control sites suggesting carbon deposition is not a sink but increased with exposure from erosion. Carbon content and erosion were also related to rainfall and topography consistent with most other studies mentioned previously.

The influence of erosion on the global carbon flux, which has increased attention due to global warming, is not always agreed upon amongst different disciplines. Sedimentologists view erosion as a carbon sink, while soil scientists refer to it as a source of emissions (Lal, 2005). In a study by Ritchie and colleagues (2007) a very similar relationship was observed between soil organic carbon and elevation and depositional areas; however, soil organic carbon distribution by erosion was analyzed within the context of topographic position and morphology. Upland slopes were found to contain less soil organic carbon similar to what was observed by Polyakov and Lal (2004), and concave, toe slopes were found to have higher levels soil carbon and toe slopes also had deep accumulations of these materials (Ritchie et al., 2007).

Project Justification

Agriculture in the Midwest is typically large-scale, intensive, row-crop production on large, level fields. The increasing scale of production, mono-cropping, and the size of equipment poses new challenges for management of heterogeneous soils. In the past, farmers worked small fields, inputs were limited, and they relied on careful adjustments of their crop rotation, and diversification in order remain productive. Technology supported by research are currently the primary means to increase agriculture production and efficiency. New tillage techniques and equipment are beginning to be adopted and evaluated which limits soil disturbance and optimize field passes. For example, Global Positioning Systems (GPS) technology in the last 25 years have allowed farmers and researchers to spatially relate data at the field scale (Stafford, 2000). GPS tools provide the ability to record continuous elevation data, create yield maps, and apply variable rates of fertilizer and seed based on location (Brisco et al., 1998). Improvements in technology, and the development of tools to assist the farmer in understanding spatial variability within their fields and adjust accordingly. Evaluation of some of these tools at the field scale by the scientific community is also necessary and is especially valuable to the farmer when completed at the field scale.

Topsoil erosion is strongly influenced by the intensity of runoff water and the shape of the landscape. The accumulation of topsoil and nutrients in concave deposition areas and depletion in convex eroded areas for a variety of reasons is well documented and supported by considerable research (Nearing et al., 1989; Lobb et al., 1995; Lowrance et al., 1988). Additionally, the connection between these dynamics, soil properties, and ultimately productivity is also well established (Changere & Lal, 1997; Kravchenko & Bullock, 2000; Kravchenko et al., 2005; Papiernik et al., 2009). Whether dissolved or bound to soil particles, mobile nutrients influence the productive capacity and the potential for nutrient pollution. This is especially true for agriculture fields where additional nutrients are applied regularly and often at a constant rate over large areas without taking soil heterogeneity into account (Vitousek et al., 2009). Knowledge of different management zones, areas that have increased or decreased capacity for production, is important for optimization. Despite this, much of the research on the effect of topographic position has been based either on subjective characterization of the landscape or specific components of the topography (eg. curvature, percent slope, flow accumulation; Changere and Lal, 1997; Kravchenko and Bullock, 2000). In large, level fields it is difficult to correctly identify these positions at eye level due to the increased scale of the landform shapes.

Several different geospatial tools and methods have been used to assist identification of topographic positions and the effect of these topographic positions (De Reu et al., 2013; Kravchenko et al, 2005; Weiss, 2001; Mitasova et al., 1995). This study utilizes a method automated by Weiss (2001) analyzing the difference from mean elevation within a set neighborhood called topographic position index (TPI). Jenness (2006) further automated landscape identification by creating an extension in ArcView that uses negative and positive TPI values to characterize slope positions, and values near zero are considered level. This method was adapted to fit the gradual rolling landscape found at the research site. 7.2 percent of the cells were identified as linear surfaces with slopes greater than two percent, and were therefore omitted from the analysis.

Soil is not a homogenous mixture of materials. The collection of materials that make up soil have different physical attributes and abilities to store nutrients. Official soil series descriptions, topography, land management, soil texture, fertility, and climate region are all good tools for placing soils into general classifications describing how they behave, however, investigating specific soil properties and interactions between soil properties within these classifications is complicated. To simplify these relationships, it is necessary to investigate general behaviors of soil at a smaller scale. Specifically, a primary determinant of chemical and physical dynamics is particle size distribution and surface area (Tiessen et al., 1983).

Both cation exchange capacity (CEC) and SOM content are useful indicators of particle surface area and charge (Sollins et al., 1996). Fine textured mineral soil and SOM typically have high surface area and charge, which is related to the capacity of the particle to hold onto soil nutrients and directly related to CEC (Gaines et al., 1994). SOM is also composed of organic forms of important nutrients, such as nitrogen (N) and phosphorus (P), which can be converted into plant usable forms over time. Additionally, SOM also has a low particle density because of the complex shapes of the organic materials which allows SOM to erode and deposit readily within agricultural fields (Ritchie et al., 2007; Baldock and Nelson, 2000). While comparatively dense, finely textured mineral soil is easily suspended in water because of its tiny particle size making it susceptible to erosion during runoff events (Lado et al., 2004).

Data presented in this thesis, as well as several other studies investigating soil erosion and deposition, suggest fine soil material preferentially moving from upland areas to lower areas of the field (Papernik et al., 2009; Polyakov & Lal, 2004; Ritchie et al., 2007). Due to the capacity of these materials to store nutrients, any of the soil properties investigated here, especially for extractable nutrients in soil tests, are affected by this preferential relocation of fine mineral soil fractions and SOM. The accumulation of fine textured mineral soil is also susceptible to runoff due to suspension, crusting, and generally poor drainage causing increased surface runoff, however, some of these properties are alleviated in soils with high SOM content (Lado et al., 2004). It is important that natural processes and formations such as soil texture, topographic position, temperature, and precipitation are not omitted from an analysis. Both management, landscape, and climate are very important. For example, in a soil runoff experiment of several watersheds over 28 years, 50 percent of the total soil loss was attributed to three storms, however, only 30 percent of the average soil loss was collected in watersheds with fields contoured with slope (Edwards & Owens, 1991).

CHAPTER 2

METHODS

Study Area

The 100 hectare study site is located along the southern border of Macon County in central Illinois and is approximately 1,200 meters (m) long by 800 m wide. Adjacent areas around the study site are also large scale row-crop agriculture occasionally bordered by small farm roads. Each of the three experimental fields within the study site were approximately 30 hectares and were separated by a 2.5 m wide grass buffer strip (Figure 3). The fields had similar soils, were under the same corn soybean rotation, fertilizer application, and pesticide application schedules. The first and northernmost field was tilled with the AerWay® Aerator (AA) after corn harvest, the center field is under no-till management, and the third field is tilled with the Great Plains Turbo-Till® (GP) after corn harvest (Figure 1). .

Figure 1. Aerway® Aerator, Great Plains Turbo-Till®, and John Deere 1775NT Planter

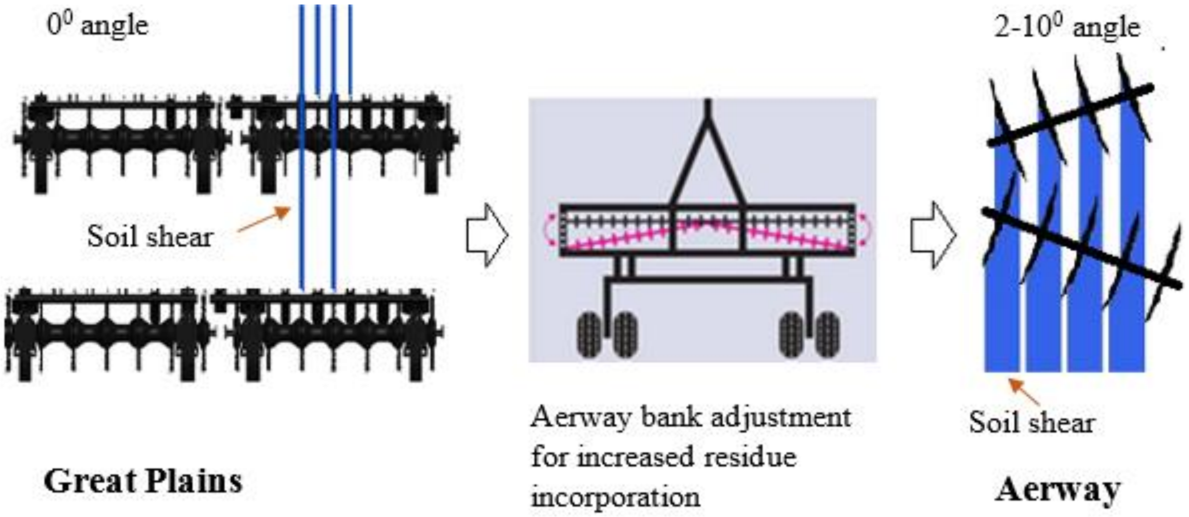


Figure 2. The effect of bank angle on soil shear and disturbance using the Great Plains and Aerway Aerator.

The dominant soil order in these fields and the surrounding area is Mollisol, a very deep soil with a thick, dark, surface horizon and at least 5.8 g kg^{-1} organic carbon (Soil Science Society of America, 2008). The parent material of the soils found in this region is primarily loess caps on glacial till or outwash. Drummer (Fine-silty, mixed, superactive, mesic Typic Endoaquolls) and Milford (Fine, mixed, superactive, mesic Typic Endoaquolls) soil series are very similar, have fine textures and moderately to high amounts of clay (Soil Survey Staff, n.d.). Both series are highly chemically active and are located in a temperate climate regime. These soils are often located in the concave slopes and are often wet with possible redox colorations due to very poor drainage. Flanagan (Fine, smectitic, mesic Aquic Argiudolls) soil series have less clay, are located in convex slope positions, and are better drained, although are still considered “poorly drained” (Soil Survey Staff, n.d.). Both of these soil series are common in the region, typically cultivated, and are considered “prime farmland” or “prime farmland if drained” (Soil Survey Staff, 2012). Maximum daily air temperatures were higher in 2011 compared to

2013 and 2014 but were lower than in 2012. The final year of the study was the coolest, followed by 2013 and then 2011. During the period of drought in 2012, the highest maximum daily temperatures and the lowest daily precipitation amounts were recorded. Daily precipitation amounts were lower in 2013 than 2014 and 2011, but all years were considerably higher than 2012 (Table 4).

Sampling Design

The field design is based on a 0.4 ha grid square with GPS coordinates marking a sample point within each sample plot outlined by the grid. Sample plots for chemical analysis were separated into strata based on the topographic position and an equal number of samples were randomly selected from each strata. The differences in the parameters were analyzed between the different strata and field management but not in the context of the entire field. Soil sampling for water stable aggregates (WSA), soil strength, residue coverage, soil temperature, soil volumetric water content (VWC), and soil bulk density (Bd) were systematically sampled within every ninth sample plot within each field. The location of the soil samples collected for physical and chemical analysis is presented in Figure 4.

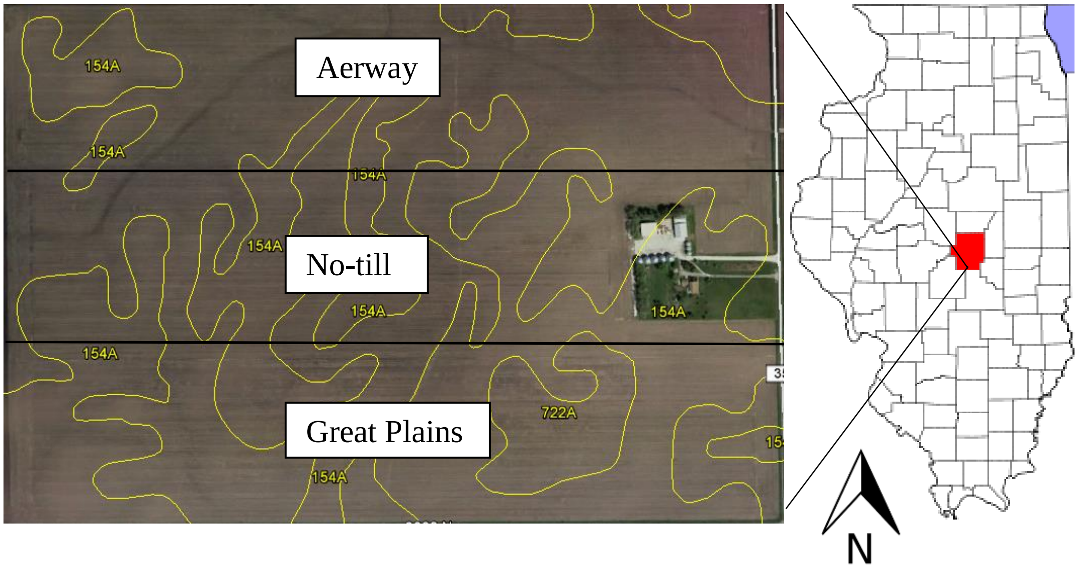
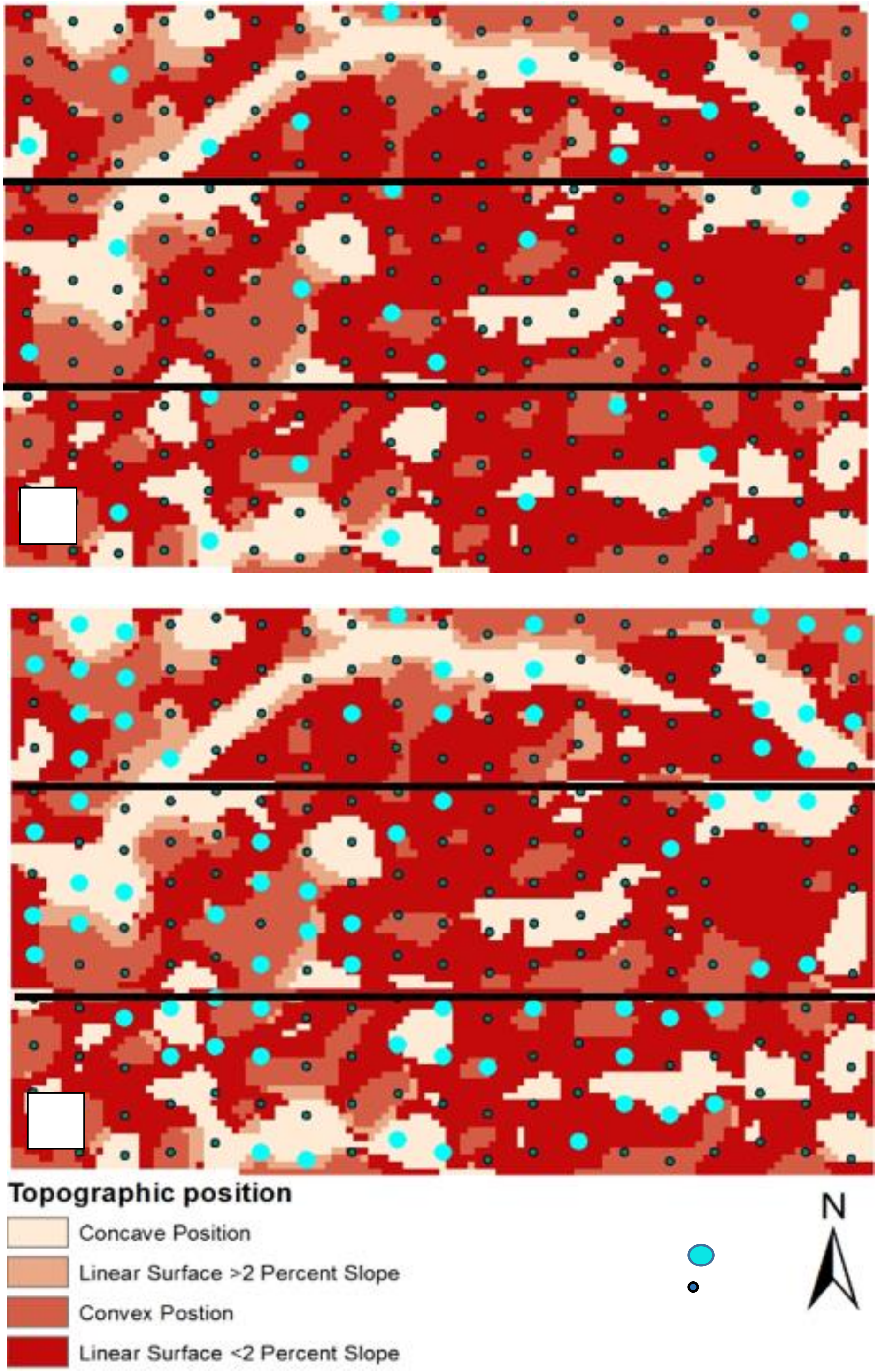


Figure 3. Location of research fields and study site with soil series boundaries Flanagan silt loam (154A) Drummer-Milford silty clay loam (722A)


Topographic position
Concave Position
Linear Surface >2 Percent Slope
Convex Postion
Linear Surface <2 Percent Slope
N

Field and Lab Procedures

Fields were all ripped before the initiation of the study in 2010. The vertical tillage implements, the AerWay® Aerator (AA) and the Great Plains Turbo-Till® (GP), were used on fields one and three, respectively, following corn harvest in 2011 and 2013. No other tillage was done in any study field over the four years of this study. The GP had an approximate working depth between four and six centimeters and the AA had an approximate working depth of 20 cm (USDA-NRCS[2], 2010). A John Deere 1770 no-tillage planter (Deere and Company, Moline, IL) was used for planting on all the fields. The Aerator utilizes pointed Shattertine® paddles that vertically mix the soil to break up compaction. Optional 250 kg concrete ballasts were added to help increase the penetration depth of the tines (Saf-Holland Equipment Ltd., Norwich, Ontario). The GP utilizes two rows of vertical coulters spaced at ten inches for leaving five inch total spacing between till lines followed by a rolling harrow and reel (Great Plains Manufacturing, Salina, KS). Anhydrous ammonia mixed with N-serve® was applied in the fall following soybean harvest. Diammonium phosphate (DAP) was also applied in the fall of 2010 and in the spring before corn planting in 2013. Fall applications of anhydrous ammonia + N-serve®, DAP, and potash were applied using variable rate technology (VRT). An additional application of nitrogen fertilizer (28-0-0) was applied during corn planting in 2011. Lime was applied late in the fall of 2011 and potash was broadcast in the winter of 2012 (Table 1). Fertilization was completed after soil samples were collected. Rates and application methods were widely representative for the region.

Table 1. Fertilizer application rates and date of application

Application	Avg. N-P-K	Lime	Season Total
Fall 2010	251-41-0		
Spring 2011	56-0-0		307-41-0
Fall 2011		2466	
Spring 2012	0-0-91		0-0-91
Fall 2012	230-0-0		
Spring 2013	7-8-0		237-8-0

All rates are average application over the entire site presented in kg ha^{-1}

Soil Physical Property Analysis

Soil physical properties (i.e., VWC, temperature, soil strength, bulk density, residue coverage, and WSA) were measured at every ninth sample point in the spring before planting corn (2013) and before planting soybeans (2014). Soil VWC was measured with a Spectrum Technologies WaterScout SM 100 soil moisture sensor, and external temperature sensor at a depth of four centimeters connected to Spectrum Technologies Watchdog^{TM} data loggers (Spectrum Technologies, Aurora, IL). Continuous VWC and soil temperatures were measured at all 9 sample points in each of the three fields during the 2013 and 2014 growing seasons. The sensors remained in the field only during the growing season and were removed over the winter months and during periods of heavy vehicle traffic. Soil strength was determined using a RIMIK CP40II penetrometer (ICT International, Toowoomba, Australia). Soil strength measurements were repeated nine times at each of the selected sites. Bulk density was determined to a depth of 15 cm using an AMS bulk density core with 292 cm^3 sleeves. Soil compaction was evaluated by analyzing both bulk density and soil strength data. Residue coverage was determined by taking a photo of a framed, 1-m^2 plot and the photos were analyzed using WinDIAS image software (Delta T, Cambridge, UK).

Samples for WSA were taken to a depth of 10 cm. After drying and sieving the samples, water stable aggregates were quantified using a wet sieving technique adapted from Kemper and Rosenau (1986). Infiltration and soil runoff rates were measured at every third of the selected sample points for a total of three per field using Cornell Sprinkle Infiltrometer (Ogden et. al, 1997). During the infiltration test for MN in the fall of 2014, the runoff water was collected to analyze the total suspended solids. Due to the small size of the ring and the low velocity of the rain drops, this runoff test was limited to soil entrained by suspension only and was not affected by slope or flow energy. Additional WSA analysis of the soil surface was collected by gently scraping the soil surface in an area similar to the area of the infiltration ring. Runoff water was collected at six minute intervals for 30 minutes allowing the timing and magnitude of soil runoff to be observed. The first time interval sample, the final time interval sample and a composite of all the samples were used in the correlation matrix. Earthworm biomass was collected from four 20 cm by 20 cm square by 20 cm deep in four cardinal directions around the runoff tests.

