THE EFFECTS OF TILLAGE AND LONG-TERM IRRIGATION ON DYNAMIC SOIL PROPERTIES AND GENESIS OF ARIDIC ARGIUSTOLLS IN WESTERN KANSAS

by

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Abstract

Soil is a dynamic resource that can undergo many changes due to altering conditions (Tugel et al., 2005). With that, humans can have a great effect on the conditions of a landscape and contribute to soil change. As soils change, the function of soils can be altered which would affect the ability of soils to support ecosystem services. The objective of this thesis is to access how management affects dynamic and inherent soil properties in western Kansas soils. Eight sites in Sheridan County, KS mapped as Keith 1-3% slopes (fine-silty, mixed, superactive, mesic Aridic Argiustolls) were described and sampled. Of the eight sites, four are in ST (ST) management and four are in no-till (NT) management. All sites have been irrigated under center pivot irrigation systems since the 1970s. Soil samples of the A horizon were taken at each site to analyze total carbon, aggregate stability, bulk density, pH and microbial respiration to assess the impacts of tillage management on dynamic soil properties. Additionally, pedons were described from the ST sites in the irrigated areas as well as outside the pivot track to represent dryland conditions. Particle size data, field descriptions, and the micromorphology of thin sections were analyzed to determine if the classification of Keith soils are affected by irrigation. Significant differences between NT and ST management were seen in microbial respiration, select water stable aggregate sizes, and pH and bulk density at certain depths. It was also found that irrigation did not affect clay illuviation nor carbonate leaching. Overall, it was concluded that inherent soil properties such as soil map unit composition and parent material can have a greater impact on soil change and prevent the recognition of changes in soil properties over a human time scale.

Table of Contents

List of Figures

List of Tables

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Dedication

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Chapter 1 - Literature Review

Description of Study Area

Location

Eight sites were selected in Sheridan County in western Kansas (Figure 0-2). These sites were mapped as Keith silt loam, 1-3% slopes (Keith fine-silty, mixed, superactive, mesic Aridic Argiustolls). The locations of the sites according to the US Public Lands Survey System are as follows: NW ¼ of Section 32, T9S, R28W; Section 5, T10S, R28W; SW ¼ of Section 34, T9S, R30W; SE ¼ of Section 8, T10S, R29W; S ½ of Section 5, T9S, R30W; SE ¼ of Section 4, T10S, R28W; NE ¼ of Section 31, T9S, R28W; and Section 1, T10S, R29E in Sheridan County, KS. According to the USDA-NRCS Land Resource Regions, this area is located in MLRA 72, The Central High Tableland, and is part of Land Resource Region H (Figure 0-1) (United States Department of Agriculture, Natural Resources Conservation Service, 2006). Of the total land in MLRA 72, 54% is in Kansas and it is a smooth landscape with nearly level to gently rolling slopes.

Parent Material

The majority of the soils in the Central High Tableland are formed from alluvial sediments that washed onto the plains from the uplift of the Rocky Mountains. Soils specific to western Kansas will typically have a loess mantle. On the Great Plains, four quaternary loess units have been extensively identified and studied. Listed from oldest to youngest, these are: Loveland Loess, the Gilman Canyon Formation, Peoria Loess, and Bignell Loess (Bettis et al., 2003; Frye, J.C., and A.B. Leonard, 1951; Schultz and Stout, 1948). Welch and Hale (1987) created a generalized map of loess distribution in Kansas, and identified the two types of loess present in western Kansas; Peoria and Bignell loess. Peoria loess (Late Wisconsin) is extensive in northwestern Kansas and can have a thickness of up to 20 m (Bettis et al., 2003). The mean particle size of Peoria Loess in Kansas is medium silt (31-15μm) (Swineford and Frye, 1951). The source of loess in the Great Plains, and Kansas, has been extensively studied for over 50 years. Welch and Hale (1987) concluded that the source of Peoria loess in Kansas is a combination of 1) glacial outwash and floodplains associated with major river systems, 2) aeolian sand, and 3) regional fluvial and aeolian erosion of the Ogallala formation. However, Muhs and Za´rate (2001) refuted Welch and Hale's conclusion by showing different Ti, Zr, Ca and Sr concentrations, and Ti:Zr and Ca: Sr ratios in Colorado and Nebraska aeolian loess and sand, compared to Kansas loess. From these differences, it was concluded that a source of Peoria Loess in Kansas could not have been from aeolian sand. Continuous work is being done to understand the sources of Peoria Loess in Kansas.

Another, younger, loess unit that has been identified in Kansas is Holocene in age and has been designated Bignell Loess (Bettis et al., 2003). Typically, Bignell Loess is about 2 m thick and has a patchy distribution. Because of its younger age, it typically overlies Peoria Loess (Bettis et al., 2003). Distinguishing Peoria Loess from Bignell Loess can be done by identifying the Brady paleosol, which forms in the upper part and caps the Peoria Loess. The Brady paleosol is a dark, organic-rich buried soil that was formed during the late Wisconsin glaciation. It formed during the Pleistocene-Holocene transition and is time transgressive. The Brady paleosol is characterized by its distinctive buried zone, high clay content, high organic materials, and high TiO_2/ZrO_2 (Jacobs and Mason, 2007). The younger, Bignell Loess unit overlies the Brady paleosol (Johnson and Willey, 2000; Mason et al., 2008).

Climate

The moisture regime for the Central High Tableland is ustic transitioning to an aridic moisture regime in the western portions of MLRA 72 (Soil Survey Staff, 1999). The average annual precipitation is 355-635 mm that typically occurs as intense thunderstorms during the growing season. Average temperature ranges from 8-14°C. Of the water in this area, 76% is groundwater that comes from the High Plains Aquifer, which includes the Ogallala Aquifer. Overall, this water is low in total dissolved solids, hard to very hard, and used heavily for local irrigation (United States Department of Agriculture, Natural Resources Conservation Service, 2006).

Land Use

The land use specific to this study area is irrigated corn production. However, most of the Central High Tableland is used for dry-farmed crops with a winter-wheat fallow rotation being the most typical. Within this study area, wind and water erosion, and soil moisture management are concerns for sustainable production (United States Department of Agriculture, Natural Resources Conservation Service, 2006). To manage for these issues, conservation practices such as high residue crops, crop residue management, and irrigation management have been promoted.

Vegetation

Short grass prairie species such as blue grama (*Bouteloua gracilis)* and buffalograss (*Bouteloua dactyloides)* are native to MLRA 72 (United States Department of Agriculture, Natural Resources Conservation Service, 2006). The sites used in this study are in irrigated corn (*Zea mays*) production with some sites using a mix of cover crops.

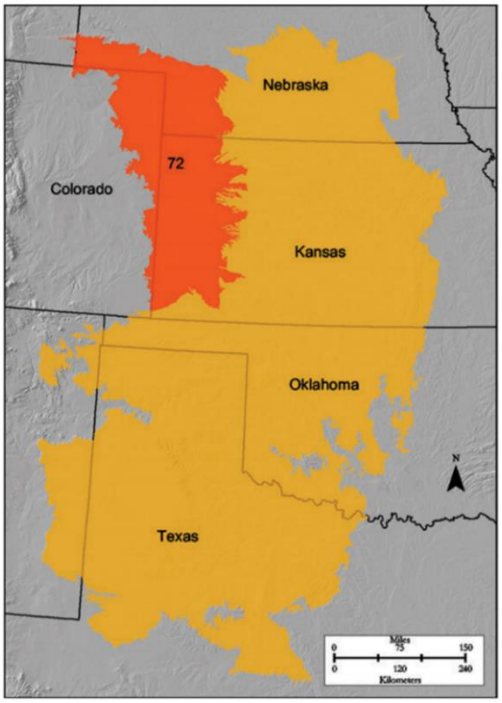

Figure 0-1. Map of MLRA 72 in Land Resource Region H (United States Department of Agriculture, Natural Resources Conservation Service, 2006)

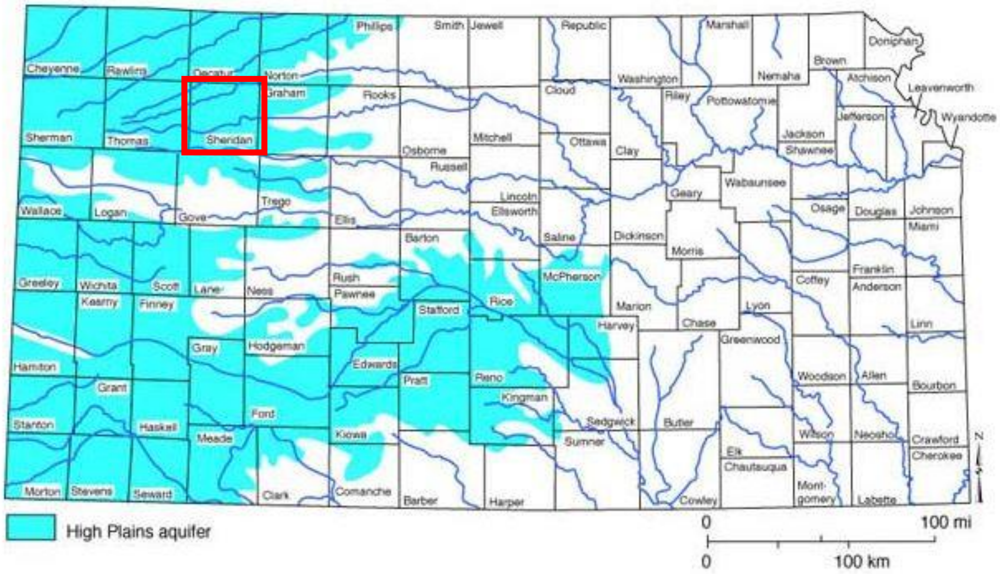

Figure 0-2. Map of Kansas with Sheridan County outlined in red. Blue color denotes the high plains aquifer. (Kansas Geological Survey, 2005)

History and Development of Dynamic Soil Properties

The basis for studying pedology was developed by Hans Jenny (1941) when he identified the five soil forming factors. The five soil forming factors: climate, organisms, relief, parent material and time made up the clorpt equation of the state factor theory. Between the times when Hans Jenny developed the five soil forming factors in 1941 and the present, the landscape has changed. It is estimated that one third to one half of the land surface has been changed by human actions (Vitousek, 1997). Whether it is altering the climate with irrigation or tilling land to plant in a corn and soybean rotation, humans can have a great impact on soil formation. Because of the large impacts of humans, debates occur on how to incorporate humans within the factors of soil formation. Organisms, as identified within the state factor theory, can drastically alter their environment, and traditionally, humans were included in the organisms' factor.

In a later publication, Amundson and Jenny (1991) identified that there are unique attributes in humans with many complexities that can affect the soil forming process. With the amount of land surface that has been impacted by humans, Richter and Yaalon (2012) purposed to identify soil as a human-natural resource rather than a natural resource. They found that knowing how soils change due to human impacts is critical to understand soil function and proper soil management techniques (Tugel et al., 2008). Richter and Yaalon (2012) also called for the importance of anthropedology within soil science. The study of anthropedology would emphasize the study of soil formation and characteristics in conjunction with the human attributes that interact with the soil body. Along with emphasizing research in anthropedology, identifying soil as a human-natural body rather than adding a sixth soil forming factor will have greater benefits to the field of soil science by expanding pedology into other disciplines such as anthropology, archeology, and geoarcheology.

In conjunction with this research, Tugel et al. (2005) developed the concept of soil change. Soil is a dynamic resource that can undergo many changes due to altering conditions of the landscape. Soil change is defined as the variation in soil properties at a specific location within a specific time scale (Tugel et al., 2005). The change in soil can be due to natural disturbances or anthropogenic influence. This study will focus on the anthropogenic influence on soil changes from over 40 years of irrigation and different types of residue management. Soil forming processes by the five soil forming factors (climate, organisms, relief, parent material, and time) are often studied over millions, thousands, and hundreds of years, which is a large time scale. When specifically looking at soil change due to anthropogenic influences, a human time scale is used. To properly assess the effects of management on soil properties, time scales of centuries and decades should be used (Richter and Markewitz, 2001) along with understanding the change of soil properties over shorter time scales such as years, seasons, and days (Tugel et al., 2005).

The term dynamic soil properties (DSPs) was defined by Tugel et al. (2005) as those that change over the human time scale. Analyzing DSPs in current soil research is imperative in making better management decisions. Tugel et al. (2005) also called for DSPs to be incorporated into the National Cooperative Soil Survey (NCSS). By using the NCSS as the tool to communicate the results of DSPs, many different people can use soil survey to make effective decisions towards proper soil management. Because of this incorporation of DSPs in the NCSS, the Natural Resource Conservation Service (NRCS) took on the responsibility of creating projects that focus on DSPs and authored the Soil Change Guide.

The Soil Change Guide (Tugel et al., 2008) went into further depth with defining dynamic soil properties as properties that vary over a human time scale in response to natural and anthropogenic stressors. This publication also provides an applied guide as to how DSPs projects should be conducted. The main importance for studying DSPs is to quantify soil change from different management practices. After reviewing this guide and other projects, the following properties are considered dynamic and will be analyzed in this study: bulk density, total carbon, pH, aggregate stability, and microbial respiration (measured using Solvita).

As a complement to DSPs, this guide also identifies inherent soil properties. These are properties are considered constant, and are strictly influenced through the five soil forming factors. Two key inherent soil properties are texture and mineralogy. These properties are seen as stable over a human time scale and beyond, and are not affected by management. Because Soil Taxonomy is largely based on inherent soil properties, it is also deemed inherent and taxonomic classification should likely not change on a human time scale. However, it is difficult to say that soil is strictly influenced by only the five soil forming factors. As identified by Richter and Yaalon (2012), soil should be considered a human-natural resource. Even in the most remote areas, where soil is in a natural state, humans can still have an influence by altering the climate through increasing greenhouse gas emissions which can greaten the effects of global climate change. This study will question whether inherent soil properties can in fact be dynamic under a human time scale. Specifically, the effects of over 40 years of irrigation on clay illuviation will be investigated.

Within current pedology research, humans have been studied as a soil forming factor and soils are now considered to be a human-impacted natural resource (Adewopo et al., 2014; Amundson and Jenny, 1991; Richter and Yaalon, 2012). Agriculture has been occurring in the United States for centuries, and it was normally not seen to have a drastic impact on soil formation because when looking at the time scale of soil formation, 200 years is not a long time.

It has come to the point in which land has been in production agriculture long enough to observe affects in soil properties. The pivotal question to the pedology field is to determine the long-term effects of intensive agriculture management systems have on DSPs and inherent soil properties (Adewopo et al., 2014).

Dynamic Soil Property Studies

Although not many studies use the term ‘dynamic soil properties’, many studies have been done to analyze how humans can impact soil properties. Typically, the studies focus on different types of agriculture management. Properties of soil that are dynamic are important to study as they directly relate to soil function (Tugel et al., 2008). To properly assess the function of a soil, physical, chemical, and biological soil properties should be analyzed as these properties collectively affect the overall function of a soil (Soil Quality Technology Development Team, 2008). Much of the research done to evaluate the effects of human activities on soil focuses on soil carbon. This is because carbon stocks in soil are extremely vulnerable and can respond to changes in land use more so than other soil properties (Victoria et al., 2012).

In Kansas, U.S.A, a twenty-three year study was done by McVay et al. (2006) to study the effects humans have on soil properties. Soil organic carbon (SOC), bulk density, and aggregate stability were analyzed, and these properties are also considered to be dynamic. Five agricultural sites were in this study with various cropping systems of corn, soybean, sorghum, and wheat rotations. All sites had areas of conventional tillage (CT), reduced tillage (RT), and no tillage (NT). Most of the disturbance was through chisels, disks, V-blade sweeps, and field cultivator action. Within this study, the three types of tillage were given based off intensity; CT being the most intense disturbance, and no-till (NT) being the least intense. A trend was found in which NT management resulted in greater SOC accumulation than RT and CT. It was also found that NT resulted in a larger diameter of stable aggregates, compared to CT, indicating that the aggregates are more stable because the soil is more resilient to disturbance. Additionally, bulk density was greater for NT than CT. Most of the significant differences observed in this study were within the top 5 cm of the soil, though the properties were studied to a depth of 30 cm. The study done by McVay et al. (2006) analyzes five different soil series, so some of the trends may have been due to the different types of soil. One of the soil series in this study, Parons, is an A lfisol and it is compared to the rest of the soils which are all Mollisols. Because these soils are taxonomically different from one another, there could be differences in how the soils react to anthropogenic disturbances.

Follett et al. (2013) focused on soil carbon dynamics in conventional tillage (CT) vs no tillage (NT) in irrigated corn systems near Fort Collins, CO. The soil studied was Fort Collins (fine-loamy, mixed, superactive, mesic Aridic Haplustalfs). Similar to Keith (Aridic Argiustoll), but differing in particle size class, this area is also an ustic moisture regime that is transitional to aridic. Samples were collected in 7.6 cm depth intervals to a depth of 123 cm, and SOC and bulk densities were measured at each increment. They found that NT systems were able to maintain more SOC and larger bulk densities than CT systems. Another significant finding was that NT systems did not have a change in SOC over the eight year study period. On the other hand, CT systems had a significant loss of SOC, which was also confirmed in a study done by Schmer et al. (2014).

Analysis of SOC is usually completed along with a determination of aggregate stability because their interaction is essential to understanding SOC dynamics (Follett et al., 2015). Aggregates present in the soil are composed of decomposing particulate organic matter (POM), clay material, and microbial products. With the presence of POM and microbial products, aggregates serve as a source of SOC (Mandiola et al., 2011) and soils with greater aggregation have higher SOC (Follett et al., 2015). SOC found in aggregates is very sensitive, and physical destruction of aggregates can degrade SOC and increase the risk of erosion (Follett et al., 2015).

Follett et al. (2015) analyzed bulk density, aggregate stability, and SOC at fourteen sites across the Great Plains. All the sites were either native land, Conservation Reserve Program land, or cropped land. They found that SOC was greatest in native land and least in cropped land. Aggregate stability was directly related to SOC and the greatest % water stable soil aggregates were in native land and the least SOC was for the cropped land. Conservation Reserve Program land had SOC stocks and aggregate stability levels between native land and cropped land. This study confirms that tillage practices disrupt aggregate formation, and overall deplete SOC stocks.

These studies focused on soil carbon dynamics within different agriculture management and land use. When assessing dynamic soil properties it is important to focus on biological, physical, and chemical properties in addition to the interaction of these properties. The study done by Follett et al. (2013) is unique in the fact that SOC dynamics were analyzed to a depth of 123 cm. It is very unusual for studies to look at dynamic properties of the entire soil profile (Veenstra and Burras, 2015). Understanding the dynamic properties within full soil profiles is very important to ecosystem functions (Richter and Yaalon, 2012).

To address this importance, Veenstra and Burras (2012) recently conducted a study in Iowa, U.S.A. to analyze the effects of over fifty years of intensive row-crop agriculture on soil properties to a depth of 150 cm. Soil survey characterization data from 1943-1963 was compared to present pedons from identical sites. Over 50 years, there was a decrease of SOC within the upper 50 cm of the soil profile, and an increase of SOC below 50 cm. Deep tillage is the cause of this, in which it mixes and disperses SOC throughout the top horizons, as opposed to NT systems where SOC is concentrated at the soil surface. Another reason for the SOC loss throughout the topsoil is due to the change of organisms. Iowa was dominated by prairie grass species with deep rooting systems that contributed to the high carbon amounts. For the past fifty years, the sites studied have been present in agriculture systems with a shorter period of crop rotations, and plants that have a shallower rooting system. Along with the changes seen in SOC, pH had also decreased throughout the soil profiles, but remained at the optimum level for corn and soybean production. Acidification processes can lead to increased mineral weathering through the dissolution of organic matter and carbonates.

Through the literature, it is apparent that SOC, pH, aggregate stability, and bulk density are dynamic under different land uses. These studies point to specific agriculture systems that can affect dynamic soil properties, and with that, affect soil function. A dynamic soil properties (DSPs) project was done by the NRCS in Nebraska, USA, that followed the guidelines set for DSPs projects by the Soil Change Guide (Tugel et al., 2008). The DSPs project done in Nebraska studied sites in CT and NT in a corn/soybean rotation. The study site was mapped as Kennebec (fine-silty, mixed, superactive mesic Cumulic Hapludolls). It was found that within 0-5 cm of NT sites, there was a higher amount of total carbon, water stable aggregates, and a higher pH ($p=0.10$) (Wills, 2012). One thing that is unique about DSPs projects is that the studies analyze the change of soil properties in the same soil series under different land uses. Focusing on a specific soil series is a protocol that is addressed in the Soil Change Guide (Tugel et al., 2008).

Although many DSPs projects have been done, the final results are usually not documented in a research journal article (Wills, 2012). As Tugel et al. (2005) states, most of the findings of DSPs projects are put directly into soil survey reports, but there is usually no final documentation of the findings. This is an issue that faces the DSPs program in USDA-NRCS because the projects have much value to producers and researchers. This project done in Sheridan County, KS hopes to fix that issue by providing final documentation of this DSPs project.

Importance of Soil Map Units in DSP Studies

The Soil Change Guide (Tugel et al., 2008) provides a protocol at which dynamic soil properties should be conducted. A very important concept is that dynamic soil properties studies are conducted as a comparison study. A comparison study is one that uses paired sites under different management systems on identical soil types. This type of study involves locating plots, collecting samples, and analyzing results to determine how soils have changed in response to different management. An important concept of the comparison study model is that it substitutes space for time and it compares soil properties in a reference state versus other management systems (Tugel et al., 2008). Using a comparison study model allows dynamic property studies to be conducted simply and efficiently. Although it does provide many benefits, a comparison study does have its limitations compared to long-term and monitoring studies. The Soil Change Guide states that using the same kind of soil under different conditions must be done in order to manage the limitation of using a comparison study. The same kind of soil is defined as soils that have the same or similar soil map unit component. Also all similar phases within a soil map unit component are considered the same kind of soil.

To conduct a comparison study of dynamic soil properties, an extensive or benchmark soil is chosen with two or more clearly defined management systems. Samples are then collected to determine differences in DSPs within a specific map unit phase. The Soil Change Guide states that multiple soils of a complex, association or catena can be analyzed and would aide in the development of landscape scale interpretations. The Soil Change Guide identifies that soil change can be properly assessed with measuring the same kind of soil under different management conditions.

Clay Illuviation

Processes of Clay Illuviation and Formation of Argillic Horizons

According to Soil Taxonomy, an argillic horizon should exhibit clay increases in the subsoil that are formed by clay illuviation (Soil Survey Staff, 1999). The central concept of argillic horizons contains two major elements: 1) increased clay content relative to an overlying horizon and 2) the orientation of clays. Both of these properties need to be formed by illuviation to contribute to the central concept of an argillic horizon. Normally, illuviation occurs from the downward movement of clay in the soil profile and accumulation in the subsoil. McKeague (1983) explained that the movement of clay can be accelerated by alternating wet and dry conditions, macrovoids, absence of cementing agents in the soil (sesquioxides or carbonates), and a pH of 4.5-6.5.

For soils in semi-arid and arid regions, calcium carbonate accumulation is an important pedogenic process. The source of calcium carbonate in Kansas soils normally occurs from aeolian dust (Gunal and Ransom, 2006; Ransom and Bidwell, 1990). The dissolution of carbonates through the soil is driven by water. So in semi-arid and arid regions, carbonates may not be as leached through the soil. When considering calcium carbonate and clay illuviation, the two processes seem contradictory to one another because Ca^{2+} tends to flocculate clay, therefore reducing illuviation (Gunal and Ransom, 2006). However, it is very common to find illuviated clay and calcium carbonate accumulations within the same horizon (Gunal and Ransom, 2006; Ransom et al., 1997; Fraser, 1990; Ransom and Bidwell, 1990; Gile and Grossman, 1968). When both of these are found in the same horizon, a complex history of carbonate leaching, deposition of secondary carbonates, and clay illuviation has occurred within the soil (Gunal and Ransom, 2006; Ransom and Bidwell, 1990; Gile and Grossman, 1968). So if carbonates are present in a soil system, leaching of the carbonates must occur first in order for clays to disperse and move via suspension into the subsoil.

The first step in clay illuviation is the dispersion of clay. This can occur from rainfall impact that will disperse the clay material from the surface of soil, and the water will carry the clay material into the subsoil through macrovoids. The voids that aid in the downward movement of clay can be present from the leaching of salts or carbonates (Ciolkosz, 1989). Once in the subsoil, the water will be absorbed into the dry subsoil and leave behind a deposit of clay material on the walls of the voids. This will result in a horizon within the subsoil that has a significantly higher amount of clay than the eluvial horizon (McKeauge, 1983). Illuviation processes include two key components, water and time. Whether water is leaching out salts or carbonates to create marcovoids or it is moving clay material, water is the main driver of illuviation. Another important component of illuviation is time; argillic horizons take at least a few thousand years to form (Soil Survey Staff, 1999). So when an argillic horizon is identified, it can be inferred that the soil has been forming for a long period of time under a stable landscape.

Clay films can be seen in the field and often are associated with voids capable of transporting clay in suspension. To classify as an argillic horizon one of the following conditions must be met (Soil Survey Staff, 2014):

1. field evidence of clay films
2. 1% or more of oriented clay observed in thin section
3. The thickness of the argillic horizon must be greater than 7.5 cm if silty, clayey or loamy, and greater than 15 cm thick if the horizon is sandy or contains lamellae

4. A significant clay increase within a vertical distance of less than 30 cm. The actual percent of a significant clay increase depends on the clay content of the eluvial layer and normally ranges from an increase of 3-8%.

It was traditionally thought that if there was a significant clay increase in the subsoil, then clay illuviation had occurred and an argillic horizon was present. However, there are cases in which a clay increase can be observed in the subsoil, but the clay increase is not from illuviation. It is from the in-situ weathering of minerals within the subsoil, which would not contribute to the central concept of an argillic horizon (Smeck et al., 1981; McKeauge, 1983; Gunal and Ransom, 2006). The main way to properly determine if clay increases in the subsoil are a result of illuviation is to analyze micromorphology through thin sections (Gile and Grossman, 1968; Smeck et al., 1981; McKeauge, 1983; Fraser, 1990; Gunal and Ransom, 2006).

A study done by Smeck et al. (1981) analyzed pedons in western Ohio that were traditionally classified with argillic horizons in the field. There were two pedons in particular that had a significant increase of clay in the subsoil to meet the definition of an argillic horizon. However, once the thin sections were analyzed, <1% of oriented clay was observed. Because of this finding, these soils met the criteria for an argillic horizon, but do not fit the central concept of an argillic horizon. It was determined that the increases of clay in the subsoil were from the in-situ weathering of shale and coarse clay particles.

As previously stated, water is a very important factor in the illuviation process of clay. Many studies have been done to determine how clay is illuviated in areas where water is limiting (Gile and Grossman, 1968; Fraser, 1990; Gunal and Ransom, 2006). Fraser (1990) and Ransom et al. (1997) analyzed the formation of argillic horizons in Richfield (fine, smectitic, mesic Aridic Argiustolls). Richfield is another extensive soil series in western Kansas where water is very limiting (400-500 mm annual precipitation). After analyzing the micromorphology of three pedons, it was found that the clay increases from the A and B horizons did not form from illuviation processes. Much like the study done by Smeck et al. (1981), the clay increases were from the in-situ weathering of minerals, specifically in Ohio, biotite. It was also found that the smectitic mineralogy and high COLE values of these soils contribute to high shrink-swell capabilities. Shrink-swell action within the soil can disrupt any illuvial argillans, and form pressure faces which may be mistaken for clay films in the field (Fraser, 1990).

Kansas, U.S.A. has a very unique climate in which the mean annual temperature is similar across the state, but the precipitation can range from 400 mm/year in western KS to 1100 mm/year in eastern KS (Gunal and Ransom, 2006). Gunal and Ransom (2006) analyzed the effects of different precipitation on clay illuviation processes by studying ten pedons across a precipitation gradient in Kansas. The pedons were formed under similar parent materials (loess) so that all other soil forming factors would be uniform in the study. When analyzed in the field and the lab, the pedons fit the definition of an argillic horizon (1.2 times more the amount of clay than the eluvial horizon). However, once the pedons were described under thin section analysis, it was found that some of the argillic horizons did not form from illuviation. The striated b-fabrics that were found in the pedons of western Kansas revealed that the clay orientation was caused by shrink-swell activity of the micromass (Gunal and Ransom, 2006). Given this, the pedons studied in western Kansas did not meet the central concept of an argillic horizon.

Gunal and Ransom (2006) point out that this is an issue when classifying an argillic horizon. It was validated through this study that clay films can form through illuviation and stress processes. Since determining the orientation of clay in the field is nearly impossible, Gunal and Ransom (2006) proposed that Soil Taxonomy should use field and laboratory evidence of clay illuviation to classify argillic horizons. Properly classifying argillic horizons is important as an argillic horizon represents a specific time-landscape relationship. Where an argillic horizon is present, it can be inferred that the landscape has been stable for quite some time, as it takes at least a few thousand years for argillic horizons to form.

Clay Illuviation- Is it Dynamic?

Now, the research question is- what happens to inherent soil properties once the five soil forming factors are altered? In a previous study, Fraser (1990) and Ransom et al. (1997) found that the clay increases in Richfield soil were from in-situ weathering of minerals rather than illuviation processes, which does not fit the central concept of an argillic horizon. Ricks Presley et al. (2004) analyzed the effects of irrigation, which almost doubles the amount of precipitation, on Richfield and Keith soils. To do this, pedons were selected and analyzed in irrigated areas and compared to the non-irrigated pedons found on the same field. It was found that ≈30 years of irrigation increased illuviation processes and mineral weathering. This was seen through more strongly expressed argillic properties in irrigated pedons vs non-irrigated pedons. Through this study, it is shown that properties that are thought to be inherent can change and be altered over a human time scale.