Soil Chemical Analysis

A composite sample of nine soil samples taken for chemical analysis at each sample point to 15 cm soil depth after harvest each year. Samples were analyzed for soil organic matter (SOM), total CEC by summation (CEC_{sum}), Melich III extractable phosphorus, potassium, sulfur, calcium, and magnesium as well as ammonium and nitrate via 1.0 N KCl extraction with cadmium reduction (Mehlich, 1984; Dahnke, 1990). Soil samples were air-dried, ground to pass a 2 mm sieve, and analyzed by Brookside laboratories. CEC_{sum} was estimated by combining the amount of extracted cations assuming there is no exchangeable acidity (Ross, 1995). SOM was determined by loss at ignition when heated to 360 degrees Celsius. .

Topographic Position Analysis

The analysis of a digital elevation model (DEM) using values from the TPI and automated in ArcView (ESRI, 1996) by Jenness (2006) and was completed in ArcMap 10.2.2 (ESRI, 2014). The topographic positions were separated into regions classified concave positions, linear positions, and convex positions. A circular neighborhood analysis of elevation 100 pixels around each 10 m by 10 m pixel within the DEM for this analysis. Rectangular neighborhood shapes, and different neighborhood sizes were compared, however, the 10 m x 10 m cell size and 100 m^2 produced the most clearly defined delineations between topographic positions. TPI values were calculated by taking the mean elevation of each neighborhood with the subject cell as the center. The elevation of subject cell is subtracted from the mean elevation of the neighborhood cells. Every cell is defined in relation to its surrounding cells position is assigned based on whether the TPI value is positive (convex), negative (concave) or near zero (linear Soil sample plots were randomly or systematically selected with each topographic position within each field so that there was an equal amount of topographic positions in each field.

Data Analysis

Data were organized with Microsoft Excel and analyzed using the PROC MIXED command in SAS version 9.4 (SAS Institute Cary, NC). A mixed model repeated measures analysis was used to test differences between topographic position, time, field, field*time interaction, and topographic position*time interaction. Significance was measured at 0.05 significance level. Tukey’s multiple comparisons adjustment of the p-values for the least-squares means was completed for the fixed effects in order to get the best pairwise comparisons despite unequal sample sizes. Log and square root transformations were used where necessary to achieve an acceptable level of normality and equality of variance. Normality of the model was determined by analyzing the linearity of Q-Q plots. Equal variance, linear relationships between data points, and absence of outliers for each model was determined by analyzing estimated versus residual plots. Field, time, and topographic position were considered fixed effects and the sample plots were repeated in time.

The mixed models repeated measures analysis was chosen due to its ability to handle missing values and to account for the same subjects (i.e., sample plots) being sampled at each time in the longitudinal analysis. The repeated measures procedure assigns a covariance structure to each time that each of the subjects were sampled. This accounts for any correlation of the response variables due to the same subjects being sampled over time (Littell, 2007). Compound symmetry (CS) and autoregressive (AR(1)) variance/covariance structures were used in the analysis based on the structure that returned the lowest Akaike's Information Criterion (AIC). Compound symmetry is the simplest structure with all variances in the matrix assumed to be homogenous and correlations constant regardless of the distance between the samples. AR(1) structure also assumes homogenous variances but the correlations decrease exponentially as samples become more variable (Kincaid, 2005). Compound symmetry fit the best for most variables in this study.

Pearson's R correlation matrix was used to analyze the correlations between yield, WSA, SOM, earthworm biomass, soil nutrients, and total suspended solids of runoff water. The Corrttest function in Microsoft Excel$^{©}$ was used to determine the significance of the correlations at a 0.01 significance level. Correlation between variables were analyzed without assuming causation.

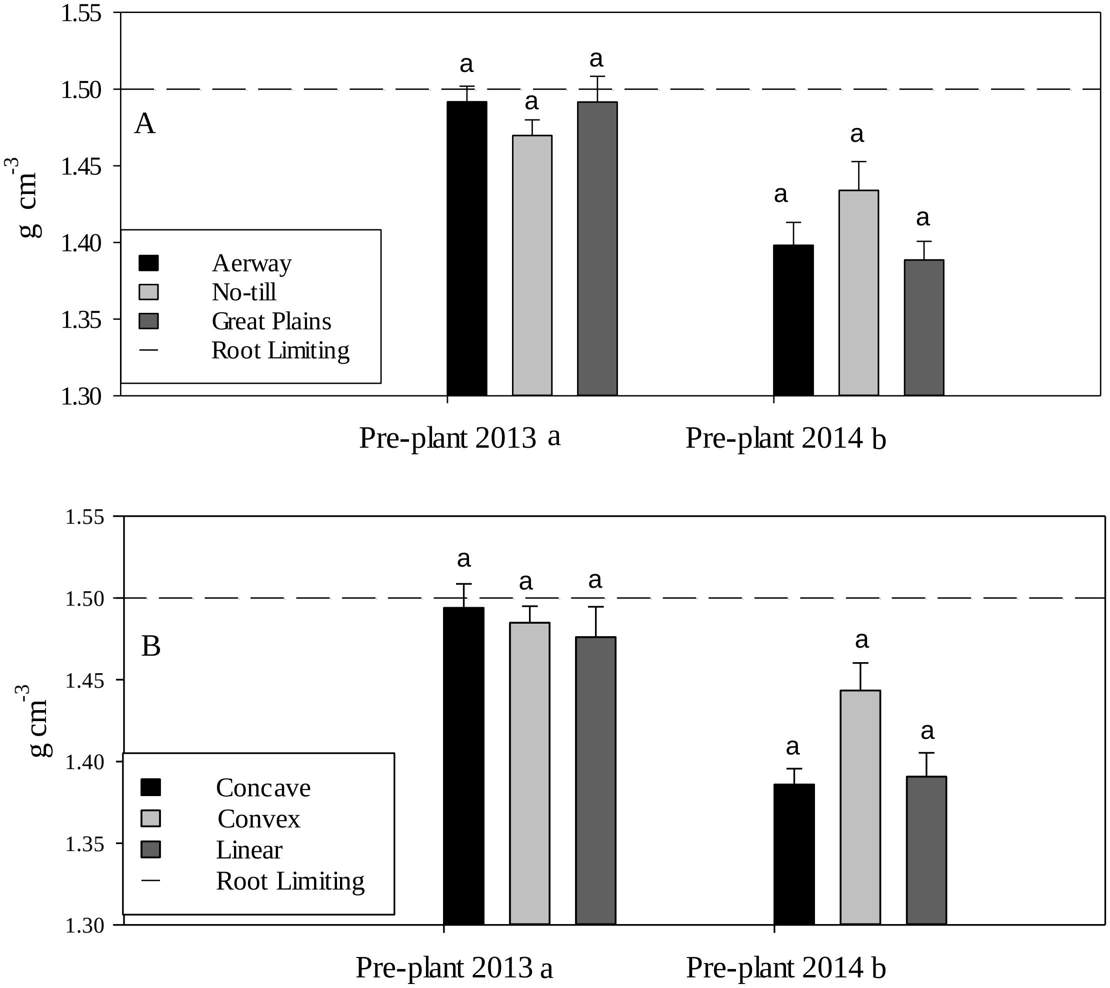
CHAPTER 3

RESULTS

Compaction

Soil physical properties were primarily affected by the tillage operations, soil moisture levels, and crop of the previous season. Largely due to the drought during the 2012 growing season, results of soil physical properties were limited to the 2013 and 2014 growing seasons. Soil bulk density was not significantly different between treatments or topographic positions (Figure 5), but it was significantly different during the spring after fall tillage (2014) compared with the previous spring (2013). Additionally, interactions were present between topographic position and time, as well as field treatment and time, but not between topographic position and field treatment (Table 2). The spring season following tillage (2014), both the AA GP had reduced bulk density and the no-till (NT) field was reduced only slightly (Figure 5). Both linear and concave topographic positions were also reduced by a greater amount in the spring following tillage and convex positions were reduced less, however, the effect was insignificant (Figure 5). All three fields and all topographic positions were similar for the spring (2013) that was not preceded by any tillage operations (Figure 5).

Differences in soil strength (resistance to penetration) between fields were more apparent in the 2013 season when tillage was not completed the previous fall (Figure 6). AA and NT fields showed an increase in soil strength compared to the GP between the soil surface and 20 cm depth (Figure 6). The field treated with the AA had significantly higher soil strength than both GP and NT between 20 cm and 30 cm (Table 3). Soil strength was affected by topographic position only in top five centimeters with concave positions having a lower soil strength than linear positions (Table 3). There was also a significant interaction between field treatment and topographic position at the surface to 2.5 cm depth and 2.5 cm to 5 cm depth intervals (Table 3).



Letters above bars indicate significant differences between treatments over both seasons.
Letters beside season indicate significant differences between seasons.

Figure 5. Soil bulk density in 2013 before tillage and 2014 after vertical tillage *(A)* and within each topographic position *(B)*

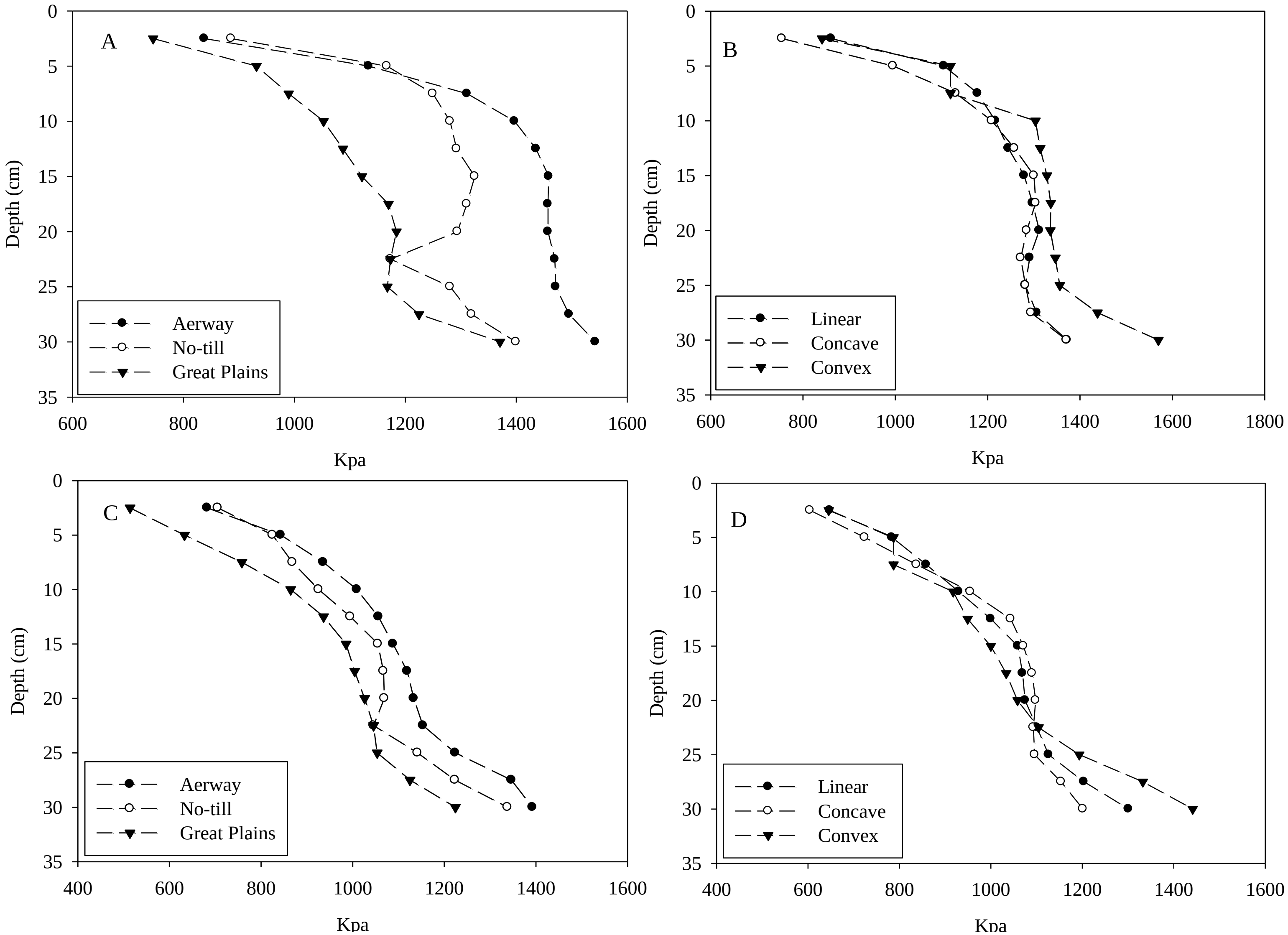


Figure 6. Penetration resistance and depth before tillage spring 2013 *(A and B)* and after vertical tillage spring 2014 *(C and D)*

Table 2. Treatment effect p-values in the least squares means for soil test results from 0 to 15 cm soil depth

Soil Property	*AA vs GP*	*AA vs NT*	*GP vs NT*	*Concave vs. Convex*	*Concave vs. Linear*	*Convex vs. Linear*	*Field*Position*	*Position*Time*	*Time*Field*
CEC	0.3655	0.6125	0.0614	<0.0001	0.0006	0.0006	0.4070	0.9342	0.8261
SOM	0.9365	0.5696	0.7813	<0.0001	0.0127	0.0368	0.3921	0.0546	0.4505
P	0.9019	0.7590	0.4919	<0.0001	0.0045	0.1886	0.1850	0.2292	0.2111
Ca	0.9912	0.4093	0.4829	<0.0001	0.0065	0.0034	0.2398	0.7895	0.6713
Mg	0.4055	0.6990	0.8800	<0.0001	0.0086	<.0001	0.2175	0.9719	0.3451
K	0.2508	0.0569	0.7409	<0.0001	0.0015	0.0084	0.0013	0.5599	0.4281
NO_3	0.9997	0.0214	0.0202	0.3406	0.8969	0.5997	0.1870	0.0224	0.0032
NH_4	0.8610	0.2290	0.4949	<0.0001	0.0229	0.0346	0.1694	0.2060	0.1410
WSA	0.9158	0.5839	0.8381	<0.0001	0.0090	0.0160	0.0729	0.5676	0.1317
Bd	0.9995	0.8702	0.8617	0.4091	0.9358	0.2313	0.8280	0.0505	0.0302
Residue	0.0478	0.0013	0.2862	0.9816	0.9994	0.9735	0.9159	0.3335	0.0999

* AA =AerWay Aerator, GP = Great Plains Turbo-till, NT = no-till. All values presented are p values (α=.05)

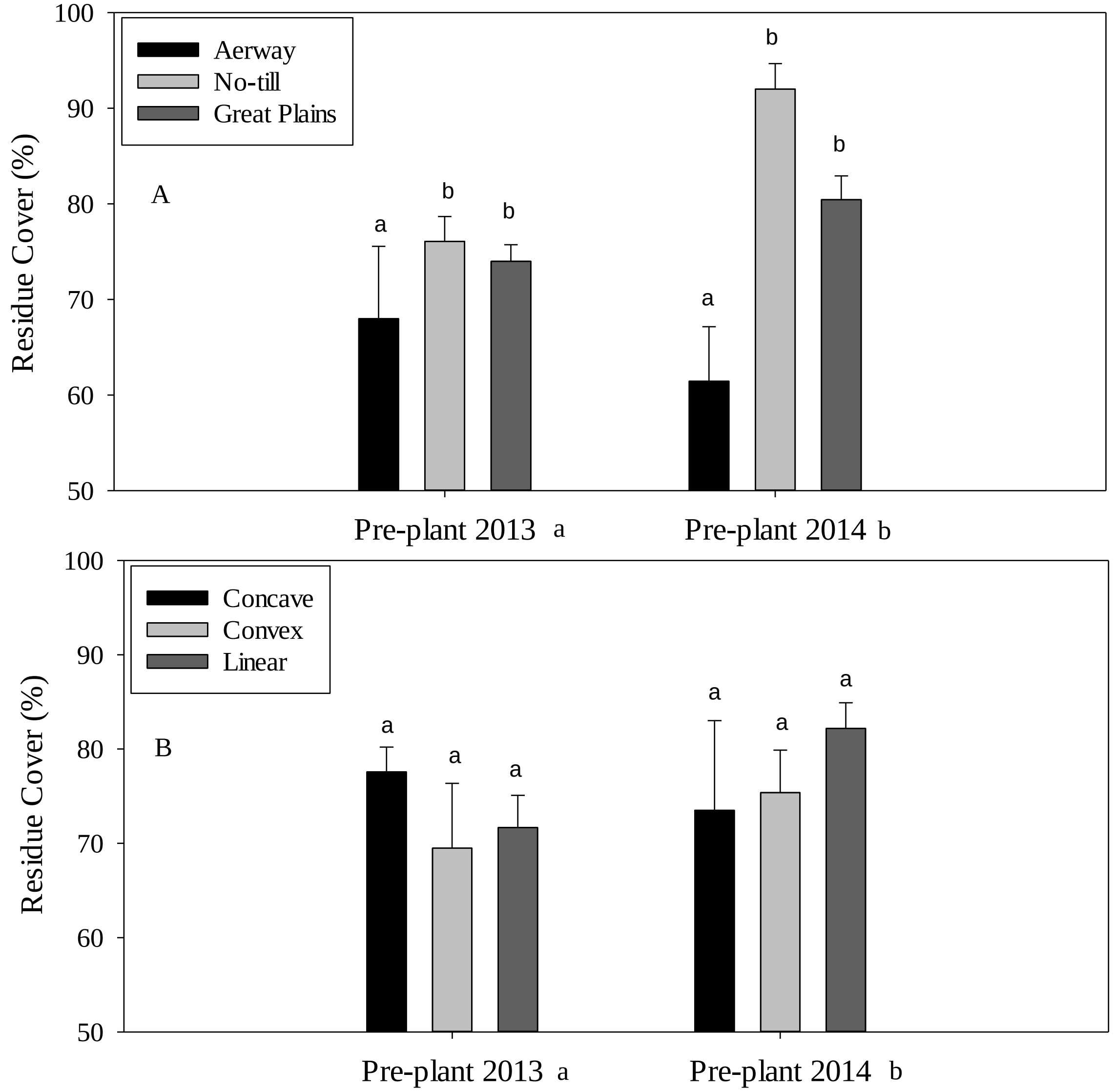
Table 3. Treatment effect significance and differences in the least squares means for soil strength results

Depth (cm)	*AA vs GP**	*AA vs NT*	*GP vs NT*	*Concave vs. Convex*	*Concave vs. Linear*	*Convex vs. Linear*	*Field*Position Interaction*
2.5	<.0001	0.8604	<.0001	0.2274	0.0104	0.2693	0.0059
5	<.0001	0.9968	<.0001	0.0996	0.0052	0.3425	0.0089
7.5	<.0001	0.3019	0.0002	0.5569	0.1177	0.5495	0.1996
10	<.0001	0.0813	0.0062	0.989	0.6059	0.6833	0.7476
12.5	0.0001	0.0743	0.0144	0.7415	0.8419	0.3929	0.8222
15	0.0001	0.1436	0.0079	0.6733	0.6986	0.2269	0.9493
17.5	0.0004	0.066	0.0514	0.7125	0.7784	0.3103	0.7812
20	0.001	0.0291	0.228	0.9391	0.6108	0.399	0.441
22.5	0.0011	0.0214	0.2916	0.8871	0.4645	0.7387	0.5134
25	0.0005	0.0296	0.1186	0.3326	0.3806	0.9925	0.9024
27.5	0.0026	0.0867	0.192	0.057	0.3182	0.5609	0.815
30	0.5041	0.0691	0.4004	0.0185	0.361	0.2314	0.6801

* AA =AerWay Aerator, GP = Great Plains Turbo-till, NT = No-till. All values presented are p values (α=0.05)

Crop Residue Coverage

Residue coverage was not different over time or topographic position. In the spring following tillage of corn residue, the NT field was significantly greater than the GP field (p=0.0478) and highly significantly greater than the AA field (p=0.0013). Sampling in 2013, which included soybean residue coverage without tillage and after the drought was also generally lower than corn residue coverage with tillage except for the AA field where it was reduced (Figure 7). Fields sampled in 2013 also were relatively similar. There were no interactions between time and topographic position, time and field treatment, or field treatment and topographic position (Table 2).

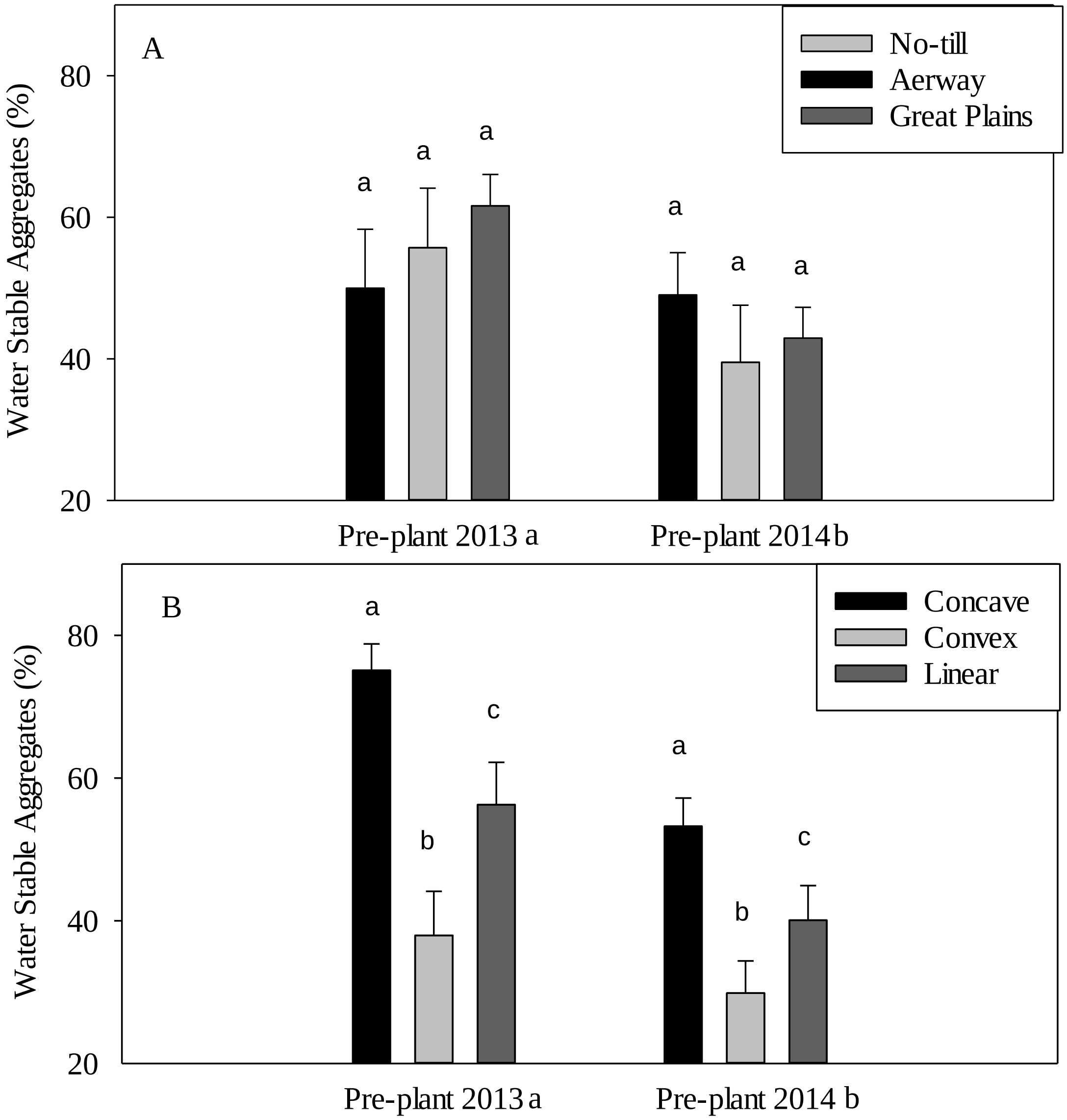


Letters above bars indicate significant differences between treatments over both seasons.
Letters beside season indicate significant differences between seasons.

Figure 7. Crop residue cover in 2013 before tillage and 2014 after vertical tillage *(A)* and within each topographic position *(B)*

Water Stable Aggregates

Water stable aggregates were not different between fields for both 2013 and 2014, but topographic positions were different. Concave positions had considerably more stable aggregates than both linear (p=0.009) and convex surfaces (p<0.0001). Linear surfaces had an intermediate level of water stable aggregates, less than concave surfaces, but greater than convex surfaces (p=0.016). There were no significant interactions between time and topographic position, time and field treatment, or field treatment and topographic position (Figure 8).



Letters above bars indicate significant differences between treatments over both seasons.
Letters beside season indicate significant differences between seasons.

Figure 8. Water stable aggregates before tillage in 2013 and after vertical tillage in 2014 *(A)* and within each topographic position *(B)*

Soil Temperature and Moisture

The 2013 growing season average soil temperature was approximately one degree Celsius higher than 2014 average growing season soil temperature (Figure 9). Soil volumetric moisture content was also higher in the 2014 growing season (Figure 10). Soil temperature and moisture are closely related to the maximum daily air temperature and precipitation data from a nearby weather station (Decatur Regional Airport, IL). The GP field was more poorly drained in the 2014 season while the NT field and the AA field drained more completely between each precipitation event. The surface VWC of the GP field remained very wet (i.e. above 35 percent) and the other fields dropped below 30 percent (Figure 10). There were also some instances of sudden increase in soil moisture without an accompanying precipitation event with the most notable increase on the 23rd of August in 2013 (Figure 10). This was most likely due to isolated precipitation in the field that was not indicated at the weather station.

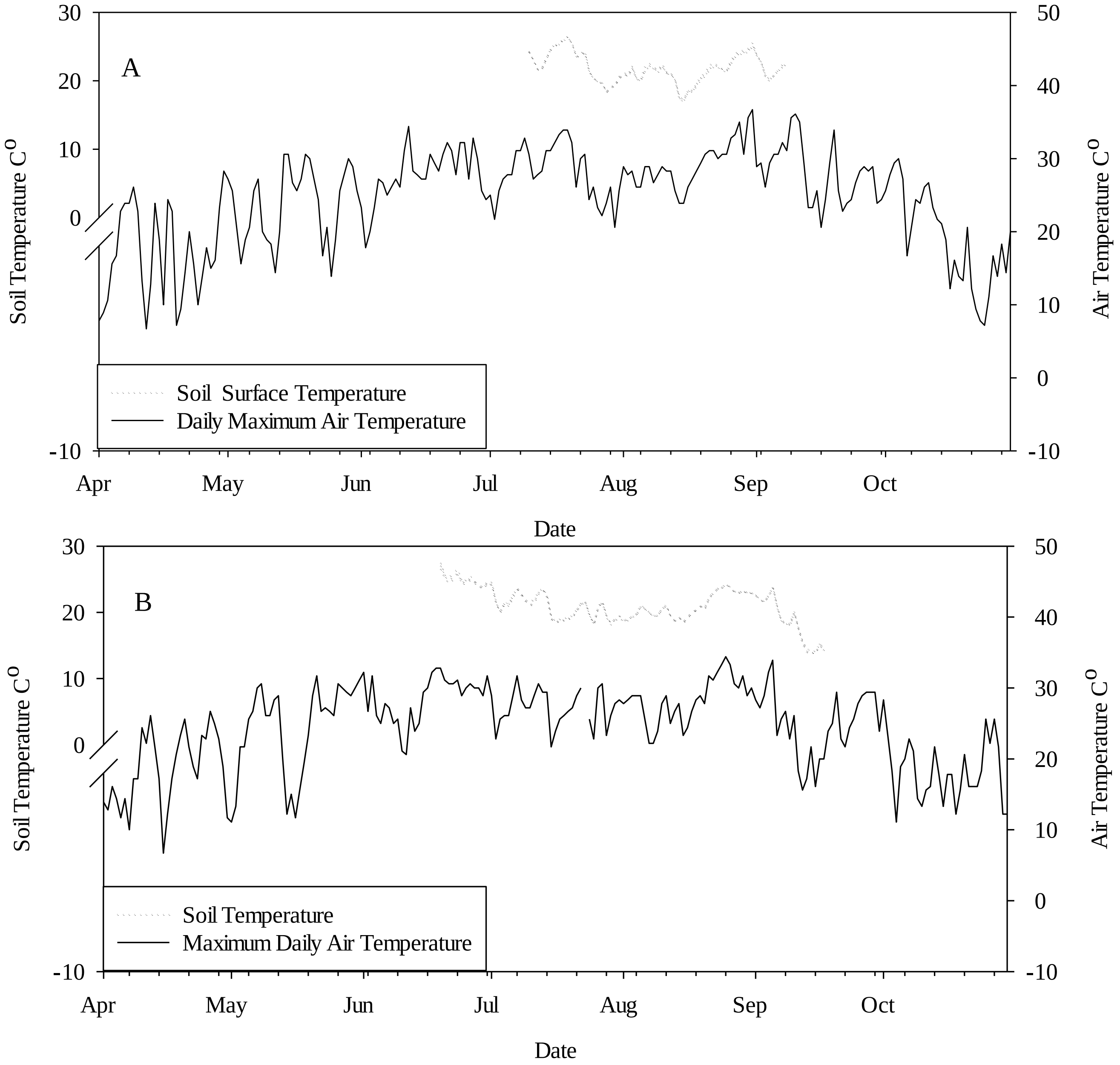


Figure 9. Daily maximum air temperature and soil temperature during the growing season in 2013 *(A)* and growing season in 2014 *(B)*.

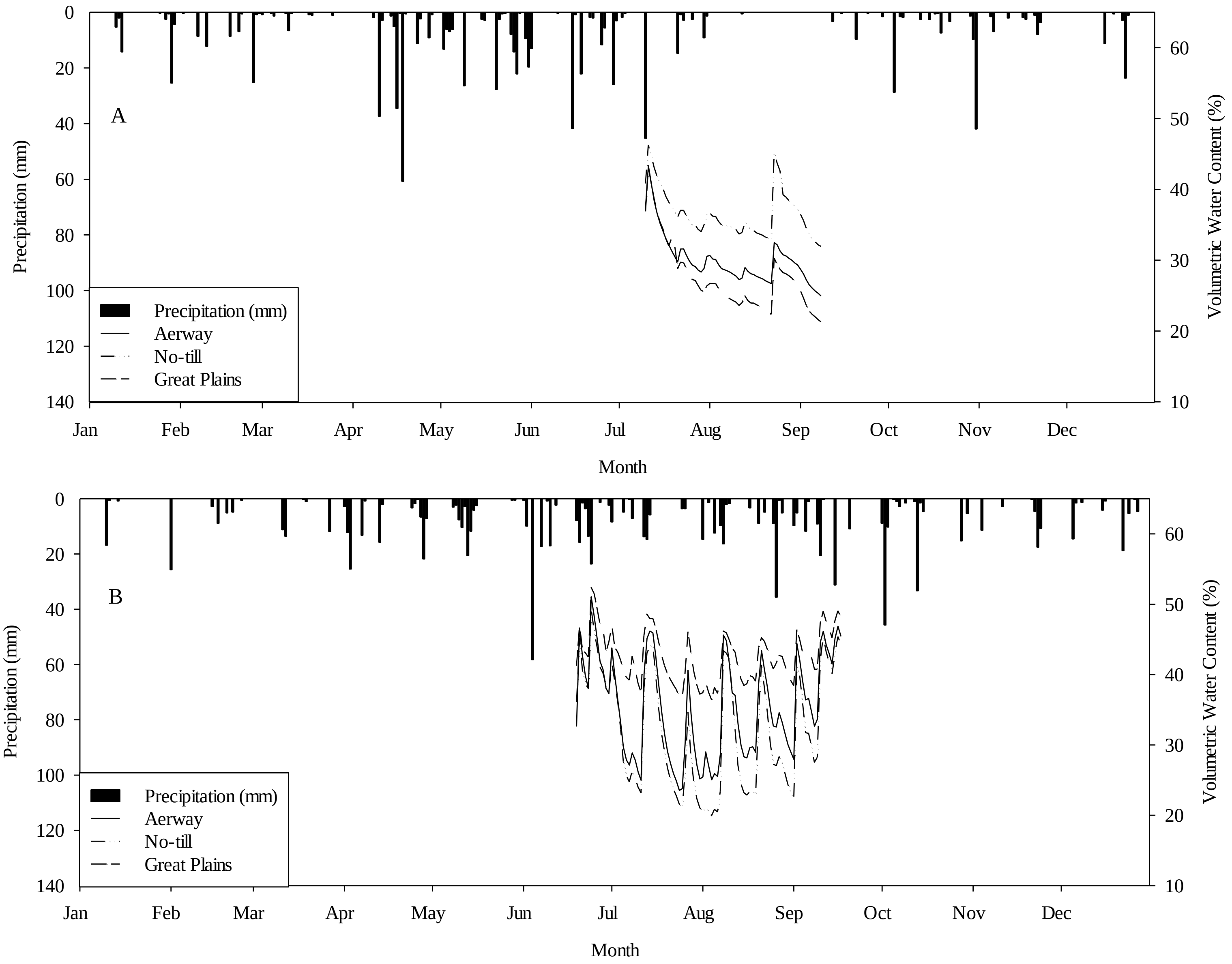


Figure 10. Soil volumetric water content and daily precipitation in 2013 (A) and 2014 (B)

Table 4. Annual precipitation, average maximum daily air temperature, volumetric water content*, and soil temperature*.

Year	Precipitation (mm)	Max Daily Temperature (C^o)	VWC AerWay (%)	VWC No-till (%)	VWC Great Plains (%)	Soil Temp AerWay (C^o)	Soil Temp No-till (C^o)	Soil Temp Great Plains (C^o)
2011	899.9	17.92	.	.	.	.	.	.
2012	664.8	19.94	.	.	.	.	.	.
2013	856.1	16.93	30.02	36.45	29.79	71.30	71.66	71.48
2014	974.9	16.04	35.39	32.20	40.54	69.74	69.83	69.98

* Soil temperature and volumetric water content were only observed during the growing season.

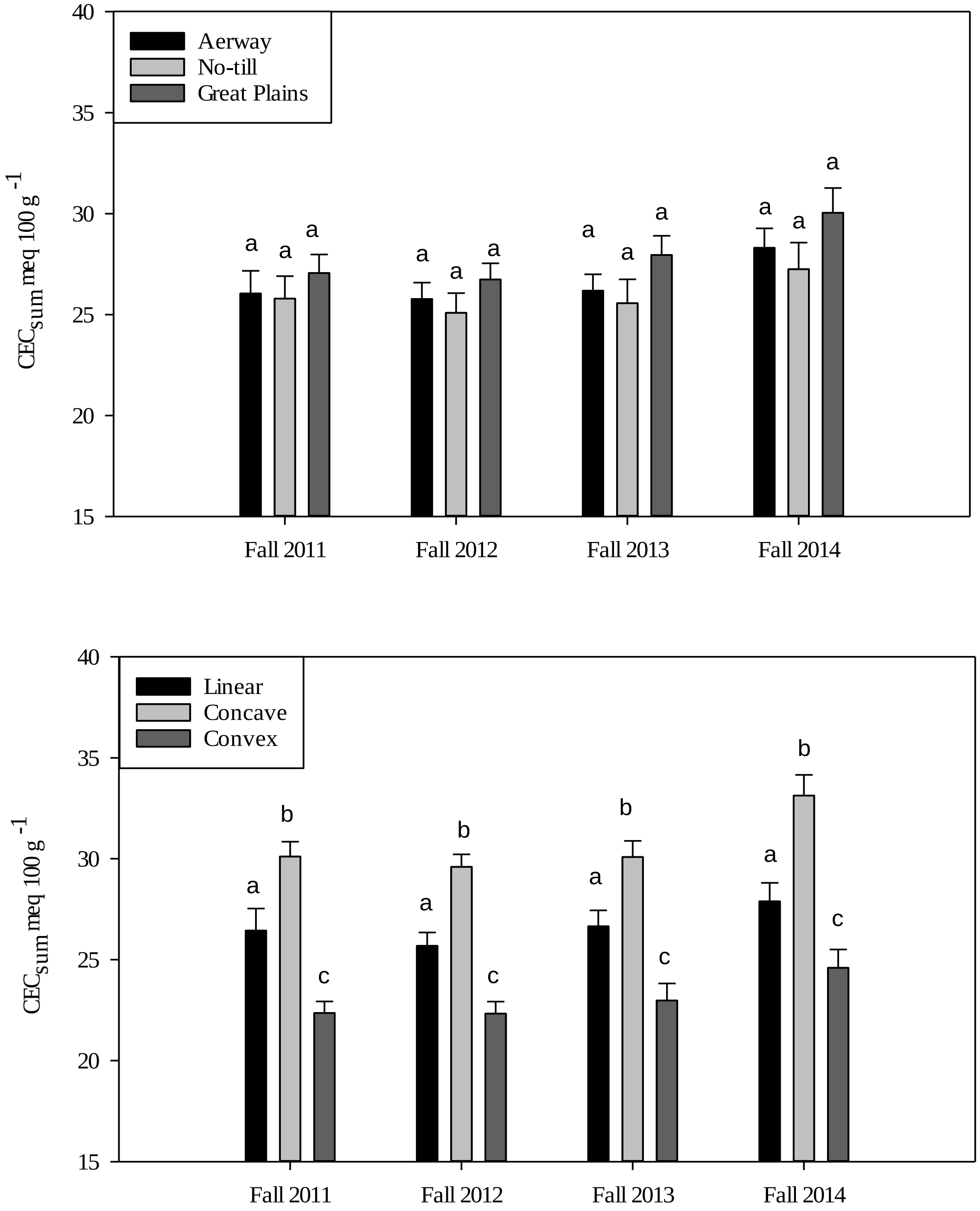
Table 5. Average maximum and minimum temperatures and total precipitation from November through March.

Year	Maximum Daily Temperature (C^o)	Minimum Daily Temperature (C^o)	Precipitation (mm)
2011-2012	10.7	-6.3	269
2012-2013	6.8	-2.8	218
2013-2014	4.1	-7.0	170

Soil Cations and Exchange Capacity

Cation Exchange Capacity by summation (CEC_{sum}) indicates highly significant increases in the amounts of major soil cations in the concave positions compared to both the convex ($p<0.0001$) and linear positions ($p=0.0006$) and linear positions are also significantly greater than the convex positions ($p=0.0006$). Conversely, there were no significant field treatment effects (Figure 11). Because this is a summation of all the major soil cations determined by standard soil tests, the amounts of these cations in the soil should be generally consistent with this result to varying degrees.

Calcium (Ca), magnesium (Mg), and potash (K), were all highly related to CEC_{sum} between the topographic positions. All three of these cations were significantly greater in the concave positions compared to the convex positions ($p<0.0001$). For potassium, concave positions were significantly greater than both linear ($p=0.0015$) and convex positions ($p<0.0001$) and linear was greater than convex positions ($p=0.0084$). While Ca, and Mg had no interactions between time, field, or topographic position, potassium had a significant interaction ($p=0.0013$) between field and topographic position and a significant three way interaction between field, topographic position, and time ($p=0.0023$). This was likely due to a sudden decrease in the no-till field in 2013 which was very close to being significantly higher ($p=0.0569$); however, the field portion of the model was not significant ($p=0.0638$; Table 2). The means for Ca and Mg were more similar between fields, differences between topographic positions were much clearer, and were more stable over time (see appendix).