Along with this study, Veenstra and Burras (2012) also studied the impacts of over fifty years of intensive row-crop agriculture on soil formation in Iowa, U.S.A. Although the climate factor remained unaltered, unlike the Ricks Presley et al. (2004) study, the organisms soil forming factor were completely altered compared to the original prairie grass species of Iowa. This study didn’t analyze the effects of agriculture practices on clay illuviation, but it looked at the morphology, which is often thought of as inherent. It was found that over fifty years of intensive agriculture, primary mineral weathering was accelerated, and the presence of redoximorphic features was not as apparent as compared to soils that had not been altered.

Both of these studies are important because they analyze how anthropogenic stressors can change both DSPs and inherent soil properties. Specifically through agriculture, soil forming factors can be altered drastically by increasing precipitation through irrigation or changing the native organisms of the landscape. The studies by Ricks Presley et al. (2004) and Veenstra and Burras (2012) both found that soil properties that are considered to be inherent can in fact be changed by anthropogenic stressors over a human time scale. As the length of time for the alteration of soil properties by agriculture increases, it is important to know how these practices can alter soil resources and affect the productivity and functionality of soils.

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Chapter 2 - A Study of Dynamic Soil Properties in Western Kansas

Introduction

As soils change with effects by humans, this can greatly impact the function of soils. It has been long debated as to how to incorporate human impacts into soil formation (Richter and Yaalon, 2012; Tugel et al. 2005; Amundson and Jenny, 1991). Tugel et al. (2005) developed the concept of soil change. Soil is a dynamic resource that can undergo many changes due to landscape alterations. Soil change is defined as the variation in soil properties at a specific location within a specific time scale (Tugel et al., 2005). This study will focus on the anthropogenic influence on soil change from the use of no-till (NT) and strip till (ST) management. Soil forming processes by the five soil forming factors of climate, organisms, relief, parent material, and time (Jenny, 1941) are often studied over millions, thousands, or hundreds of years. A human time scale may be more appropriate when looking at soil change due to anthropogenic influences. To properly assess the effects of management on soil properties, time scales of centuries and decades should be used (Richter and Markewitz, 2001) along with understanding the change of soil properties over shorter time scales such as years, seasons, and days (Tugel et al., 2005).

The term dynamic soil properties (DSPs) was defined by Tugel et al. (2005) as soil properties that change over the human time scale. Analyzing DSPs in current soil research is imperative in making better management decisions. Tugel et al. (2005) also called for DSPs to be incorporated into the National Cooperative Soil Survey (NCSS)

The Soil Change Guide (Tugel et al., 2008) went into further depth with defining dynamic soil properties as properties that vary over a human time scale in response to natural and anthropogenic stressors. After reviewing this guide and other projects, the following properties are considered dynamic and will be analyzed in this study: bulk density, total carbon, pH, aggregate stability, and microbial respiration. These properties are important to analyze as they can affect soil function. Tugel et al. (2008) addresses the importance of analyzing soil function as it can be used to plan for productive and sustainable management systems, retain the important ecosystem services provided through soil, and make effective management decisions based off the results of dynamic soil property studies.

Many studies compare NT (NT) to reduced- and conventional-tillage (CT) management. In general, it has been found that NT management can increase soil organic carbon, aggregate stability, microbial respiration, and bulk density (Schmer et al. 2014; Follet et al., 2013; Ismail et al., 2013; Stone and Schlegel et al., 2010; Whitehair, 2010; Zhang et al., 2007; McVay et al., 2006; Dam et al., 2005; Feng et al., 2003; Sainju et al., 2002). Veenstra and Burras (2012) found that over fifty years of intensive row cropping resulted in a decrease of soil organic carbon and a reduced pH throughout soil profiles. When specifically analyzing carbon contents of soil, it has been found that carbon contents increase with less tillage due to better aggregation that retains carbon content in soils (Follet et al., 2015; Schmer et al., 2014; Mandiola et al., 2011; McVay et al., 2006). Soil organic carbon found in aggregates is very sensitive, so analyzing aggregate stability, or the ability of a soil to resist physical disturbance, is very important. Systems disturbed through increased tillage have been found to have a weaker aggregate stability, and therefore less carbon (Follet et al., 2015; McVay et al., 2006).

This study analyzes DSPs in Sheridan County, in western Kansas. The study area is located in MLRA 72, the Central High Tableland, and is part of Land Resource Region H. This area classifies with an ustic moisture regime, receiving an average annual precipitation of 355-635 mm. These soils are quite fertile and, with irrigation, they can be very productive and highly profitable. Within this study area, wind erosion, and soil moisture management are concerns for sustainable production (United States Department of Agriculture, Natural Resources Conservation Service, 2006). To manage for these issues, conservation practices such as high residue crops, crop residue management, and irrigation management have been promoted in this area. Specifically within Sheridan County, a growing amount of producers have adopted NT management. The objective of this study is to assess how different agriculture management affects DSPs in western Kansas.

Methods

Location Information and Sampling Methods

The sites used in this study were all located by USDA-NRCS area soil scientists and district conservationists. Land use of each study site can be found in Table 2-1. All sites are within the Keith silt loam, 1-3% slopes mapping unit. It was very important that the sites were mapped using the same major component name for the mapping unit to minimize random variablity. Sampling was conducted in March 2015. Center pivot irrigation systems are common in this area, and well-defined boundaries exist between the irrigated and non-irrigated portions of the field. Three points were randomly sampled at each site within the irrigated portion of the field. At each sample point, the entire Ap horizon was sampled. The depths of Ap horizons were based off profile descriptions done in September 2014 for NT1, NT2, NT3, and ST1, and in March 2015 for NT4, ST2, ST3, and ST4 (see Table 2-1 for Site ID legend). An additional sample was taken at site ST3TAX. It was included in analyses as it did not have an impact on the distribution of data. Profile descriptions were done by USDA-NRCS area soil scientists using the Field Book for Describing and Sampling Soils (Schoeneberger, 2012).

The collection of samples for pH and bulk density followed procedure 3B4 of the Soil Survey Laboratory Methods Manual (Soil Survey Staff, 2004). Aluminum rings with a height of 5.00 cm, a width of 7.50 cm, and a volume of 221 cm^3 were driven into the ground using a wooden block and hammer to obtain a soil sample of a known volume. For pH and bulk density samples, this procedure was done at each 5-cm increment of the entire Ap horizon. Soil was collected from the top 5 cm of each Ap horizon for SOC analysis using procedure 3B4 (Soil Survey Staff, 2004). Finally, a bulk sample of the entire Ap horizon was collected to analyze for aggregate stability and Solvita (a commercialized laboratory test developed by Haney et al., 2008).

Table 2-1. Land use of each site and classification of soils used in DSPs study

Site ID	Management Type	Cropping System	Sampling ID	Soil Series of Major Component
		†		‡
NT1	NT for >15 years	corn/soybean rotation or corn/corn/soybean, depends on year	NT 101	Keith
			NT 102	Keith
			NT 103	Keith
NT2	NT for 4 years	UNK	NT 201	Ulysses
			NT 202	Keith
			NT 203	Keith
NT3	NT for 13 years with cover crops	Typical rotation: corn/soy/wheat/ cover crops/sunflower/milo/corn. Depends on market	NT 301	Keith taxadjunct
			NT 302	Keith taxadjunct
			NT 303	Keith taxadjunct
NT4	NT for 13 years with cover crops	Typical rotation: corn/soy/wheat/ cover crops/sunflower/milo/corn. Depends on market	NT 401	UNK
			NT 402	UNK
			NT 403	UNK
ST1	ST for 5-6 years	corn/soybean rotation	ST 101	Ulysses
			ST 102	Keith
			ST 103	Ulysses
ST2	ST	UNK	ST 201	Keith
			ST 202	Ulysses
			ST 203	Keith
ST3TAX	ST	UNK	ST 301TAX	Keith
ST3	ST for 8-10 years	Continuous corn since 1992	ST 301	UNK
			ST 302	UNK
			ST 303	UNK
ST4	ST	UNK	ST 401	Keith
			ST 402	Richfield
			ST 403	Keith

All information was obtained from phone conservations with producers or from local NRCS District Conservationist

†UNK= Unknown information; could not speak with producer

‡Keith= fine-silty, mixed, superactive, mesic Aridic Argiustolls; Ulysses=fine-silty, mixed, superactive mesic, Aridic Haplustolls; Keith taxadjunct= same classification as Keith, but these soils had mollic colors described deeper than 60cm; UNK=Ap horizons were only sampled, no full description done; Richfield= fine, smectitic, mesic Aridic Argiustolls

Bulk Density

Determination of bulk density was done following procedure 3B4a of the Soil Survey Laboratory Methods Manual (Soil Survey Staff, 2004). The soil collected in the field was brought back to the laboratory where it was oven-dried in a pre-weighed tin at 105°C for at least 48 hours. After the soil was dried, the soil material was weighed, and the bulk density was calculated using the following formula:

$$\rho_b = \frac{\text{oven dried soil wt.} - \text{tin wt.}}{220.89\text{cm}^3}$$

where ρ_b is bulk density in g cm^{-3}, oven dried soil wt. and tin wt. (g), and 221 cm^3 was the volume of the ring (height= 5.00 cm, width= 7.50 cm).

pH

The oven dried soil sample from the bulk density procedure was then ground and passed through a 2 mm sieve and was used to determine soil pH. Procedures 4C1a2a for 1:1 soil/water pH and procedure 4C1a2a2 for 1:2 soil/0.01 *M* $CaCl_2$ were used (Soil Survey Staff, 2004). Ten g of soil were mixed with either 10 mL of deionized water in a plastic disposable container. Another ten g of soil was mixed with 20 mL of 0.01 *M* $CaCl_2$ in a plastic disposable container. Each sample solution was stirred and allowed to equilibrate for 30 minutes, and then stirred again and allowed to equilibrate for an additional 30 minutes. After the additional 30 minute equilibration time, the solution was stirred, and pH was read immediately after using a pH electrode. The electrode used in this procedure was a Thermo Scientific Orion Sure-Flow Combination pH electrode. Two replications were done of each sample and needed to be within 0.2 of each other for quality control purposes. To obtain a final pH for 1:1 soil/water and 1:2 soil/1:2 0.01 *M* $CaCl_2$, the replicates were averaged.

Total Carbon

Total Carbon was analyzed by the Soil Testing Laboratory at Kansas State University. Between 0.34 and 0.36 g of soil were weighed and analyzed using a LECO TruSpec CN Carbon/Nitrogen combustion analyzer. Total carbon (inorganic and organic) was reported in percentages and then converted to Mg ha^{-1} using the following formula:

$$\mathrm{TC_{mass}} = (\mathrm{TC_{\%}})(\rho_{\mathrm{b}})(\mathrm{Depth})$$

where $\mathrm{TC_{mass}}$ (Mg ha^{-1}) is total carbon on a mass basis, $\mathrm{TC_{\%}}$ is the total percentage of carbon as given by the LECO reading, ρ_b is bulk density (g cm^{-1}), and depth (cm) which in all of these samples was 5 cm.

Aggregate Stability

This procedure of aggregate stability measures a soil's ability to resist water erosion by determining the portion of water stable aggregates that occur after disturbance from water. To begin, soil from the field was air-dried and sieved to collect aggregates between 4.75 mm and 8 mm in size. Between 20-50 g of the sieved aggregates were oven dried for at least 48 hours at 105°C to obtain gravimetric water content.

The size distribution and mean weight diameter of water stable aggregates were determined using the wet sieving method developed by Kemper and Chepil (1965) and Kemper and Rosenau (1986). This method involved the use of four nests of sieves where each sieve was 127 mm in diameter and 40 mm in depth. Each nest of sieves contained five individual sieves with screen openings of 4.75, 2.00, 1.00, 0.50, and 0.25 mm. The sieves were arranged with the largest opening sieve (4.75 mm) on top and the smallest opening sieve (0.25 mm) on the bottom. The four nests of sieves were set on a machine (Grainger, Inc., Lake Forest, IL) that would move in an up and down motion in four 5-gallon sized buckets. Once the nests of sieves were set on the machine, the buckets would be filled up until the water line hit the wiring of the 4.75 mm sieve (Figure 2-1). 50 g of soil aggregates between 4.75 mm and 8.0 mm were placed on the top sieve (4.75 mm opening) and left to saturate for 10 minutes (Figure 2-1). After the aggregates were saturated, the machine was turned on to move the nest of sieves in an up and down motion through a vertical displacement of 35 mm at 30 cycles/minute for 10 minutes. Once the mechanical sieving was finished, the soil remaining on each sieve was quantitatively transferred into a pre-weighed glass jar and dried for at least 48 hours at 105°C. The dried soil mass was measured, and about 50 mL of a 13.9 g/L sodium hexametaphosphate solution was added to the dried soil to disperse fine particles from the coarse fragments. The soil was soaked in the dispersing agent for 24 hours, and then the samples were re-washed through the corresponding sieves. Whatever material remained on the sieve was collected and dried for at least 48 hours and 105°C to obtain the coarse fragment content.

The amount of WSA was calculated using a method from Stone and Schlegel (2010):

$$\mathrm{WSA} = (\mathrm{m_m} - \mathrm{m_f})/(\mathrm{m_t} - \mathrm{m_f})$$

where WSA is the concentration of WSA that remained on each of the five sieves, m_m is the oven dried mass (g) of soil material after the initial sieving, m_f is the dried mass (g) of coarse fragments, and m_t is the total sample dry mass (g). The MWD of water stable aggregates was calculated using the following formula (Stone and Schlegel, 2010):

$$\mathrm{MWD} = \sum_{\mathrm{i}=1}^{6} (\mathrm{w_i} / \mathrm{m_a})\, \mathrm{x_i}$$

where MWD is (mm), w_i represents the dry mass (g) of soil material after initial sieving, w_1-w_5 are calculated by (m_m-m_f), w_6 is the dry mass of soil passed through the smallest (0.25 mm) sieve, m_a is the sum of dry mass (g) aggregates (w_1-w_6), and x_i is the mean diameter (mm) of each of the six size factions with the smallest fraction, x_6, calculated as (0.25 mm/2).

Figure 2-1. Photos of machine used to measure WSA. Left photo is the entire machine, right photo shows the aggregates saturating for 10 minutes

Microbial Respiration

A measurement of microbial respiration was done using Solvita, a commercialized laboratory test developed by Haney et al. (2008). The specific method used within Solvita was the CO_2 burst procedure. From the field, 20 g of soil was air-dried, ground, and passed through a sieve with 2 mm openings. The soil material was put into a perforated plastic beaker with a filter paper placed at the bottom of the beaker to ensure soil material would stay in the beaker. The beaker was then placed into the center of a Solvita jar, and 6 mL of water were added to the soil using a top-down wetting method (Brinton, 2015). This wetting will trigger a flush of CO_2, and a probe is placed into the jar alongside the beaker to measure the flush of CO_2. The lid was screwed tightly and left at ambient temperature (22-25°C) for 24 hours. After 24 hours, the probe was then removed, and the color was read on a Solvita Digital Color Reader. The Digital Color Reader reports colors in correspondence with a color chart number and also reports CO_2-C in ppm. By measuring CO_2-C ppm burst within one day, conclusions of the active microbial biomass can be made (Haney et al., 2008). As this method is rather new and still developing, each sample was replicated two times.

Statistical Analyses

For non-depth measurements (total carbon, aggregate stability, and microbial respiration), the general experimental design was an unbalanced completely randomized design with subsampling (sampling point). The treatment structure was a one-way factorial for combination of tillage type and crop cover (till_cover) with three levels: NT without cover crops (NT_N), NT with cover crops (NT_Y), and ST without cover crops (ST_N). The experiment was unbalanced in regards to number of sites (experimental units) per treatment. An ANOVA table outlining the levels of treatment, experimental unit, and subsampling can be found in Appendix

B. The data was also analyzed as a one-way factorial (till) with two levels: no till (NT) and ST (ST). A linear mixed model was fitted for normally distributed responses using Mixed procedure of SAS/STAT® software 9.4 (SAS Institute Inc., 2016). A generalized linear mixed model with a beta distribution and logit link function was fitted using the Glimmix procedure of SAS/STAT software for the responses of WSA sizes and total WSA, continuous proportions converted into a decimal format.

By-depth measurements (pH and bulk density) had a similar experimental design, but with an additional repeated measures on the subsampling unit (sampling point). The treatment structure became a two-way factorial with three levels for till and cover (NT_N, NT_Y, and ST_N) by five levels of depth (0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, and 20-25 cm). Measurements beyond 25 cm were excluded from analysis due to incomplete information across sites due to the differing depths of Ap horizons (within each sampling point). Similar to the non-depth measurements, a proc mixed procedure was done to compare normalized responses and fit data to a linear mixed model. The data were also analyzed with two levels of till: no till (NT) and ST (ST).

For by-depth and non-depth measurements, if the F-test was conducted and a significant difference was found, a pair-wise comparison was done to determine which treatments were different from one another. An analysis of simple effects was done with a slice statement to analyze the LS-means for an interaction among treatments. A significance level of α=0.10 was used for all by-depth and non-depth measurement analyses.

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Results and Discussion

Total Carbon

Mean average total carbon of the 0-5 cm depth among treatments can be found in Tables 2-2 and 2-3. A distribution of total carbon in three different treatments (NT, NT with cover crops, and ST) can be found in Figure 2-2. When looking at the three different treatments, statistically soil carbon stocks are the same in all management systems.

NT will typically have higher amounts of total carbon because NT increases aggregation which protects soil organic carbon (Follett et al., 2015). Physical disruption of aggregates can create a flush of soil organic carbon and increase mineralization, but NT practices will maintain and conserve greater carbon concentrations (Follett et al., 2015; Sainju et al., 2002). Along with NT practices, the additions of cover crops can increase total carbon content. This study found that cover crops did not increase total carbon. However, Liu et al. (2005) did find that carbon concentration in soils with cover crops varied from year to year, but were consistently larger than soils without cover crops. Additionally, Mazzoncini et al. (2011) found that soil organic carbon was conserved more in a NT system, even without incorporation of cover crops, compared to conventional till systems.

A reason for the results of this study could simply be due to timing. As Liu et al. (2005) states, carbon contents can vary from year to year. With the design of this study, sampling for total carbon only once might obscure changes in soil organic carbon dur to management. Along with timing, one of the NT sites without cover crops has been in NT production for a longer time compared to the other NT sites and so it would make sense for the highest amount of carbon to be in the soil that has been in NT longest.

Another important factor to analyze when estimating carbon stocks of soil is the amount of nitrogen fertilizer that is added in production. Nitrogen fertilizers can influence soil carbon concentrations through increases of biomass production (Follett et al., 2013; Mazzoncini et al., 2011; Lui et al., 2005). When speaking with producers, most could not give a specific rate of N-fertilizer as it can vary from year to year based on soil testing results. It is possible that this study could be repeated in a different season or year and observe different findings solely based on different N-fertilizer applications. Future studies in this area could incorporate sites with different rates of N-fertilizers applications.

Aggregate Stability

This study evaluated aggregate stability with two parameters: MWD, and total water stable aggregates (WSA). MWD is the sum of weighted mean diameters with the weight factor of each class defined as the proportion of the total sample weight (Nimmo and Perkins, 2002). Tables 2-2, 2-3 and Figure 2-3 shows MWD within the different treatments. It was found that the MWD was not statistically different among the treatments. This result could have been from the higher amount of ST samples compared to NT with cover crops. To analyze MWD using a proc mixed procedure in SAS 9.4 (SAS Institute Inc., 2013), a log transformation needed to be done in order to normalize the data (Appendix B). Overall, statistical analyses showed that the differences in MWD among different management was not significant.

Tables 2-4 and 2-5 shows the percent of WSA for each size class. Statistical analyses found that the percent of WSA of each size classes were mostly the same. However, when looking at the 2.0 mm size faction class of NT with cover crops, it had a significantly higher value compared to the NT and ST systems. It was also seen that in NT and ST systems, there was a large difference between the percent of WSA in the 4.0 mm class and the 2.0 mm class.

Whereas in the NT with cover crop system, the difference between the 4.0 mm and 2.0 mm classes is not as large. The addition of cover crops may increase the stability of aggregates in a range of aggregate classes rather than just the largest aggregate size class. Figure 2-4 shows the distribution of total WSA in each treatment with the NT treatment having the lowest mean total WSA.

Whitehair (2010) found similar results to this study by concluding that certain vertical tillage types actually had a higher MWD than NT. On the contrary, many studies have found that MWD and percent WSA were greater with less tillage (Follett et al., 2015; Zhang et al., 2007; McVay et al., 2006; Pinheiro et al., 2004). Most of these studies analyzed aggregate stability of the top 5 cm of the soil, which is the most affected by tillage practices. This study analyzed aggregate stability of the entire Ap horizon, which in most cases, was deeper than 5 cm. This may be why this study did not find many significant differences in aggregate stability among the treatments.

Future studies should analyze how different types of cover crops can affect aggregate stability. Lui et al. (2005) analyzed three different types of cover crops: annual ryegrass, fall rye, and spring barely. It was found that spring barely had statically the same MWD as bare soils. The highest MWD was in annual ryegrass. The cover crop used in this study was a mix that included radishes. So it would be very important to look at cover crops as different types may not have the same effects on aggregate stability.

Microbial Respiration

The Solivta method and N-mineralization potential is a newer method for analyzing microbial respiration and is still being studied and developed to ensure its accuracy. Microbial respiration measured by the Solvita CO_2 Burst Procedure was significantly higher in NT management compared to ST management (Table 2-2). NT with cover crops has the highest respiration when compared with NT and ST management (Table 2-3 and Figure 2-5). This was expected to happen as NT with cover crops management would add more organic matter to the system. With a higher amount of organic matter, soil microbes will be more active and have higher respiration and carbon mineralization. A benefit of using the Solvita CO_2 is that the results can be used to help predict N-mineralization potential. The N-mineralization potential for each sample can be found in Table 2-6. These potentials are based off the CO_2 Burst test relationship to N-mineralization developed by Haney et al. (2008). When analyzing the N-mineralization of each sample, it was found that the potentials were either moderately high or high in NT management. The potential of moderately high indicates that there may not be a need for additions of nitrogen. NT management that had cover crops were all rated with a moderately high N-mineralization potential. Compared to NT management, ST management had mostly moderate N-mineralization potentials with some moderately low ratings.

The method outlined above was modified to address non-homogenous variation as discussed in Appendix 2.

Overall, this study determined that as organic matter inputs increase with NT and NT with cover crops management, the mineralization of carbon will increase along with the N-mineralization potential. Similar results were found in Staben et al. (1997) and Feng et al. (2003).

Bulk Density

When comparing bulk density values, there was no difference with treatment. However, there was a significant difference of bulk density between the depths. There was also a significant interaction between bulk density and depth, meaning that the bulk density was significantly different due to management at different depths (Table 2-7 and 2-8).

Studies have analyzed the relationship between bulk density and depth in NT and conventional till systems and found that bulk density was only significantly different in the 0-5 cm depth, and did increase with depth (Ismail et al., 1992). Bulk density was higher in the upper layer of NT soils compared to reduced tillage and conventional tillage soils (Dam et al., 2005; Tebrügge and Düring, 1999; Wander et al., 1998). A study by Mazzoncini et al. (2011) found that the addition of cover crops did not affect bulk density in the upper 10 cm, but NT systems had a larger bulk density than conventional tilled systems. Our results found that the first 0-5 cm statistically had the same bulk density. In contrast to other studies, the lack of a statistically different bulk density in the 0-5 cm depth could have been from the soil surface being worked through planting or other production equipment. Figure 2-6 shows that even though the bulk density is the same at the surface increment, the bulk density increases at a much shallower depth in the NT soils than ST soils. The bulk density is similar in the bottom 20-25 cm increment, but the ST soils increase gradually in bulk density with changes in depth. Bulk density changed with depth significantly (P-value <0.0001), and it was significantly different at depths 5-10 cm and 10-15 cm among the different treatments. This is directly related to tillage, as ST soils are tilled to depths around 15 cm, and NT soils are not. Much like Mazzoncini et al. (2011) found, cover crops did not appear to have an effect on bulk density.

pH

Measurements of pH were done with 1:1 H_2O and 1:2 $CaCl_2$ as part of standard procedure and to understand the true pH of the soil. The 1:1 pH in H_2O was significantly different among the different management (P-value=0.08), at different depth measurements (P-value=0.005), and within the interaction of depth and management (<0.0001). The pH in 1:2 $CaCl_2$ was not different among the different management, but it was significantly different at depth increments (P-value=0.02) and within the interaction of depth and management type (P-value=<0.0001). Specifically, pH 1:1 H_2O and pH 1:2 $CaCl_2$ was different in the 0-5 cm depth and in the 15-20 cm depth among the different management systems (Table 2-7 and 2-8). This finding directly correlates with the typical fertilizer applications in NT and ST systems. Fertilizers can acidify soil conditions. Typically, in NT management, fertilizers are broadcasted on the surface in order to prevent disturbance of the soil, this is why the pH is significantly lower from 0-5cm in NT management. ST soils had a significantly lower pH at the 15-20 cm depth and this is because fertilizers (specifically anhydrous ammonia) are typically injected between the 15-20 cm depth. Sampling for this study occurred in the end of March when producers may be applying fertilizers, so pH was lower than normal. The NT with cover crop management did have a higher pH than NT soils and this could be due to different timing of fertilizer application. The NT with cover crop sites were operated by the same producer who may have not added fertilizer at the time sampling was conducted.

Along with this study, Ismail et al. (1992) found that pH was significantly different in the 0-5 cm depth between NT and conventionally tilled soils. A contrasting study done by Thomas et al. (2007) found that pH was not affected by tillage from 0-10 cm. This would suggest that pH isn’t necessarily dependent on the type of tillage, but more of the management of fertilizers. It also brings up the importance of sample timing with pH measurements, and pH can be changed drastically due to management throughout the year.

Table 2-2. Total carbon (Mg ha^{-1}), mean weight diameter (mm), and microbial respiration (CO_2-C ppm) in two different management systems: NT and ST. NT include sites that have cover crops. For each treatment, there were 4 sites and 12 replicates. Therefore, the values reported are for 12 measurements.

Treatment	Total Carbon	Mean Weight Diameter	Microbial Respiration
	Mg ha^{-1}	mm	CO_2-C ppm
NT	11.00a†	1.93a	53.64a
ST	10.50a	2.22a	36.02b

†Within columns, means followed by the same letter are not significantly different at $p \geq 0.10$

Table 2-3. Average total carbon (Mg ha^{-1}), mean weight diameter (mm), and microbial respiration (CO_2-C ppm) in three different management systems: NT, NT with cover crops, and ST. For NT and NT with cover crops there were 2 sites and 6 replicates; values are for 6 measurements. For ST there were 4 sites with 12 replicates; values reported are for 12 measurements.

Treatment	Mean Average Carbon	Average Mean Weight Diameter	Microbial Respiration
	Mg ha^{-1}	mm	CO_2-C ppm
NT	11.41a†	1.70a	48.57ab
NT with cover crops	10.83a	2.13a	61.30a*
ST	10.50a	2.22a	36.02b

†Within columns, means followed by the same letter are not significantly different at $p \geq 0.10$
*Significantly different at $p=0.05$

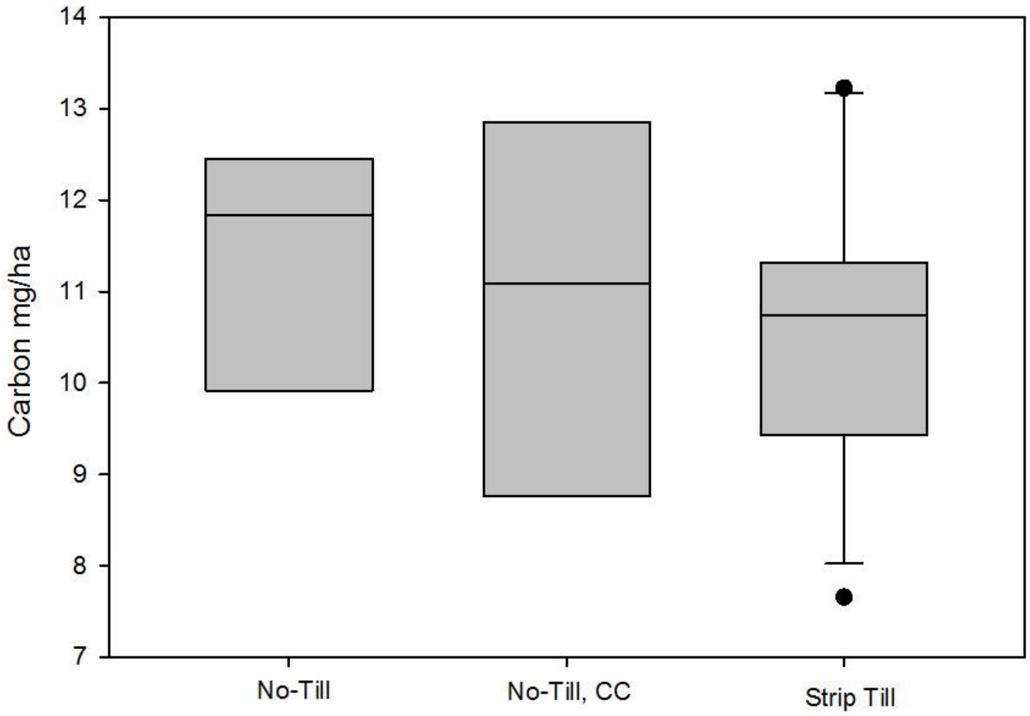

Figure 2-2. Total Carbon (Mg ha^{-1}) in three different management: NT, NT with cover crops, and ST.

Table 2-4. Average amount of water stable aggregates (WSA) for each size class in two different management systems: NT and ST. For each treatment, there were 4 sites and 12 replicates. Therefore, the values reported are for 12 measurements.

	4.75 mm	2.0 mm	1.0 mm	0.5 mm	0.25 mm	<0.25 mm	Total WSA
	----------	----------	----------	%----------	----------	----------	----------
NT	17.2a†	14.7a	9.1a	10.6a	16.1a	32.3a	67.1a
ST	23.1a	12.1a	10.0a	13.4a	14.6a	26.8a	72.9a

†Within columns, means followed by the same letter are not significantly different at p≥0.10

Table 2-5. Average amount of water stable aggregates (WSA) for each size class in three different management systems: NT, NT with cover crops, and ST. For NT and NT with cover crops there were 2 sites and 6 replicates; values are for 6 measurements. For ST there were 4 sites with 12 replicates; values reported are for 12 measurements.