Letters indicate significant treatment differences over time

Figure 11. CEC post-harvest within each field *(A)* and within each topographic position *(B).*

SOM, Nitrogen, Phosphorus, and Crop Yield

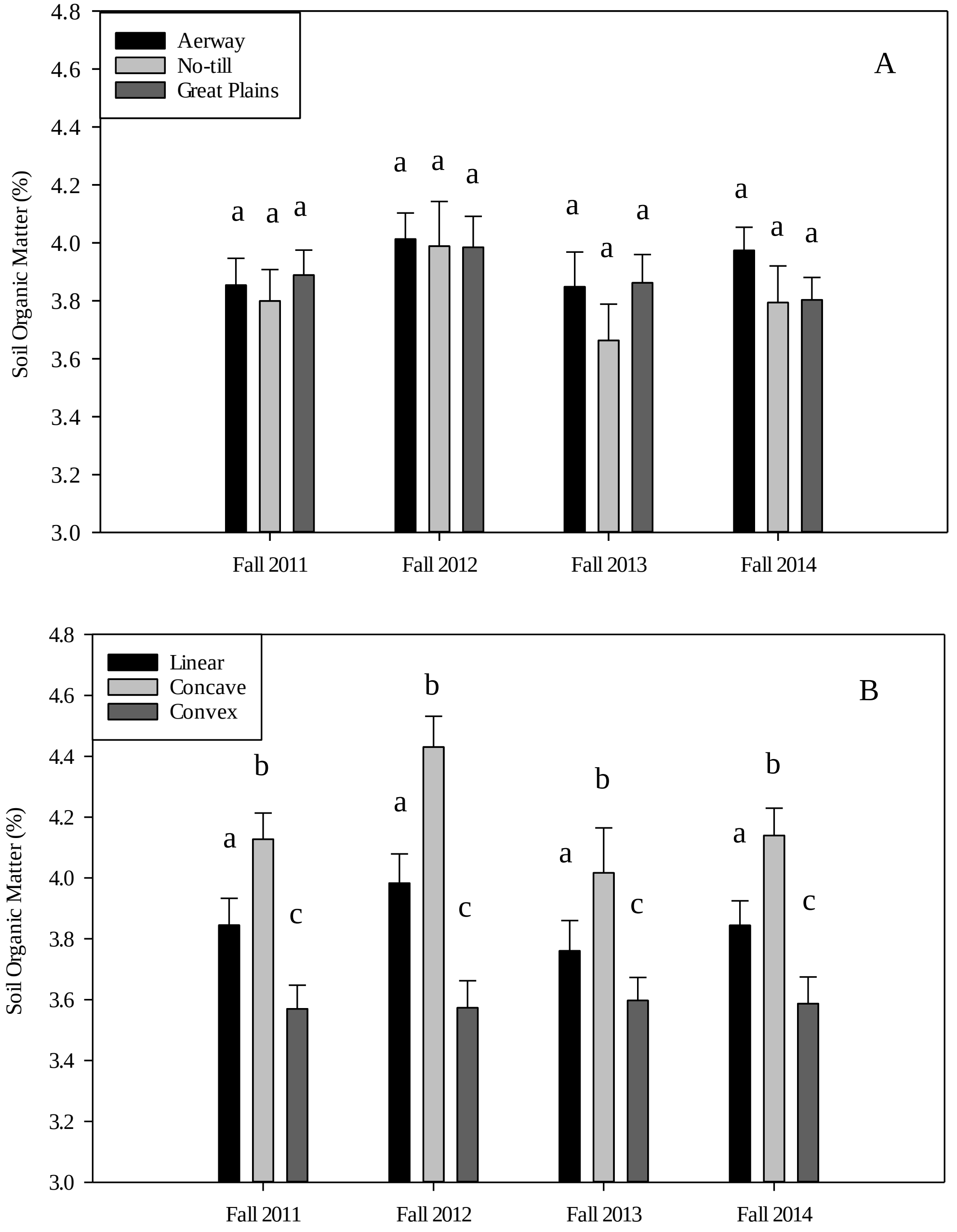
Similar to the relationship between cations and CEC_{sum}, soil cations, mineral and organic phosphorus as well as ammonium were positively associated with organic matter content of the soil in most years. Soil organic matter content (SOM) is presented as a percentage of total soil weight and was significantly higher in the concave positions compared to convex positions ($p<0.0001$) and linear positions ($p=0.0127$). Convex positions were also significantly lower than the linear positions ($p=0.0368$). There were no significant differences between the fields (Figure 12). There was, however, a significant interaction between time and topographic position which was most likely due to the drought in 2012 where all nutrients increased except for nitrate (Figure 15). The increase in SOM over the drought was primarily in the concave positions slightly in linear positions and convex positions remained stable throughout all years (Figures 13 & 15).

Soil test phosphorus (P) was similar to SOM except that the linear and the convex positions were not different ($p=0.1886$) and there was no interaction between time and topographic position. Soil P was closely related to SOM content over all four years and also had similar dynamics between topographic positions and the drought (Figure 14). Ammonium (NH_4) behaved similar to soil P and to other soil cations with accumulations in the concave topographic positions and decreased amount in the convex positions with no effect due to differences in conservation tillage, however, the differences were not as distinct as the others. Nitrate (NO_3), was affected by field treatment and was not affected by topographic position, but similar NH_4, SOM, and P there was also a significant difference in time (Figure 13). Nitrate was significantly lower in the NT plots compared to the plots treated with vertical tillage, however, there were interactions between field and time, topographic position and time, and a three-way interaction between time, topographic position, and tillage treatment (Table 2). Total residual nitrogen was generally higher in the 2011 season which was more heavily fertilized, however, the difference between fertilization rates and the difference between residual nitrogen were not similar (Figure 11). Yield was not significantly greater between treatments but was different over time due to crop rotation (Figure 16).

Table 6. Correlations between SOM and yield within each year and between years.

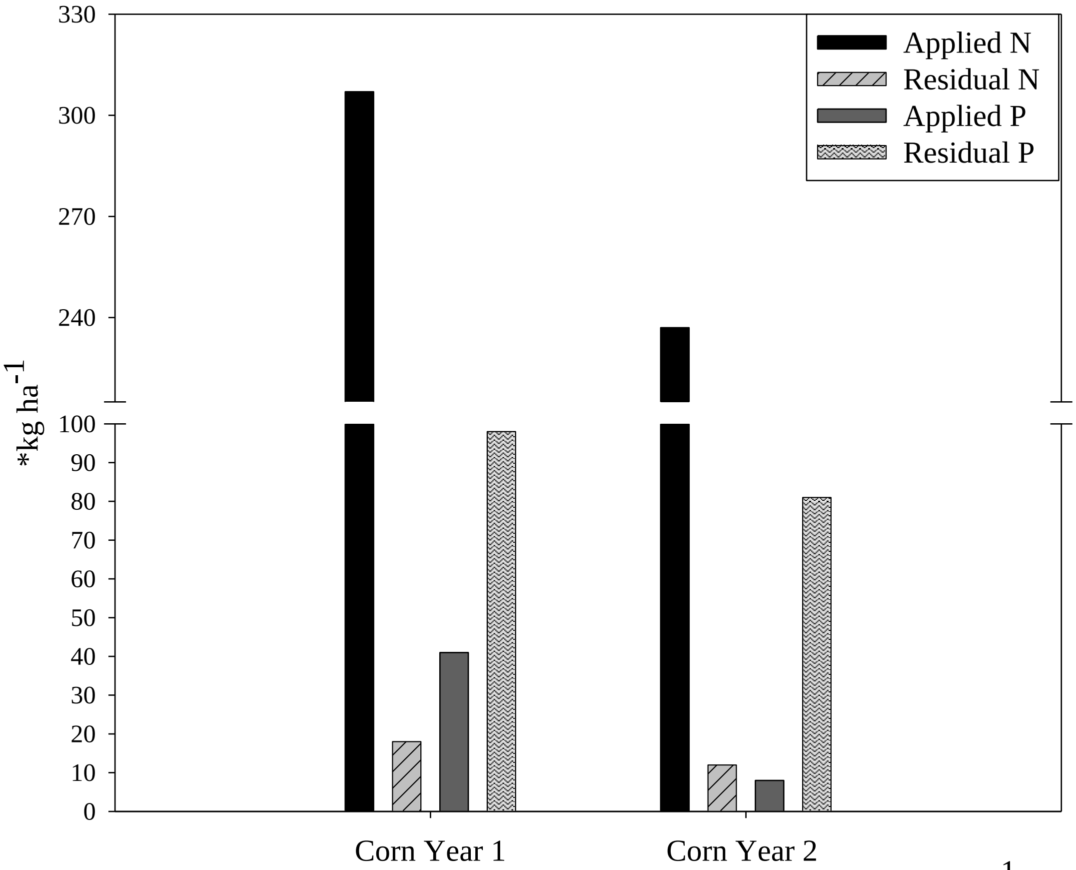
	Yield 2011	Yield 2012	Yield 2013	Yield 2014	SOM 2011	SOM 2012	SOM 2013
Yield 2011							
Yield 2012	0.31*						
Yield 2013	0.14	-0.02					
Yield 2014	0.25	0.15	0.01				
SOM 2011	0.04	0.16	-0.12	0.13			
SOM 2012	-0.03	0.10	-0.26	0.11	0.77**		
SOM 2013	-0.26	-0.05	0.00	-0.11	0.49**	0.47**	
SOM 2014	0.01	0.05	-0.16	0.22	0.76**	0.87**	0.46**

* Indicates significant at α=0.01 ** Indicates highly significant α=0.001



Letters indicate significant treatment differences over time

Figure 12. Soil organic matter content after harvest within each field *(top)* and within each topographic position *(bottom).*



*Residual nutrients were calculated assuming soil bulk density of 1.4 g cc^{-1}

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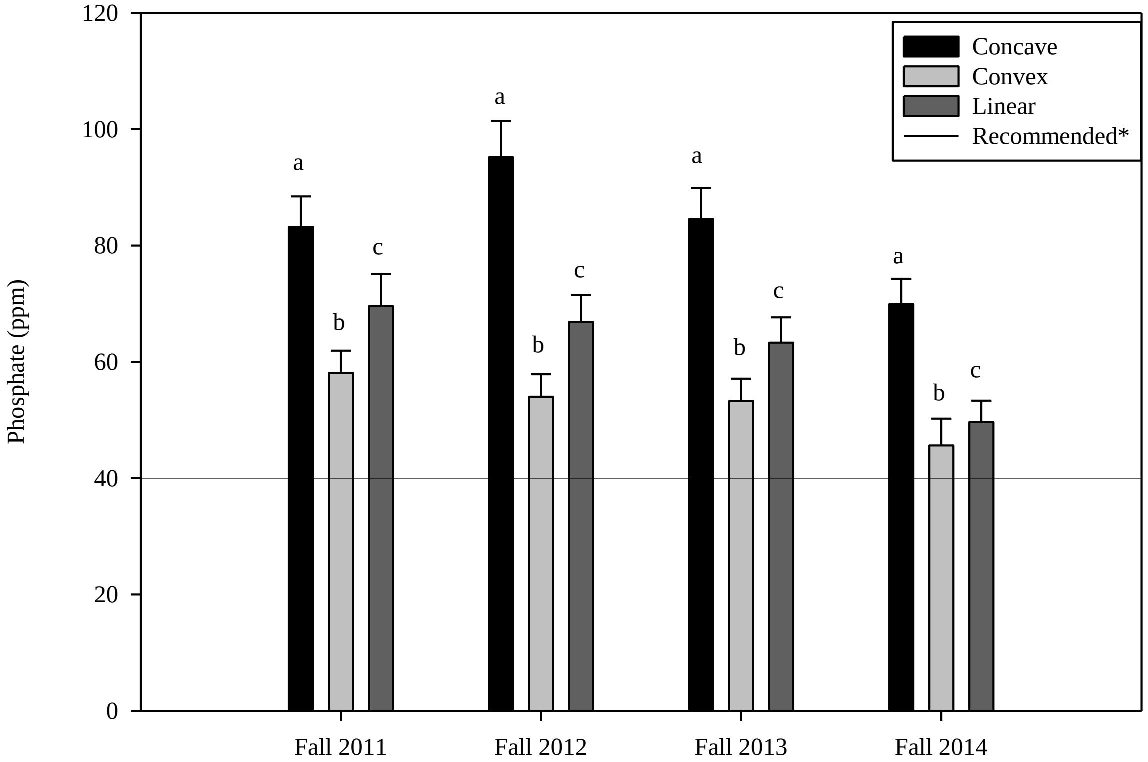
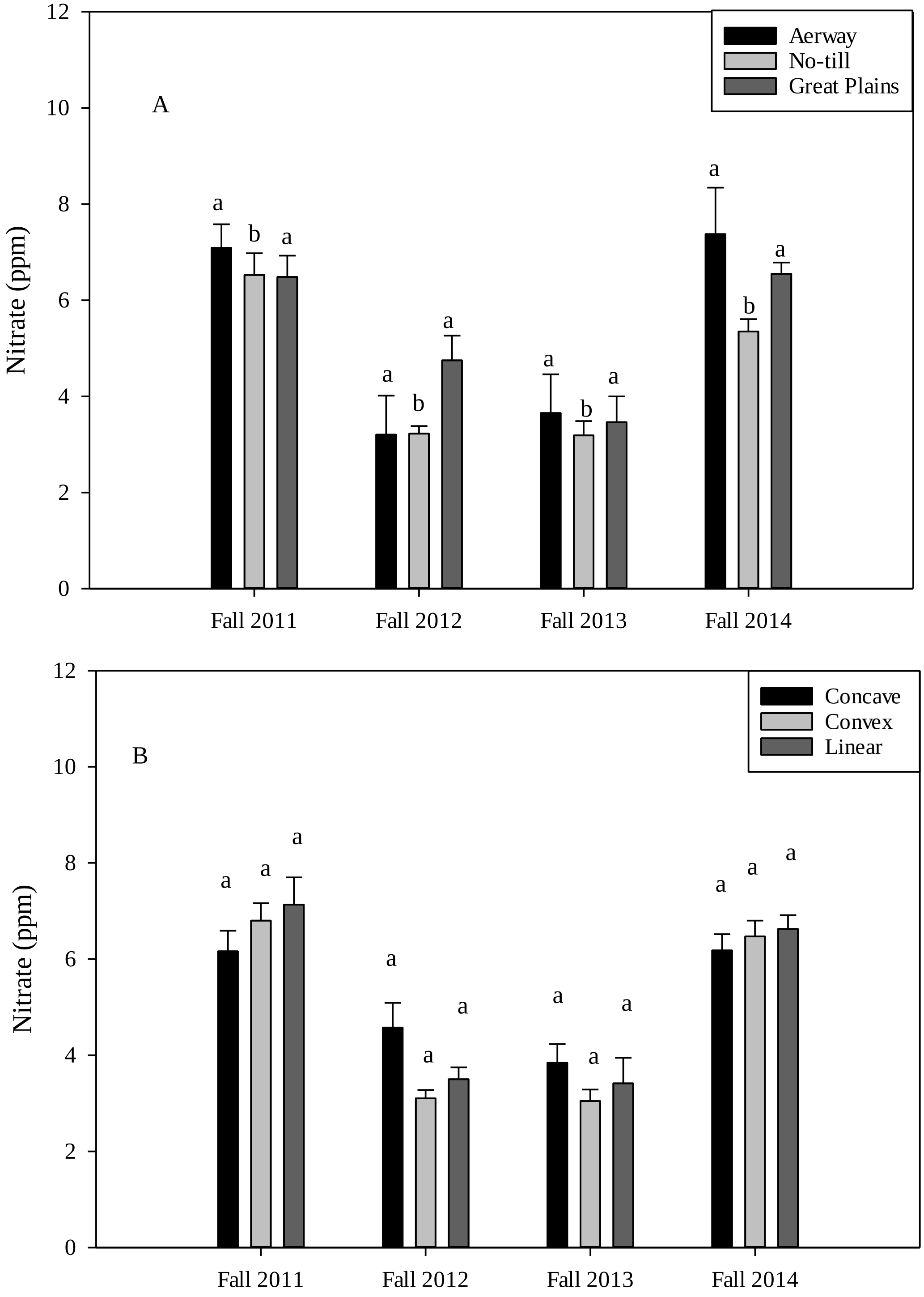
Figure 13. Applied and residual nitrogen and phosphorus for 2011 and 2013 corn seasons



* No fertilization required for 11.3 Mg ha^{-1} corn yield (Vitosh et al., 2000)

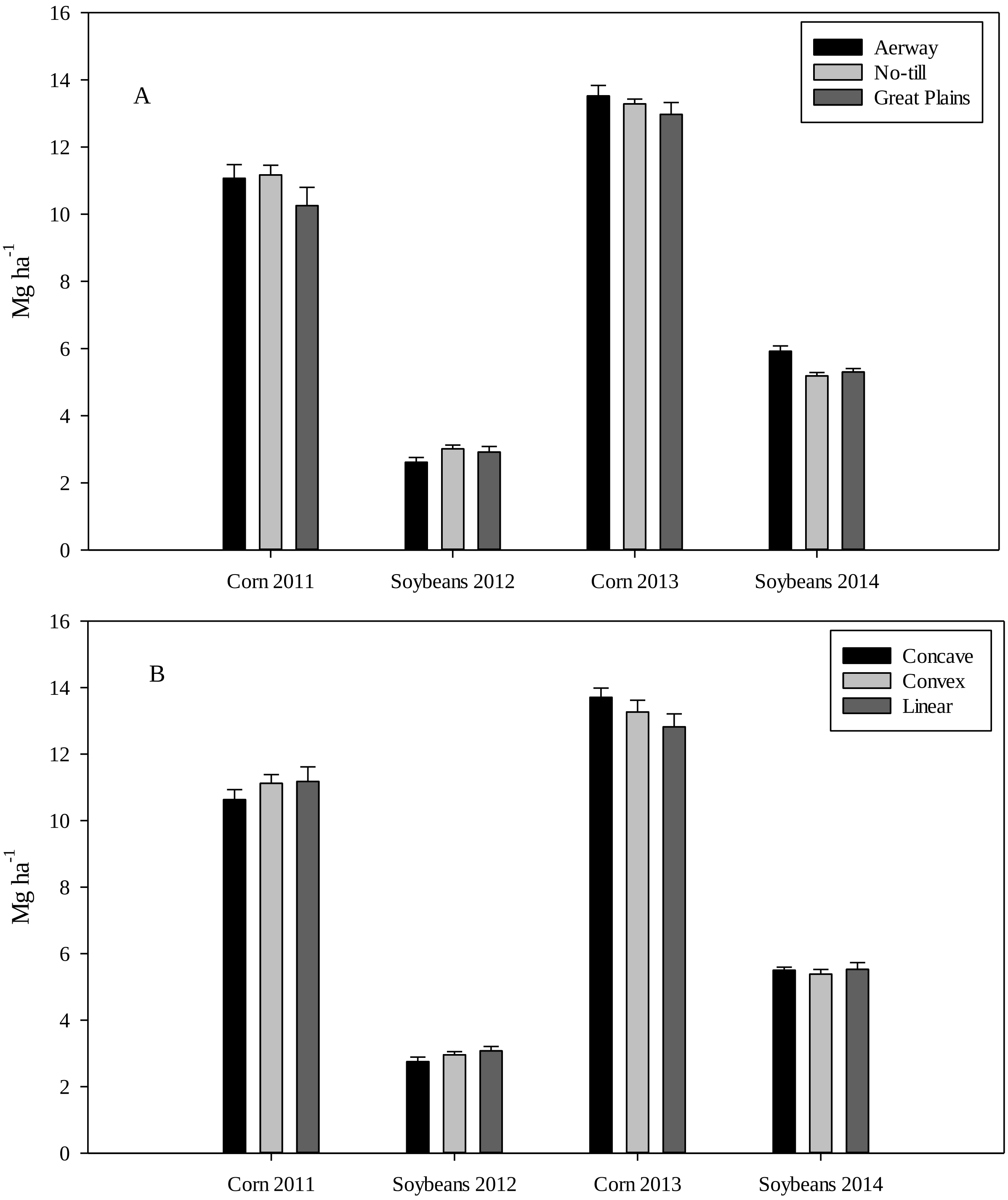
Letters indicate significant treatment differences over time.

Figure 14. Residual phosphorus within each topographic position.



Interactions between time and tillage, topographic position and time, and three-way between time, topogrpahic position, and tillage were all significant. Letters indicate significant treatment differences over time.

Figure 15. Residual nitrate within each tillage treatment *(A)* and topographic position *(B)*.



Treatment effects were not significant.
Significant interaction (p=0.05) between tillage and topogrphic position.

Figure 16. Crop yield within each field *(A)* and within each topographic position *(B).*

Soil properties related to TSS of runoff water

Soil runoff decreased in each successive time interval for the concave and convex locations, but linear positions did not follow the same trend during the infiltration test and was more varied between time intervals (Figure 18; see appendix). Total suspended solids (TSS) eroded from convex positions was greater than linear and concave positions (Figure 17). Earthworm biomass, percent water stable soil aggregates (WSA), yield, and data from the soil chemical samples were collected to analyze correlations with TSS and time interval (Table 7). Results suggest that WSA content, Ca, CEC, were negatively correlated with TSS; however, earthworm biomass was found to be highly positively correlated (Table 7). Yield was negatively correlated with the WSA sample and the final interval that TSS was collected. Earthworm biomass was also negatively correlated with CEC (Table 7).

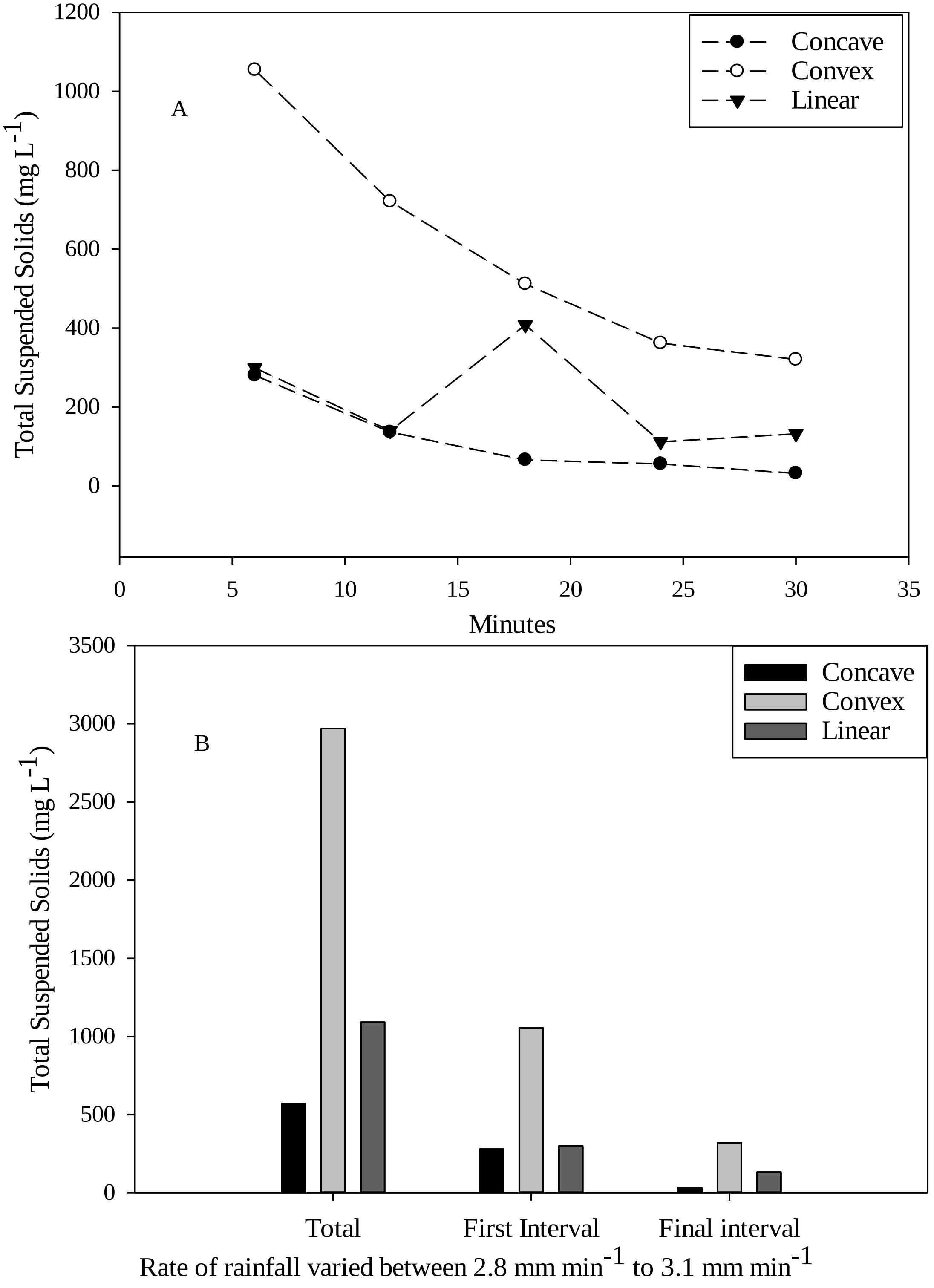


Figure 17. Soil runoff over time within each topographic position *(A)* and total runoff, first time interval and final time interval *(B)*.

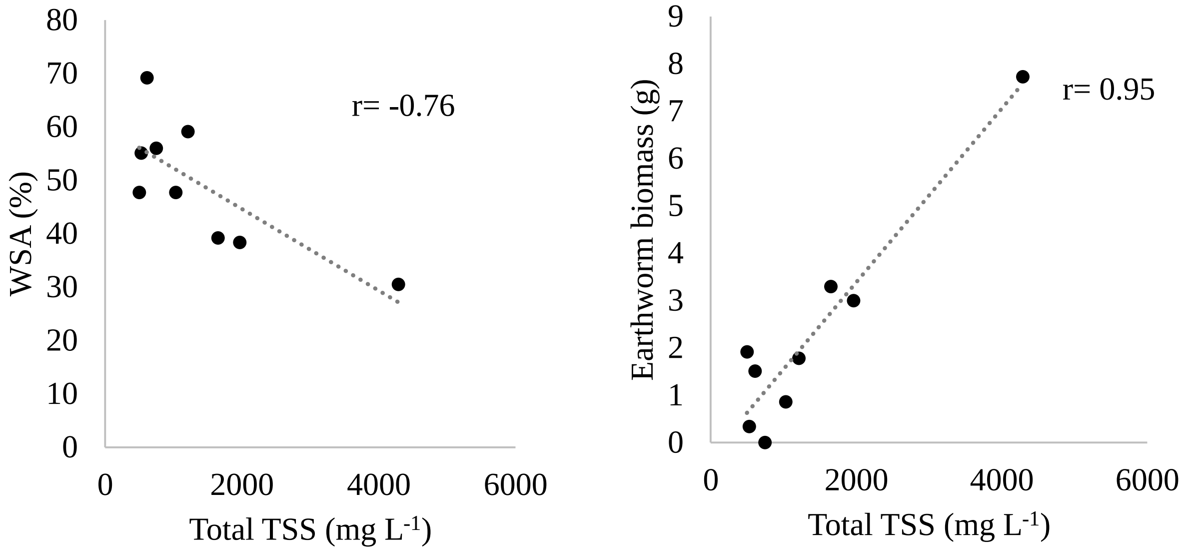


Figure 18. Correlations between WSA and TSS *(left)* and earthworm biomass and TSS *(right).*

Table 7. Correlations between soil properties and total suspended solids.

	Total	First Interval	Final Interval
SOM	-0.63	-0.38	-0.35
Earthworm biomass	0.95**	0.90**	0.70*
CEC	-0.68*	-0.46	-0.35
Ca	-0.69*	-0.57	-0.45
WSA	-0.76*	-0.59	-0.51
Yield	0.55	0.60	0.67*

* Indicates significant at α=0.01 ** Indicates highly significant α=0.001

Relationships between soil chemical properties over time

SOM was positively correlated to most soil nutrients, with the exception of nitrate and soil phosphorus during the 2013 season following the drought (Table 8). Ca, Mg, and K were all positively correlated to each other in all years. Soil K was also positively correlated with soil phosphorus in all years. Ca and Mg were also positively correlated to soil phosphorus except for the 2013 season. Ammonium was not related to nitrate during any year or soil K except for 2014.

Nutrients were also all positively correlated to each other solely in 2014, but ammonium, K, and soil P were also positively correlated in all years (Table 8). Nitrate, however, was only positively correlated to soil K and soil P following the drought in 2012, and soil Ca and Mg in 2013. Nitrate was negatively correlated with yield after corn years, but positively correlated during 2014 soybean year (Figures 20 & 21). Yields were also negatively correlated with soil Ca, and Mg in 2013 following the drought, but were positively correlated during 2014. Yields were not significantly correlated to any soil nutrient during 2012. Positive correlations between SOM and CEC, P, Ca, Mg, and ammonium were all weakened or not significant during the 2013 year (Table 8; Figure 21).

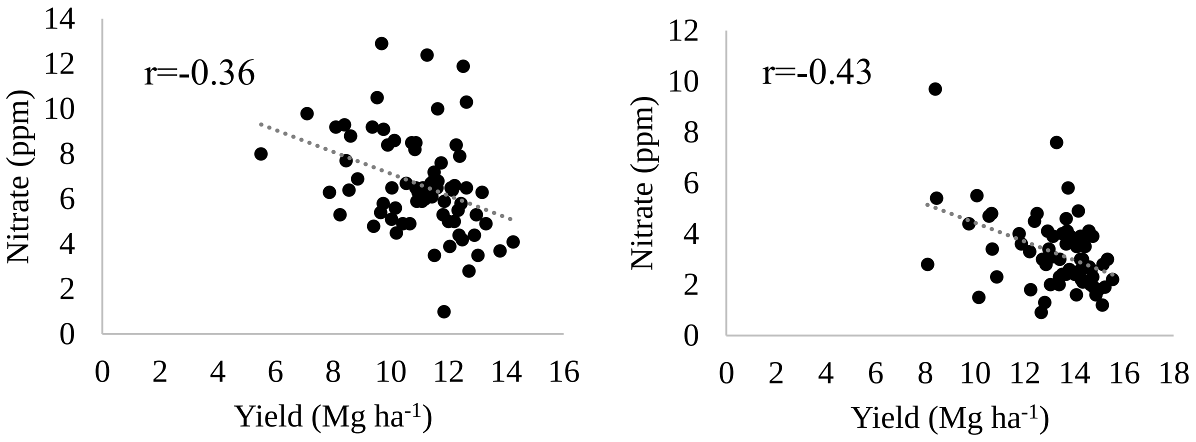


Figure 19. Correlations between residual nitrate and corn yield in 2011 *(left)* and 2013 *(right).*

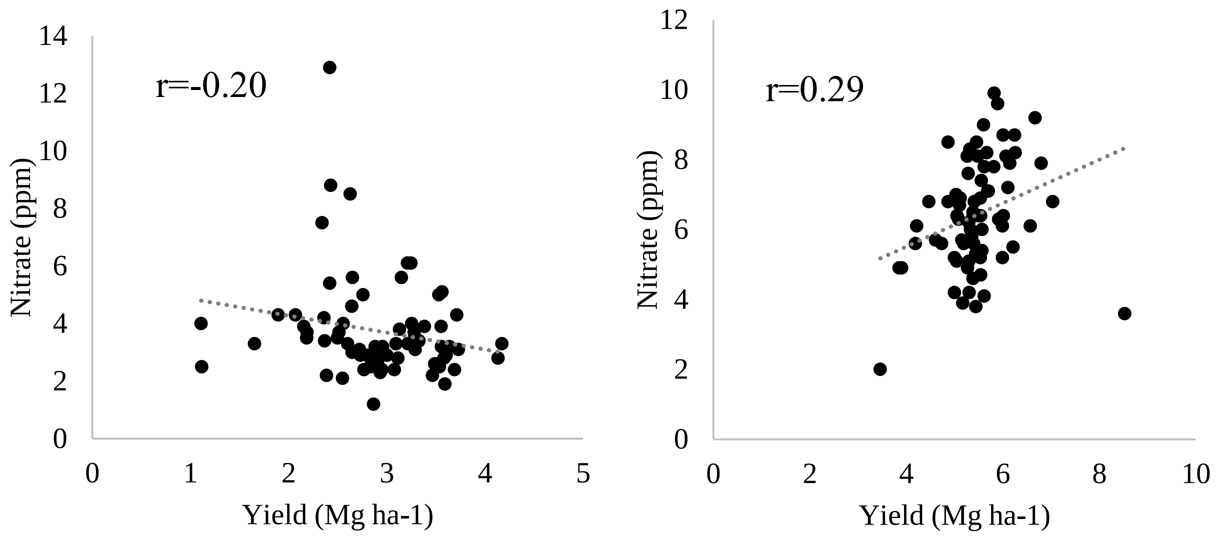


Figure 20. Correlations between residual nitrate and soybean yield in 2012 *(left)* and 2014 *(right)*

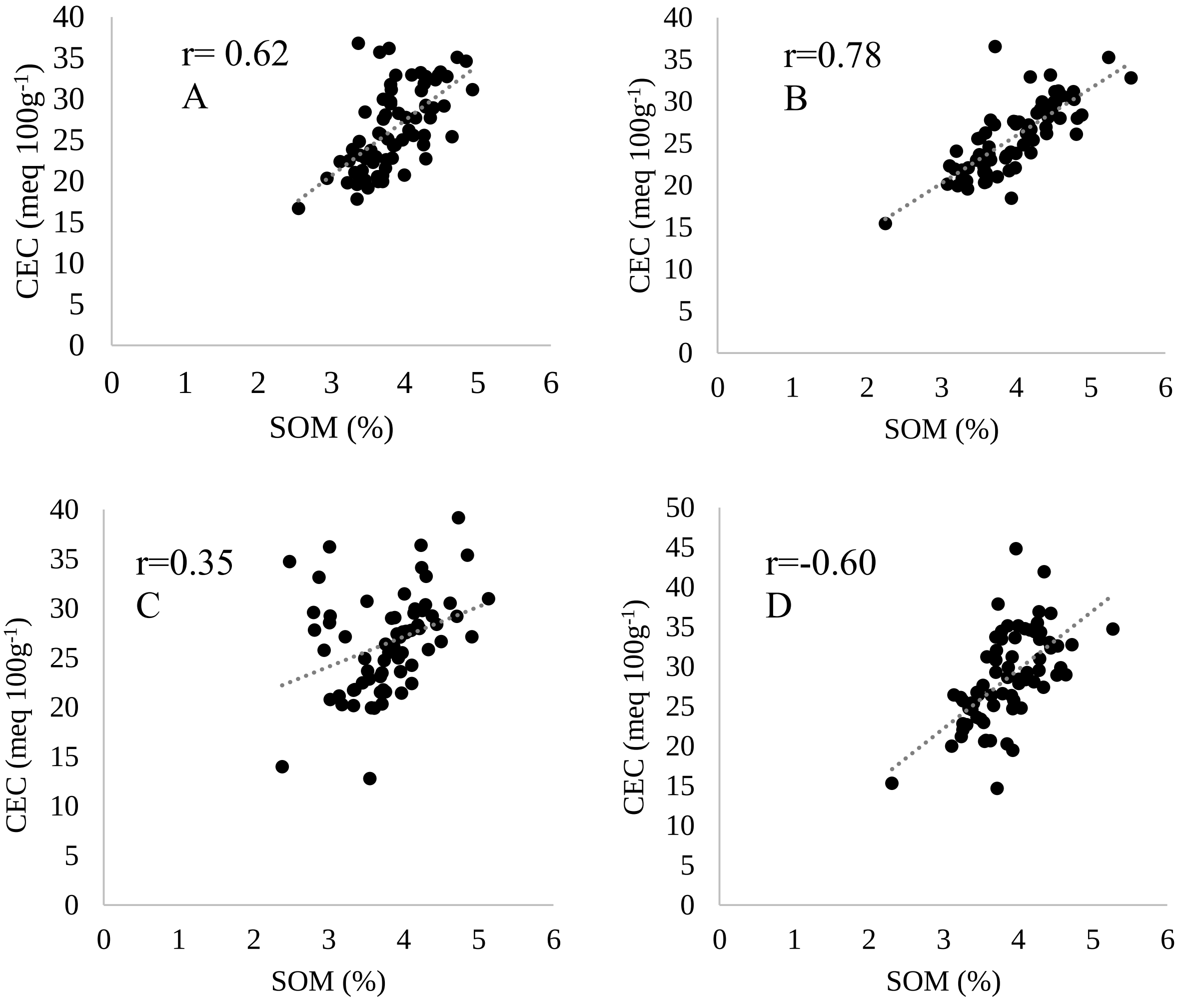


Figure 21. Correlations between SOM and CEC in 2011 *(A)*, 2012 *(B)*, 2013 *(C)*, and 2014 *(D)*

Table 8. Soil chemical property relationships over time and rotation

Soil Property	Year	Rotation	SOM	CEC	K	Ca	Mg	P	NH4	NO3
SOM	2011	corn	1							
	2012	soybean	1							
	2013	corn	1							
	2014	soybean	1							
CEC	2011	corn	0.62**	1						
	2012	soybean	0.78**	1						
	2013	corn	0.35*	1						
	2014	soybean	0.60**	1						
K	2011	corn	0.46**	0.47**	1					
	2012	soybean	0.50**	0.53**	1					
	2013	corn	0.50**	0.33*	1					
	2014	soybean	0.43**	0.67**	1					
Ca	2011	corn	0.71**	0.87**	0.40**	1				
	2012	soybean	0.75**	0.86**	0.50**	1				
	2013	corn	0.20	0.64**	0.60**	1				
	2014	soybean	0.58**	0.86**	0.67**	1				
Mg	2011	corn	0.56**	0.87**	0.34*	0.89**	1			
	2012	soybean	0.69**	0.53**	0.40**	0.87**	1			
	2013	corn	0.13	0.67**	0.50**	0.86**	1			
	2014	soybean	0.57**	0.85**	0.56**	0.87**	1			
P	2011	corn	0.51**	0.51**	0.47**	0.52**	0.35*	1		
	2012	soybean	0.51**	0.54**	0.62**	0.45**	0.36*	1		
	2013	corn	0.24	0.19	0.44**	0.28	0.20	1		
	2014	soybean	0.40**	0.53**	0.61**	0.50**	0.41**	1		
NH4	2011	corn	0.29	0.38**	0.19	0.46**	0.37**	0.21	1	
	2012	soybean	0.47**	0.42**	0.14	0.31*	0.42**	0.06	1	

	2013	corn	0.14	0.51**	0.28	0.48**	0.47**	0.22	1	
	2014	soybean	0.54**	0.57**	0.34*	0.48**	0.57**	0.33*	1	
NO3	2011	corn	0.05	-0.10	0.10	-0.18	-0.23	-0.03	-0.11	1
	2012	soybean	0.22	0.22	0.36*	0.16	0.02	0.47**	-0.18	1
	2013	corn	-0.01	0.40**	0.16	0.48**	0.52**	0.16	0.12	1
	2014	soybean	0.19	0.03	0.11	-0.07	-0.10	-0.02	0.14	1
Yield	2011	corn	0.08	0.16	0.17	0.21	0.23	0.16	0.10	-0.36*
	2012	soybean	0.11	0.16	-0.19	0.07	0.15	0.09	0.16	-0.20
	2013	corn	<0.01	-0.32*	-0.15	-0.34*	-0.30*	-0.05	-0.24	-0.43**
	2014	soybean	0.24	0.22	0.16	0.32*	0.32*	0.08	0.19	0.29*

* Indicates significant at α=0.01 ** Indicates highly significant at α=0.001

CHAPTER 4

DISCUSSION

Compaction and Crop Residue Disturbance

Bulk density was not significantly different between fields or topographic positions; however, the vertical tillage plots, concave, and linear positions were all reduced in the second year of sampling. Both the NT field and the convex positions in all the fields remained constant and similar in both sample times. The differences between these were also discrete because there was no interaction between the field and topographic position. While an overall decrease in bulk density of soils in the AA and GP fields are obviously affected by vertical tillage operations, lower bulk densities in the concave and linear positions may suggest temporary deposition of light, easily eroded materials within these lower positions. It should be noted that bulk densities in all topographic positions are considered high (between 1.38 g cm^{-3} and 1.49 g cm^{-3}) for plant production for these soils (USDA-NRCS[1], 1996).

Working depth of the tillage tool and length of time from the tillage being applied is important to distinguish when analyzing the differences in soil strength between the fields. The vertical tillage treatments are only completed after corn harvest (e.g., every other year) and the AA disturbs the soil to depth of 20 cm, whereas the GP only disturbs the top five or six cm (NRCS-USDA[2], 2010). Data between the field treatments suggest lower soil strengths in the spring following the fall when the tillage was completed. Both the AA field and the GP field become more similar to the intermediate NT field the spring after tillage was completed, but the AA field is still highest and the GP is still the lowest at most of the depth intervals (Figure 6). In a study by Wiatrak and colleagues (2009), using the same penetrometer, they determined that changes in soil strength are influenced differently by tillage depending on the electrical conductivity of the soil which was used as an indicator of soil texture. Soil texture analysis, moisture content at each depth, and sampling over a longer period may be necessary in order to determine how much these differences are affected by clay content and tillage individually and how these may interact. An analysis of the electrical conductivity of the field may have been useful in this study as an indicator of soil texture.

The AA had the highest soil strength at all levels for both sampling periods, but was not different than the NT plot until approximately 20 cm, directly beneath the working depth of the tines. Higher soil strengths persisted for another 7.5 cm after which the soil strengths were again no longer different than NT. This may suggest the formation of a weak plow pan underneath the tillage depth for the AA compared to the GP and NT. This could be due to the focused pressure exerted by the points of the triangular tines. It is also important to note that there also was no reduction in compaction on either the surface or at any depth in either sampling period (Figure 6). When comparing the field differences in soil strength between NT and GP, data indicated that NT was more compacted to a depth of 20 cm. After this depth, both NT and GP were not different and both had lower soil strength than the AA. AA management did not produce improved results compared to no-till, but these results depend greatly on how the implement is used (e.g., bank angle, depth, ballast) and the soil conditions during tillage (Brummer et al. 1999; Delaune & Sij, 2012). The AA implement has an adjustable bank angle which increases soil disturbance of the implement and incorporation of residue (Figure 2).

Differences in soil strength between the topographic positions in the first five cm depth of soil and the last five cm of soil were also significant (Table 3). Concave positions were lower than the linear positions in the first five cm and lower than the convex in the last five cm. Not surprisingly, there also was an interaction between the tillage and topographic position for the first five cm, which complicates an explanation of the differences at these depth intervals. The convex topographic positions also were higher in bottom five cm (i.e. 25cm-30cm) with no tillage treatment interaction and could be due to soil texture changes associated with entering a subsurface soil horizon. Increased erosion from the convex positions and increased deposition across the linear and concave positions could decrease the distance from the surface to these less fertile subsurface horizons (Indorante et al., 2014).