	4.75 mm	2.0 mm	1.0 mm	0.5 mm	0.25 mm	<0.25 mm	Total WSA
	----------	----------	----------	-----%-----	----------	----------	----------
NT	16.7a†	8.8a	8.9a	11.8a	17.3a	36.4a	63.0a
NT with cover crops	17.7a	20.6b*	9.3a	9.4a	14.8a	28.2a	71.1a
ST	23.1a	12.1a	10.0a	13.4a	14.6a	26.8a	72.9a

†Within columns, means followed by the same letter are not significantly different at p≥0.10
*Significantly different at p=0.05

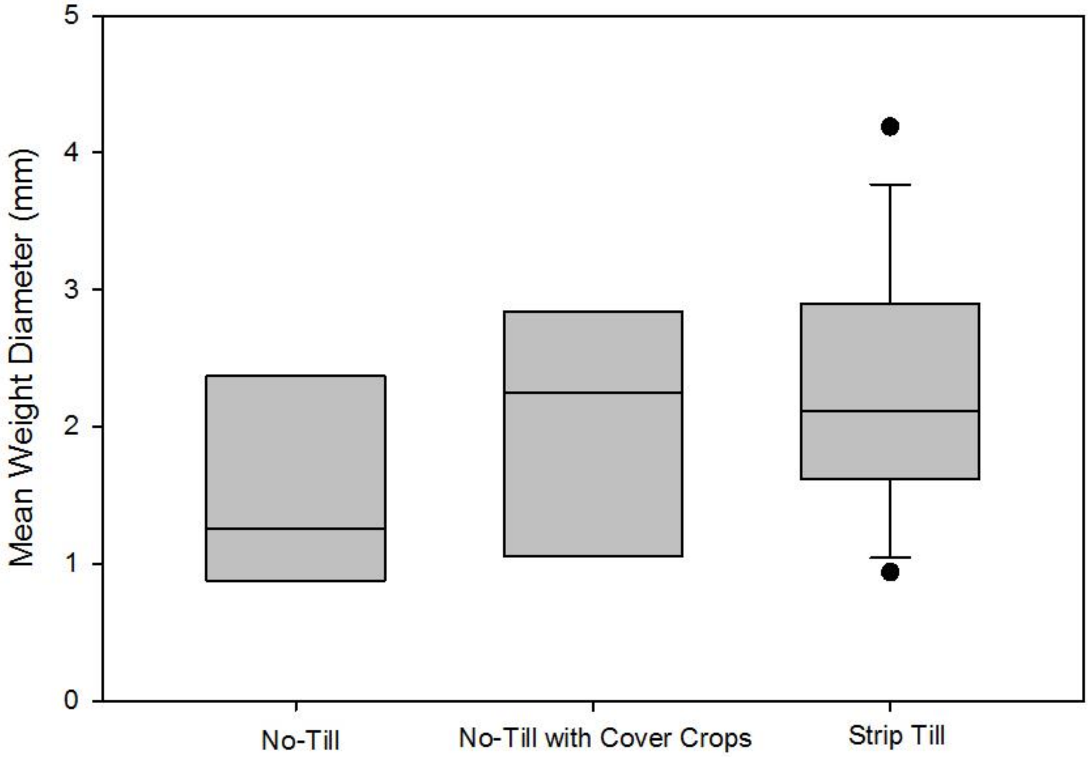

Figure 2-3. Mean Weight Diameter (mm) in three different management systems: NT, NT with cover crops, and ST

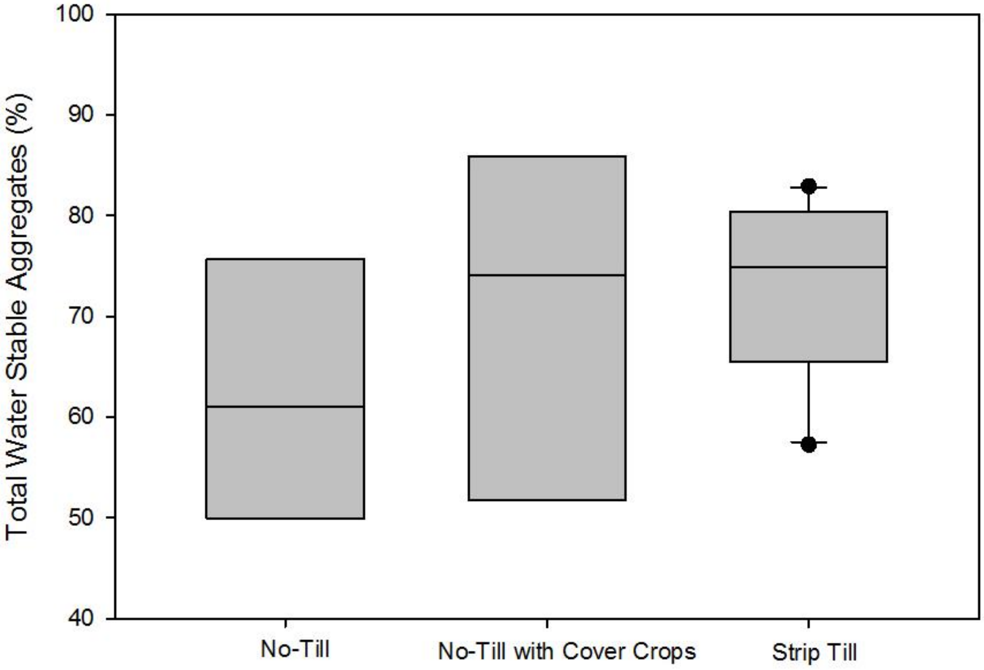

Figure 2-4. Total Water Stable Aggregates (%) in three different management systems: NT, NT with cover crops, and ST.

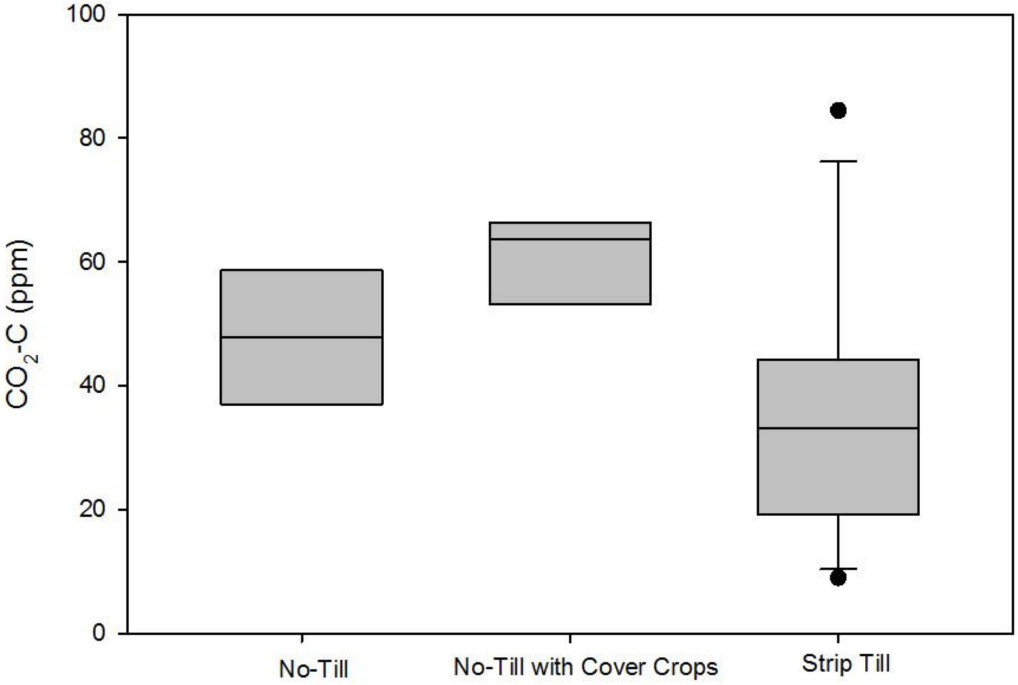

Figure 2-5. Microbial respiration (CO_2-C ppm) in three different management systems: NT, NT with cover crops, and ST

Table 2-6. Complete data for carbon (Mg ha^{-1}), mean weight diameter (mm), microbial respiration (CO_2-C ppm), and N-Mineralization potential in three management systems: NT, NT with cover crops, and ST

Site	Tillage Type	Cover Crop	Carbon	Mean Weight Diameter	Microbial Respiration	N-Mineralization Potential
	†	‡	mg ha^{-1}	mm	CO_2-C ppm	§
NT1	NT	N	12.64	1.71	69.22	MH
NT1	NT	N	12.39	1.37	41.31	M
NT1	NT	N	11.82	0.94	54.28	M
NT2	NT	N	9.94	4.35	55.08	M
NT2	NT	N	11.84	1.15	38.21	M
NT2	NT	N	9.85	0.67	33.33	M
NT3	NT	Y	11.41	2.22	52.99	M
NT3	NT	Y	8.36	2.28	53.25	M
NT3	NT	Y	12.89	1.02	63.37	MH
NT4	NT	Y	8.89	3.58	65.37	MH
NT4	NT	Y	12.83	2.59	64.06	MH
NT4	NT	Y	10.76	1.07	68.74	MH
ST1	ST	N	9.43	2.15	14.09	ML
ST1	ST	N	9.52	1.73	8.97	ML
ST1	ST	N	13.09	2.11	38.44	M
ST2	ST	N	13.22	2.89	46.31	M
ST2	ST	N	10.74	2.91	84.42	MH
ST2	ST	N	11.23	1.60	42.12	M
ST3TAX	ST	N	9.42	4.19	33.1	M
ST3	ST	N	10.84	2.62	24.09	ML
ST3	ST	N	10.48	1.63	27.59	ML
ST3	ST	N	11.40	1.74	40.08	M
ST4	ST	N	7.66	3.14	63.94	MH
ST4	ST	N	8.58	1.20	12.5	ML
ST4	ST	N	10.91	0.94	32.61	M

†NT=NT; ST=ST

‡N=no; Y=yes

§Scale based of Haney et al. (2008); ML=moderately low, M=moderate, MH=moderately high

Table 2-7. Average bulk density (g/cm^3), pH 1:1 H_2O, pH 1:2 $CaCl_2$ of each 5-cm increment of the Ap horizon in two different management systems: NT and ST.

Depth	Bulk Density		pH 1:1 H_2O		pH 1:2 $CaCl_2$	
	NT	ST	NT	ST	NT	ST
cm	-----g/cm^3-----					
0-5	0.91a†	0.90a	6.3a*	7.0b*	6.2a	6.8b
5-10	1.21a*	1.04b*	6.8a	6.8a	6.6a	6.7a
10-15	1.30a*	1.08b*	6.7a	6.0b	6.4a	6.0a
15-20	1.27a*	1.10b*	6.6a*	5.6b*	6.4a*	5.6b*
20-25	1.23a	1.28a	6.6a	6.0a	6.4a	5.8a

†Within rows and the same measurement, means followed by the same letter are not significantly different at $p \geq 0.10$

*Significantly different at $p < 0.05$

Table 2-8. Average bulk density (g/cm^3), pH 1:1 H_2O, pH 1:2 $CaCl_2$ of each 5-cm increment of the Ap horizon in three different management systems: NT, NT with cover crops, and ST

Depth	Bulk Density			P-Value†	pH 1:1 H_2O			P-Value	pH 1:2 $CaCl_2$			P-Value
	NT	NT_CC	ST		NT	NT_CC	ST		NT	NT_CC	ST	
cm	----------g/cm^3-----------			†				†				†
0-5	0.93	0.90	0.90	0.89	5.8	6.9	7.0	0.001	5.7	6.7	6.8	0.01
5-10	1.19	1.22	1.04	0.08	6.8	6.8	6.8	0.97	6.6	6.6	6.7	0.89
10-15	1.33	1.28	1.08	0.04	6.5	6.9	6.0	0.11	6.3	6.6	6.0	0.37
15-20	1.29	1.27	1.10	0.19	6.5	6.8	5.6	0.01	6.3	6.5	5.6	0.06
20-25	1.22	1.23	1.28	0.36	6.5	6.7	6.0	0.18	6.4	6.5	5.8	0.27

NT=NT, NT_CC= NT with cover crops, ST=ST

†Differences are statistically significant if the p-value≤0.10

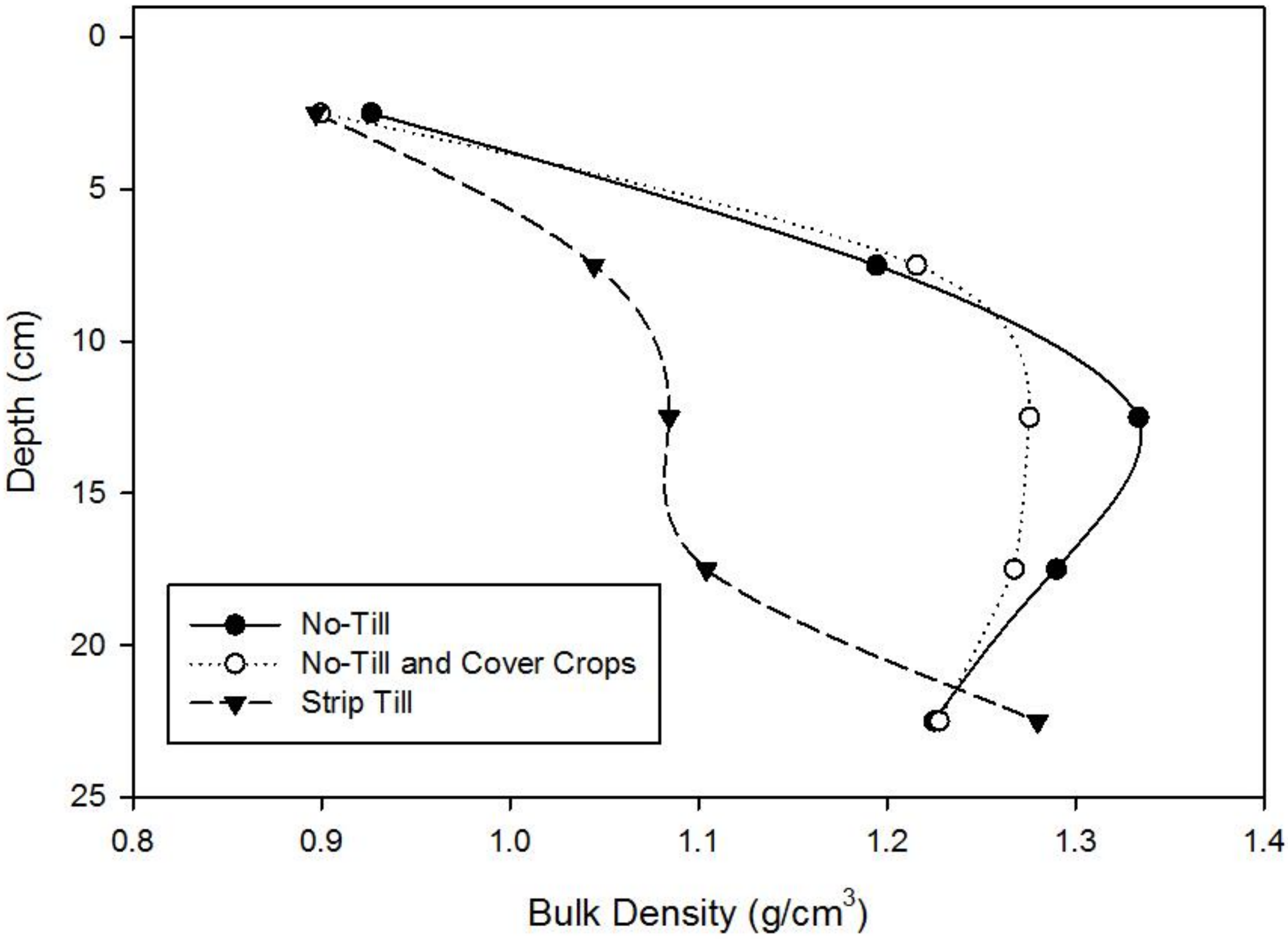

Figure 2-6. Distribution of bulk density (g/cm^3) with depth of Ap horizon.

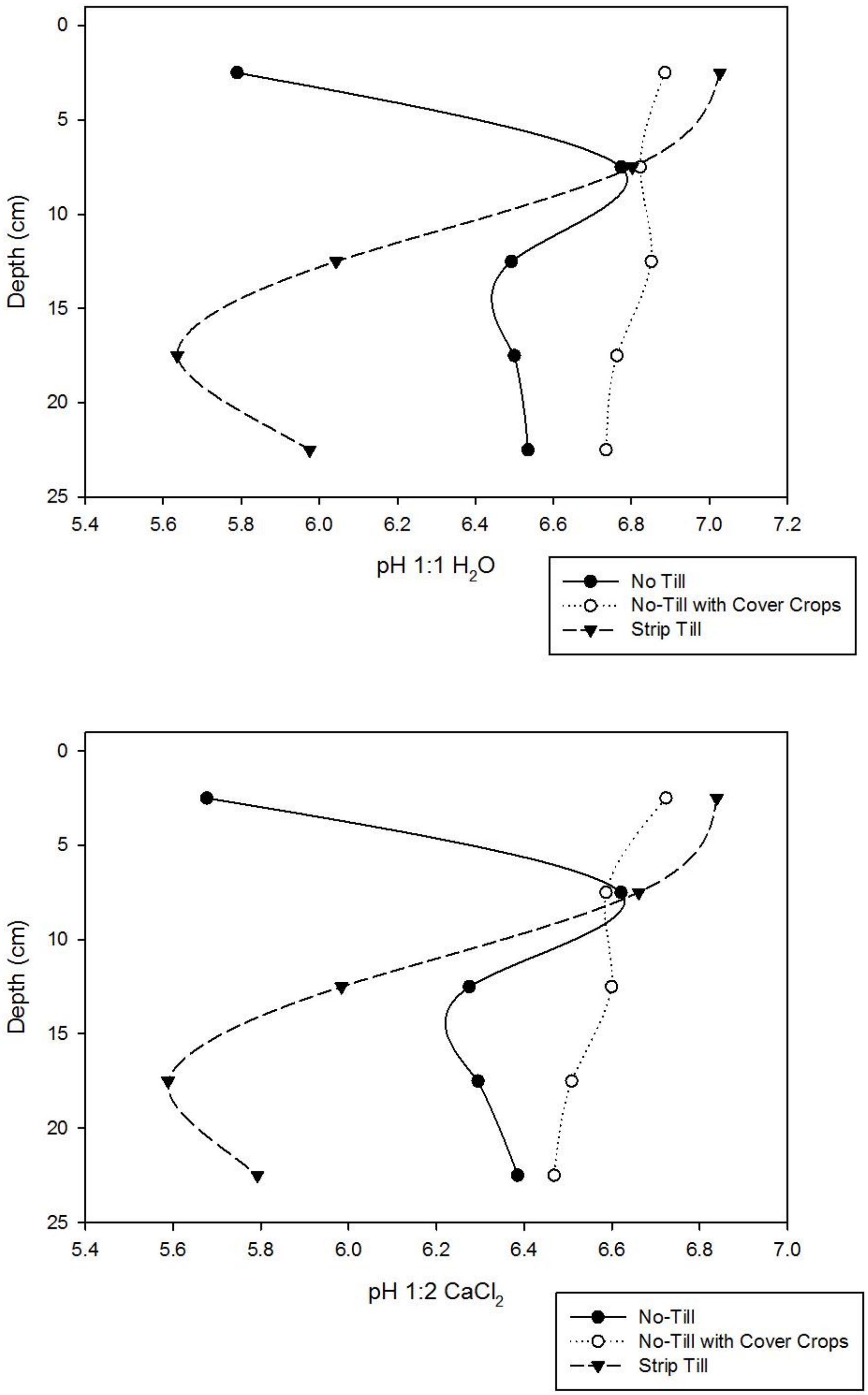

Figure 2-7. Top: pH 1:1 H_2O distribution with depth Bottom: pH 1:2 $CaCl_2$ distrubtion with depth

Conclusions

Significant differences due to management were seen in microbial respiration, select water stable aggregate sizes, and pH and bulk density at certain depths. As previously discussed, timing of sampling collection was a very important factor in this study. Tugel et al. (2008) addresses that soil properties can vary over years, and this may be why expected trends weren't seen in this study. This study agrees with the importance of analyzing soils that are at a steady state and have been in a given management for a long time in order to properly assess soil change (Tugel et al., 2008).

When analyzing tillage effects on soil properties, many studies compare NT to reduced and conventional tillage management. However, the most significant differences are found when comparing NT to conventional tillage management (Schmer et al., 2014; Follet et al., 2013; Ismail et al., 2013; Stone and Schlegel et al., 2010; Whitehair, 2010; Zhang et al., 2007; McVay et al., 2006; Dam et al., 2005; Feng et al., 2003; Sainju et al., 2002). Given this, there may not be as many significant differences in an intermediate tillage method such as ST.

Another important factor that is further discussed in Chapter 3 of this thesis is the importance of analyzing the same soils in dynamic soil property studies. The same kind of soil is defined as a soil with the same or similar map unit component phase (Tugel et al., 2008). Personal communication with the Soil Survey Regional Director (Remley, 2016) identified that for the purpose of this study and dynamic soil property studies in Kansas, a similar soil is defined as a soil that has similar interpretations for agronomic uses. The similar soils within map unit Keith silt loam, 1-3% slopes would include Ulysses and Richfield soils, both of which were classified in this study area (Table 2-1.). Although measuring dynamic soil properties off a given soil map unit component provides uniformity to a study, map unit inclusions will typically be present. Moreover, the inclusions could react differently to management and could account for variability in some measurements.

Overall, this study identifies 1) the importance of analyzing dynamic soil properties in management systems that have reached steady state, 2) the influence of map unit inclusions on dynamic soil properties, and 3) that NT and ST management may not have that significant influence on soil change.

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Chapter 3 - Argillic Horizon Formation of Aridic Argiustolls in Western Kansas

Introduction

A basis for the fundamental study of pedology was developed by Hans Jenny (1941) when he identified the five soil forming factors of climate, organisms, relief, parent material, and time. Between the time at which Jenny discussed the five soil forming factors in 1941 to now, the landscape has changed drastically mainly due to human actions. Whether it's altering the climate through irrigation or tilling land to plant a corn and soybean rotation, humans can have great impacts on the soil formation factors. As soils change caused by human activity, this can greatly impact the function of soils. It has been long debated as to how to incorporate human impacts into soil formation (Richter and Yaalon, 2012; Tugel et al., 2005; Amundson and Jenny, 1991).

Recently, the USDA Natural Resources Conservation Service has been developing studies of dynamic soil properties to determine how humans impact soil formation. Tugel et al. (2005) and Tugel et al. (2008) define dynamic soil properties as soil properties that change over a human time scale in response to natural and anthropogenic stressors. The Soil Change Guide (Tugel et al. 2008) is an applied guide that provides protocols for conducting dynamic soil property (DSP) studies. Examples of soil properties that are considered to be dynamic are bulk density, pH, total carbon, pH, aggregate stability, and microbial respiration.

In contrast to DSPs, there are also inherent soil properties. These are properties that are strictly influenced through the five soil forming factors. Two key inherent soil properties are texture and mineralogy (Tugel et al. 2008). These properties are seen as stable over a human time scale and beyond, and are not affected by management. Because Soil Taxonomy is based on soil properties that are not easily modified by management, it is also deemed inherent and does not change over a human time scale. However, it is difficult to say that soil is strictly influenced by only the five soil forming factors. Richter and Yaalon (2012) proposed that soil should be considered a human-natural resource given the amount of influence humans have on soil formation processes. Now, the research question is- what happens to inherent soil properties once the five soil forming factors are altered by humans?

Specifically, argillic horizon genesis and clay illuviation processes have been identified as inherent in the past. According to Soil Taxonomy, an argillic horizon should exhibit clay increases in the subsoil that are formed by clay illuviation (Soil Survey Staff, 1999). The central concept of argillic horizons contains two major elements: 1) an increase in clay content with depth and 2) the orientation of clays. Both of these properties need to be formed by illuviation to contribute to the central concept of an argillic horizon. Studies done by Gunal and Ransom (2006), Ricks Presley et al. (2004), and Fraser (1990) found that argillic horizons in western Kansas classify by Soil Taxonomy's definition of an argillic horizon. However, the clay increases of soils in western Kansas tend to result from in-situ weathering of minerals, and this would not necessarily fit the central concept of an argillic horizon. The average precipitation for western Kansas per year is between 355-635 mm, classifying with an ustic moisture regime. Because water is limited in this area, clay illuviation is inhibited in this area because water is a very important factor in illuviation.

To support crop production in western Kansas, much of the land in production is irrigated. As over 40 years of center pivot irrigation systems have been used, it is possible that clay illuviation processes are affected by irrigation management over a human time scale. Hence, clay illuviation, accelerated by irrigation, could be considered a dynamic soil property. Ricks

Presley et al. (2004) analyzed the effects of irrigation, which almost doubles the amount of precipitation, on Richfield and Keith soils. In this study, pedons were selected and analyzed in irrigated areas and compared to non-irrigated pedons found on the same field. It was found that over thirty years of irrigation increased illuviation processes and mineral weathering. This was seen through more strongly expressed argillic properties in irrigated pedons vs non-irrigated pedons. Through this study, it is shown that properties that are thought to be inherent can change and be altered over a human time scale, and that clay illuviation can be considered a dynamic soil property.

Along with clay illuviation, the leaching of carbonate is another important process in the formation of soils in western Kansas. Most of the soils in western Kansas are formed in Peoria loess which had calcium carbonate initially present in the unweathered loess. Before clay illuviation processes occur, calcium carbonate must be leached through the soil as calcium carbonate will cause clay to flocculate which will inhibit clay illuviation. Calcium carbonate accumulation in soils is also considered to be an inherent soil property. In the same study done by Ricks Presley et al. (2004), depth to calcium carbonate was not affected by long-term irrigation. Therefore, it would be considered an inherent soil property.

The objectives of this study are to 1) analyze the processes that form soils in western Kansas and to 2) determine if long-term irrigation affects clay illuviation processes and the distribution of calcium carbonate.

Methods

Location Information and Sampling Methods

All the sites used in this study were identified by USDA-NRCS area conservationists and soil scientists in Sheridan County, KS. Four sites mapped as Keith silt loam, 1-3% slopes are in strip till (ST) irrigated corn production. According to protocol from the Soil Change Guide (Tugel et al. 2008), the same kind of soil under different conditions must be used to compare soils under different management. For this study the same soil was defined as the same or similar soil map unit component phase. Table 3-1 shows the classification of each pedon based on field descriptions. Ulysses, Kuma and Richfield series were considered similar to Keith silt loam, 1-3% slopes, and all are considered as the same soil. Because these sites are in an ustic moisture regime, center pivot irrigation systems are used to support corn production. A center pivot irrigation system consists of a well drilled into the center of the field and a sprinkler system that extends out from the well and then will rotate around the entire field to irrigate. To ensure that water is not wasted and production is maximized, the inside circle of the field is irrigated and is often in corn production in the study area. The corners of the field are not irrigated and are typically in dryland wheat production in the study area (Figure 3-1). To observe the effects of irrigation on soil properties, three pedons were sampled inside the center pivot irrigated area, and three pedons were sampled in the non-irrigated corner (Figure 3-1). The sites used in this study were in ST management to ensure that differences in soil properties would only be due to irrigation. Each pedon was described by a USDA-NRCS area soil scientist using protocol from the Field Book for Describing and Sampling Soil (Schoeneberger, 2012). Pedons were sampled using a Giddings Probe, and bulk samples of each horizon were collected. Additionally, clods were collected from each subsoil horizon (Bw, Bt, Btk, or Bk horizons). Each clod was carefully shaved to appropriate size, the clod was covered in a hairnet, and the top of the clod was marked with a staple.

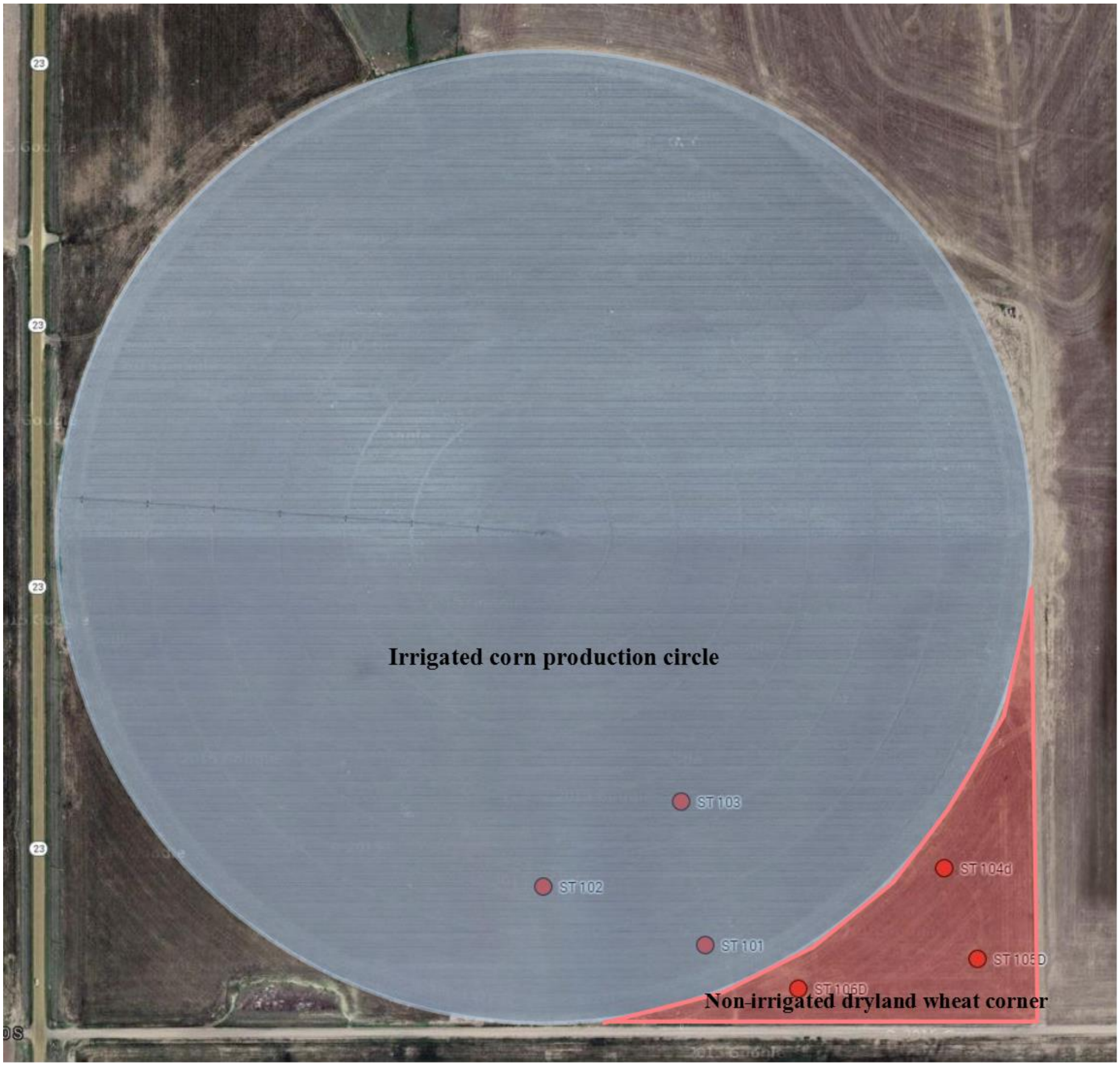

Figure 3-1. Photo of field with the irrigated circle shaded in blue and the non-irrigated corner shaded in red. Markers are placed at locations of the pedons

Table 3-1. Soil series of each pedon used in this study.