In terms of soil compaction and residue disturbance, the GP vertical tillage seems to be the most beneficial within relatively heavy Flannigan, Drummer, and Drummer-Milford soil series compared with NT and the AA. Klingberg and Weisenbeck (2011) noticed a very low level of soil disturbance and residue conservation with the GP as long as only one pass was completed. Delaune and Sij (2012) also confirmed that aeration with the Aerway does not improve infiltration or soil runoff compared to no-till in no-till wheat systems, but it was an improvement over conventional tillage. In a study of the effect of aeration and nitrogen application rates on pasture production and quality, Brummer and colleagues (1999) found that aeration did not improve forage quality or yield overall, but added that field response to aeration depended on soil conditions. They suggested that any tillage in wet, low-lying areas decreased production significantly (Brummer et al., 1999). A combination of ample precipitation, soil moisture, and fine soil textures may have made these fields more susceptible to the issues mentioned in these studies.

There are several limitations to this analysis related to the data available and the number of times samples were taken. For example, soil texture analysis at every sample point would allow for a comparison between soil texture and other soil properties, and increased sampling over a longer time would capture differences which take more time to develop and would also help normalize variation due to climate. Crop rotation likely also affected variation in soil properties and was not represented in the model. Soil nutrients and SOM were more closely related following soybean harvest and were more weakly related following corn harvest (Figure 21). Different root structures of corn and soybeans were also found to affect the soil strength and moisture content differently even with similar precipitation. Alberts and colleagues (1985) observed an increase of soil loss in soybean cultivation compared to corn, which they attributed to both protection from the increased residue coverage, and “C factors” of which differences in the root morphology of the two species were a part. Corn roots were observed to “encapsulate and hold tightly” underlying soil instead of pushing through it and they also observed that the root structure, as well as the residue, were much more recalcitrant (Alberts et al., 1985). This tendency of corn roots may contribute to the decrease in soil loss as well as a possible increase in compaction. Increased soil moisture in the second sampling period also could have reduced soil strength at sampling (Vazquez et al., 1991). In addition to increased rainfall, VWC of the soil in 2014 that the GP managed field was more poorly drained compared to the other fields (Figure 11, Table 5). A longer sample period is necessary to accurately evaluate the differences between these management techniques and topographic positions.

Crop residue coverage was very clearly dependent on the tillage application. The GP and NT fields both had the similar amounts of residue in corn and soybean years. The AA incorporated crop residue more aggressively than GP which exposed more of the soil surface. Increased soil contact with the residue caused faster decomposition and prevented residue buildup, which is an important factor in preventing soil loss (Henriksen et al., 2002; Alberts et al., 1985). Both NT and the GP had higher coverage even in the years where tillage was not completed which could be due to the buildup of residue from previous years. Increased residue coverage did not affect soil properties for the duration of this study; however, if the study was continued for a longer time (e.g., ten years) and treatments included more aggressive tillage, differences may be more apparent (Edwards & Owens, 1991; Alberts et al., 1985).

Soil Organic Matter, CEC, and WSA

Contrary to residue coverage and compaction, WSA seemed to be primarily influenced by the topographic position within which the sample was collected and no tillage. Evidence of stabilization of soil aggregates by organic materials and cations, which are more available in the concave and linear positions compared to the convex positions, was indicated by several researchers (Papiernick et al., 2009; Tisdall, 1994). Alternatively, SOM may be protected from mineralization within soil aggregates increasing SOM content with increasing aggregate stability (Beare et al., 1994, Oades, 1984). Even if soil aggregates are initially disturbed by physical destruction, they reform quickly in the presence of these materials. . High CEC and organic materials will be preferentially sorted by high particle surface area within accumulation areas (Changere and Lal, 1997; Papiernik, 2009). After drying, these fine particles reform into stronger microaggregates and macroaggregates, which have increased resistance to slaking (Tisdall and Oades, 1982; Lado et al., 2004). In short, these data suggest that the stability of soil aggregates in central Illinois soils seem to be more influenced by chemical dynamics than changes in physical attributes.

Unlike soil physical properties, most soil chemical properties were primarily affected by topographic position within this study. Generally, soil cations were highest in the concave positions, intermediate in the linear positions, and lowest in the convex positions without any significant interactions between field, time, and topographic position. Separately, tillage effects, topographic position and time all interact to affect soil test K, however, which suggests a more complex relationship between soil test results and soil moisture content (Schneider, 1997). The reliability of the soil test K is a matter of debate among soil science researchers, but the importance of this nutrient for plant function is undeniable (Bar-Yosef et al., 2015; Khan et al., 2013). Anions, such as nitrate and sodium (not presented) were not affected by topographic position at all. Overall, Trends in extractable cations within each topographic position are consistent and are well summarized by the CEC_{sum}. The levels of these cations are all high enough that soil fertility is most likely not a limiting factor and none of the cations tested are considered pollutants. However, they are important for the formation of soil microaggregates and, therefore, have implications for soil erosion and delivery of nutrients that are considered potential pollutants (Kemper et al., 1985; Tisdall and Oades, 1982). While they also are present in the organic fraction, cations such as K, Ca, Mg, and NH_4 are strongly affected by and associated with the mineral fraction of the soil (Sawhney, 1972).

In addition to fine textured mineral soil, high CEC may also indicate high levels of SOM (Baldock & Nelson, 2000). Nichols (1984) found organic carbon to be strongly correlated to fine soil fractions (r^2= 0.86) and especially clay in Mollisols (r^2= 0.90). SOM not only contains plenty of exchange sites, but also are considered an important source of many important soil nutrients. It is generally accepted that SOM is five percent nitrogen although some research has suggested that this is higher in some cases (Kapland and Estes, 1985). While not correlated with nitrate and only correlated with ammonium after soybean years in this study, other research has found organic nitrogen forms and SOM to be highly related (Kapland and Estes, 1985; Stevenson, 1982). Available nitrogen and P from the mineralization of SOM represent an important source of nutrients for plant production and a potential source of nitrogen pollution (Carpenter et al, 1998). Available P is closely associated with SOM content with organic P being the primary source of P for plants (Sharpley, 1995). Erosion and deposition of SOM in different landscape positions represent an important source and sink for soil nutrients (Changere & Lal 1997).

Poor plant nutrient uptake and slow mineralization of organic materials during the 2012 growing season likely affected the sudden increase in SOM in that year. Nichols (1984) suggested that mean annual precipitation was indeed a predictor of organic carbon (r^2= 0.45), however, his analysis was taken only at one point in time and on a regional scale. In this broad analysis, a positive correlation existed between organic carbon and rainfall because only one observation was made in several different locations rather than in one location over a period of time. The positive correlation in the regional case could be attributed to greater vegetative production in areas that have greater precipitation (Stevenson, 1994). Both VWC of the soil, and vegetative production were unreliable indicators of SOM due to sampling restricted to a single field with high SOM and samples being related over several consecutive seasons. The mobility of SOM and its tendency to accumulate in some areas and erode in others weakened these associations and even caused the reversal of the relationship between soil moisture and organic materials. Additionally, VWC at the soil surface was neither related to topographic position nor any other attribute, and was highly variable and not useful. Differences caused by microsite conditions around the probe, and the shallow depth of the probe could explain some of the variance. For example, some probes were more sheltered from the sun than others, some were closer to plant roots, and others were disturbed or dislodged by fauna under and above ground. Leaving the sensors in the field for the entire growing season and only having one probe per area proved to be problematic for this study.

The connections between precipitation, SOM content, and available nutrients in this dataset are also complex. In this study, high SOM contents were sampled immediately after the drought in 2012 followed by a sudden depletion of SOM content in the 2013 growing season. This may suggest, among other factors, poor SOM mineralization in 2012 due to lack of moisture followed by increased mineralization in 2013. Poor or negative correlation between many soil nutrients and SOM and negative correlations between yield and soil nutrients in the 2013 season could have been due to lower N and P fertilizer application rates in the previous fall and the improved yields in that year suggesting greater nutrient uptake. The increased utilization of organic nutrients following that season was also accompanied by a sudden decrease in SOM in the linear and concave topographic positions, but not in the convex positions. Additionally, SOM content and relationships between soil chemical properties and SOM seemed to rebound suddenly in the final season of the study. The sudden decrease of SOM in 2013 from the gains made in 2012 season suggests that the SOM can accumulate and mineralize quickly mainly in the concave and linear topographic positions. A strong positive relationship between the sum of the exchangeable cations (CEC) and SOM was weakened during the 2013 growing season, but quickly returned in 2014 (Figure 19). Fertilization rates, crop rotation, and precipitation all strongly influence SOM content (Johnson et al., 2006).

SOM and yield relationships were even more complex than the relationship between SOM and nutrients. Much research focus in the relationship between SOM (more specifically soil organic carbon) and yield has been centered around carbon sequestration potential and not the effect SOM on yield directly (Kong et al., 2005; Johnson et al., 2006) Quantification of the replacement of organic carbon by crop residue and the mineralization on carbon and nitrogen has proved difficult and variable dependent on crop residue quality, climate, and management (Johnson et al., 2006; Nicolardot et al, 2001). Bauer and Black (1994) found an increase of aerial biomass of 35.2 kg ha^{-1} and 15.6 kg ha^{-1} yield in wheat increases SOM by 1 Mg ha^{-1}. In a study by Johnson and colleagues (2006) presented projected organic carbon return to the soil by total crop residue including roots and exudates separated by crop type and study location. The model results varied considerably but were primarily based on yield. For example, the authors calculated a possible return of 8.52 Mg C ha^{-1} for corn verses only 2.47 Mg C ha^{-1} for soybeans in Illinois. Instead of estimating the amounts of SOM returned by crop residue, this study attempted to find a relationship between SOM content and yield within a single year or between different years of the study. Interestingly, yield was rarely correlated to yield in another year the same position and was not correlated to SOM within any one year or between any of the previous years. SOM content of the soil, however, was always directly related to the SOM content of all the other years (Table 6).

A possible explanation for the consistent areas of high SOM content in certain areas despite inconsistent yield relationships is that SOM accumulates consistently in certain areas and there are many more factors influencing yield each season. Whether the sample point was located in a source or a sink area influences these amounts more than plant production and surface residue. Reduced fertilization rates and greater yield in 2013 were also accompanied by lower SOM content, a weaker relationship between SOM contents that year and the contents in the other years, as well as weaker relationship between exchangeable nutrients and SOM content (Table 6; Figure 19). This may indicate an increased utilization of organic nutrients in that year and the immobilization of nutrients in others influenced by higher fertilization (2011), the drought (2012), and the productive soybean crop (2014).

Erosion and Deposition

The erosion and preferential accumulation of fine textured soil materials has been observed at a variety of spatial scales (Papiernik et al., 2009; Jacinthe et al., 2004; Rhoton et al., 2002). Topographic positions were shown to have an effect on soil chemical and physical properties on the field scale. Total soil runoff collected from the infiltration test was also related to these properties within each site. For example, WSA, Ca, CEC had significant inverse relationship and SOM nearly had a significant inverse relationship with the total soil runoff collected over thirty minutes (Table 7). Barthes & Roose (2002) also observed a negative relationship between soil resistance to slaking and soil runoff in many locations. For example, in a study by Lado and collegues (2004) it was found that an increase of approximately one percent SOM soils exhibited both increased aggregate stability, decreased dispersivity, and reduced surface crusting. The effect SOM content has on soil erosion, however, is complex and clay mineralogy and percentage may influence soil erosion more strongly than SOM content especially if SOM content is generally high (Krull et al., 2004; Lado et al., 2004; Wakindiki & Ben-Hur, 2002). It is clear from these results that CEC is a much more reliable indicator of suspended soil runoff than SOM, even though SOM has a strong influence on CEC (Figure 16; Table 7).

While WSA, CEC, and Ca were reasonably inversely related to the total soil runoff via suspension, earthworm biomass was even more closely directly related to total soil runoff and runoff in any single time interval (Figure 16). Furthermore, earthworm biomass was negatively related to WSA and CEC. Using earthworm biomass as an indicator of increased soil runoff and factor in aggregate stability has been debated in literature (Blanchart et al, 2004; Hedde et al, 2013). Schrader and Zhang (1993, 1997) have consistently demonstrated a mostly negative effect of endogeic earthworm activity on water stability of aggregates and tensile strength of cast formed and burrow wall aggregates compared with non-disturbed aggregates. The discussion of the effects of earthworms has mostly focused on the development of large macropores, WSA, and compaction by burrowing on soil and the influence this has on water infiltration, which directly influences the amount of overland flow (Bastardie et al, 2004, Blanchart et al, 2004).

Another common conclusion of many earthworm experiments has been that differences in stability of soil aggregates in water and SOM content have been observed depending on worm functional group (i.e., epigeic, endogeic, and anecic), diet, and soil characteristics (Hedde et al, 2013; Schrader & Zhang, 1997). Schrader and Zhang (1997) found that *A. caliginosa* (endogeic) casts were less stable in water within soils with higher clay contents, and slightly higher in low clay soils. Palm and colleagues (2013) also found decreases in organic carbon, clay content, and increases in soil moisture to be highly associated with the presence of endogeic earthworms. Samples collected in this study were exclusively endogeic species, *Lumbricus rubellus* and *Aporrectodea caliginosa,* which helps explain the associated decrease in soil water stability similar to the results presented by Schrader and Zhang. Because these species consume mineral soil and the soils have a relatively high clay content, their casts may have a negative effect on water stability. Alternatively, earthworm biomass may only be an indicator of favorable habitat conditions, which also may be vulnerable to suspension in water and have little effect on the soil itself.

Sediment and Nutrient Pollution

Sedimentation of surface water can be detrimental for surface water quality and ecology for several reasons. Physically, sediment clouds water and can reduce sunlight and oxygen transfer for organisms. Sediment coats food sources, decreases prey abundance, and spawning ground (Zuazo et al., 2009; Wood et al., 1997). Eutrophication of surface water from excess nutrients also greatly effects both the ecology and quality of surface water. Excessive growth of algae and other primary producers because of the available nutrients causes a sudden increase of oxygen demand as they decompose (Carpenter, 1998). Neurotoxins and other toxic compounds are also released from after the death of these algae blooms. These compounds pose a significant risk to aquatic organisms, and in some extreme cases, livestock and humans (Carmichael, 2001).

Organic forms of nitrogen and P are considered relatively stable in the soil compared to dissolved forms, however, these immobilized nutrients can become labile quickly particularly in high concentrations (Sharpley et al., 1992; Allen et al., 2002; Carpenter et al., 1998). Typically, organic sources of nitrogen and phosphorus do not hold much weight when determining fertilization rates due to uncertainty relating to its rate of mineralization. In order to reduce uncertainty, many farmers will apply nutrients without fully considering the amounts released by organic material. This may lead to over fertilization in areas where these nutrients are accumulating which may worsen nutrient loading in waterways. The concentration of SOM in low areas of the field may also lead to greater amounts of dissolved nutrients, which are more easily transported by runoff even if the sediment stays in place (McDowell & Sharpley, 2001; Kleinman et. al., 2000). This is potentially further compounded by poor plant uptake in saturated areas. Poorly drained soils with high levels of organic material, as were present in this study, are particularly prone to surface runoff and transport of either dissolved nutrients or sediment (Zuazo et al., 2009).

Despite the stability of nitrogen and phosphorus within SOM, SOM accumulating in low lying topographic positions still represents an accumulation of these nutrients. This is supported by elevated levels of extractable P and ammonium accumulating in these positions (see app.). As suggested above, SOM content is associated with increased extractable nutrients in every year however it was weaker in 2013 with decreased fertilization and higher yields and nitrate. Also, levels of SOM, P, and ammonium were not associated with yield in any year. Conversely, nitrate indicated negative associations with yield in corn years and a weak positive association in the soybean year with normal precipitation and yield. Ca and Mg exhibited similar behavior as nitrate but positive associations were weak in the first year of the study (Table 8). Organic forms of nitrogen, which could become available and/or eventually move into surface water, and P (Carpenter, 1998).

A possible indicator of excessive fertilization, especially in 2011, was that soil nutrient availability in the fall soil samples were rarely associated with yield. Residual soil nutrients should be affected in areas where there were greater yields. Decreased residual nitrate was more strongly associated with areas of high yields during the 2013 corn season where there was reduced fertilization, and was less associated in the 2011 season when fertilization rates were higher (Table 8). For example, it is recommended to apply fertilizer nitrogen at rates approximately 1 kg ha^{-1} N per 63 kg ha^{-1} potential corn yield of the following year for corn (Vitosh et al., 2000). In the fall of 2010, a total of 307 kg ha^{-1} of nitrogen was applied, and corn yield ranged between 10.6 and 11.2 MT ha^{-1} (Table 1; Figure 14). According to recommendations by Vitosh and colleagues (2000), the fertilizer requirement for that yield was actually between 168 kg ha^{-1} N and 178 kg ha^{-1} of applied nitrogen fertilizer. Nitrogen fertilization was approximately 42 percent higher than the aforementioned crop fertilizer recommendation for that year. The following corn season, only 237 kg ha^{-1} was applied, and residual nitrogen decreased in a similar ratio to the decrease in fertilization (i.e., 33 percent). Even taking into account considerable loss from the fall application, 2011 fertilization rate was excessive and likely contributed to significant nutrient loss.

Applications of phosphorus to this soil were also excessive as even convex topographic positions had greater than 40 ppm soil phosphorus and concave positions were nearly 80 ppm

(Figure 12). For residual phosphorus levels at or above 40 ppm, no fertilizer application is recommended (Vitosh et al., 2000). These results suggest the farmer managing this field has an incentive to apply fertilizer in excess of crop recommendations even with this information, however, the reasons for this are beyond the scope of this research. Before the 2013 corn season, spring applications of nitrogen fertilizer were removed completely, less than a third of the amount of DAP applied in the spring instead of the fall, and corn yields were approximately 20 percent higher than 2011 (Figure 15; see app.). Additionally, despite a slight increase in available nutrients and SOM content determined from soil tests were relatively similar each fall over all time periods suggesting that applied N in excess of crop demand had little effect on residual N, P, and SOM content as well as crop yield.

There was considerable potential for losses of N and P throughout 2011, and to a lesser extent during the winter months of 2012-2013, due to excessive N and P fertilization and warmer winters with higher rates of precipitation (Shipley et al., 1992; Tables 3 and 4). During the growing season in 2012, there was very little precipitation, which led to the accumulation of organically immobilized nutrients (i.e., SOM) and soil P, especially within the concave and linear topographic positions. The sudden release of these organic nutrients over one growing season in 2013, indicated by the decrease in SOM and the decrease in the association between the nutrients and SOM content accompanied by lower fertilization and higher yields, suggest that SOM represents a considerable amount of quickly and slowly released nutrients. As previously noted, the moisture content was the primary factor affecting nearly all soil processes and crop production during 2012 and likely indirectly affected 2013 as well. Exceedingly dry conditions prevented SOM from mineralizing, and caused high residual P due to poor plant production and uptake. Interestingly, the increase of residual P in the concave topographic positions was similar to the reductions in the linear and convex positions (Figure 12). Residual nitrogen (i.e., ammonium and nitrate) was low during the drought in 2012 and in 2013, which had reduced fertilization rates and high yields, and high during the productive soybean year and 2011, which received more nitrogen fertilizer (Figure 14; Figure 12; see appendix). This suggests poor nutrient return and possible ammonium fixation during the drought, accompanied by slow mineralization of the immobilized organic nutrients, which caused the general increase in SOM but resulted in low extractable residual nitrogen (Rovira & Vallejo, 2002; Figure 10). Excellent yields and improved crop uptake in 2013, as well as a reduction in applied fertilizer would suggest reduced nutrient loss compared to the 2011 growing season and possibly the 2014 growing season (Figure 11).

Productivity and Yield

Precipitation is one of the primary factors controlling yield and soil properties (which also directly influence yield). The driest season affected both production in the season and also the relationship between soil nutrients and yield in the next season, which received relatively normal precipitation. Although residual nutrient levels and SOM content are important indicators of fertility over the growing season, they were not the best indicators of yield differences. Only nitrate, Ca, and Mg were related to yield in any of the years, and they were only related in the final (most productive) seasons of the study (Table 8). Yield also was not correlated directly to SOM in any year, likely because the release of organic nutrients can be affected by differences in soil moisture and weather conditions. Additionally, the mobility of SOM makes it difficult to spatially link increased yield with organically sourced nutrients and the increased return of these organic nutrients over multiple seasons (Leavitt et al., 1996). Some soil nutrients became negatively correlated with yield and more weakly correlated to SOM content in 2013, possibly because of changes in nitrogen and phosphorus fertilization and/or increased utilization or mineralization of organic nutrients.