Site Number †	Pedon Number ‡	Series §
ST 1	101	Ulysses
	102	Richfield
	103	Ulysses
	104d	Keith
	105d	Keith
	106d	Keith
ST 2	201	Keith
	202	Ulysses
	203	Keith
	204d	Keith
	205d	Kuma
	206d	Richfield
ST 3	301	Keith
	302	Keith
	303	Keith
	304d	Keith
	305d	Richfield
	306d	Keith
ST 4	401	Keith
	402	Richfield
	403	Keith
	404d	Keith
	405d	Keith
	406d	Keith

† ST=ST followed by site numbers of the four sites (1-4) in this study

‡First digit signifies site number (1-4); third digit indicates pedon number (1-6); d=dry non-irrigated pedon

§ Ulysses= fine-silty, mixed, superactive, mesic Aridic Haplustolls; Richfield=fine, smectitic, mesic Aridic Argiustolls; Keith= fine-silty, mixed, superactive, mesic Aridic Argiustolls; Kuma= fine-silty, mixed, superactive, mesic Pachic Argiustolls;

Particle Size Analysis

Sample Preparation

Samples from the field were air-dried, ground using a wooden rolling pin, and passed through a sieve with 2 mm openings to obtain the fine earth fraction. If the Ap horizon had a total carbon content >1.72%, the samples were pretreated to remove organic matter prior to particle size analysis. The removal of organic matter followed the procedure by Jackson (2005) in which a corrected sample size was weighed out using the following formula:

$$\text{Corrected sample size (g)} = 10.0 + 0.1[(\%\text{O.C.} * 1.74) - 3]$$

Periodically, amounts of 30% H_2O_2 were added to the soil to remove organic matter, and the samples were placed in a water bath at 80^{o}C to speed up this reaction. Once the organic matter was removed, the samples were quantitatively transferred into a 250 mL centrifuge bottle, and 10 g of NaCl were added to aid in the dispersion of the soil samples. Next, the samples were centrifuged in an IEC Model K centrifuge for 5 minutes at 1500-1800 rpm, the supernatant was decanted, and 150 mL of deionized water were added to the sample. Cycles of centrifuging and washing with deionize water were done until the soil sample was dispersed. Once dispersed, the samples were then used in the standard particle size analysis procedure.

Particle Size Analysis Procedure

The procedure followed a method used by Kilmer and Alexander (1949) and method 3A1 from the Soil Survey Laboratory Methods Manual (Soil Survey Staff, 2004). 10 g of soil and 10 mL of a dispersing agent were put into a 450 mL sedimentation bottle. The dispersing agent contained 71.4 g of sodium hexametaphosphate ($NaPO_3$) and 15.86 g of sodium carbonate ($NaCO_3$) dissolved in 2 L of deionized water. After the sedimentation bottles were filled up about half-way with deionized water, the bottles were capped and placed on a shaker overnight set at 120 oscillations/min. The next day, all the sedimentation bottles were brought up to a final weight of 390 g. This weight includes the 10 g of soil, 10 g of dispersing agent, and 370 g of deionized water. The samples were then stirred on an electric mixer for 1 minute and then set on the lab bench to begin sedimentation. Exact sedimentation times for each soil fraction were calculated using the following equation from Jackson (2005) that is based off of Stoke's Law:

$$t = \frac{18nh}{g(s_p - s_1)D^2}$$

where t is the sedimentation time in seconds, n is the viscosity of water (g cm^{-1} sec^{-1}), h is the depth of fall (cm), s_p-s_1 is the difference in specific gravity between the particle relative to the liquid (g cm^{-1}), and D is the particle diameter (cm).

Once the appropriate sedimentation time had passed, the samples were pipetted with a 6 mL pipet at 8 cm from the top of the solution to collect an aliquot of the <20 µm fraction. This procedure was repeated to collect aliquots of the <5 µm and <2 µm fraction except the pipetting was done 5 cm from the top of the solution. The aliquots were then put into a pre-weighed crucible, dried at 105°C overnight, and quantitatively weighed the next day.

Fine clay (<0.2 µm) was also measured in this procedure where the solution leftover from the <20 µm, <5 µm, <2 µm readings was stirred on an electric mixer for 1 minute, and then left for about 1.5 minutes to allow the sand particles to settle. A 25 mL aliquot was pipetted from the center of the solution and placed into 50 mL centrifuge tubes. The tubes were then centrifuged in an IEC Model K centrifuge at 2200 rpm for the appropriate time using the following equation from Jackson (2005):

$$t = \frac{63.0 \text{ x } 10^8 \log R/S}{N_m^2 \, D_u^2 (s_p - s_1)}$$

where t is the centrifugation time in minutes, R and S are distances (cm) from the center of gravity of the centrifuge head to the top of the sediment and to the top of the suspension, N_m is the rpm of the centrifuge, D_u is the particle size diameter (μm), and s_p-s_1 is the differential specific gravity (g cm^{-1}). After the appropriate centrifugation time had passed, a 6 mL aliquot was pipetted at 2 cm from the top of the solution. The solution was put into a pre-weighed crucible and dried at 105°C overnight and quantitatively weighed the next day.

The percent of <20 μm, <5 μm, <2 μm, and <0.2 μm fractions were calculated using the following equation:

$$\% = [(\text{wt. of crucible} + \text{soil suspension}) - \text{wt. of crucible} - \text{SF})(\text{PF})(\text{sample wt.})]$$

where (wt. of crucible + soil suspension) is the oven dried mass (g) of the crucible and soil material, wt. of crucible is the pre-weighed (g) crucible, SF is the salt factor, PF is the pipet factor, and sample weight is the initial sample size (10 g). The salt factor is calculated to correct for the weight of salts in the dispersing agent. 10 mL of the dispersing agent were placed into a sedimentation bottle and brought up to a weight of 380 g by adding deionized water. The solution was stirred on an electric mixer for one minute. Then, a 6 mL aliquot was pipetted from solution, dispensed into a pre-weighed crucible, dried overnight at 105°C, and quantitatively weighed the next day. The salt factor was calculated using the following formula:

$$\text{SF} = (\text{wt. of crucible} + \text{salt}) - \text{wt. of crucible}$$

where (wt. of crucible + salt) is the oven-dried weight (g) of the crucible and salt material, and wt. of crucible is the pre-weighed (g) crucible. The pipet factor was determined using the following formula:

$$\text{Pipet Factor} = \frac{370\text{ mL of }H_2O + 10\text{ mL of dispersing agent} + 3.77\text{ mL of soil}}{\text{Pipet volume} = 6\text{ mL}}$$

After all the pipettings for the <20 µm, <5 µm, <2 µm, and <0.2 µm fractions were completed, the remaining solution was washed through a 300 mesh sieve with openings of 50 µm to collect the sand fraction. The sand material was quantitatively transferred from the 300 mesh sieve into a 50 mL beaker and then dried at 105°C overnight. The dried samples were then placed onto a nest of sieves which were in the following order from top to bottom with openings of: 1.0 mm (very coarse sand), 0.5 mm (course sand), 0.25 mm (sand), 0.107 mm (fine sand), and 0.046 mm (very fine sand). The nests of sieves were placed on a Gilson Model S-5 vibratory 3 inch sieve shaker and shook vigorously for 1 minute. After 1 minute, the material left on each sieve was weighed and calculated using the following formula:

$$\% = (\text{wt. of sand fraction (g) x } 10)$$

The total amount of sand was calculated using the following equation where all weights are in grams:

$$\%\text{TS} = (\text{VCS wt.} + \text{CS wt.} + \text{S wt.} + \text{FS wt.} + \text{VFS wt.})$$

Thin Section Preparation and Micromorphology

Clods of subsoil horizons (Bw, Bt, Btk, Bk) were collected in the field, and sent to Texas Petrographic Services Inc. in Houston, TX. This facility prepared thin sections by impregnating the clods with clear epoxy under a vacuum, trimming the impregnated soil to a suitable size, and grinding the cut sample on to a 25 x 46 mm petrographic slide.

The slides were examined using a petrographic microscope (Model: Optiphot-Pol, Nikon, Melville, New York) with plane and cross polarized light. Pedofeatures and micromass were qualitatively described using terminology by Stoops (2003). Pictures of the thin sections were taken using a Moticam 580 5.0 MP digital camera that was attached to the microscope.

Statistical Analysis

To determine the difference in characteristics between irrigated and non-irrigated soils, a paired t-test was used. The four sites are considered blocking factors with twelve replicates of irrigated soils and twelve replicates of non-irrigated soils. A paired t-test compared the irrigated and non-irrigated population means to determine if they were statistically different.

Results and Discussion

Field Description Analysis

Site ST 1

Field Description

Field descriptions of representative irrigated and non-irrigated pedons can be found in Tables 3-2 and 3-3. Three irrigated pedons were described, and two were classified as Ulysses (fine-silty, mixed, superactive, mesic Aridic Haplustolls). One pedon classified as Richfield (fine, smectitic, mesic Aridic Argiustolls). Since mollic colors (moist chroma and value ≤3) were described to depths that ranged from 27 to 46 cm, all pedons classified with a mollic epipedon. Surface textures were described as silt loam and silty clay loam with clay increases in the subsoil. Clay films were described in the irrigated Richfield pedon, indicating that illuviation processes were occurring that resulted in clay increases in the subsoil. The two Ulysses pedons had clay increases required of an argillic horizon, but pressure faces were described, rather than clay films. Pressure faces were described in all irrigated pedons, and solely described in the Ulysses pedons. Pressure faces indicate that shrink-swell processes occur in these soils. Carbonate masses were described below Bt or Bw horizons beginning at depths between 44 and 75 cm. Carbonate masses were described with either a threadlike or irregular shape.

Three non-irrigated pedons were described and classified as Keith. Mollic colors were described to depths that ranged from 23 to 46 cm, resulting in classification with a mollic epipedon. Much like the irrigated soils, the surface textures were described as silt loam and silty clay loam in the subsoil with clay increases. Between 1 and 10 % clay films were described in Bt horizons, indicating that illuviation processes had occurred in these soils. Along with clay films, pressure faces were described in some Ap2 and Bk1 horizons, indicating that shrink-swell processes have occurred in these soils. Threadlike and irregular carbonate masses were described below Bt horizons beginning at depths between 46 and 89 cm, which was similar to irrigated soils.

Field descriptions indicated that management did not have an effect on soil morphology properties. Instead, differences in soil properties could be from map unit inclusions of different soils. Along with map unit inclusions, it is important to note that this site has had precision land leveling occur in the past. Although the land owner did not know the exact date when the leveling occurred, precision land leveling would take or put soil material from the irrigated portion of the field and move it to or from other areas of the field. This process could drastically alter the soil material and potentially expose more of the subsoil to weathering processes.

Lab Characterization Analysis

Characterization data and distribution of clay can be found in Tables 3-4 and 3-5, and Figure 3-2. Particle size data confirmed textures in the field, with some exceptions. Specifically, the Richfield irrigated pedon was originally classified as Keith in the field. From characterization data, the family particle size class was fine, rather than fine-silty, which would then classify this soil as Richfield. Additionally, it was found that one of the Ulysses irrigated pedons did have the clay increase needed to classify with an argillic horizon, but again, clay films were not described. Hence, it is still classified as Ulysses. Fine clay particles (<0.2 μm) are the smallest clay fraction and the most mobile. Because of this, the ratio of FC:TC is higher in illuvial horizons and lower in eluvial horizons. From Figure 3-2, the irrigated pedon has the highest clay content and FC:TC ratio in the surface horizon. This distribution was not expected, and it could be the result of a more recent deposition of a clay-rich parent material (i.e., Bignell loess). The laboratory characterization data suggested there were differences between irrigated and non-irrigated pedons. However, these are not the result of different management, because map unit inclusions of different soils, and additions of younger parent materials may be the cause of these differences.

Table 3-2. Abbreviated field description of ST 102 irrigated Richfield (fine, smectitic, mesic Aridic Argiustolls) pedon from ST 1

Depth	Horizon	Matrix Color	Structure	Ped and Void Surface Features	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-9	Ap1	10 YR 2/2	2-f-gr	#	#
9-18	Ap2	10 YR 2/2	3-vf-abk	#	#
18-28	Bt	10 YR 3/3	3-f-abk	CLF 5% D D VF CLF 2% D D HF	#
28-46	Bk1††	10 YR 3/3	2-f-pr	PRF 5% D D VF	#
46-82	Bk3	10 YR 5/4	1-f-pr	#	CAM 2% M I MAT CAM 3% F T MAT
82-151	Bk3	10 YR 5/4	1-m-pr	#	CAM 2% F I MAT
151-230	Bk4	10 YR 4/4	1-co-pr	#	CAM 1% F T SPO CAM 1% F I MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

††28-46 changed from Bw to Bk1 after micromorphology analysis

Table 3-3. Abbreviated field description of ST 104d non-irrigated Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls) pedon from ST 1

Depth	Horizon	Matrix Color	Structure	Ped and Void Surface Features	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-5	Ap1	10 YR 3/3	1-m-sbk/1-f-gr	#	#
5-23	Bt1	10 YR 3/3	2-f-pr/2-f-sbk	CLF 2% D C PF	#
23-46	Bt2	10 YR 4/3	1-f-pr	CLF 1% D D VF PRF 2% D D VF PRF 2% D D HF	#
46-144	Bk1	10 YR 5/4	1-m-pr/ 1-m-sbk	#	CAM 2% F I MAT
144-230	Bk2	10 YR 5/4	1-f-pr/1-co-gr	#	CAM 1% F T MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

Table 3-4. Soil characterization data from ST 102 irrigated Richfield (fine, smectitic, mesic Aridic Argiustolls) pedon in ST 1

Depth	Horizon	Sand	Silt	Clay	Fine Clay	FC:TC†	Textural class‡
cm		----------------	----------------	%	----------------		
0-9	Ap1	11.5	49.8	38.8	26.6	0.7	sil
9-18	Ap2	12.3	54.1	33.6	18.9	0.6	sil
18-28	Bt	9.5	53.4	37.1	23.2	0.6	sicl
28-46	Bk1	10.8	59.9	29.4	15.1	0.5	sicl
46-82	Bk3	13.3	62.9	23.8	6.0	0.3	sil
82-151	Bk3	10.2	67.0	22.9	6.2	0.3	sil
151-230	Bk4	13.4	63.1	23.5	5.3	0.2	sil

†Ratio of fine clay (<.2 μm) to total clay
‡sil=silt loam, sicl=silty clay loam, sic=silty clay, l=loam

Table 3-5. Soil characterization data for ST 104d non-irrigated Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls) pedon in ST1

Depth	Horizon	Sand	Silt	Clay	Fine Clay	FC:TC†	Textural class‡
cm		-----------------------	-----------------------	%	-----------------------		
0-5	Ap1	12.2	62.0	25.8	14.0	0.5	sil
5-23	Bt1	10.1	56.0	33.9	22.2	0.7	sicl
23-46	Bt2	9.5	61.6	28.9	11.1	0.4	sicl
46-144	Bk1	11.9	68.9	19.2	5.3	0.3	sil
144-230	Bk2	15.4	63.5	21.1	4.9	0.2	sil

†Ratio of fine clay (<.2 µm) to total clay
‡sil=silt loam, sicl=silty clay loam, sic=silty clay, l=loam

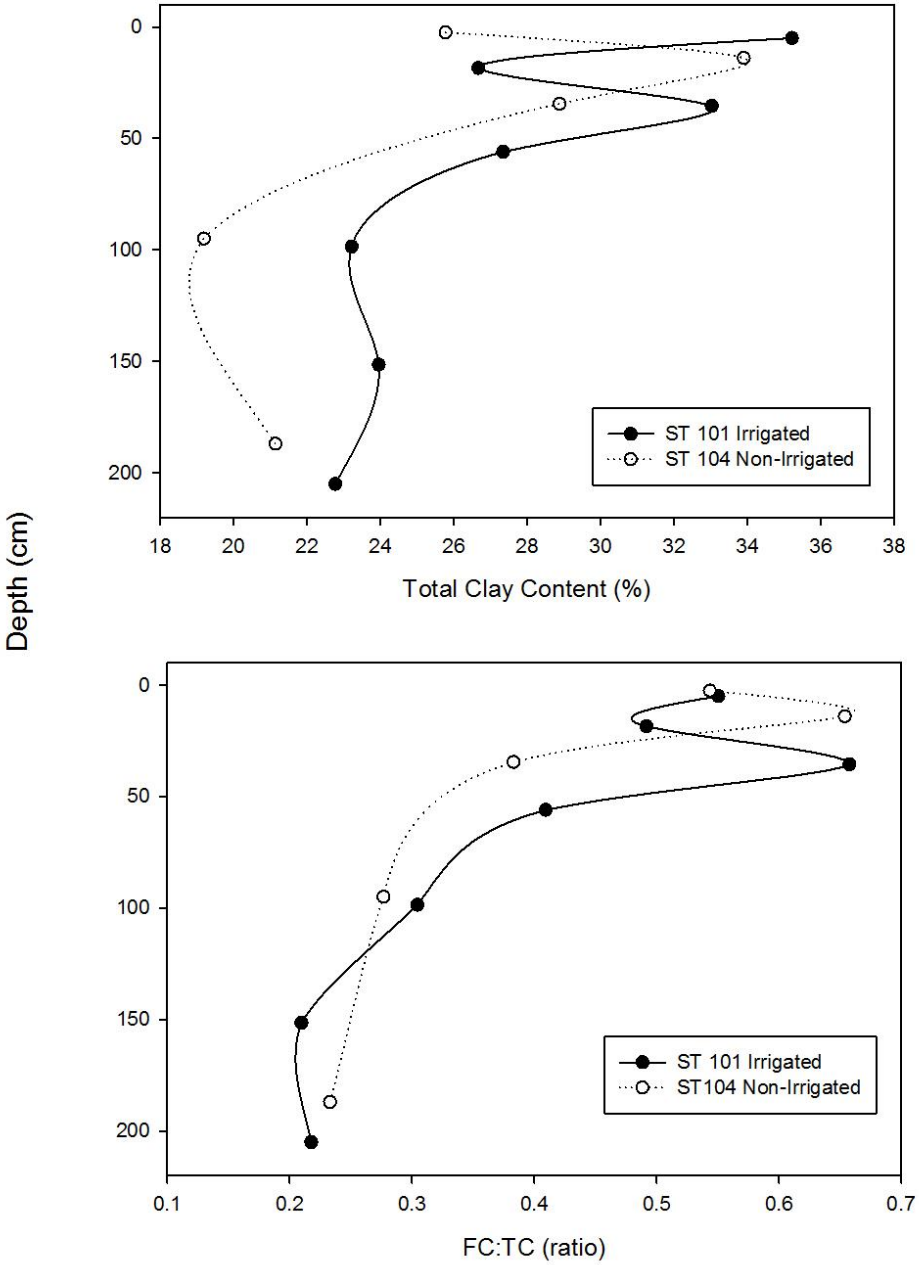

Figure 3-2. Top: total clay content (%) distribution with depth (cm) of selected irrigated (ST 102) and non-irrigated (ST 104d) pedons. Bottom: ratio of fine clay to total clay distribution with depth (cm) of selected irrigated and non-irrigated pedons.

Site ST 2

Field Description

Abbreviated field descriptions for selected irrigated and non-irrigated pedons can be found in Tables 3-6 and 3-7. Of the three irrigated pedons described, two were classified as Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls), and one was classified as Ulysses (fine-silty, mixed, superactive, mesic Aridic Argiustolls). Irrigated pedons had mollic colors (moist value and chroma ≤3) described to depths between 21 and 34 cm, classifying all with a mollic epipedon. Textures were silt loam on the surface, and the clay content increased in the subsoil for textures of silty clay loam. The irrigated pedon that classified as Ulysses did have a significant clay increase to meet the requirements for an argillic horizon. However, clay films were not described. Pressure faces were described which prevent this soil form being classified as Keith with an argillic diagnostic subsurface horizon. The two irrigated pedons that classified as Keith had between 1-5% clay films described on ped faces, which would indicate that clay is being illuviated. Carbonate masses were described below Bt horizons beginning at depths between 38 and 59 cm. Masses were described as threadlike and irregularly shaped.

Three non-irrigated pedons were described. One was classified as Keith, one as Kuma (fine-silty, mixed, superactive, mesic Pachic Argiustolls), and one as Richfield (fine, smectitic, mesic Aridic Argiustolls). Non-irrigated pedons had mollic colors described to at least 25 cm, indicating classification with a mollic epipedons. The Kuma pedon had mollic colors described to 50 cm, classifying it in a Pachic subgroup. Much like the irrigated pedons, textures were described as silt loam on the surface, and silty clay loam and silty clay in the subsoil with increased clay contents. The only pedon with a silty clay texture in the subsoil was the non-irrigated Richfield pedon. Since Richfield soils have a fine particle size class, they will have a finer texture in the subsoil. All pedons had clay films (<10%) present indicating that clay illuviation has occurred. The higher amount of clay films observed in non-irrigated pedons, could be the result of because drier soil moisture status that causes clay films to be more visible. Along with illuviation, slickensides and pressure faces were described, indicating that shrink-swell processes are occurring in these soils as well. Carbonate masses were described below Bt horizons beginning at depths between 44 and 70 cm. They were described as threadlike and irregular in shape. The distribution of carbonate masses was not different from what was seen in irrigated pedons.

Overall, management did not have an effect on soil morphological properties. Within site ST 2, there were map unit inclusions of different soils, specifically Richfield and Kuma soils, which make these comparisons very difficult. Along with map unit inclusions, soil moisture status made clay films more easily seen in non-irrigated soils.

Lab Characterization Analysis

Characterization data and distribution of clay in selected irrigated and non-irrigated pedons can be found in Tables 3-8 and 3-9, and Figure 3-3. Field textures were confirmed by laboratory data with some exceptions. Figure 3-3 shows that the non-irrigated soil exhibited a higher amount of clay in the subsoil. There were no significant differences in clay content between the irrigated and non-irrigated pedons. This, again, could be the result of map unit inclusions of different soils. Fine clay particles (<.2 μm) are the smallest clay fraction and the most mobile. Because of this, fine clay to total clay ratios (FC:TC) will be higher in illuvial horizons and lower in eluvial horizons. Figure 3-3 shows that the FC:TC was similar in irrigated and non-irrigated pedons, but the FC:TC in non-irrigated pedons were lower at a shallower depth compared to the irrigated pedon.

After analyzing laboratory characterization data, management did not affect soil morphology properties. Instead, differences in soil properties are from map unit inclusions of different soils. Particularly in ST 2, the non-irrigated pedons were classified as three different soils. With such differences, it is very difficult to make accurate comparisons.

Table 3-6. Abbreviated field description of ST 203 irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon from ST 2

Depth	Horizon	Matrix Color	Structure	Ped and Void Surface Features	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-5	Ap1	10 YR 2/2	2-f-pl/1-f-gr	#	#
5-12	Ap2	10 YR 2/2	2-co-gr	#	#
12-34	Btk††	10 YR 2/1	1-m-pr/1-f-sbk	CLF 2% D D APF	#
34-59	Bt2	10 YR 3/4	2-f-pr/1-f-sbk	CLF 1% F P APF PRF 5% F D VPF	#
59-115	Bk1	10 YR 5/4	1-f-pr	#	CAM 1% F T MAT CAM 2% F I MAT
115-230	Bk2	10 YR 5/4	1-co-pr	#	CAM 2% F I MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

††12-34 changed to Btk from the initial field nomenclature of Bt based off of micromorphology

Table 3-7. Abbreviated field description of ST 204d non-irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon from ST 2

Depth	Horizon	Matrix Color	Structure	Ped and Void Surface Features	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-11	Ap1	10 YR 3/2	2-f-gr	#	#
11-15	Ap2	10 YR 3/2	2-m-pl/2-f-gr	#	#
15-29	Bt1	10 YR 3/3	2-f-pl	CLF 10% D D PF	#
29-44	Bt2	10 YR 5/3	2-f-pl/2-f-sbk	CLF 5% D D VPF	#
44-87	Bk1	10 YR 5/3	2-m-sbk	#	CAM 4% F I TOT CAM 2% F I RPO CAN 3% M I TOT CAM 1% F T TOT
87-130	Bk2	10 YR 5/3	1-m-sbk	#	CAM 3% F T TOT CAM 1% M I TOT
130-165	Bk3	10 YR 5/3	1-m-sbk	#	CAM 1% F T TOT
165-204	Bk4	10 YR 5/3	1-m-sbk	#	CAM 1% F I TOT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores RPO=along root pores

#None present

Table 3-8. Soil characterization data from ST 203 irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon in ST 2

Depth	Horizon	Sand	Silt	Clay	Fine Clay	FC:TC†	Textural class‡
cm		---	---%---		---		
0-5	Ap1	11.9	62.2	25.9	13.9	0.5	sil
5-12	Ap2	10.1	62.9	27.0	15.3	0.6	sicl
12-34	Btk	9.6	59.3	31.1	20.0	0.6	sicl
34-59	Bt2	10.2	57.6	32.2	19.3	0.6	sicl
59-115	Bk1	10.8	65.5	23.8	7.5	0.3	sil
115-230	Bk2	12.1	66.5	21.4	5.6	0.3	sil

†Ratio of fine clay (<.2 µm) to total clay
‡sil=silt loam, sicl=silty clay loam, sic=silty clay, l=loam

Table 3-9. Soil characterization data from ST 204d non-irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon in ST 2

Depth	Horizon	Sand	Silt	Clay	Fine Clay	FC:TC†	Textural class‡
cm		---%---					
0-11	Ap1	13.7	61.9	24.4	12.6	0.5	sil
11-15	Ap2	12.8	57.5	29.7	18.5	0.6	sicl
15-29	Bt1	10.2	55.6	34.2	20.3	0.6	sicl
29-44	Bt2	11.7	62.1	26.2	7.7	0.3	sil
44-87	Bk1	11.4	65.0	23.6	4.7	0.2	sil
87-130	Bk2	12.2	65.1	22.7	4.8	0.2	sil
130-165	Bk3	12.9	64.4	22.7	6.8	0.3	sil
165-204	Bk4	13.8	65.7	20.6	4.5	0.2	sil

†Ratio of fine clay (<.2 μm) to total clay
‡sil=silt loam, sicl=silty clay loam, sic=silty clay, l=loam

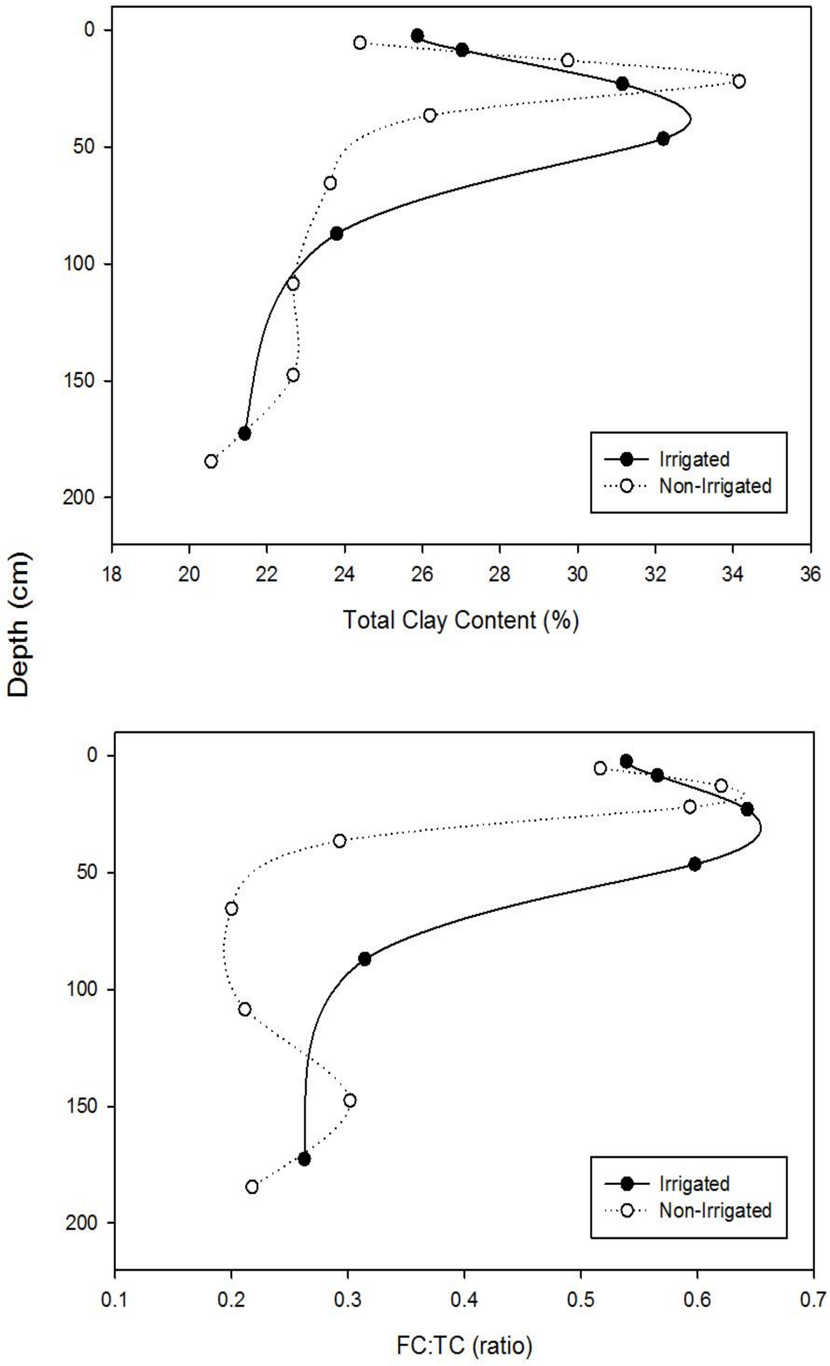

Figure 3-3. Top: total clay content (%) distribution with depth (cm) of selected irrigated (ST 203) and non-irrigated (ST 204d) pedons. Bottom: ratio of fine clay to total clay distribution with depth (cm) of selected irrigated and non-irrigated pedons.