SOM and yield relationships were difficult to observe. Bauer and Black (1994), Johnson and colleagues (2006), and many others used crop yield and residue production to predict contributions to SOM. As noted previously, the distribution of SOM content, regardless of yield in the previous seasons, suggests that the relationship between crop production and the level of SOM in the soil is complex. Sample point location in a source or a sink area (i.e., concave or convex topographic position) influenced SOM content more than the annual replacement by crops. Fertilization rate also affects SOM content. In 2011 and 2012, there was a significant build-up of SOM with high residual nutrient levels and slow mineralization during the drought, followed by reduced fertilization rates and declining SOM content in 2013 (Figure 10). In the 2014 soybean season, SOM content, residual nutrients, and the positive relationship between soil nutrients and SOM returned (Figure 13; Figure 21). The sudden reduction in SOM, and fewer nutrients associated with the SOM that remained, supports the utilization of immobilized organic nutrients as applied inorganic nutrients became scarcer. (Figure 21). It was unclear how much of the nutrient requirement was provided by the organic nutrients provided from mineralization of SOM to crop production, but there is evidence that the relationship between SOM and soil nutrients was affected during the year that there were reduced fertilization and high yields. Soybean yield, SOM mineralization, and mobility were likely limited by lack of moisture in 2012, which may have also delayed the effects until the following season.

Other soil nutrient relationships with yield were also affected by crop rotation. During the productive soybean year in 2014, nitrate is weakly positively correlated with yield, likely due to nitrogen fixation by the soybeans. Patterson and LaRue (1983) also reported similar findings, noting significant nitrogen fixation in soils that were not fertilized with nitrogen. Soybeans are also more responsive to the presence of Ca and Mg in the soil than corn, which was also indicated by a positive relationship between these cations and soybean yield; however, there was a negative correlation between these cations and yield in the previous corn year (Vitosh et al., 2000). Both of these years were more productive than the previous two years (Figure 16).

Yield was also rarely associated with a certain topographic position or volumetric water content of the soil in this study. However, Kravchenko and Bullock (2000) found a modest association between higher SOM and lower elevation positions with higher yields. A micro-scale analysis by Kapland and Estes (1985) also confirmed higher above- and below-ground plant production within pots of greater SOM content. Variable precipitation within each of the growing seasons in this study may have affected the speed at which SOM was mineralized and how nutrients such as K and ammonium were fixed or made available under dry conditions (Rovira et al, 2002; Liu and Barak, 1997). This also may have blurred the connection between SOM accumulation and yield. Yield was also much more affected by overall lack of moisture in 2012 than the amounts of available nutrients or presence of SOM.

Limitations

The primary limitations of this study are the amount of sample times that were collected, length of time, variability in weather, and number of fields. In order to accurately determine the effects of tillage management, crop rotation, and topographic position, data need to be collected over a longer period of time to account for uncontrollable climatic variability (e.g., precipitation). Soil chemical properties seemed to be affected by the lack of precipitation in two of the four seasons and soil physical properties were only collected in two seasons. An analysis of only two seasons is not sufficient to determine if the changes are consistent over time and between crops.

Additionally, there was only one annual sampling for both physical and chemical soil properties, which were not collected at similar points in the season. Not taking the samples at the same time made it difficult to observe any interactions between soil physical and chemical properties. More sampling periods, instead of annual collections, would allow a more focused analysis of trends in soil properties over single seasons. The large, field scale design of the project and the distance of the fields from the university prohibited the additional sampling necessary for a more focused time analysis. More fields and sampling periods would allow for a more robust analysis of the potential effects of time, management, and topographic position.

CHAPTER 5

CONCLUSIONS

Synthesis

Differences in conservation tillage management and topographic position were found to have an effect on soil chemical and physical properties. With the exception of soil strength, soil physical properties were affected by differences between the fields, more so than by topographic positions. Conservation tillage was clearly a factor affecting soil compaction and burying crop residue. Topographic position, on the other hand, affected samples which isolated shallow soil depths, as was possible with the soil strength results. Most of the samples for soil physical properties were a generalization of the soil to 15 cm, which may have diluted the differences at the soil surface that were effected by topographic position. This is not to suggest that topographic position has no indirect effect on physical attributes. For example, while not affected by topographic position at all depths, topographic position interacted significantly with time to affect bulk density and soil strength at shallow depth intervals (Table 2).

In contrast to compaction and residue coverage, WSA samples were primarily affected by topographic position and less so by disturbance from conservation tillage. The WSA portion of soil represents an important connection in which chemical properties, such as exchangeable soil nutrients, texture, and SOM, influence physical attributes of soil especially in the absence of excessive physical disturbance. Soil chemical properties were also primarily associated with topographic position rather than management or other field differences. Soil nutrients and SOM accumulate and deplete even in level, poorly drained fields influenced by topographic position. Three topographic positions (i.e. concave, convex, and linear) delineated by TPI analysis designed by Wiess (2001) and automated by Jenness (2006) were found to be an effective method for delineating zones characterized by soil chemical properties for this study.

Soil nutrients in both the mineral soil fraction and SOM are also affected by weather conditions and rate and timing of fertilization. For example, poor yield after over-fertilization in the spring of the first year of the study resulted in high residual nitrate and P. The drought in 2012 lifted SOM between 0.3% in linear areas and nearly a half of a percent in concave areas due slow mineralization in the dry 2012 growing season. The following corn year, 2013, yields were above average, and while they applied a similar amount of fertilizer N in the fall, the application rate of diammonium phosphate (DAP) was reduced and applied in the spring. The spring application of urea-ammonium nitrate solution (UAN) that was completed in 2011 was omitted in this year. In contrast to 2011, negative residual nitrate correlations with yield, generally low residual N and P, as well as pre-drought levels of SOM were determined from the soil samples. SOM was also not positively associated with all of the cations, as it was in previous and following years. This suggests that corn yields do affect residual nitrate, P, and SOM content particularly when fertilization is more in line with crop demand. Both inorganic nutrients held by SOM exchange sites or organic nutrients slowly mineralized from SOM are a considerable portion of available nutrients, and particularly in soils which five percent or higher SOM is common (Table 2.3). The rapid response of SOM content to fertilization rates may also provide evidence for the existence of quickly mineralized and slowly mineralized fractions of SOM (Leavitt et al., 1996; Rovira, 2002).

The agronomic importance of the accumulation and depletion of soil nutrients due to surface runoff is well established in the literature and holds implications on soil physical properties and nutrient pollution (Sharpley, 1995; Kleinmann et al., 2000; Ritchie et al., 2007).

Additionally, this study suggests that failing to account for organic delivery of nutrients, crop requirement, and movement of nutrients leads to considerable losses of resources. Much of the excess nutrients applied before the first planting of corn in this study was likely lost to the atmosphere or water bodies, and therefore did not provide a yield benefit. An analysis of the speed and quantity of suspended soil runoff and associations between suspended soil runoff, yield, and soil properties suggests that valuable soil materials suspend and move quickly during a precipitation event with overland flow. Also, earthworm biomass and WSA were observed to be excellent indicators of the risk of soil suspension in this study (Figure 18). It is clear from this study that most soil processes and attributes are closely associated and the outcome of their interactions is dependent on differences in management and weather dynamics over several years.

Management Implications

Soil disturbance from tillage and fertilizer application is an important factor in the optimization of crop production and soil quality. Among the conservation tillage methods evaluated here, it was determined that the GP tillage treatment was the most beneficial in terms of soil compaction and residue conservation. The field treated with the AA was slightly more resistant to penetration below 20 cm than NT and at any depth compared to the GP. Data suggest that there is no benefit of using the AA over NT as a conservation tillage practice in this site. Additionally, it may or may not be beneficial to use the GP over NT depending on the cost of application. An analysis of bulk density between two seasons also suggested the potential benefit of tillage; however, natural variation in bulk density is also present in the NT field. An evaluation of more seasons would be necessary in order to improve accuracy of the analysis as well as to evaluate benefits of each tool compared to NT.

The effects of fertilization rates and timing on residual nutrients and crop yield also have many implications for management. Excessive fertilization in the fall of 2010 and spring of 2011 had little effect on crop yield and residual nutrients in the fall of 2011. The next season that corn was planted, 2013, all fertilization was greatly reduced. However, yields were 20 percent higher, likely due to more favorable weather. While the residual nutrients were reduced compared to the previous 2011 corn season, they were not reduced by the same ratio as fertilization. This suggests that excessive fertilization does not increase yields, is a poor use of resources, and is probably a pollution concern. While it is impossible to predict favorable and non-favorable conditions a crop will face beyond nutrient availability, it is prudent to apply fertilizer in amounts close to a realistic estimation of crop uptake. Therefore, maintaining detailed records of the effects of tillage and fertilizer management, and awareness of topographic position on field conditions are necessary for efficient and sustainable levels of production.

Future Research

These findings should be substantiated by further research, particularly in the areas of soil nutrient availability, loss, and erosion and how these affect crop yield. In order to better analyze the relationships between soil physical attributes and fertility, additional soil samples should be taken in the spring and possibly during the growing season. The addition of spring soil samples would allow the evaluation of potential losses of fall applied fertilizer over the winter as well as crop response to higher soil fertility. A trend analysis of physical and chemical dynamics as well as how rapidly soils respond to changes in management with more sampling times per season. For example, during the drought year it would be possible to see how fast SOM accumulates and how fast it was released the following season. This would also be useful for determining how SOM and soil nutrients are eroding and accumulating in different topographic positions.

Further elucidation of the connection between earthworm biomass and suspended soil runoff as well as other important soil attributes would also be beneficial. This research suggests that earthworm biomass was an excellent indicator of soil instability in water; however, more samples would be needed to determine causality and to increase the strength of the test. To that end, more evaluation of the soil runoff test would further determine if this is a useful method for determining soil susceptibility to runoff via suspension. Despite a clear connection between WSA and total suspended solids within each sample site, more tests and testing in different periods of the season would be needed to establish this tests validity as well.

Finally, more research at the field scale could be accomplished using the topographic positions delineated by TPI values as designed by Wiess (2001) and automated by Jenness (2006). Analysis of soil samples within these topographic position boundaries suggests that this method is an effective way to model soil characteristics in regards to productivity and pollution risk. There are many applications for this tool particularly with research on the field scale. For example, SOM and nutrient movement and deposition could be easily demonstrated using these positions as separate plots. Also, this tool is useful for determining these positions in level areas like the Midwest where it is difficult to correctly distinguish a concave area from a convex area. Understanding soil data within a spatial context at the field scale is important for the continuation of informed research and more efficient and sustainable farming practices.

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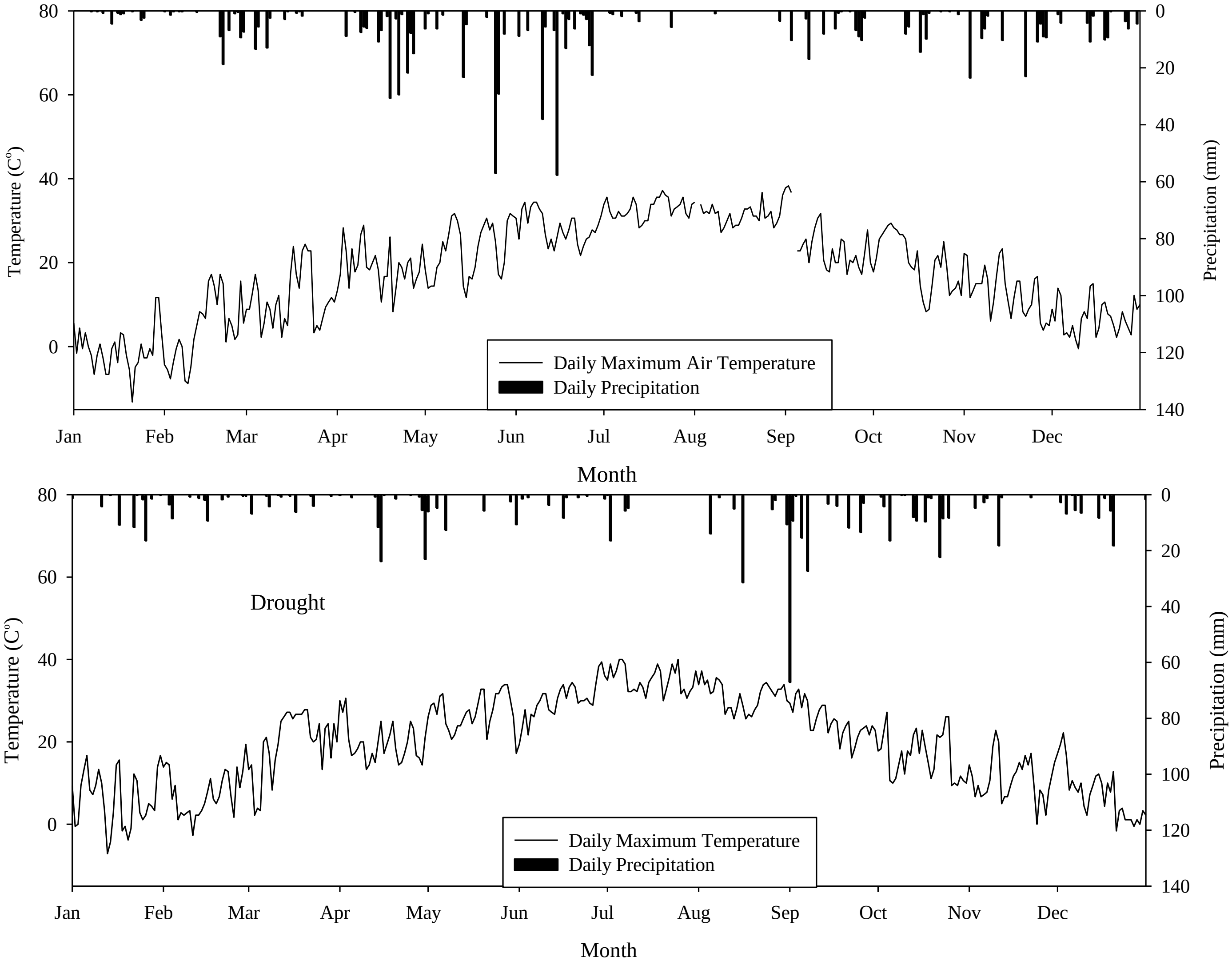
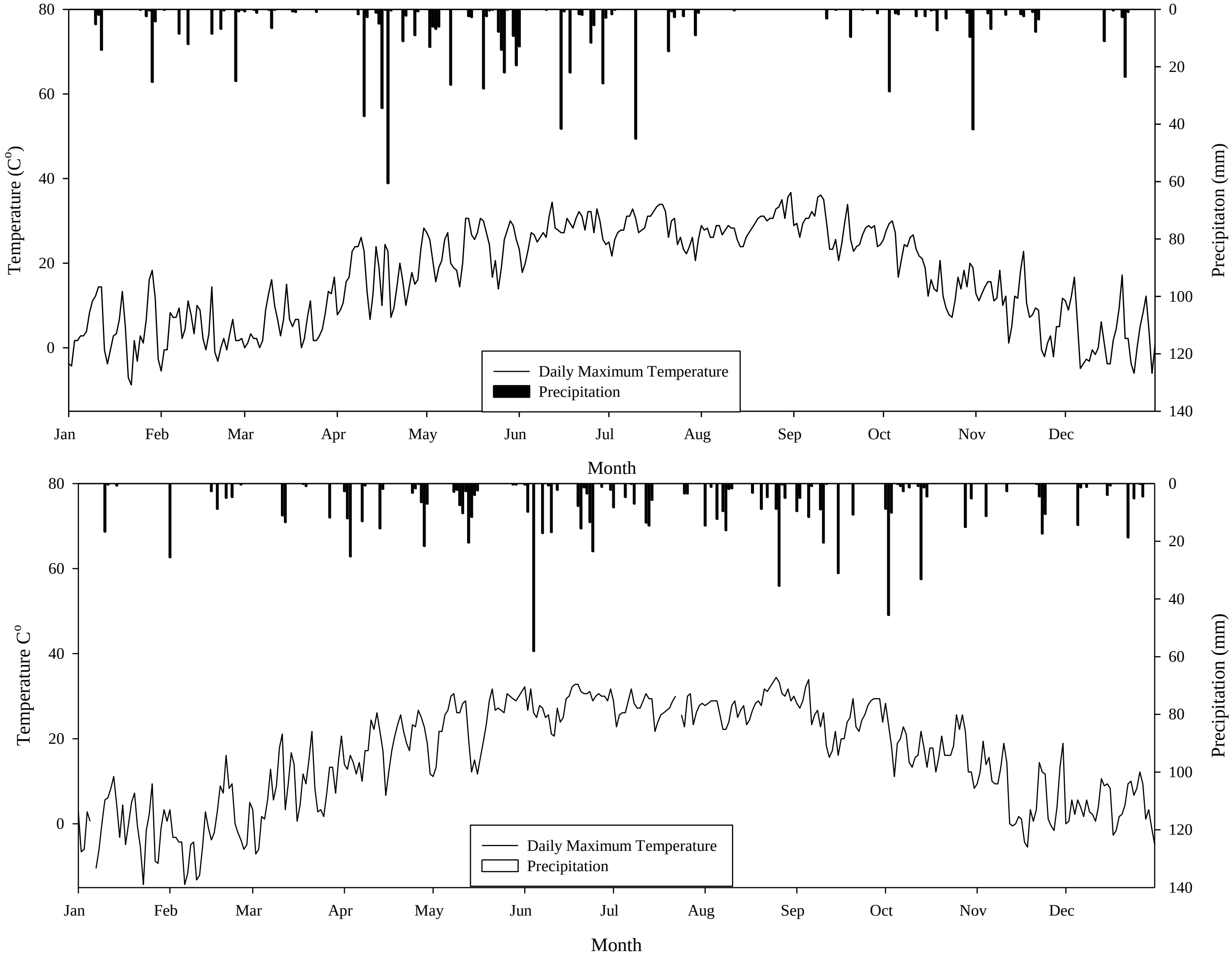
APPENDICES



A 1. Daily maximum air temperature and precipitation for 2011(*top),* and 2012 *(bottom)*



A 2. Daily maximum air temperature and precipitation for 2013(*top),* and 2014 *(bottom)*

A 3. Means of soil physical properties with standard errors

Year	Aerway	No-till	Great Plains	Linear	Concave	Convex
WSA (%)						
2013	49.98±8.34	55.71±8.40	61.64±4.43	56.29±5.93	75.10±3.71	37.97±6.17
2014	49.06±5.96	39.53±8.07	42.95±4.34	40.11±4.85	53.27±3.95	29.85±4.52
Bd (g cc^{-1})						
2013	1.49±0.01	1.47±0.01	1.49±0.02	1.49±0.01	1.48±0.01	1.48±0.02
2014	1.40±0.01	1.43±0.02	1.39±0.01	1.39±0.01	1.44±0.02	1.39±0.01
Crop Residue Coverage (%)						
2013	67.99±7.58	76.08±2.61	74.00±1.72	77.57±2.66	69.48±6.88	71.67±3.42
2014	61.44±5.71	92.00±2.67	80.44±2.48	73.50±9.52	75.38±4.52	82.20±2.72

A 4 Means of soil chemical properties with standard errors

Year	Aerway	No-till	Great Plains	Linear	Concave	Convex
CEC (meq 100^{-1})						
2011	36.46±1.57	36.11±1.55	37.89±1.29	37.01±1.54	42.15±1.03	31.3±0.8
2012	36.09±1.14	35.13±1.36	37.43±1.13	35.96±0.92	41.43±0.86	31.26±0.82
2013	36.67±1.13	35.8±1.65	39.13±1.33	37.32±1.11	42.11±1.13	32.17±1.18
2014	39.64±1.35	38.16±1.84	42.05±1.72	39.04±1.28	46.37±1.44	34.43±1.28
SOM (%)						
2011	5.4±0.13	5.32±0.15	5.44±0.12	5.38±0.12	5.78±0.12	5±0.11
2012	5.62±0.13	5.58±0.22	5.58±0.15	5.58±0.13	6.2±0.14	5±0.12
2013	5.39±0.17	5.13±0.17	5.41±0.14	5.26±0.14	5.62±0.21	5.04±0.11
2014	5.56±0.11	5.31±0.18	5.32±0.11	5.38±0.11	5.8±0.13	5.02±0.12
P (kg ha^{-1})						
2011	97.94±7.74	90.71±6.42	106.58±7.86	97.42±7.68	116.49±7.33	81.32±5.37
2012	99.4±6.9	91.35±8.23	111.71±9.88	93.63±6.48	133.23±8.69	75.6±5.4