Site ST 3

Field Description

Abbreviated field descriptions for irrigated and non-irrigated pedons can be found in Tables 3-10 and 3-11. All three pedons described in the irrigated area were classified as Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls). Irrigated pedons were described with mollic colors (moist value and chroma <3) to depths between 23 and 30 cm, classifying with a mollic epipedon. In some pedons, the thickness of the mollic epipedon was <25 cm. However, the thickness was at least 1/3 of the depth to carbonates, fitting the depth requirement of a mollic epipedon. Field textures, much like sites ST 1 and ST 2, were described as silt loam on the surface and silty clay loam in the subsoil with clay content increases. Between 1 and 10% clay films were described in all Bt horizons indicating that clay illuviation has occurred. Pressure faces were described along with clay films, indicating that these soils are prone to shrink-swell processes. Carbonate masses and nodules were present in the subsoil and began at depths between 24 and 61 cm. Most masses and nodules were described as threadlike or irregularly shaped, and were fine or medium in size.

Of the non-irrigated pedons described, two were classified as Keith, and one was classified as Richfield (fine, smectitic, mesic Aridic Argiustolls). Much like irrigated soils, mollic colors were described to at least 25 cm, indicating classification with a mollic epipedon. Field textures of the surface horizon were silt loam. The clay content increased in the subsoil with silty clay loam or silty clay textures. Clay films were described in all Bt horizons indicating that illuviation processes had occurred in non-irrigated soils. A Bt horizon had 15% clay films described, which was a greater amount than the irrigated pedons. This could be because the clay films are more visible when the soil is dry. Carbonate masses were present below Bt horizons and began at depths between 38 and 53 cm.

An analysis of field descriptions showed that management does not affect soil morphology properties. Differences observed in the amount of clay films were from the soil moisture condition, which made it easier to identify clay films in non-irrigated soils. It is difficult to compare these soils because there are map unit inclusions of different soils.

Lab Characterization Analysis

Soil characterization data and distribution of clay in selected irrigated and non-irrigated pedons can be found in Tables 3-12 and 3-13, and Figure 3-4. Field textures in irrigated and non-irrigated pedons were confirmed by laboratory data with some exceptions. In particular, non-irrigated pedons 304 and 306 were classified as Keith in the field with a fine-silty particle size class. Although laboratory data did confirm this, the average weighted clay of the control section for non-irrigated pedons 304 and 306 were 34.3% and 34.0%, respectively. To classify with a fine particle size class, the average weighted clay of the control section must be greater than 35%. The main difference between Keith and Richfield is that Richfield has a fine particle size class. So non-irrigated pedons 304 and 306 were classified as Keith, but they have a rather high weighted average clay content compared to other Keith pedons analyzed. Figure 3-4 shows that irrigated and non-irrigated have similar maximum clay contents, but the clay content in irrigated soil decreases at a much shallower depth than the non-irrigated soil. The same thing is seen in the fine clay to total clay ratio (FC: TC); the ratios are similar overall, but the FC:TC ratio decreases at a much shallower depth compared to the non-irrigated soil. This could be because the non-irrigated Keith pedons have higher weighted average clay content compared to other Keith pedons. Fine clay particles (<.2 μm) are the smallest clay fraction and the most mobile. Because of this, FC:TC will be higher in illuvial horizons and lower in eluvial horizons. Higher clay contents and FC:TC occurred in the surface horizons. This could have resulted from the deposition of another clay-rich parent material (i.e., Bignell loess).

Analyzing laboratory characterization data showed that management did not have an effect on soil morphology properties. Differences could be seen from map unit inclusions of different soils, and depositions of another parent material.

Table 3-10. Abbreviated field description of ST 302 irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon from ST 3

Depth	Horizon	Matrix Color	Structure	Ped and Void Surface Features	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-5	Ap1	10 YR 3/2	2-f-pl	#	#
5-24	Bt	10 YR 2/2	2-f-pr/2-f-sbk	CLF 1% F D APF PRF 5% D C VPF	#
24-40	Btk	10 YR 4/3	2-f-pr	CLF 1% F P VPF PRF 5% F D PRF APF	CAN 1% F IR MAT CAM 1% F IR MAT
40-72	Bk1	10 YR 5/3	1-f-pr/1-f-sbk	#	CAM 2% M IR MAT
72-197	Bk2	10 YR 6/4	1-co-pr	#	CAM 2% F TH MAT CAM 2% F IR MAT
197-230	Bk3	10 YR 6/4	1-co-pr/1-f-sbk	#	CAM 1% F IR MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

Table 3-11. Abbreviated field description of ST 306d non-irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon from ST 3

Depth	Horizon	Matrix Color	Structure	Ped and Void Surface Features	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-12	Ap1	10 YR 3/2	2-f-gr	#	#
12-18	Ap2	10 YR 3/1	1-m-sbk/2-f-gr	#	#
18-40	Bt1	10 YR 3/2	2-f-pr	CLF 20% P C PF	#
40-53	Bt2	10 YR 5/2	2-f-pr/2-f-sbk	CLF 10% P C VPF	#
53-76	Bk1	10 YR 5/3	1-f-pr/2-f-sbk	#	CAM 2% F T OT
76-121	Bk2	10 YR 5/3	1-f-pr/2-f-sbk	#	CAM 3% F I TOT CAM 2% F T TOT
121-169	Bk3	10 YR 5/3	1-f-pr/1-f-sbk	#	CAM 3% F I RPO CAM 1% F T TOT
169-228	Bk4	10 YR 5/3	1-m-pr	#	CAM 1% F I RPO CAM 1% F T TOT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores, RPO=along root pores

#None present

Table 3-12. Soil characterization data from ST 302 irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon in ST 3

Depth	Horizon	Sand	Silt	Clay	Fine Clay	FC:TC†	Textural class‡
cm		---%---					
0-5	Ap1	13.4	55.8	30.9	27.3	0.9	sicl
5-24	Bt	12.6	57.1	30.3	17.4	0.6	sicl
24-40	Btk	11.9	52.9	35.2	17.7	0.5	sicl
40-72	Bk1	12.5	61.7	25.8	8.7	0.3	sil
72-197	Bk2	13.1	64.6	22.3	4.7	0.2	sil
197-230	Bk3	13.5	66.3	20.2	5.0	0.2	sil

†Ratio of fine clay (<.2 μm) to total clay
‡sil=silt loam, sicl=silty clay loam, sic=silty clay, l=loam

Table 3-13. Soil characterization data from ST 306d non-irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon in ST 3

Depth	Horizon	Sand	Silt	Clay	Fine Clay	FC:TC†	Textural class‡
cm		---	---	%	---		
0-12	Ap1	12.4	50.7	36.9	30.6	0.8	sicl
12-18	Ap2	11.9	62.7	25.4	12.7	0.5	sil
18-40	Bt1	11.7	53.8	34.5	21.9	0.6	sicl
40-53	Bt2	12.8	54.0	33.2	18.2	0.5	sicl
53-76	Bk1	11.0	62.7	26.3	9.2	0.4	sil
76-121	Bk2	11.9	66.6	21.5	4.3	0.2	sil
121-169	Bk3	13.3	64.3	22.4	4.8	0.2	sil
169-228	Bk4	13.2	64.5	22.4	3.6	0.2	sil

†Ratio of fine clay (<.2 μm) to total clay

‡sil=silt loam, sicl=silty clay loam, sic=silty clay, l=loam

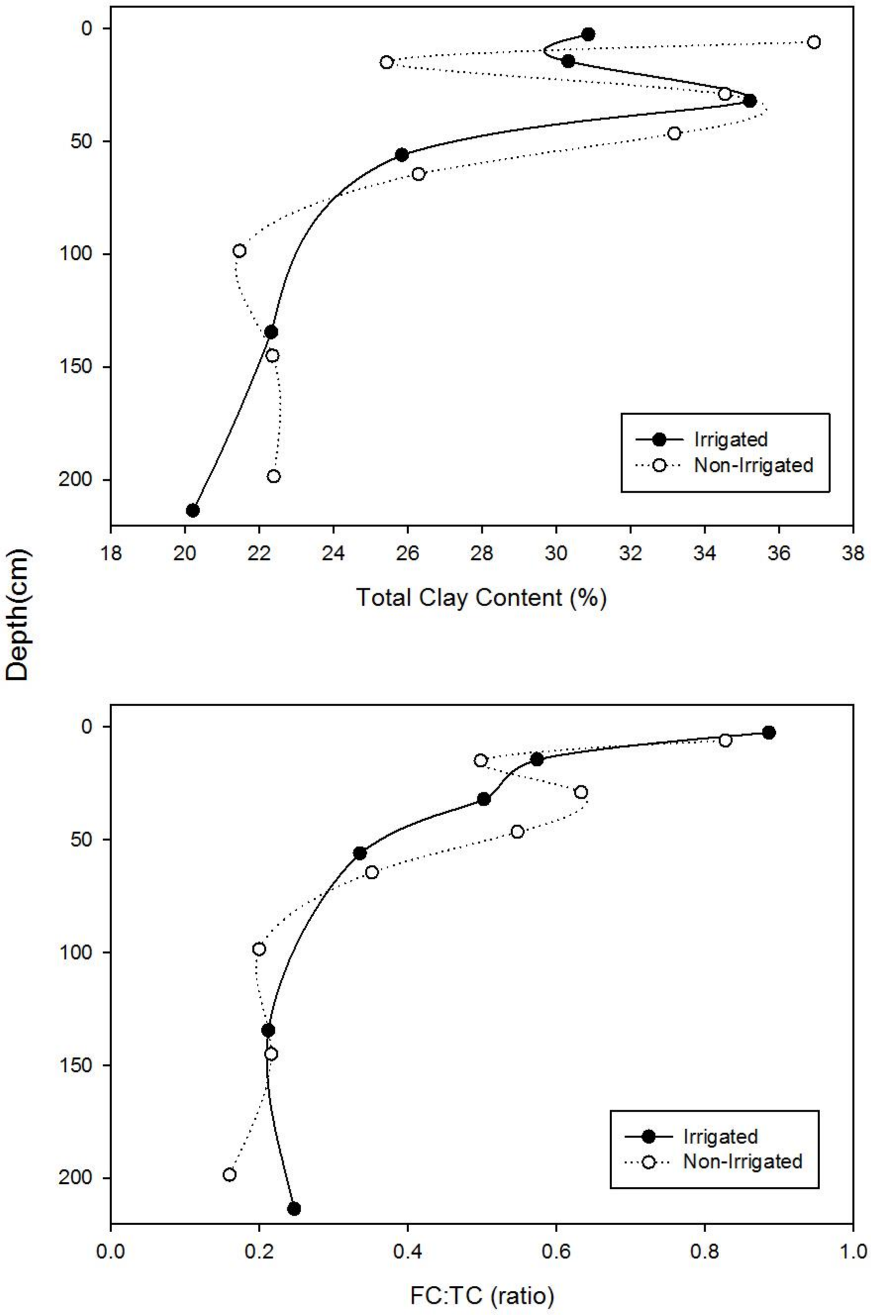

Figure 3-4. Top: total clay content (%) distribution with depth (cm) of selected irrigated (ST 302) and non-irrigated (ST 306d) pedons. Bottom: ratio of fine clay to total clay distribution with depth (cm) of selected irrigated and non-irrigated pedons

Site ST 4

Field Description

Abbreviated field descriptions for selected irrigated and non-irrigated pedons can be found in Tables 3-14 and 3-15. In the field, two of the irrigated pedons were classified as Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls), and one irrigated pedon was classified as Richfield (fine, smectitic, mesic Aridic Argiustolls). Irrigated pedons had mollic colors (moist value and chroma <3) described to depths between 29 and 48 cm, classifying all with a mollic epipedon. Field textures were silt loam on the surface and silty clay loam or silty clay in the subsoil. Clay films were described in all Bt horizons indicating that clay illuviation has occurred in these soils. Pressure faces were also described in some Ap2 and Bk1 horizons indicating that shrink-swell processes are occurring in these soils. The pedon classified as Richfield had more clay films described than the Keith pedons. This is because it has a higher clay content in the subsoil. Hence, more illuviation processes have occurred. Irregularly and threadlike carbonate masses and nodules were described below Bt horizons beginning at depths between 29 and 83 cm.

All three non-irrigated pedons were classified as Keith. Non-irrigated pedons had mollic colors described to least 25 cm, indicating classification with a mollic epipedon. Field textures were similar to irrigated pedons with silt loam surface textures, and silty clay loam and silty clay in the subsoil. Clay films were described in the field with a higher abundance (15-20%) than irrigated pedons. This could have been because fields were being irrigated to prepare for planting. Clay films are more visible when the soil is at a dry moisture status, so clay films may have been just as abundant in irrigated soils, but they were harder to identify. Pressure faces were also described indicating that shrink-swell processes occur in these soils. Much like in the irrigated soils, irregularly and threadlike carbonate masses were described below the Bt horizons beginning at depths between 46 and 64 cm.

A comparison of field descriptions showed that management does affect soil morphology properties. The observed differences seen could have been from map unit inclusions of other soils, or the soil moisture status that favored clay films being seen more easily in non-irrigated soils.

Lab Characterization Analysis

Soil characterization data and distribution of clay for selected irrigated and non-irrigated pedons can be found in Tables 3-16 and 3-17, and Figure 3-5. Laboratory particle size data confirmed field textures in the field with a few exceptions. Irrigated pedon 401 was classified as Richfield in the field with a fine particle size class and an average weighted clay content of >35%. Calculations based on particle size analysis data showed an average weighted clay content of 31%. Consequently, this pedon had a fine-silty particle size class and was classified as Keith. Figure 3-5 shows that non-irrigated soils did have a higher clay content, and the fine clay to total clay (FC:TC) ratio was higher compared to irrigated pedons. Fine clay particles (<.2 μm) are the smallest clay fraction and the most mobile. Because of this, FC:TC will be higher in illuvial horizons and lower in eluvial horizons. Although differences were observed, these differences were not significant difference because map unit inclusions of different soils make it difficult to make comparisons of properties of these soils. An analysis of laboratory data showed that management does not affect soil morphology properties.

Table 3-14. Abbreviated field description of ST 401 irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon from ST 4

Depth	Horizon	Matrix Color	Structure	Ped and Void Surface Features	CaCO$_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-6	Ap1	10 YR 2/2	1-f-gr	#	#
6-15	Ap2	10 YR 2/1	1-f-sbk	PRF 5% F D PF	#
15-29	Bt1	10 YR 2/1	2-f-pr	CLF 3% F D PF	#
29-39	Bt2††	10 YR 3/3	2-f-sbk	PRF 3% F D VF	#
39-80	Bk1	10 YR 5/3	1-f-pr/1-f-sbk	#	CAM 1% F T MAT CAM 2% M I MAT CAN 1% F I MAT
80-118	Bk2	10 YR 5/4	1-f-sbk	#	CAM 1% F I MAT
118-230	C	10 YR 5/4	1-co-pr	#	#

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

††29-39 changed to Bt2 from original field nomenclature of Bw based off of micromorpholgy

Table 3-15. Abbreviated field description of ST 404d non-irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon from ST 4

Depth	Horizon	Matrix Color	Structure	Ped and Void Surface Features	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-16	Ap1	10 YR 2/2	2-m-pl/2-f-gr	#	#
16-28	Ap2	10 YR 2/2	2-f-sbk/2-f-gr	#	#
28-47	Bt1	10 YR 3/2	2-f-pr	CLF 10% D D PF	#
47-64	Bt2	10 YR 4/3	2-f-pr	CLF 20% D D PF	#
64-118	Bk1	10 YR 5/3	1-f-pr/2-f-sbk	CAF 3% F VPF	CAM 2% F T TOT CAM 2% M I RPO CAM 1% M I TOT
118-153	Bk2	10 YR 5/3	1-f-pr	#	CAM 1% F T TOT CAM 3% M I RPO
153-224	Bk3	10 YR 5/3	1-f-pr	#	CAM 2% M I RPO CAM 1% F T TOT CAM 1% M I APF

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules, CAF=carbonate films; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores, RPO=along root channels, APF=all ped faces

#None present

††29-39 changed to Bt2 from original field nomenclature of Bw based off of micromorpholgy

Table 3-16. Soil characterization data from ST 401 irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon in ST 4

Depth	Horizon	Sand	Silt	Clay	Fine Clay	FC:TC†	Textural class‡
cm		---	----------	---%---	---		
0-6	Ap1	13.4	61.5	25.1	15.3	0.6	sil
6-15	Ap2	13.3	63.9	22.8	12.2	0.5	sil
15-29	Bt1	12.2	57.9	29.9	18.3	0.6	sicl
29-39	Bt2	10.9	56.6	32.5	17.5	0.5	sicl
39-80	Bk1	10.6	60.2	29.2	10.9	0.4	sicl
80-118	Bk2	12.6	64.3	23.2	4.7	0.2	sil
118-230	C	14.2	63.4	22.4	4.0	0.2	sil

†Ratio of fine clay (<.2 μm) to total clay
‡sil=silt loam, sicl=silty clay loam, sic=silty clay, l=loam

Table 3-17. Soil characterization data from ST 404d non-irrigated Keith (fine, mixed, superactive mesic Aridic Argiustolls) pedon in ST 4

Depth	Horizon	Sand	Silt	Clay	Fine Clay	FC:TC†	Textural class‡
cm		--	-------------------%	-------------------	--		
0-16	Ap1	12.2	61.5	26.3	14.9	0.6	sil
16-28	Ap2	11.1	56.9	32.0	20.9	0.7	sicl
28-47	Bt1	11.4	52.9	35.8	25.0	0.7	sicl
47-64	Bt2	11.6	55.1	33.3	18.9	0.6	sicl
64-118	Bk1	12.6	62.3	25.2	5.5	0.2	sil
118-153	Bk2	12.4	64.6	22.9	3.9	0.2	sil
153-224	Bk3	13.2	65.2	21.6	3.8	0.2	sil

†Ratio of fine clay (<.2 μm) to total clay
‡sil=silt loam, sicl=silty clay loam, sic=silty clay, l=loam

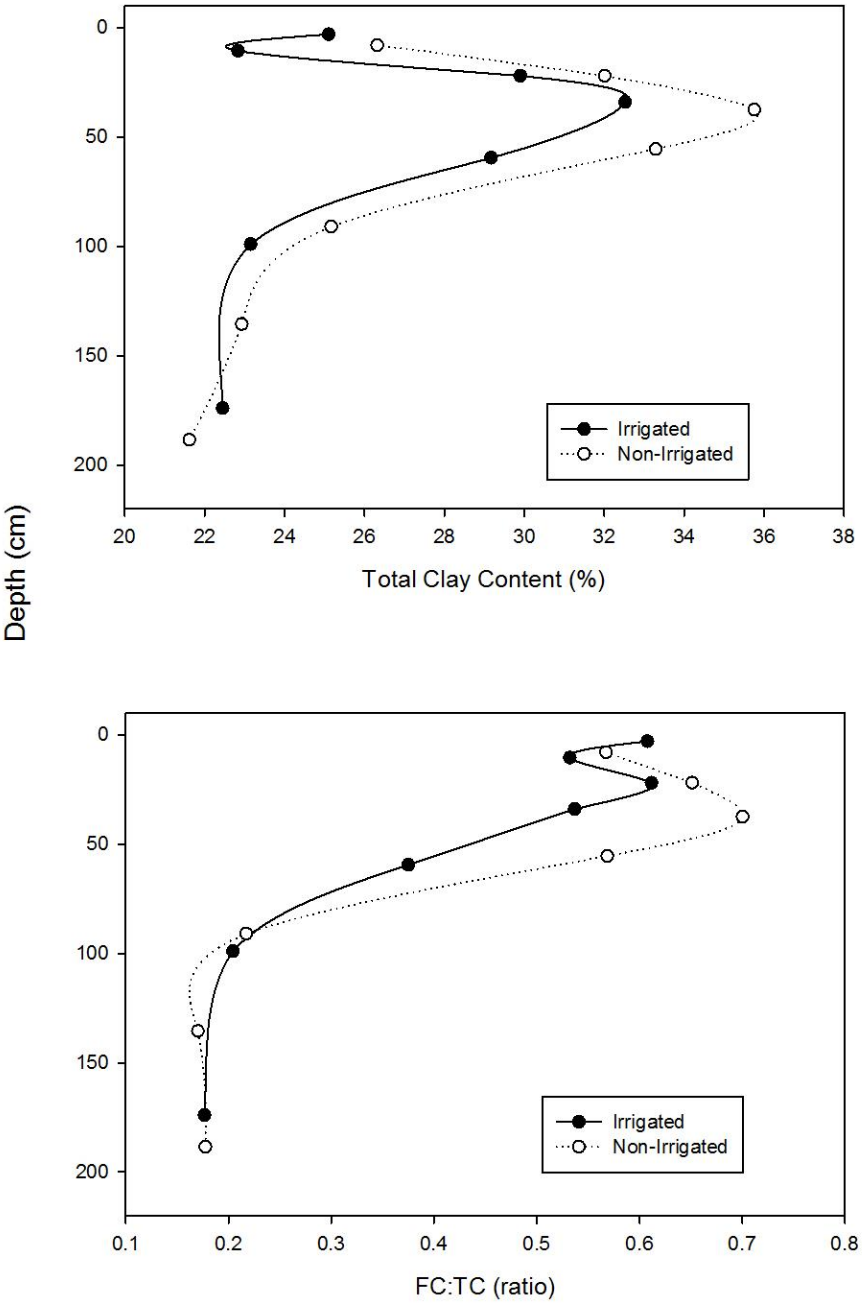

Figure 3-5. Top: total clay content (%) distribution with depth (cm) of selected irrigated (ST 401) and non-irrigated (ST 404d) pedons. Bottom: ratio of fine clay to total clay distribution with depth (cm) of selected irrigated and non-irrigated pedons

Micromorphology Analysis

Site ST 1

The micromorphological descriptions for representative pedons ST 101 irrigated and ST 104 non-irrigated are found in Table 3-18 and Table 3-19. Full micromorphology descriptions for all pedons can be found in Appendix D. At ST-1, the micromorphology was examined for two irrigated pedons and two non-irrigated pedons. The two irrigated pedons were classified as Ulysses (fine-silty, mixed, superactive, mesic Aridic Haplustolls) and Richfield (fine, smectitic, mesic Aridic Argiustolls). The two non-irrigated pedons were both classified as Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls). Most of the b-fabrics were described as granostriated, with the exception of the ST 101 irrigated Bk2 and the ST 104 non-irrigated Bt1 horizon in which the b-fabric was monostriated. When comparing irrigated and non-irrigated pedons, there was more evidence of clay illuviation in ST 104 non-irrigated. Looking at Figure 3-6, there are more illuvial argillans present in the non-irrigated pedon compared to the irrigated pedon. ST 101 irrigated was classified as Ulysses, which does not have an argillic horizon, and the micromorphology analysis showed no increases of clay material and supports the field description. Even when comparing the irrigated Richfield pedon (ST 102) to the non-irrigated Keith pedons (ST 104 and 106), there were more illuvial argillans present in the non-irrigated pedons. The differences in the amount of illuvial argillans probably result from map unit inclusions of a more developed soil.

Although illuvial argillans were present, most of the clay material were identified as stress features. Since visibly weathered mica crystals occurred in all horizons, the weathering of mica is an obvious source of clay material. Mica weathering and the reorganization of weathered clay as stress features were also observed by Gunal and Ransom (2006) Ricks Presley et al. (2004); Ransom et al. (1997); Ransom and Bidwell (1990) and, Fraser (1990).

Adjustments about the distribution of calcium carbonate with depth were made following micromorphological examination. The ST 101 irrigated Bk1 horizon was originally described as a Bw horizon in the field. After analyzing the micromorphology, enough calcium carbonate was present to describe the horizon as a Bk1 horizon. Additionally, carbonates were described at a shallower depth in pedons ST 102 irrigated and ST 106 non-irrigated. Figure 3-7 shows carbonate superimposed onto illuvial argillans. This has been observed in many soils of Kansas (Gunal and Ransom, 2006; Ransom and Bidwell, 1990). In order for clay to be illuviated, the leaching of carbonates must occur first because Ca^{2+} will tend to flocculate clay, therefore reducing clay illuviation (Gunal and Ransom, 2006). By seeing carbonate material covering illuvial clay features, it can be concluded that an addition of a newer carbonate-rich parent material was deposited and then leached over the existing illuvial clay features. It is thought that a Bignell loess cap was deposited on these soils and serves as a younger source of calcium carbonate. Additionally, it was found that calcium carbonate distribution was not affected by irrigation which supports the findings by Ricks Presley et al. (2004)

Table 3-18. Micromorphology description for ST 101 irrigated Ulysses (fine-silty, mixed, superactive, mesic Aridic Haplustolls)

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bk1††	27-44	None	Very few, thin grain argillans	Granostriated	Few masses, 25-75µm	Common quasi and masses ranges from 100µm-2000µm	Common
Bk2	44-68	None	Very few, thin grain argillans, but more than previous horizon	Granostriated	None	Frequent quasi and masses ranges from 100µm-2000µm	Common
Bk3	68-129	Very few, thin, discontinuous illuvial argillans along voids	Few, thin grain argillans	Monostriated	None	Frequent quasi and masses ranges from 100µm-2000µm	Common

† Used to describe oriented clay and stress feature: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%)

††Change from Bw to Bk1 based off of micromorphology;

Table 3-19. Micromorphology description of ST 104d non-irrigated Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls)

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	5-23	Very few, thin, discontinuous illuvial argillans along voids	Frequent, thin grain argillans	Monostriated	Very few nodules (30-100µm) and masses (100-400µm)	None	Common- Not intact
Bt2	23-46	Very few, thin, discontinuous illuvial argillans along voids; hypocoatings associated with voids	Frequent, thin grain argillans.	Granostriated	None	None	Common- not intact
Bk1	46-144	None	Common, thin grain argillans.	Granostriated	Very few nodules and masses 100-400µm	None	Common- not intact
Bk2	144-230	None	Very few, thin grain argillans	Granostriated	None	Quasi-carbonate coatings	Common- intact

† Used to describe oriented clay and stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%)

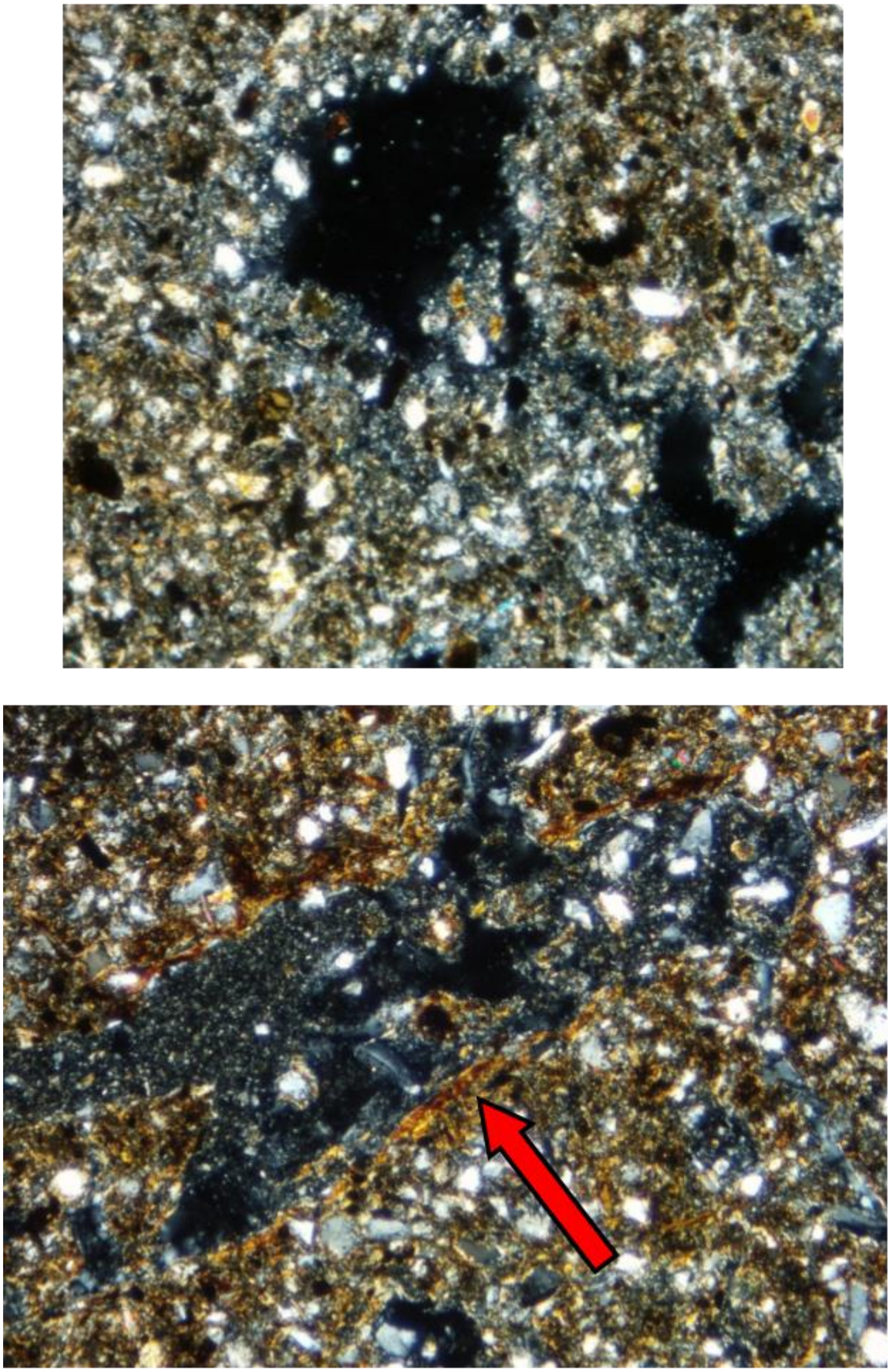

Figure 3-6. Thin section photos. Top: ST 101 irrigated Bk1 horizon (27-44 cm) granostriated b-fabric, with no illuvial or stress clay features seen. Bottom: ST 104 non-irrigated Bt2 (23-46 cm) horizon, granostriated b-fabric. Arrows show illuvial clay features. Photos taken with cross polarized light using a 4x objective with a frame length of 1410µm

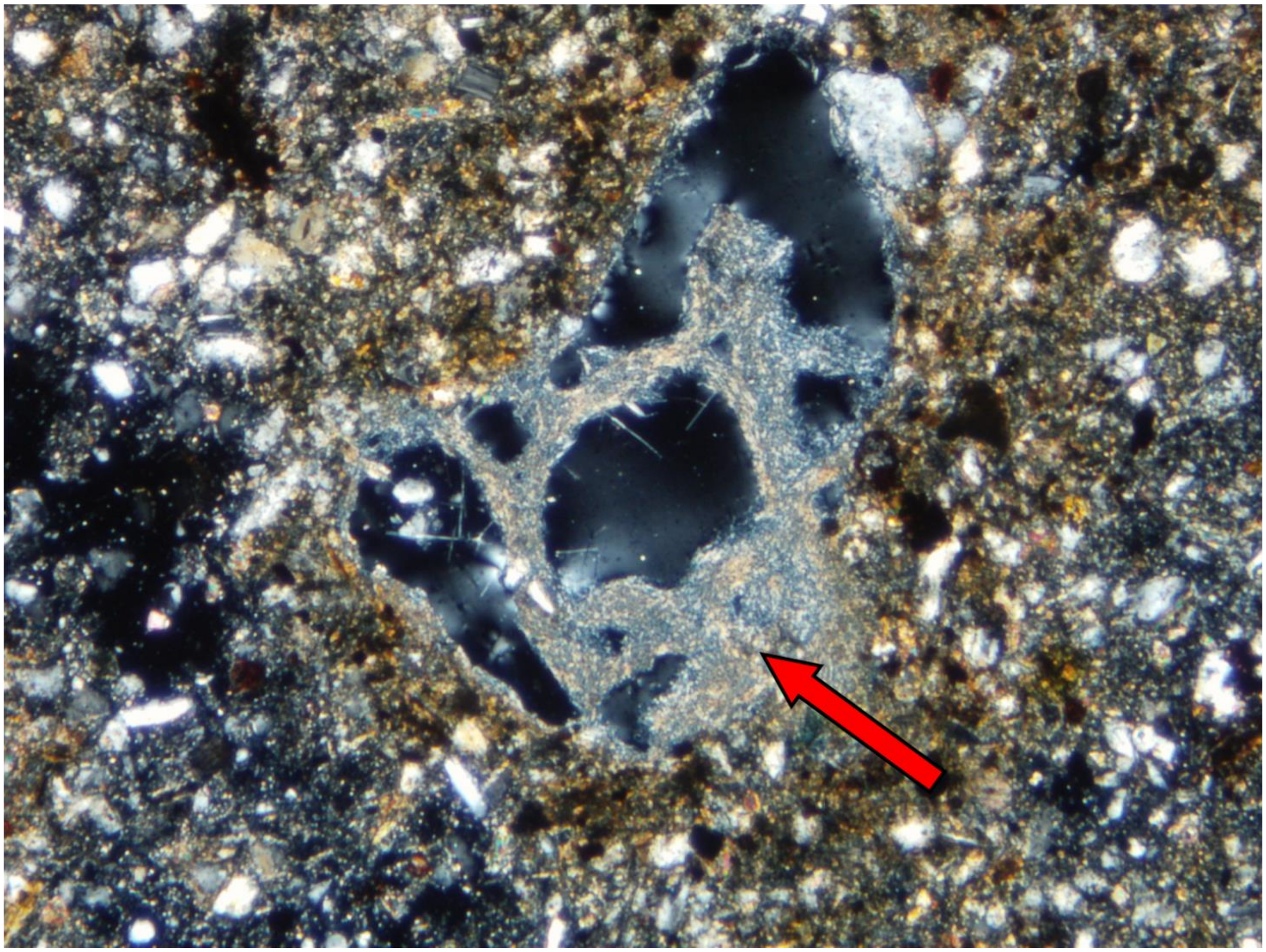

Figure 3-7. Thin section photo of ST 106 non-irrigated Bt2 46-69 cm. Arrow shows pedogenic carbonate superimposed onto illuvial clay features. Photo taken with cross polarized light at a 4x objective with a frame length of 1410µm.

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Site ST 2

The micromorphological descriptions for ST 201 irrigated and ST 204 non-irrigated pedons are found in Table 3-20 and Table 3-21. Micromorphology descriptions of all pedons can be found in Appendix D. For ST-2, the micromorphology was examined for two irrigated pedons and three non-irrigated pedons. The irrigated pedons were classified as Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls) and the non-irrigated pedons were classified as Keith, Kuma (fine-silty, mixed, superactive, mesic Pachic Argiustolls), and Richfield (fine, smectitic, mesic Aridic Argiustolls). B-fabrics of the irrigated Keith pedons were all described as granostriated. Non-irrigated pedons were described with a granostriated b-fabric in the Bk horizons and some Bt horizons. The Bt1 and Bt2 horizons of ST 206 non-irrigated were described with a monostriated b-fabric. Monostriations are stress features and indicates that this soil has been through shrink-swell processes (Figure 3-8).

When comparing illuvial clay features, it was apparent that non-irrigated pedons had more evidence of clay illuviation. Pedons ST 205 non-irrigated and ST 206 non-irrigated had higher amounts of illuvial argillans. This could be due to the fact that ST 205 non-irrigated is classified as Kuma fine-silty, mixed, superactive, mesic Pachic Argiustolls, and ST 206 non-irrigated is classified as Richfield fine, smectitic, mesic Aridic Argiustolls. These soils are different from the irrigated Keith pedons and the Kuma and Richfield soils could be more prone to illuviation processes. However, even when comparing the two irrigated Keith pedons to the ST 204 non-irrigated Keith pedon, the non-irrigated Keith pedon displayed a higher amount of illuvial argillans. Figure 3-9 compares illuvial features of ST 201 irrigated and ST 204 non-irrigated pedons.

Much like the soils of ST 1, most of the clay material in soils of ST 2 were identified as stress features by the thin uniform grain argillans. Because there were mica crystals present in every horizon, and visibly weathered, it is concluded that mica is a source of clay material. This supports what was found in ST 1 and in other studies that analyzed argillic horizon formation in Kansas (Gunal and Ransom, 2006; Ricks Presley et al., 2004; Ransom et al., 1997; Fraser, 1990).

Similar to ST 1, it was seen that calcium carbonate features were described at a shallower depth in thin section compared to field observations. Originally, ST 201 irrigated was described with Bt1 and Bt2 horizons, and after the micromorphology was described, there was enough carbonate to describe Btk1 and Btk2 horizons. Figure 3-9 (Top) shows carbonate superimposed on clay material, and it can be concluded that a cap of Bignell loess was deposited over these soils and now calcium carbonate is being leached. This was concluded in studies by Gunal and Ransom (2006) and Ransom and Bidwell (1990).

Table 3-20. Micromorphology description of ST 201 irrigated Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls)

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Btk1††	4-28	None	Dominant, thin grain argillans	Granostriated	Common nodules 20-50µm	Common masses and nodules typically located along void	Frequent
Btk2††	28-44	None	Dominant, thin grain argillans	Granostriated	Common nodules 20-50µm	Common very large masses and nodules; frequent hypocoatings and quasi associated with voids.	Frequent
Bk1	44-116	None	Frequent, thin grain argillans	Granostriated	Few nodules 20-50µm	Dominant coatings and hypocoatings associated with voids.	Frequent
Bk2	116-168	None	Frequent, thin grain argillans	Granostriated	Very few nodules 20-50µm	Frequent fine disseminated carbonate material	Frequent
Bk3	168-230	None	Frequent, thin grain argillans	Granostriated	None	Frequent hypocoatings, nodules, masses and quasi associated with voids.	Frequent

†Used to describe oriented clay and stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

††4-44 changed from Bt1 and Bt2 to Btk1 and Btk2 based off of micromorphology

Table 3-21. Micromorphology of ST 204d non-irrigated Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls) pedon.

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	15-29	Thin, common illuvial argillans; hypocoatings associated with voids.	Thin, dominant grain argillans.	Granostriated	Few concentrations 30-50µm	None	Frequent
Bt2	29-44	Thin, common illuvial argillans; dominant hypocoatings associated with voids	Thin, dominant grain argillans. Grain argillans are thicker and easier to see around voids.	Granostriated	Few concentrations 30-50µm	None	Frequent
Bk1	44-87	None	Thin, common grain argillans	Granostriated	Few Concentrations 30-50µm	Common nodules hypocoatings, and fine disseminated carbonate material	Frequent

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%)

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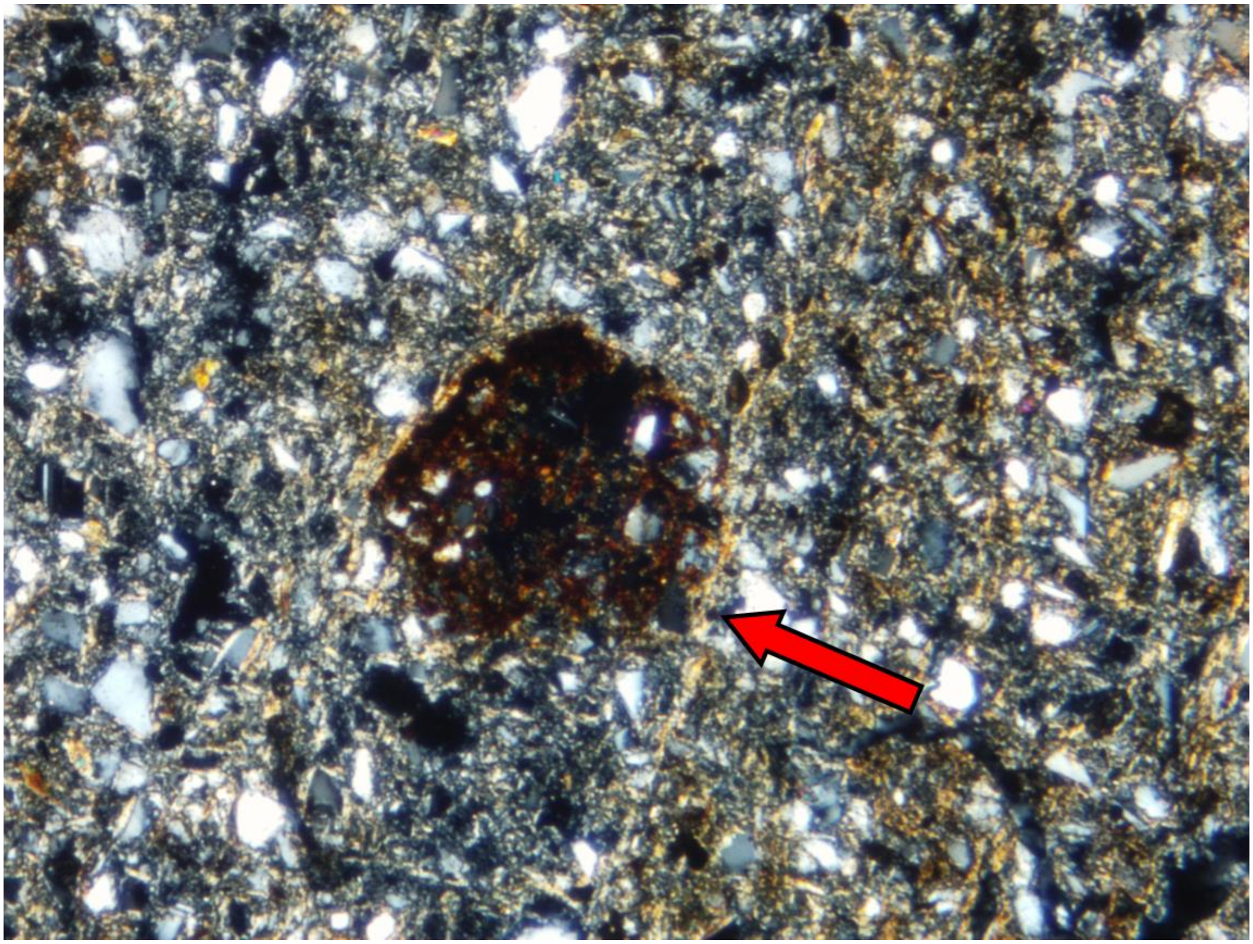

Figure 3-8. Thin section photo. ST 206 non-irrigated Richfield Bt2 (33-51 cm) horizon. Arrow points to monostriation next to a Fe-Mn nodule. Photo taken with cross polarized light using a 4x objective with a frame length of 1410µm.

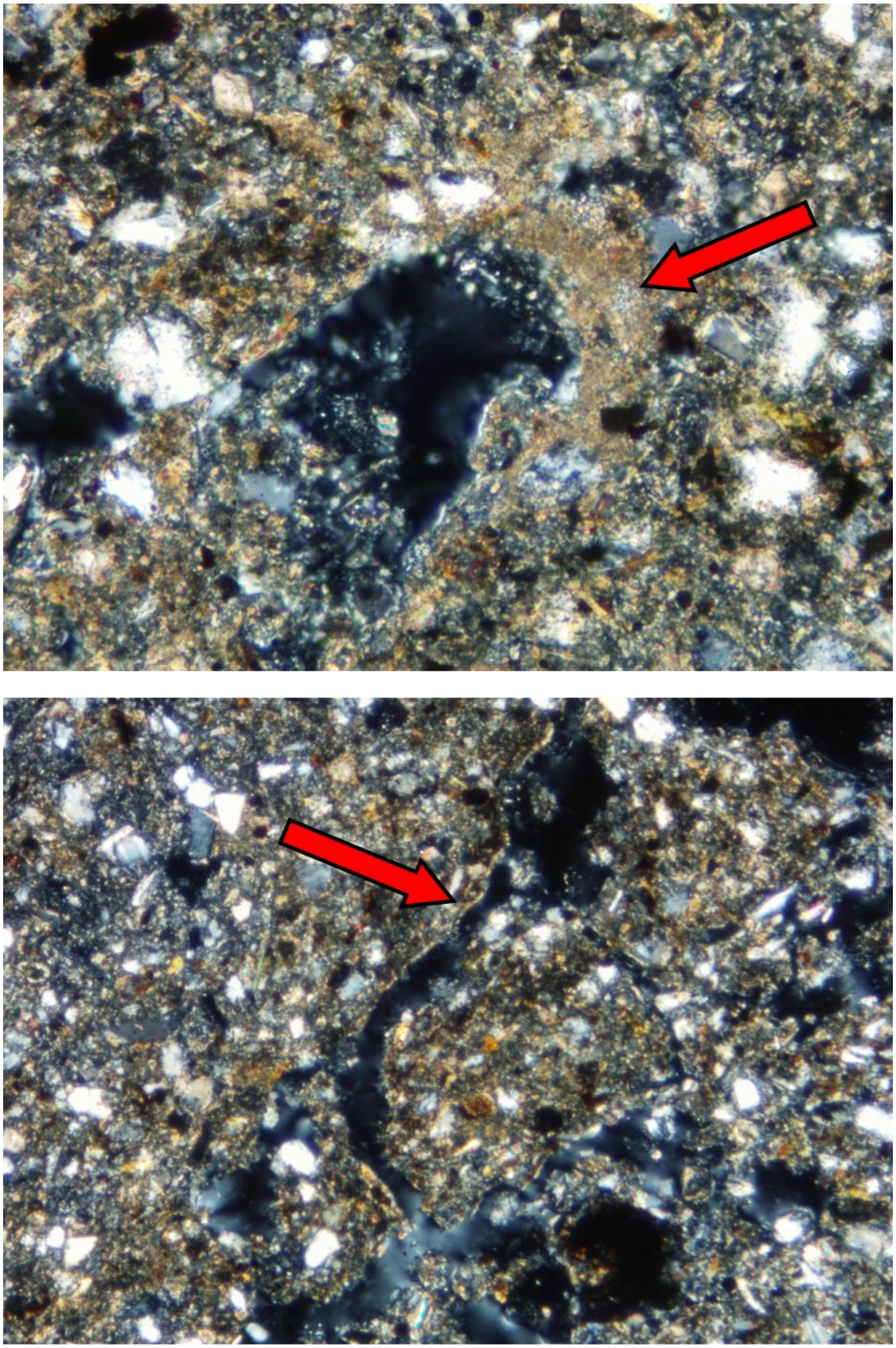

Figure 3-9. Thin section photos. Top: ST 102 irrigated Btk1 horizon (4-28 cm) with grain argillans surrounding quartz grains. Arrow points to carbonate superimposed onto grain argillans. Bottom: ST 104 non-irrigated Bt2 horizon (29-44 cm) with grain argillans present. Arrow points to thin illuvial argillan. Both photos taken with cross polarized light using a 4xobjective with a frame length of 1410µm.

Site ST 3

The micromorphology description of pedons ST 301 irrigated and ST 304 non-irrigated can be found in Table 3-22 and Table 3-23. Micromorphological descriptions of all described pedons can be found in Appendix D. At this site, the micromorphology of two irrigated pedons and two non-irrigated pedons were described. The two irrigated pedons were classified as Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls), and the non-irrigated pedons were described as Keith and Richfield (fine, smectitic, mesic Aridic Argiustolls). In the micromorphology that was analyzed at this site, all the b-fabric was described as granostriated. Similar to ST 1, ST 2, and multiple other studies done on the formation of argillic horizons in Kansas, most of the clay material present in these soils are grain argillans. Because the grain argillans are very thin, and they aren't associated with voids, it is concluded that the grain argillans have formed through the in-situ weathering of mica and stress, rather than illuviation (Gunal and Ransom, 2006; Ricks Presley et al., 2004; Ransom et al., 1997; Fraser, 1990). When comparing ST 301 irrigated and ST 304 non-irrigated, they are both classified as Keith, but it was apparent that there were more illuvial argillans present in the non-irrigated soils. Figure 3-10 shows thin section photos from ST 301 irrigated and ST 304 non-irrigated and although there are illuvial argillans present in both pedons, the illuvial argillans are thicker and more prominent in the non-irrigated soil. Unlike what was found in the ST 2, the Keith non-irrigated pedon had more evidence of illuviation than the Richfield non-irrigated pedon.

The distribution of calcium carbonate followed what was seen in the field, with the exception of ST 302 irrigated. Originally, a Btk horizon was originally described from 24-40 cm. After no carbonate forms were described in the micromorphology, the horizon was described as a Bt2. Calcium carbonate was mostly seen as masses and nodules, but also fine disseminated carbonate material. Irrigation had no effect on calcium carbonate distribution.

Table 3-22. Micromorphology of ST 301 irrigated Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls) pedon

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	23-38	Common, thin, discontinuous illuvial argillans; common hypocoatings associated with voids.	Dominant, thin grain argillans	Granostriated	Common nodules 30-50µm	None	Frequent
Bt2	38-61	Few, thin, discontinuous illuvial argillans; common hypocoatings associated with voids	Dominant, thin grain argillans.	Granostriated	Common nodules 30-50µm	Common nodules 30-100µm, masses 50-200µm and quasi 50-100µm associated with voids.	Frequent
Bk1	61-87	None	Frequent, thin grain argillans.	Granostriated	Common nodules 30-50µm	Frequent quasi 50-100µm associated with voids; few Nodules 50-100µm	Frequent

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%)

Table 3-23. Micromorphology of ST 304d non-irrigated Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls) pedon

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	23-38	Common, thin, discontinuous illuvial argillans; common hypocoatings associated with voids.	Dominant, thin grain argillans	Granostriated	Nodules 30-50µm	None	Frequent
Bt2	38-61	Few; thin, discontinuous illuvial argillans; common hypocoatings associated with voids	Dominant, thin grain argillans	Granostriated	Nodules 30-50µm	Common nodules 30-100µm, masses 50-200µm and quasi 50-100µm associated with voids.	Frequent
Bk1	61-87	None	Frequent, thin grain argillans	Granostriated	Nodules 30-50µm	Frequent quasi 50-100µm associated with voids; few Nodules 50-100µm	Frequent

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

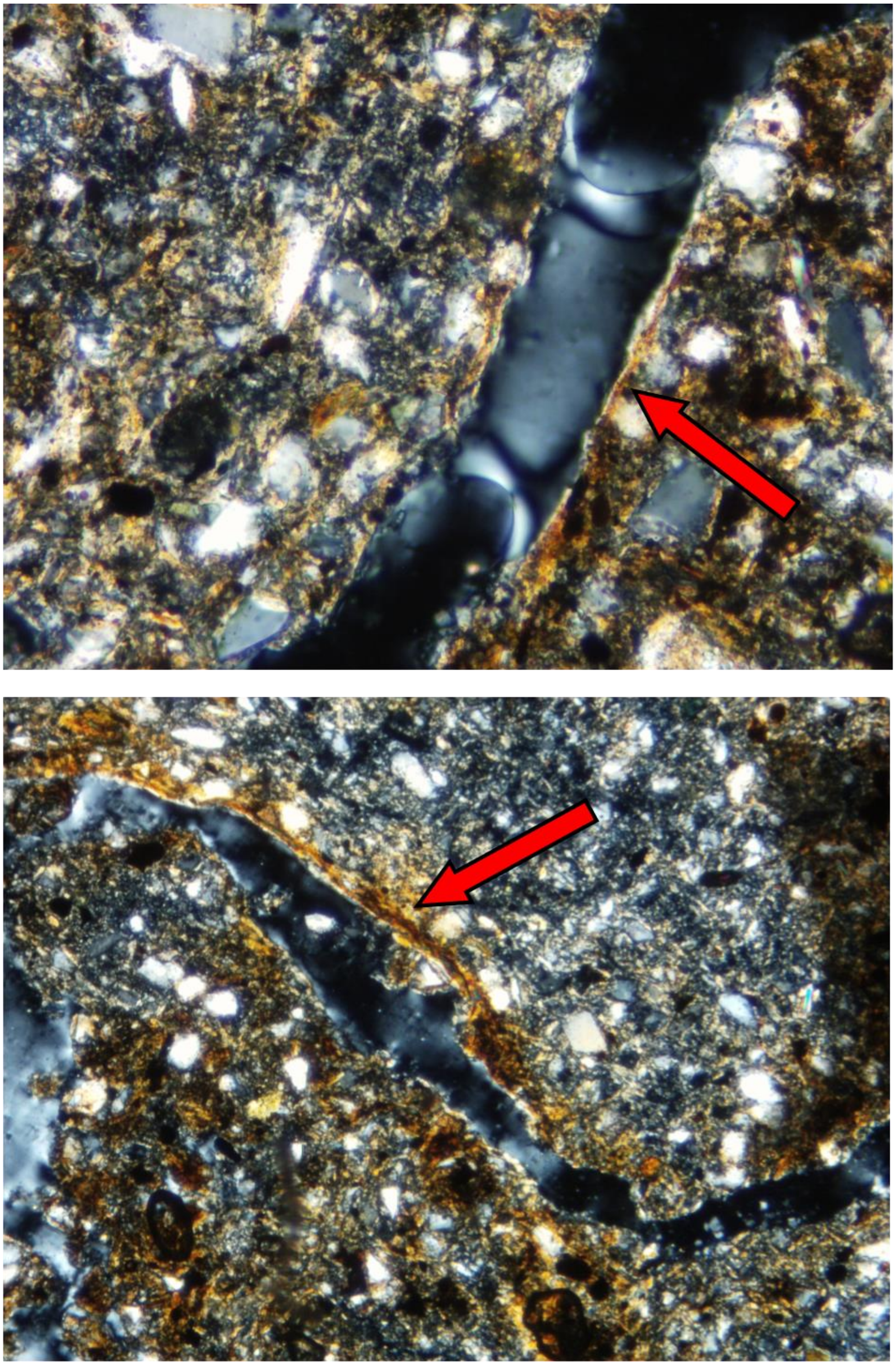

Figure 3-10. Thin section photos. Top: ST 302 irrigated Keith pedon. Arrow points to thin illuvial argillan. Photo taken with 10x objective, and with a frame length of 560µm. Bottom: ST 304 non-irrigated Keith Bt2 (25-38 cm) horizon. Arrow points to medium illuvial argillan. Photo taken at a 4x objective with a frame length of 1410µm. The non-irrigated pedon has thicker, more prominent illuvial argillans

Site ST 4

Micromorphological descriptions for ST 402 irrigated and ST 405 non-irrigated can be found in Table 3-24 and Table 3-25. Micromorphological descriptions of all described pedons can be found in Appendix D. At this site, the micromorphology of two irrigated Richfield (fine, smectitic, mesic Aridic Argiustolls) and two non-irrigated Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls) were described. The b-fabrics of pedons were mostly described as granostriated. However, some of the b-fabrics with high amounts of clay in irrigated and non-irrigated pedons were described as monostriated. Monostriations are formed through stress from shrink-swell processes of the soil (Figure 3-11). Similar to other sites, there is a high amount of grain argillans present that have formed through stress and the in-situ weathering of mica. Compared to the other sites, ST 4 had much more abundant illuvial argillans with illuvial argillans present in every pedon. Although there were illuvial argillans present in all pedons, the non-irrigated pedons had more, and even some continuous, illuvial argillans. Figure 3-12 shows the presence of illuvial argillans in irrigated and non-irrigated soils. In contrast to other irrigated pedons, ST 401 and 402 irrigated pedons showed a greater amount of illuvial clay. This could be due to the fact that these were the only two pedons to be classified as Richfield, which has a finer family textural class than Keith soils.

Calcium carbonate was described as quasi, masses, nodules, and fine disseminated carbonate. The non-irrigated Keith pedon (ST 405) showed calcium carbonate nodules and finely disseminated carbonate material in the Bt1 horizon, but not in the Bt2 horizon. Normally, carbonate would be found deeper in the subsoil because it is leached through the soil first. Since carbonate occurred at a shallow depth and was absent in the next deeper horizon, another, younger, parent material (i.e., Bignell Loess) was probably deposited (i.e. Bignell Loess) on top of the more commonly occurring Peoria Loess. Irrigation did not have any effect on the distribution of calcium carbonate.

Table 3-24. Micromorphology description of ST 402 irrigated Richfield (fine, smectitic, mesic Aridic Argiustolls) pedon.

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	25-48	Very few, thin, discontinuous illuvial argillans associated with voids; few hypocoatings associated with voids	Dominant grain argillans; abundance higher when associated with voids	Granostriated	Dominant hypocoatings associated with voids; frequent nodules 20-50µm	None	Frequent-not intact
Bt2	48-83	Few, thin, discontinuous illuvial argillans associated with voids; few hypocoatings associated with voids	Very dominant grain argillans.	Monostriated	Few hypocoatings associated with voids; common nodules 20-50µm.	None	Frequent-not intact
Bk1	83-165	None	Few grain argillans; very thin and very hard to see	Granostriated	Common nodules 20-50µm	Frequent quasi associated with voids; common nodules 100-200µm	Frequent-intact minerals
Bk2	165-230	None	Few grain argillans; very thin and very difficult to see	Granostriated	Common nodules 20-50µm	Frequent quasi associated with voids; few nodules 50-100µm; other carbonate was fine disseminated carbonate material.	Frequent-intact minerals

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness-thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

Table 3-25. Micromorphology description of ST 405d non-irrigated Keith (fine-silty, mixed, superactive, mesic Aridic Argiustolls) pedon.