2013	93.39±6.45	93.86±7.14	94.27±8.5	88.61±6.08	118.36±7.43	74.55±5.4
2014	78.75±7.54	71.98±5.66	80.5±6.62	69.48±5.16	97.88±6.11	63.88±6.45
K (kg ha^{-1})						
2011	336.29±13.06	327.48±15.56	330.05±15.51	324.45±14.12	362.78±13.23	306.6±14.47
2012	381.27±15.97	350.88±18.45	370.88±16.47	363.01±13.52	420.93±17.12	319.08±13.57
2013	371.58±12.36	332.62±16.96	325.73±13.64	340.14±9.73	384.77±12.49	305.03±17.02
2014	296.45±10.65	278.78±15.42	285.08±11.37	280.64±8.92	327.89±9.46	251.77±13.77
Ca (kg ha^{-1})						
2011	4324.19±170.12	4213.3±195.77	4438.58±145.56	4396.47±169.21	4857.71±130.38	3721.9±124.7
2012	4653.6±1.14	4437.24±187.84	4646.54±138.73	4612.24±121.43	5115.19±132.85	4009.95±131.54
2013	4565.4±1.13	4262.24±207.27	4388.18±121.94	4349.51±116.13	4960.14±122.43	3906.18±151.83
2014	4824.4±1.35	4577.36±218.01	4807.6±153.57	4738.24±128.64	5332.37±160.42	4138.75±160.61
Mg (kg ha^{-1})						
2011	673.17±44.45	668.38±42.18	638.63±31.89	675.44±35.82	799.63±34.38	505.11±20.89
2012	701.63±1.14	660.33±38.56	634.14±29.46	677.19±29.12	796.66±30.38	522.26±22.75
2013	690.61±1.13	655.38±45.51	606.49±27.09	656.95±31.56	789.25±34.17	506.28±25.99
2014	702.45±1.35	686.82±45.42	651.23±34.5	686.88±35.05	829.15±35.91	524.48±25.86
NO3 (kg ha-1)						
2011	7.09±0.49	6.53±0.45	6.48±0.45	7.13±0.57	6.16±0.43	6.8±0.36
2012	3.2±0.81	3.23±0.16	4.75±0.51	3.5±0.25	4.58±0.51	3.1±0.17
2013	3.65±0.81	3.19±0.3	3.46±0.54	3.42±0.53	3.84±0.39	3.05±0.24
2014	7.38±0.97	5.35±0.26	6.55±0.23	6.63±0.29	6.18±0.34	6.47±0.33
NH4 (kg ha-1)						
2011	6.98±0.35	6.92±0.52	7.42±0.31	7±0.35	7.79±0.41	6.53±0.41
2012	4.45±0.81	3.76±0.26	3.68±0.32	3.82±0.28	4.31±0.28	3.76±0.22
2013	5.44±0.81	5.41±0.27	5.66±0.22	5.78±0.28	6.08±0.24	4.66±0.27
2014	7.14±0.97	6.55±0.41	7.02±0.28	6.85±0.24	8.05±0.33	5.81±0.21
Yield (MT ha^{-1})						

2011	11.07±0.41	10.72±0.29	10.69±0.33	11.12±0.27	11.18±0.44	10.63±0.3
2012	2.72±0.14	2.89±0.11	3.04±0.11	2.95±0.1	3.07±0.13	2.75±0.14
2013	13.52±0.31	12.75±0.38	12.97±0.37	13.26±0.36	12.82±0.4	13.7±0.28
2014	5.92±0.16	4.98±0.14	5.3±0.1	5.38±0.14	5.53±0.2	5.5±0.09

A 5. Area of each of the topographic positions in hectares

Field	Concave	Convex	Linear	Linear > 2% slope
Aerway	6.84	7.7	14.99	4.34
No-till	8.45	7.5	20.89	1.83
Great Plains	7.41	6.55	17.61	1.05
Total	22.7	21.8	53.49	7.22

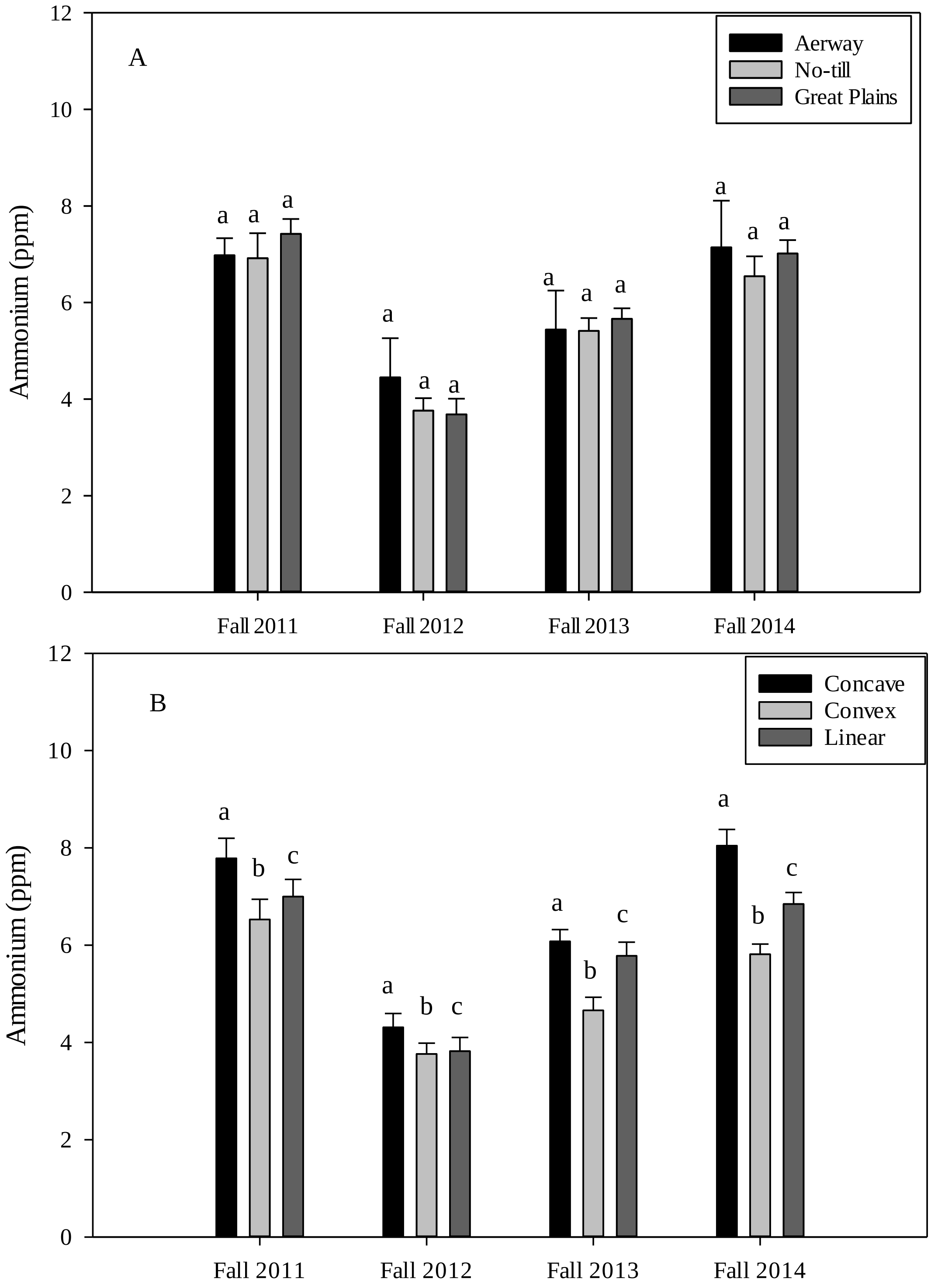
A 6. Soil runoff, yield, earthworm biomass and chemical properties

Plot ID	WSA (%)	Composite (mgL^{-1})	First Interval (mgL^{-1})	Final Interval (mgL^{-1})	SOM (%)	Earthworm Biomass (g)	Yield (bu ha^{-1})	Ca (kg ha^{-1})	Mg (kg ha^{-1})	P (kg ha^{-1})	CEC (meq 100 g^{-1})
27	69.2	611.5	349.5	20.5	4.1	1.5	70.3	3258	594	23	28.4
45	39.2	1651.5	627.5	173.5	4.08	3.3	87.0	3293	404	30	25.6
54	59.2	1212.5	391.5	263.5	3.94	1.8	78.0	3826	633	75	29.8
85	30.5	4288.5	1481.5	467.5	3.44	7.7	87.0	2766	415	43	24.4
129	56.0	745.5	283.5	80.5	4.95	0.0	72.6	4375	835	87	38.9
149	38.4	1966.5	194.5	24.5	3.31	3.0	75.5	3020	371	55	22.7
202	47.7	498.5	246.5	44.5	4.31	1.9	83.2	3969	564	55	34.6
213	47.8	1034.5	380.5	248.5	3.95	0.9	84.4	3502	491	35	31.8
222	55.2	529.5	210.5	43.5	3.91	0.3	68.7	4923	824	79	35.5

A 7. Correlations between soil properties during the Cornell infiltration test

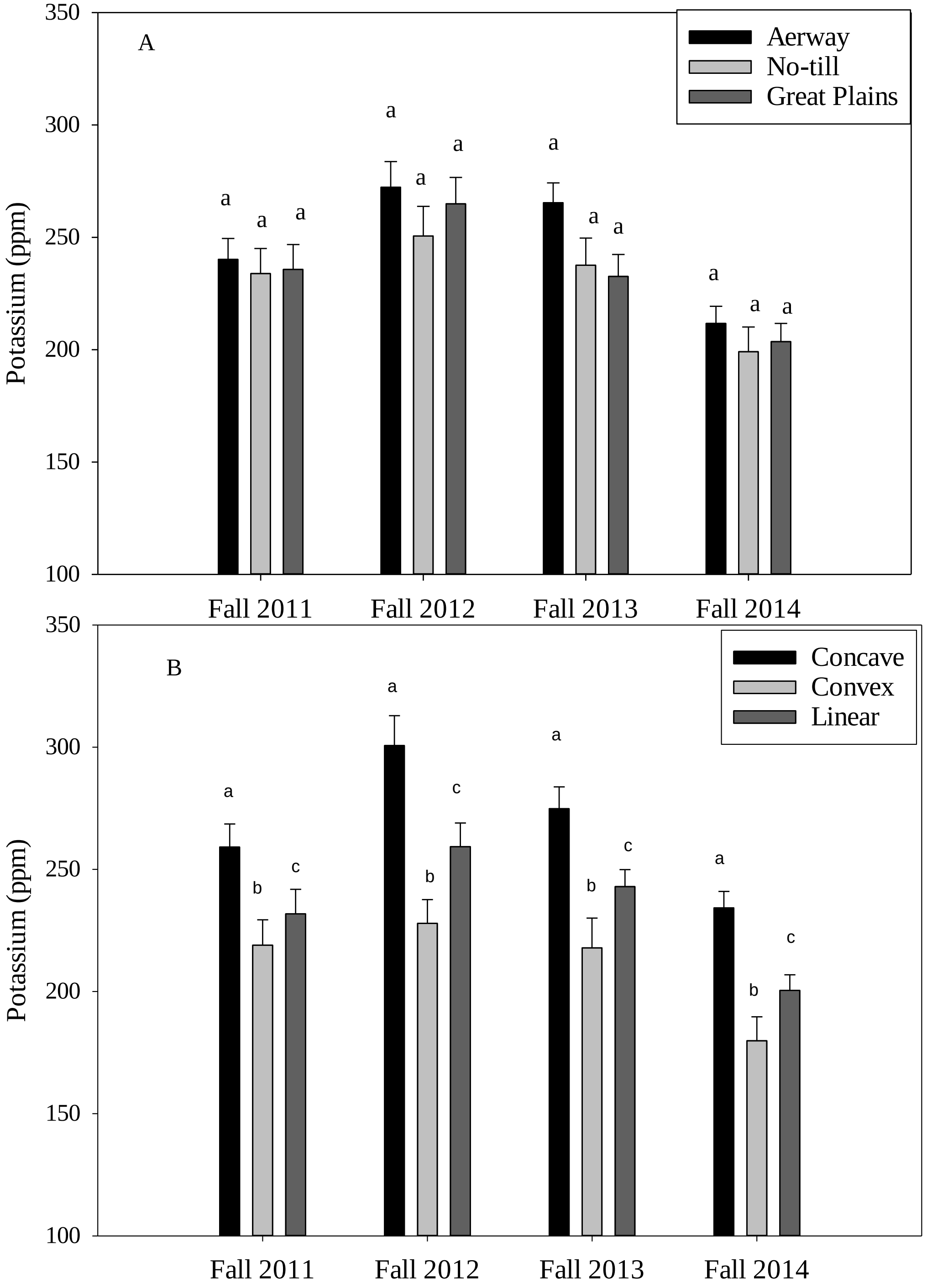
	SOM	Earthworm Biomass	CEC	WSA	Phosphorus	Infiltration
SOM						
Earthworm biomass	-0.63					
CEC	0.81**	-0.73*				
WSA	0.53	-0.74*	0.53			
Phosphorus	0.34	-0.39	0.61	0.19		
Infiltration	-0.16	-0.04	-0.09	0.35	0.27	
Yield	-0.23	0.61	-0.39	-0.72*	-0.46	-0.10

* Indicates significant at α=0.01 ** Indicates highly significant α=0.001



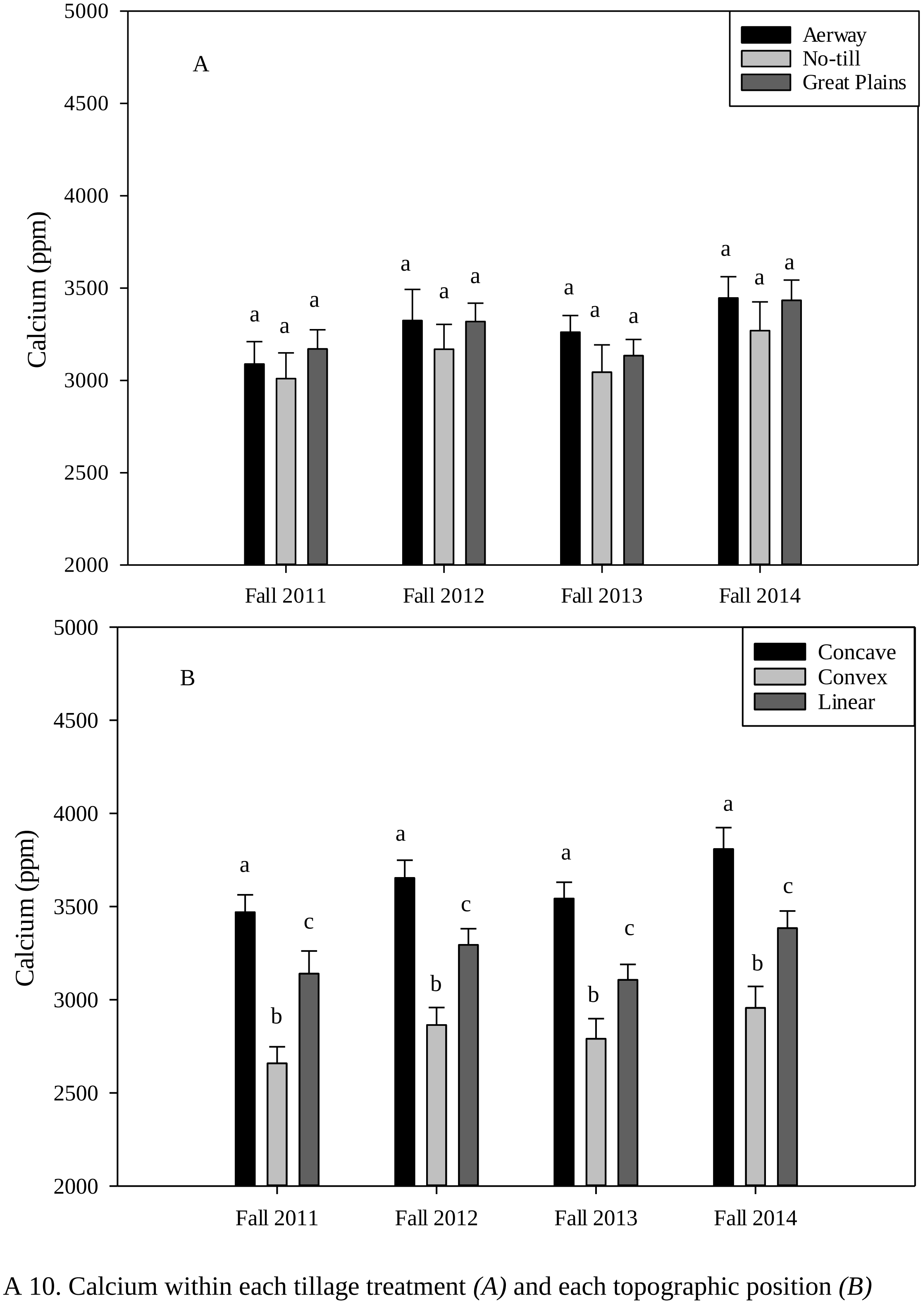
There were no significant interactions. Letters indicate significant differences over time.

A 8. Residual ammonium within each tillage treatment *(A)* and each topographic position *(B)*

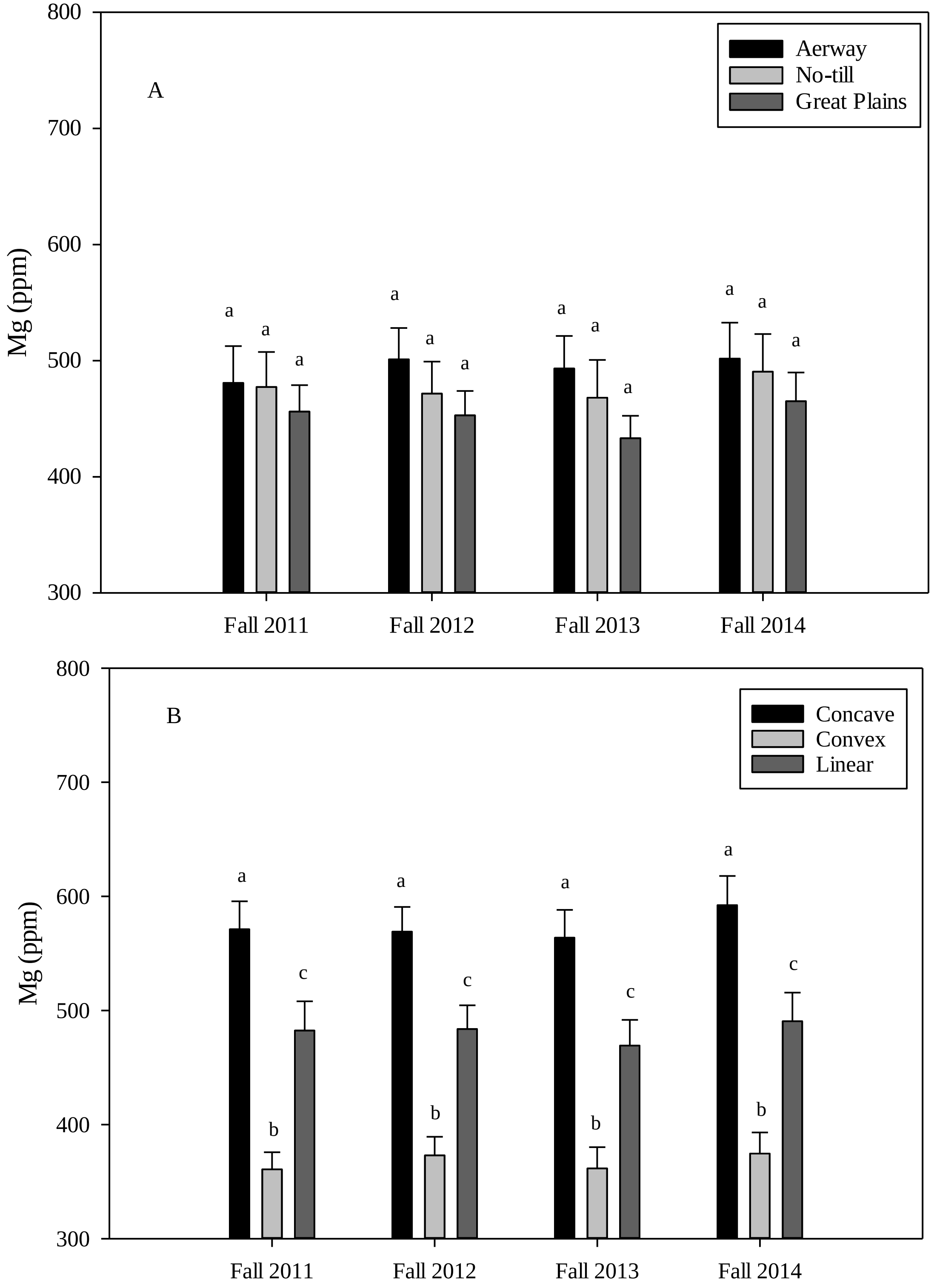


letters indicate significant differences in treatments over time.
There was also a significant tillage and topogaphic position interaction (p=0.0013)

A 9. Potassium within each tillage treatment *(A)* and each topographic position *(B)*



A 10. Calcium within each tillage treatment *(A)* and each topographic position *(B)*



A 11. Magnesium within each tillage treatment *(A)* and each topographic position *(B)*

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Mellinger, A.M., J.E. Schoonover, R. Cook, and J. Groninger. Impact of topographic position and management on soil properties in central Illinois. UCOWR annual conference, Las Vegas, Nevada. June 2015. Oral Presentation