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Btk††	15-32	Frequent, thin-medium, illuvial argillans. About 60% are discontinuous, 40% are continuous; common hypocoats associated with voids	Dominant, thin, grain argillans	Granostriated	Common Fe-Mn nodules 20-50 µm; few hypocoats associated with voids	Few nodules 20-100µm; fine disseminated carbonate material	Frequent-not intact
Bt	32-46	Frequent thin-medium illuvial argillans. 50% continuous, 50% discontinuous; frequent hypocoats associated with voids	Dominant, thin, grain argillans	Monostriated	Common Fe-Mn nodules 20-50µm; very few hypocoats associated with voids	None	Frequent-not intact
Btk´	46-64	Few thin, discontinuous illuvial argillans	Frequent, thin grain argillans	Granostriated	Few Fe-Mn nodules 20-50µm	Frequent quasi and masses associated with voids; few nodules 50-100µm; fine disseminated carbonate material	Frequent-not intact

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

††15-32 cm changed from Bt1 to Btk based off of micromorphology

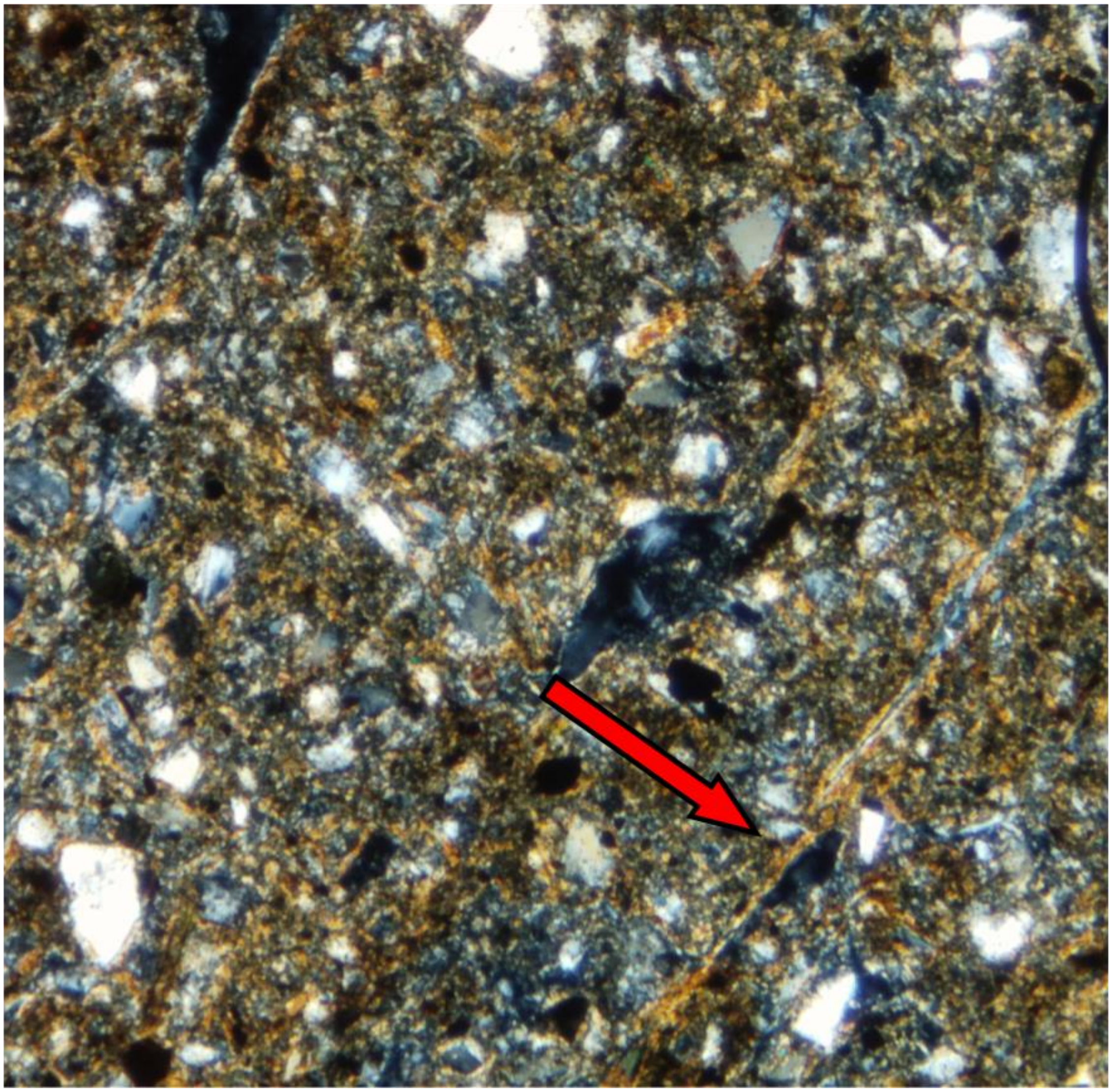

Figure 3-11. Thin section photo. ST 405 non-irrigated Keith Bt2 (32-46 cm) horizon. Arrow points to monostriation. Photo taken with cross polarized light using a 4x objective with a frame length of 1410 µm.

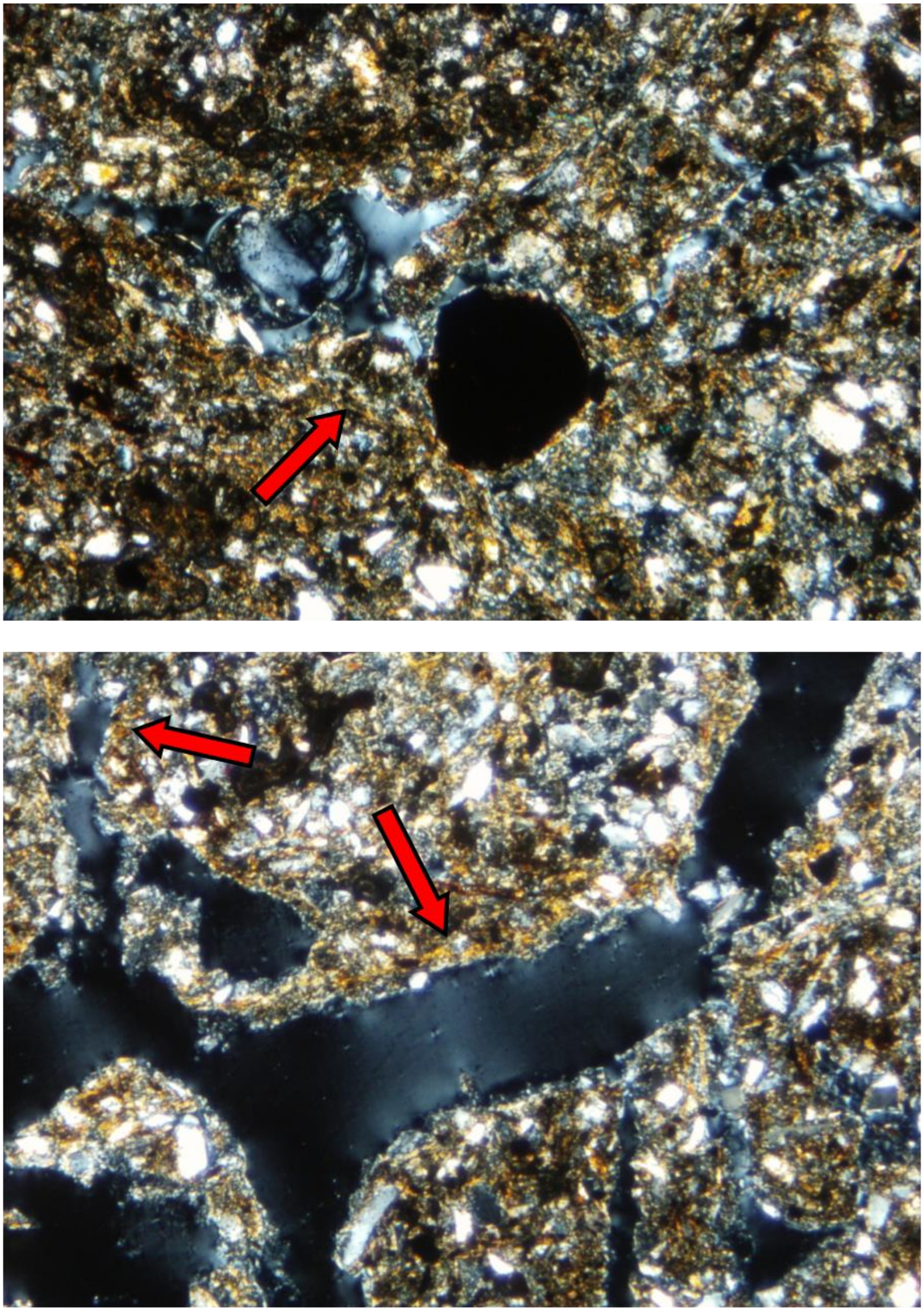

Figure 3-12. Thin section photos. Top: ST 402 irrigated Richfield Bt2 (48-83 cm) horizon. Arrow points to illuvial argillan. Bottom: ST 405 non-irrigated Keith Bt2 (32-46 cm) horizon. Arrow points to illuvial argillans. Both photos taken with cross polarized light using a 4x objective with a frame length of 1410 µm.

Discussion

An analysis of the field descriptions, soil characterization data, and micromorphology of all pedons shows that management did not affect clay illuviation processes. Much of the increase in clay content with depth resulted from in-situ weathering processes rather than illuviation processes. In the field, clay films were described at every site in irrigated and non-irrigated soils. However, they were described at a relatively low abundance (quantities of clay films were mostly between 1-10%). At some sites, a higher abundance of clay films were described in the non-irrigated soils. Typically, clay films are more visible in dry soils. At the time of sampling, producers were irrigating to prepare for planting. Therefore, the clay films in irrigated soils might have been harder to see in the field. Pressure faces were also described at every site which would indicate that shrink-swell processes are occurring in these soils.

The soil micromorphology indicates that clay increases in these soils are dominantly formed through in-situ weathering processes. Most of the oriented clay material in these soils occurred as grain argillans, which were identified as stress features rather than illuvial features. Clay material that surrounded grains was thin (<20μm), and it was uniform around the grain. The uniformity of clay material surrounding the grains suggests that the clay was oriented by shrink-swell processes. Because illuviation processes are not dominating in these soils, the increases in clay are probably from the in-situ weathering of mica, specifically biotite. Weathered mica minerals were commonly found in every horizon. Figure 3-13 depicts a partially-weathered mica fragment that is surrounded by a weathering rind. Clay material appears to be in the process of being released from the mica weathering, and this material surrounds mineral grains that are nearby. Clay material is then redistributed through shrink-swell processes.

Evidence of shrink-swell processes were seen through monostriations and stress features in thin section analysis, and pressure faces in the field. Although COLE values were not measured in this study, Appendix E includes full characterization data for a Keith pedon from Cheyenne County, Kansas as obtained by the USDA-NRCS. The COLE values measured on this particular pedon are 0.05 or less. However, the mineralogy of the clay fraction is dominated by 2:1 layer silicates that are prone to shrink-swell cycles.

Analyzing the micromorphology with plane-polarized light showed that clay material is formed through the in-situ weathering of mica minerals. Figure 3-14 shows very few intact mica minerals in a horizon that had high amounts of clay material described. There were also a high abundance of visible intact mica minerals seen when there was low amount of clay material described. This trend indicates that the clay increases in the subsoil are formed through in-situ weathering of mica minerals rather than illuviation.

Soil characterization data supported the conclusion that management does not affect clay illuviation processes. The data showed that non-irrigated soils had a slightly higher maximum clay content, higher average clay content, higher fine clay to total clay ratios, and thicker argillic horizons. However these differences were not statistically significant (Table 3-26). Most pedons showed a traditional distribution of clay with silt loam surface textures and silty clay loam or silty clay textures in the subsoil. When an argillic horizon was described in the field, soil characterization confirmed significant clay increases.

Although these soils meet the Soil Taxonomy definition of an argillic horizon by having a significant clay increase and at least 1% oriented clay in thin section, the central concept of an argillic horizon is not met because the clay increases are not from illuviation. Similar results of the formation of argillic horizons in western Kansas were found by Gunal and Ransom (2006), Ricks Presley et al. (2004), Ransom et al. (1997), and Fraser (1990).

Based on field descriptions, soil characterization data, and micromorphology analysis, irrigation did not have an effect on clay illuviation or mineral weathering. This differs from the findings of Ricks Presley et al. (2004). In fact, at sites ST1, ST2, and ST3 there was more evidence of clay illuviation in non-irrigated soils. Ricks Presley et al.(2004) did find that clay movement in Richfield (fine, smectitic, mesic Aridic Argiustolls) irrigated soils was greater than in non-irrigated Richfield soils. Only site ST 4 had Richfield soils mapped in the irrigated section, and there was evidence of clay illuviation processes. However, irrigation did not have an effect on the amount of illuvial clay. The study by Ricks Presley et al. (2004) also found that mineral weathering was increased with irrigation. In this study, it was determined that clay increases in the subsoil are dominantly formed through the in-situ weathering of mica minerals. After analyzing mica minerals in irrigated and non-irrigated soils, there was no evidence to suggest that irrigation affected the weathering of mica minerals.

Additionally, irrigation did not have an effect on calcium carbonate distribution, and similar results were found by Ricks Presley et al. (2004). Based on field descriptions, calcium carbonate nodules and masses were present at similar depths in irrigated and non-irrigated soils.

This study found that there were two critical reasons why irrigation did not affect clay illuviation and carbonate distribution: 1) the addition of a younger parent material and 2) the presence of map unit inclusions.

Micromorphological analysis and supplemental characterization data indicated that a younger parent material was deposited in this study area. The deposition of a younger parent material affected the distribution of clay material and carbonate. Thin section analysis showed that in many cases, carbonate was described in thin sections at a much shallower depth than in the field. Figures 3-7 and 3-9 show pedogenic carbonate superimposed on clay material and Figure 3-15 shows carbonate hypocoatings covering illuvial argillans. Gunal and Ransom (2006), Ransom et al. (1997), and Ransom and Bidwell (1990) obtained similar observations and concluded that the superimposed carbonate features contradict normal illuviation processes and are the result of a change in parent material. They concluded that when argillans are superimposed by carbonate, the deposition of a younger parent material has leached calcium carbonate into an existing argillic horizon.

Further evidence was found through comparing field descriptions and micromorphology. Specifically, site ST 2 had carbonate described at a much shallower depth in thin sections at a depth of 4cm, compared to the field description of 44 cm. Figure 3-9 (Top) shows a Btk1 horizon from 4-28 cm with carbonate masses along the void. Soils that have formed in Peoria loess have had climate conditions and enough time for carbonate to leach much deeper in the profile (Jacobs and Mason, 2007). In another pedon at site ST 2, it was found that there was a discontinuation of carbonates. Figure 3-16 shows the presence of carbonates in the Btk (12-34 cm) horizon. No carbonates were described from 34-59 cm (Bt), and then carbonates were described below 59 cm. The discontinuation of carbonates indicates that a younger parent material was deposited and that younger carbonates are currently leaching through the system. Unfortunately, no thin sections of Ap horizons were analyzed, so the distribution of carbonate material throughout the whole profile is unknown.

Soil characterization data also showed further evidence for the deposition of a younger parent material. Although most soils had the highest clay content in the subsoil, irrigated soils at ST 1 and non-irrigated soils at ST 3 had the highest average clay content in the surface horizon

(Figures 3-2 and 3-4). Additionally, fine clay to total clay ratios (FC:TC) were calculated in order to determine the mobility of clay material because fine clay particles (<0.2 μm) are the most mobile clay separate. Hence, the FC:TC will be higher in illuvial horizons and lower in eluvial horizons. However, it was found that at some sites, specifically ST 3, the highest FC:TC ratios were found in the surface horizon (Figure 3-4). These average clay contents and FC:TC do not follow the typical distribution of clay material in Keith soils. It was concluded that a younger parent material was deposited and would result in higher clay contents and FC:TC ratios at the surface, and the clay material has not been illuviated through the soil.

The new parent material consists of a thin cap of Bignell loess that has buried Peoria loess. Based off field descriptions, soil characterization data, and micromorphology, the range of Bignell loess in this study area is between 25 and 69 cm thick. Evidence of Bignell loess was identified in the following pedons: ST 101 (44 cm thick), ST 102 (46 cm thick), ST 201 (44 cm thick), ST 203 (34 cm thick), ST 205d (25 cm thick), ST 301 (61 cm thick), ST 405d (32 cm thick). The Bignell loess serves as a younger source of carbonate that is leached after the occurrence of clay illuviation. The Bignell loess has been reported in Sheridan County by Bayne (1956) and in soil surveys (Welch and Hale, 1987), but ages of the Bignell loess were not reported. Findings of the Bignell loess in central Kansas have been dated with a maximum age between 10,091-13,250 YBP (Bettis et al., 2003). The Bignell loess is also distributed in a very thin (<2 m) and patchy pattern (Bettis et al., 2003). Along with being a carbonate rich source, Bignell loess also serves as a clay-rich source (Mason and Jacobs, 2007), and may be the reason for the higher clay contents in the surface horizons of some soils in the study area.

The deposition of Bignell loess may also be inhibiting clay illuviation because calcium carbonate present in Bignell loess flocculates clay. The occurrence of this younger parent material could also be a reason why conclusions from Ricks Presley et al. (2004) did not apply to this study, and irrigation did not impact clay illuviation.

Another critical reason as to why irrigation did not affect soil properties is because there were map unit inclusions present in the study area. Soil maps for each site can be found in Appendix A along with the full map unit description for map unit Keith silt loam, 1-3% slopes. The main objective of soil mapping is to separate the landscape into soils that have similar responses for land-uses and management. A map unit delineation on the landscape represents an area dominated by one or more major kinds of soils. A map unit is composed of many soil components that are related to one another and may be contrasting or non-contrasting. This is different from a taxonomic classification of soils. Taxonomic classifications define a soil by a set of soil properties with exact limits. Along with the main objective, soil surveys also provide information to evaluate and predict the effects of land-use on the environment (Soil Survey Staff, 2016).

Map unit Keith silt loam, 1 to 3% slopes is mainly composed of Keith and a minor component of Pleasant (fine, smectitic, mesic Torrertic Argiustolls). In this study, Richfield, Ulysses and Kuma soils were described within map unit Keith silt loam, 1 to 3% slopes, even though these taxonomic soil classifications are not described within the map unit. When comparing the description of Keith silt loam, 1 to 3% slopes in Web Soil Survey versus the Soil Survey of Sheridan County published in 1981, it was found that the description was not changed. Normally, frequent transect data is observed to update map unit compositions, but an update on Keith silt loam, 1 to 3% slopes has not been done since 1981.When measuring dynamic soil properties, it is imperative to analyze the same soil map unit to accurately compare how soils resist change (Tugel et al., 2008). The description of Keith silt loam, 1 to 3% slopes states the map unit is composed 98% of Keith and similar soils. Personal communication with the Soil Survey Regional Director (Remley, 2016) identified that for the purpose of this study and dynamic soil property studies in Kansas, similar soils are defined as soils that exhibit similar interpretations for agronomic uses. The similar soils within map unit Keith silt loam, 1-3% slopes would include Ulysses, Kuma, and Richfield soils. At some sites like ST 2 and ST 3, Ulysses silt loam, 3-6% slopes was mapped separately because the area was seen as comprised of purely Ulysses soils, and interpretations would change because of the high quantity of Ulysses soils.

Although measuring dynamic soil properties using a given soil map unit component provides uniformity to a study, map unit inclusions will typically be present, and the inclusions could react differently to management. Ricks Presley et al. (2004) found that different soil series were affected differently from long-term irrigation. With inclusions of different soils on every site, it is very difficult to compare soils solely on the fact if they are irrigated or not. Many properties make these soils unique from one another. Hence, they will not all be affected the same way from long-term irrigation. In this study, the variability of soils within a soil map unit are an inherent soil property. It is difficult to conclude that all soils will respond to management the same way because the map unit included inclusions of different soils. The definition of ‘similar soils’ within a soil map unit are not clearly defined, and this can greatly affect the results of these studies concerning dynamic soil properties.

Table 3-26. Summary of characteristics from field descriptions and soil characterization data comparing irrigated and non-irrigated soils.

Characteristic	Average Irrigated Value	Average Non-Irrigated Value	p-value
Depth of Ap Horizon (cm)	15.4	17.9	0.53
Depth to Mollic Colors (cm)	32.4	34.75	0.53
Thickness of Argillic Horizon (cm)	22.0	31.4	0.19
Maximum Clay Content (%)	34.6	37.1	0.15
Depth to Maximum Clay Content (%)	18.4	23.5	0.37
Weighted Average Clay Content of Control Section (cm)	30.8	32.5	0.20
Weighted Average FC:TC (ratio) of Control Section	0.50	0.60	0.57
Depth to Carbonates (cm)	49.0	53.5	0.46

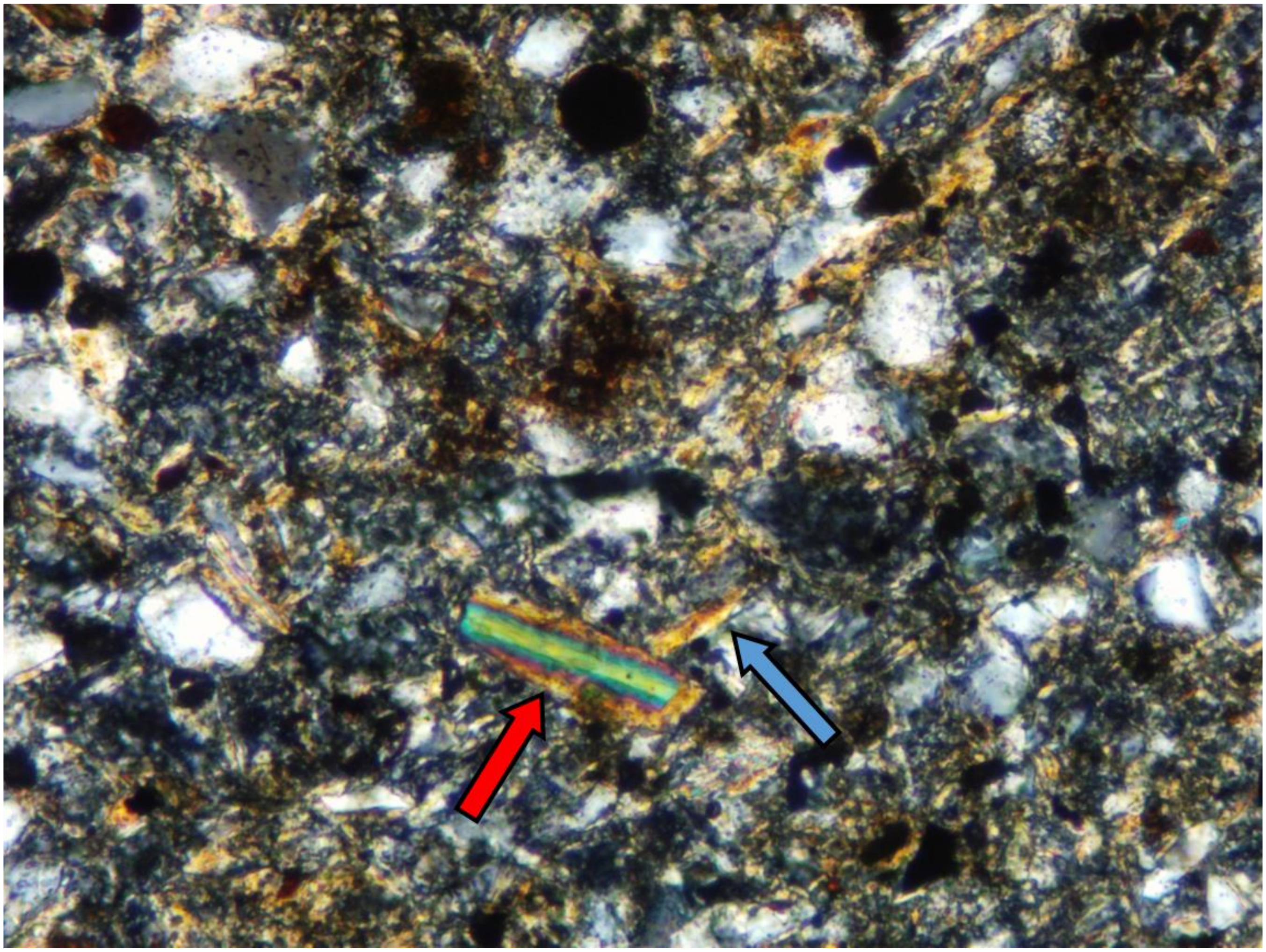

Figure 3-13. Thin section photo that depicts the redistribution of clay material from mica weathering. The red arrow points to a mica mineral with a weathering rind around it. The blue arrow points to clay material coming off the mica mineral. Photo was taken of ST 104 non-irrigated Keith Bk1 (46-144 cm) horizon with cross polarized light using a 4x objective. Frame length is 1410 µm.

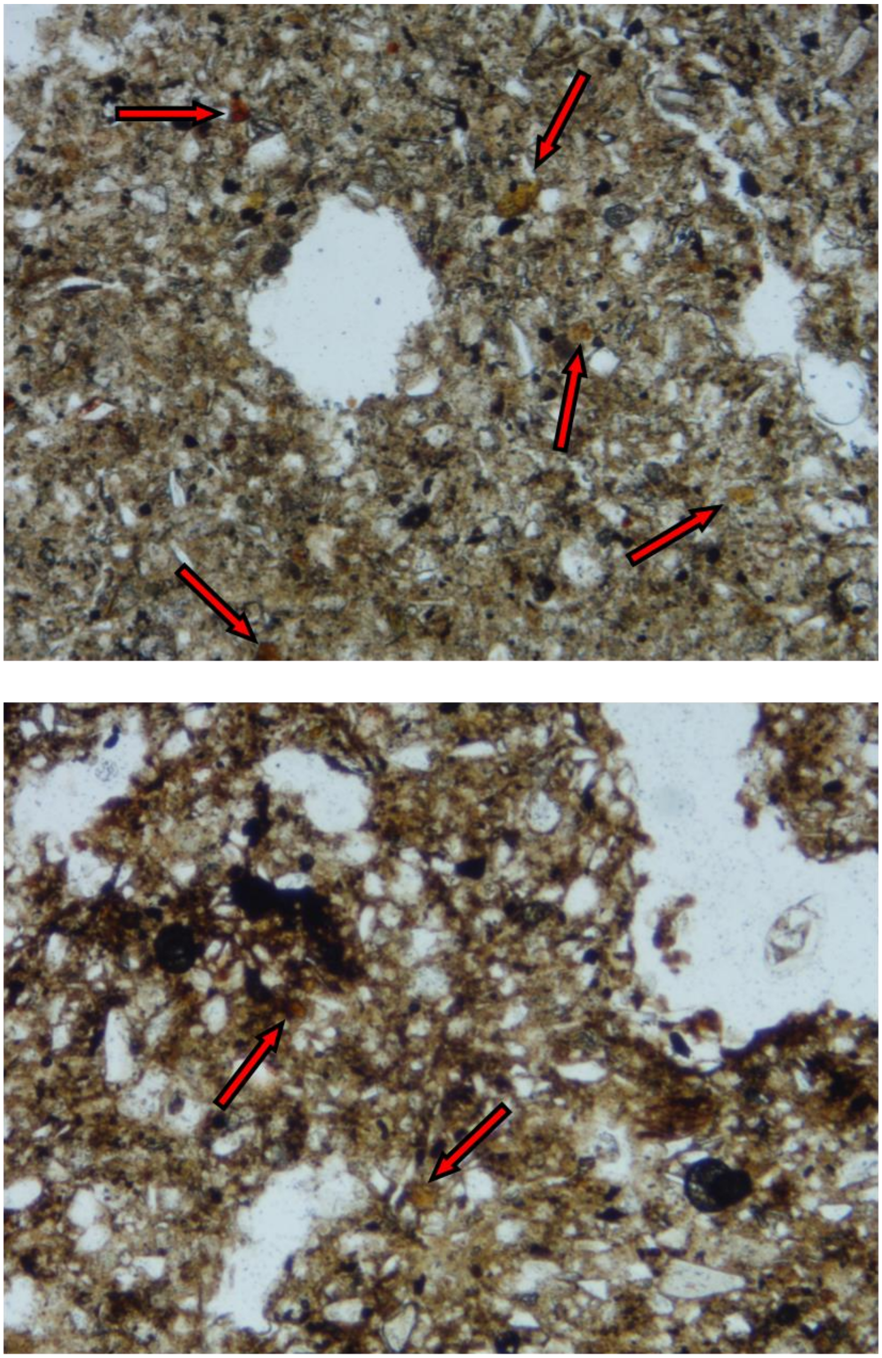

Figure 3-14. Thin sections photos. Top: ST 104 non-irrigated Keith Bt2 (23-46 cm) horizon. Arrows point to intact mica minerals. There was not a lot of clay material present in this horizon, because mica minerals have not been weathered. Bottom: ST 102 Bt (18-28 cm) irrigated Keith Bt (18-28 cm) horizon. Arrows point to mica minerals. There was a lot of clay material present in this horizon, because mica has been weathered into clay material. Both photos taken with plane polarized light using a 4x objective with a frame length of 1410 µm.

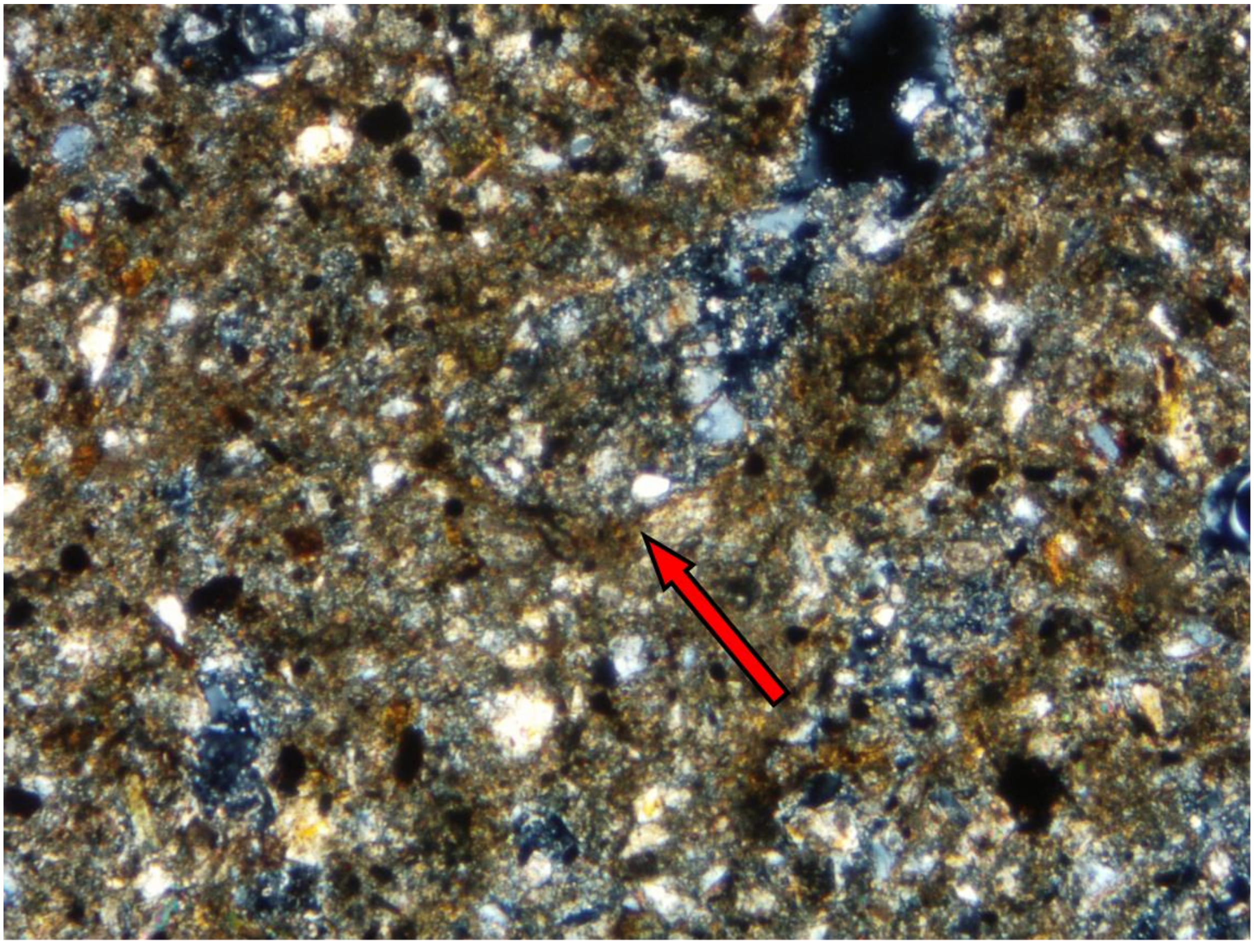

Figure 3-15. Thin section photo. ST 4 non irrigated Btk (15-32 cm) horizon. Arrow points to a carbonate hypocoating that is covering an illuvial argillan on an old void. Photo taken with cross polarized light using a 4x objective with a frame length of 1410 µm.

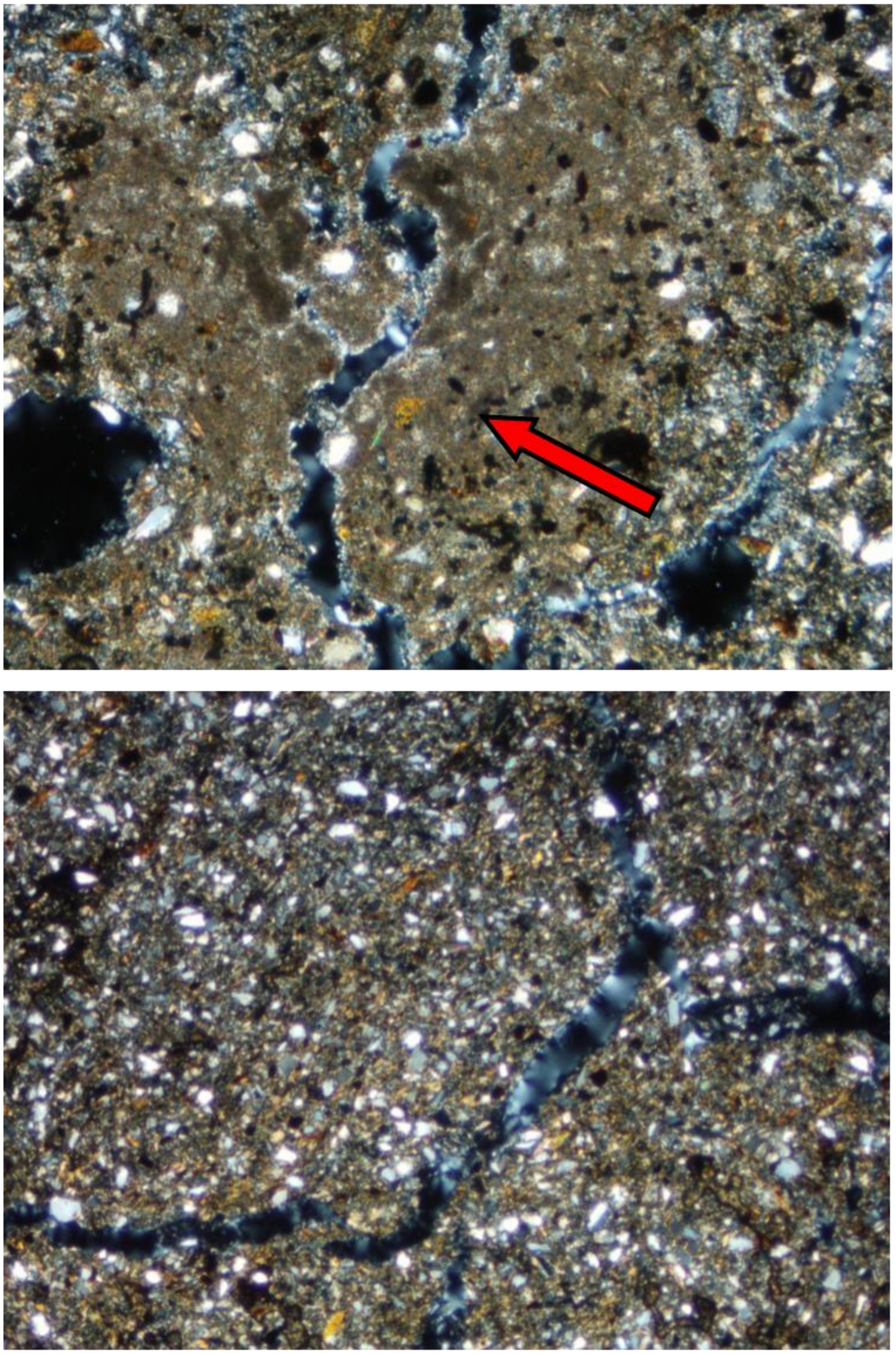

Figure 3-16. Thin section photos. Photos show discontinuous distribution of carbonate in the same pedon. Top photo shows carbonate present in Btk horizon from 12-34 cm. Bottom photo shows no carbonate present in the Bt horizon below from 34-59 cm. Carbonate is then described below 59 cm in this pedon. Both photos taken with cross polarized light using a 4x objective with a frame length of 1410 µm.

Conclusions

Field descriptions, soil characterization data, and soil micromorphological descriptions indicated that irrigation does not affect clay illuviation or carbonate distribution in soils of this study in western Kansas. Although clay films and illuvial argillans were observed, most of the oriented clay in these soils is formed through the in-situ weathering of mica minerals. Technically, 1% or more oriented clay meets the definition for an argillic horizon. However, since this clay does not result from an illuvial process, these oriented clay features do not meet the central concept of an argillic horizon. Micromorphology of these soils suggested that there was a younger deposition of carbonate and clay-rich Bignell loess. As identified off field descriptions, soil characterization data, and micromorphology, Bignell loess occurred in eight out of the twenty four pedons with a thickness that ranges from 25-69 cm thick. This deposition of a thin, younger loess may be inhibiting clay illuviation processes.

When considering if inherent properties such as clay and carbonate content can change over a human time scale and be dynamic, it is important to take the soil map unit composition into account. Although all soils used in this study were mapped as Keith silt loam, 1-3% slopes, there were inclusions of different soils. Because each map unit inclusion has a unique classification, each soil could react differently to management.

Overall, inherent soil properties such as soil map unit composition and parent material can have a greater impact on soil change and prevent detection of changes in soil properties over a human time scale.

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Chapter 4 - Synthesis

The objective of this thesis was to determine how management affects dynamic and inherent soil properties of western Kansas soils. An evaluation of eight sites in Sheridan County, KS mapped as Keith silt loam, 1-3% slopes showed differences between no-till and ST management in microbial respiration, select water stable aggregate sizes, and pH and bulk density at certain depths. Although significant differences were observed, there were properties, such as mean weight diameter, that were not affected by different management and did not follow expectations.

Overall, this thesis points out three important characteristics that are critical in evaluating soil change: steady state of soils, parent material, and map unit inclusions. Soil properties can vary over years. This is why The Soil Change Guide (Tugel et al., 2008) emphasizes the importance of analyzing soils at a steady state to address the limitations of a comparison study design. Finding replications of steady state soils and determining what steady state soils are can be very difficult. Without analyzing soil at a steady state, a comparison design will have implications, and it may be difficult to see trends.

An analysis of inherent soil properties, such as clay illuviation and carbonate leaching, found that these properties were not affected by long-term irrigation. Thin section analysis showed a deposition of thin, patchy Bignell loess throughout the sites. Bignell loess is Holocene aged, and therefore has not been exposed as long to soil forming factors as the late-Wisconsin aged Peoria loess. The more recent deposition of Bignell loess may have been the reason why clay illuviation was not increased with irrigation because the calcium carbonate in the Bignell loess flocculates clay and inhibits illuviation.

In both studies, it is difficult to compare dynamic and inherent soil properties among different management because map unit inclusions of different soils occurred in this study. Within the area mapped as Keith silt loam, 1-3% slopes, Richfield (fine, smectitic, mesic Aridic Argiustolls), Ulysses (fine-silty, mixed, superactive mesic Aridic Haplustolls) and Kuma (fine-silty, mixed, superactive, mesic Pachic Argiustolls) were described. Even though those soils were identified as the same soil at the beginning of this study, they are taxonomically different which is why expected trends were not observed. The variability of soils within a soil map unit are an inherent soil property. It is difficult to conclude that all soils will respond to management the same way.

For future DSPs studies, it is important to understand the variability of soils on landscape. The diverse amount of soils present in a study area can create too much variability in the study, which will make relationships difficult to find. It is important to not look through the landscape and only analyze a very specific soil series, as this does not properly represent the variability of soils across a landscape. The definition of ‘similar soils’ within a soil map unit are not clearly defined by the Soil Change Guide (Tugel et al., 2008), and do not take variability of soils into account. Excluding this from DSPs studies cannot properly assess how soils will change due to anthropogenic disturbances or stressors.

Appendix A - Soil Survey of Study Area

Map Unit Description:1623—Keith silt loam, 1 to 3 percent slopes, south Sheridan County, Kansas

Map Unit Setting

National map unit symbol: 2r2fq

Elevation: 2,610 to 4,000 feet

Mean annual precipitation: 18 to 23 inches

Mean annual air temperature: 50 to 54 degrees F

Frost-free period: 140 to 160 days

Farmland classification: All areas are prime farmland

Map Unit Composition

Keith and similar soils: 98 percent

Minor components: 2 percent

Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Keith

Setting

Landform: Rises

Landform position (two-dimensional): Backslope

Landform position (three-dimensional): Side slope

Down-slope shape: Linear

Across-slope shape: Linear

Parent material: Loess

Typical profile

Ap - 0 to 7 inches: silt loam

Bt1 - 7 to 15 inches: silty clay loam

Bt2 - 15 to 22 inches: silt loam

Bk - 22 to 46 inches: silt loam

C - 46 to 79 inches: silt loam

Properties and qualities

Slope: 1 to 3 percent

Depth to restrictive feature: More than 80 inches

Natural drainage class: Well drained

Runoff class: Low

Capacity of the most limiting layer to transmit water (Ksat):

Moderately high (0.20 to 0.60 in/hr)

Depth to water table: More than 80 inches

Frequency of flooding: None

Frequency of ponding: None

Calcium carbonate, maximum in profile: 10 percent

Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)

Available water storage in profile: Very high (about 12.6 inches)

Interpretive groups

Land capability classification (irrigated): 2e

Land capability classification (nonirrigated): 2e

Hydrologic Soil Group: C

Ecological site: Loamy Upland (South) Draft (April 2010) (PE 16-20) (R072XB015KS)

Minor Components

Pleasant

Percent of map unit: 2 percent

Landform: Playas

Landform position (two-dimensional): Toeslope

Landform position (three-dimensional): Base slope

Down-slope shape: Concave

Across-slope shape: Concave

Ecological site: LAKEBED (PE17-20) (R077XY011KS)

Data Source Information

Soil Survey Area: Sheridan County, Kansas Survey Area Data: Version 14, Sep 8, 2015

Map Unit Description: Keith silt loam, 1 to 3 percent slopes, south---Sheridan County, Kansas

1623 Keith

Natural Resources Conservation Service Web Soil Survey National Cooperative Soil Survey

5/9/2016

Map Unit Description: 1859—Ulysses silt loam, 3 to 6 percent slopes

Sheridan County, KS

Map Unit Setting

National map unit symbol: 2mb5b

Elevation: 2,610 to 3,920 feet

Mean annual precipitation: 14 to 25 inches

Mean annual air temperature: 50 to 57 degrees F

Frost-free period: 135 to 210 days

Farmland classification: Prime farmland if irrigated

Map Unit Composition

Ulysses and similar soils: 79 percent

Minor components: 21 percent

Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Ulysses

Setting

Landform: Hillslopes

Landform position (two-dimensional): Backslope

Landform position (three-dimensional): Side slope

Down-slope shape: Linear

Across-slope shape: Linear

Parent material: Loess

Typical profile

Ap - 0 to 11 inches: silt loam

Bw - 11 to 24 inches: silt loam

Bk - 24 to 79 inches: silt loam

Properties and qualities

Slope: 3 to 6 percent

Depth to restrictive feature: More than 80 inches

Natural drainage class: Well drained

Runoff class: Low

Capacity of the most limiting layer to transmit water (Ksat):

Moderately high to high (0.60 to 2.00 in/hr)

Depth to water table: More than 80 inches

Frequency of flooding: None

Frequency of ponding: None

Calcium carbonate, maximum in profile: 20 percent

Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)

Available water storage in profile: High (about 9.9 inches)

Interpretive groups

Land capability classification (irrigated): 3e

Land capability classification (nonirrigated): 3e

Hydrologic Soil Group: B

Ecological site: Loamy Upland (South) Draft (April 2010) (PE 16-20) (R072XB015KS)

Minor Components

Buffalo park

Percent of map unit: 20 percent

Landform: Hillslopes

Landform position (two-dimensional): Backslope

Landform position (three-dimensional): Side slope

Down-slope shape: Linear

Across-slope shape: Convex

Ecological site: Limy Upland (South) Draft (April 2010) (PE16-20) (R072XB012KS)

Duroc

Percent of map unit: 1 percent

Landform: Draws

Landform position (two-dimensional): Toeslope

Landform position (three-dimensional): Base slope

Down-slope shape: Linear

Across-slope shape: Concave

Ecological site: Loamy Upland (South) Draft (April 2010) (PE 16-20) (R072XB015KS)

Other vegetative classification: Loam (G072XA100KS)

Data Source Information Soil Survey Area: Sheridan County, Kansas

Survey Area Data: Version 14, Sep 8, 2015

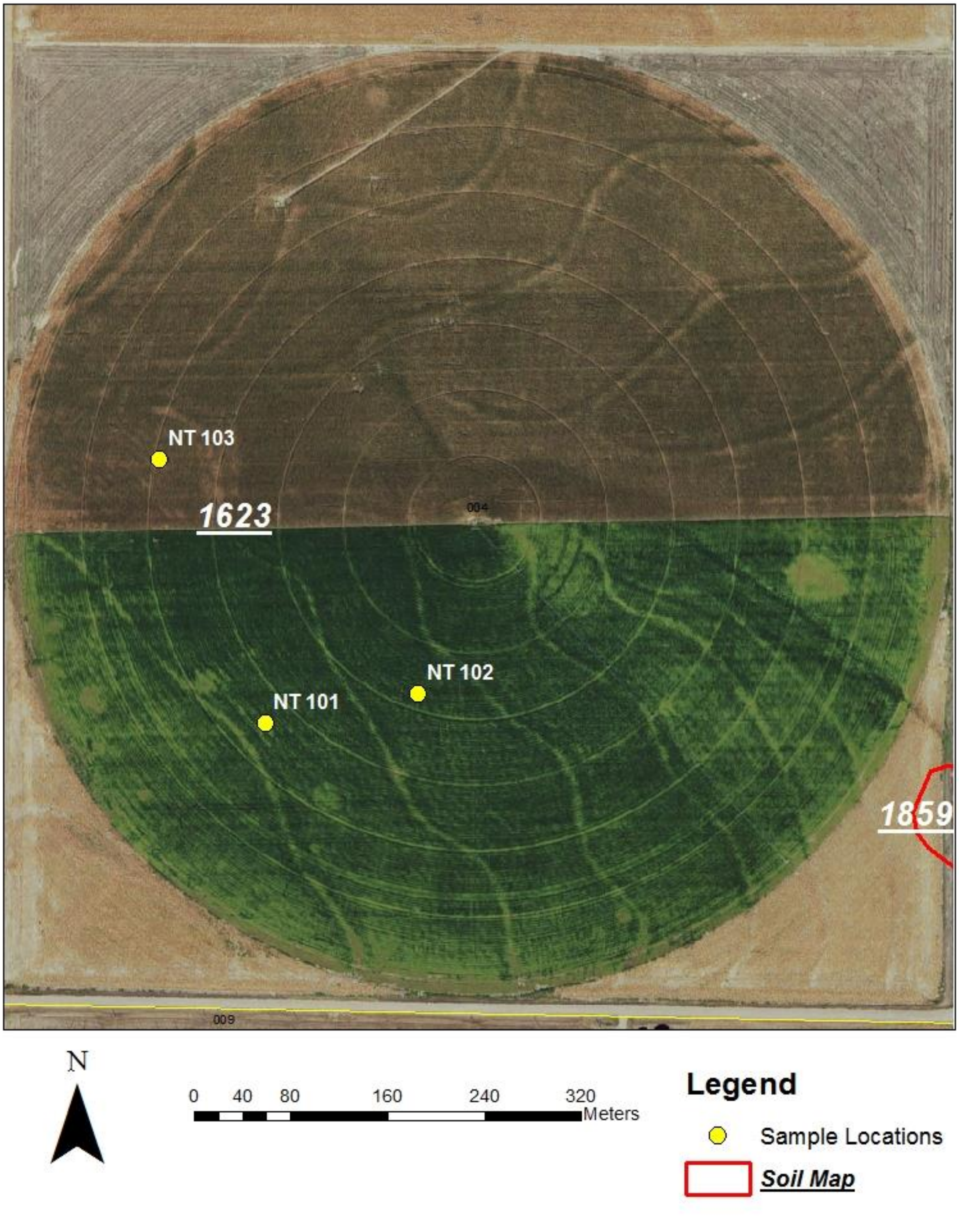
Map Unit Description: Ulysses silt loam, 3 to 6 percent slopes---Sheridan County, Kansas 1859

Ulysses

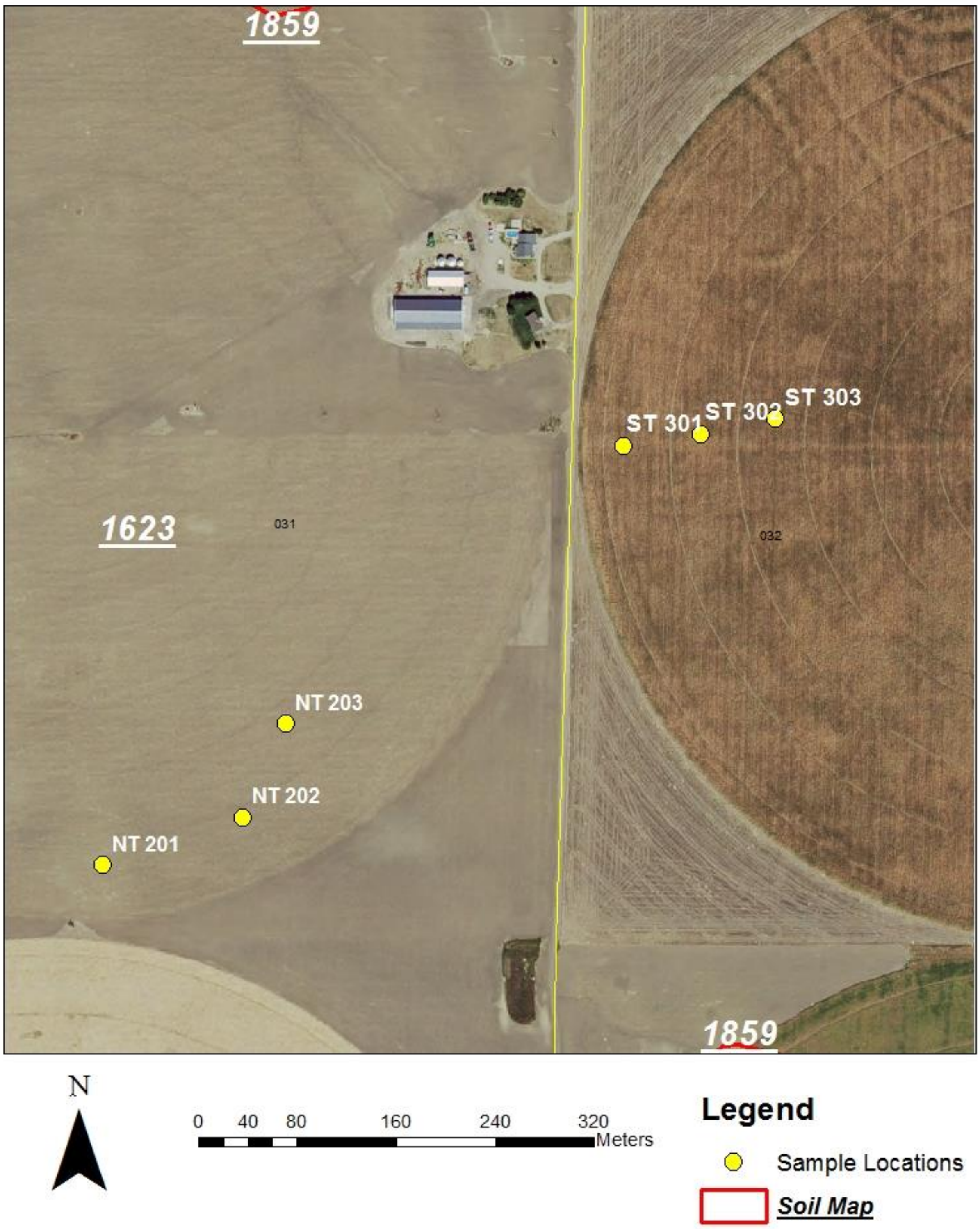
Natural Resources Conservation Service Web Soil Survey National Cooperative Soil Survey

5/9/2016

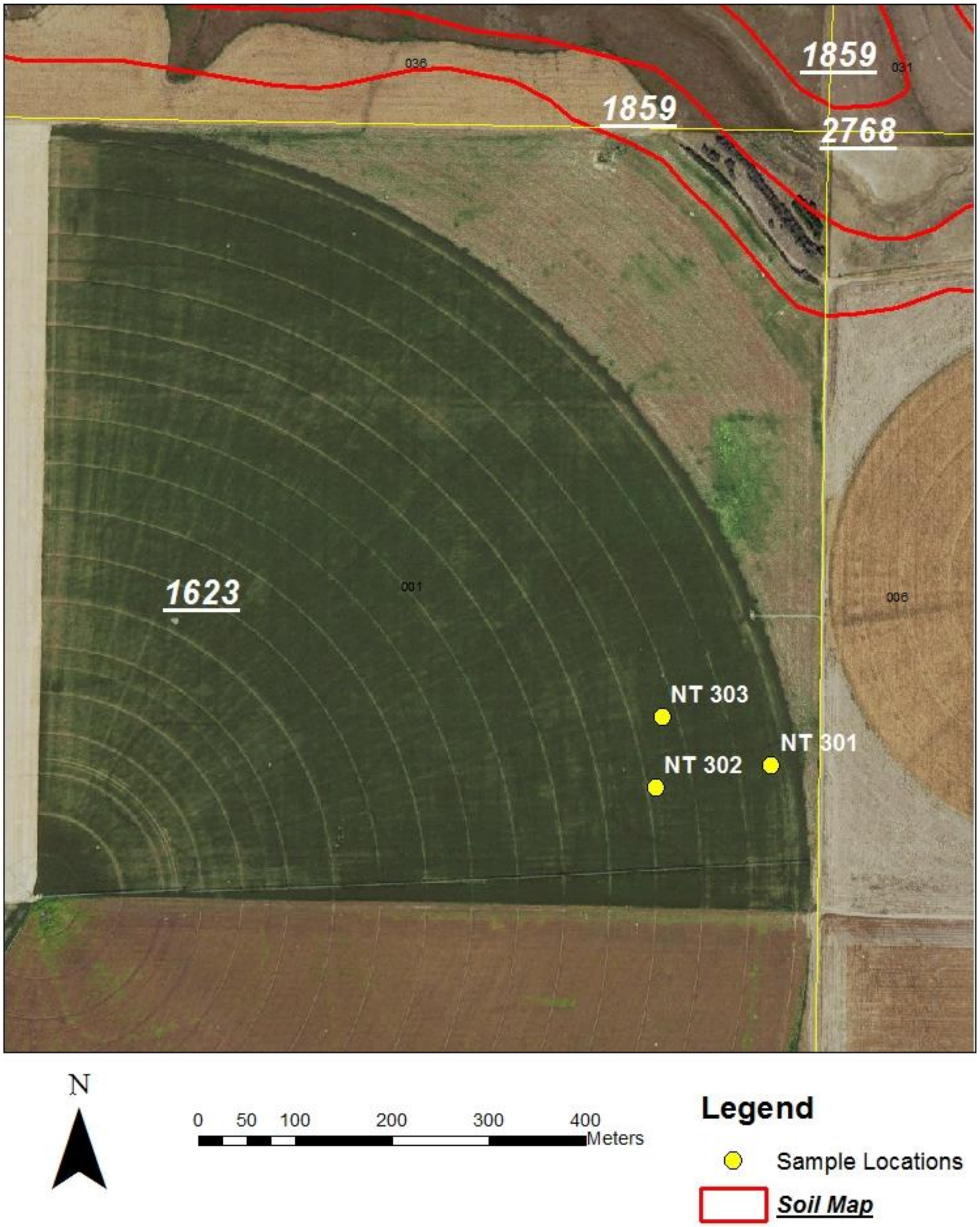
Soil Map of NT 1



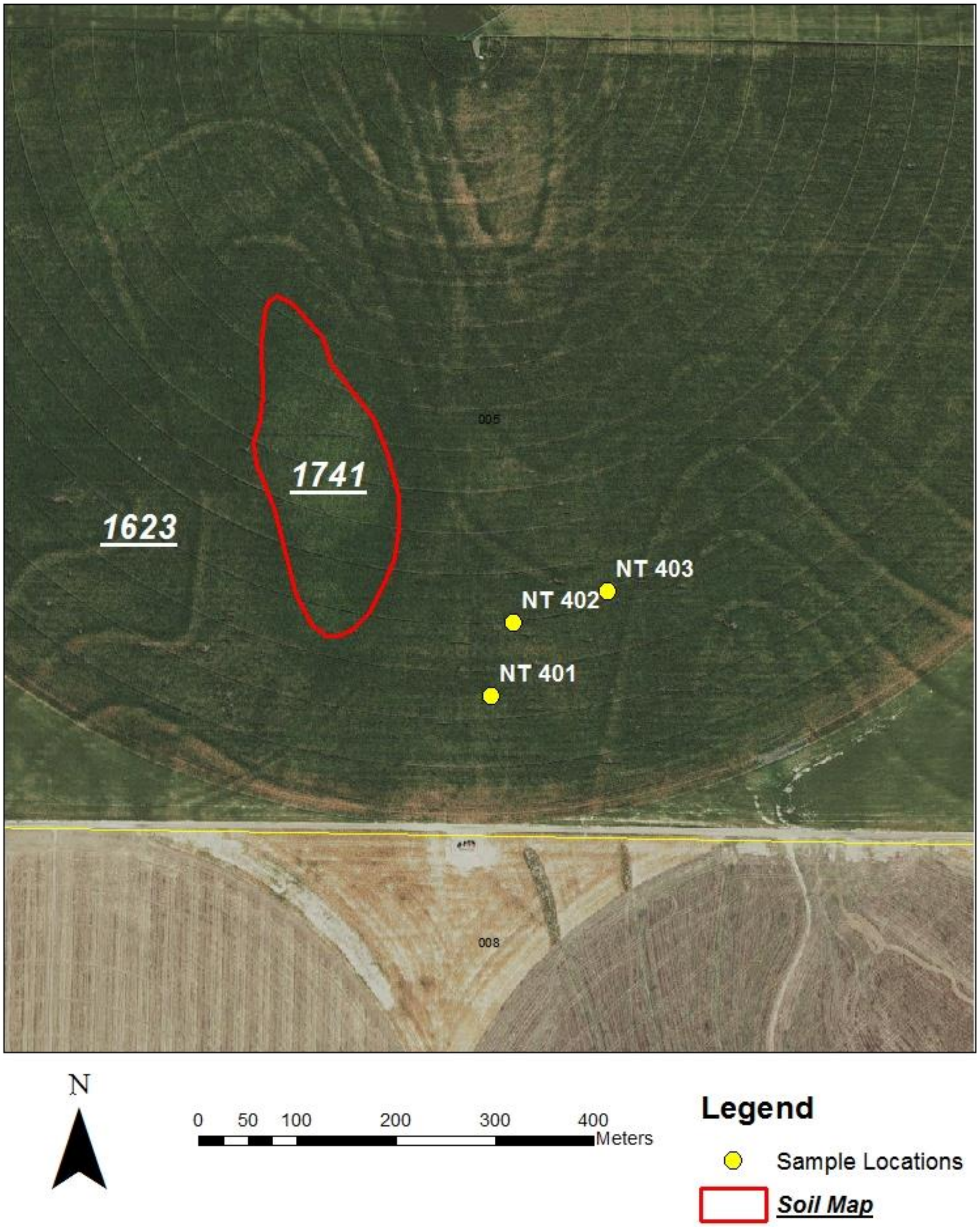
Soil Map of NT 2 and ST 3DSP



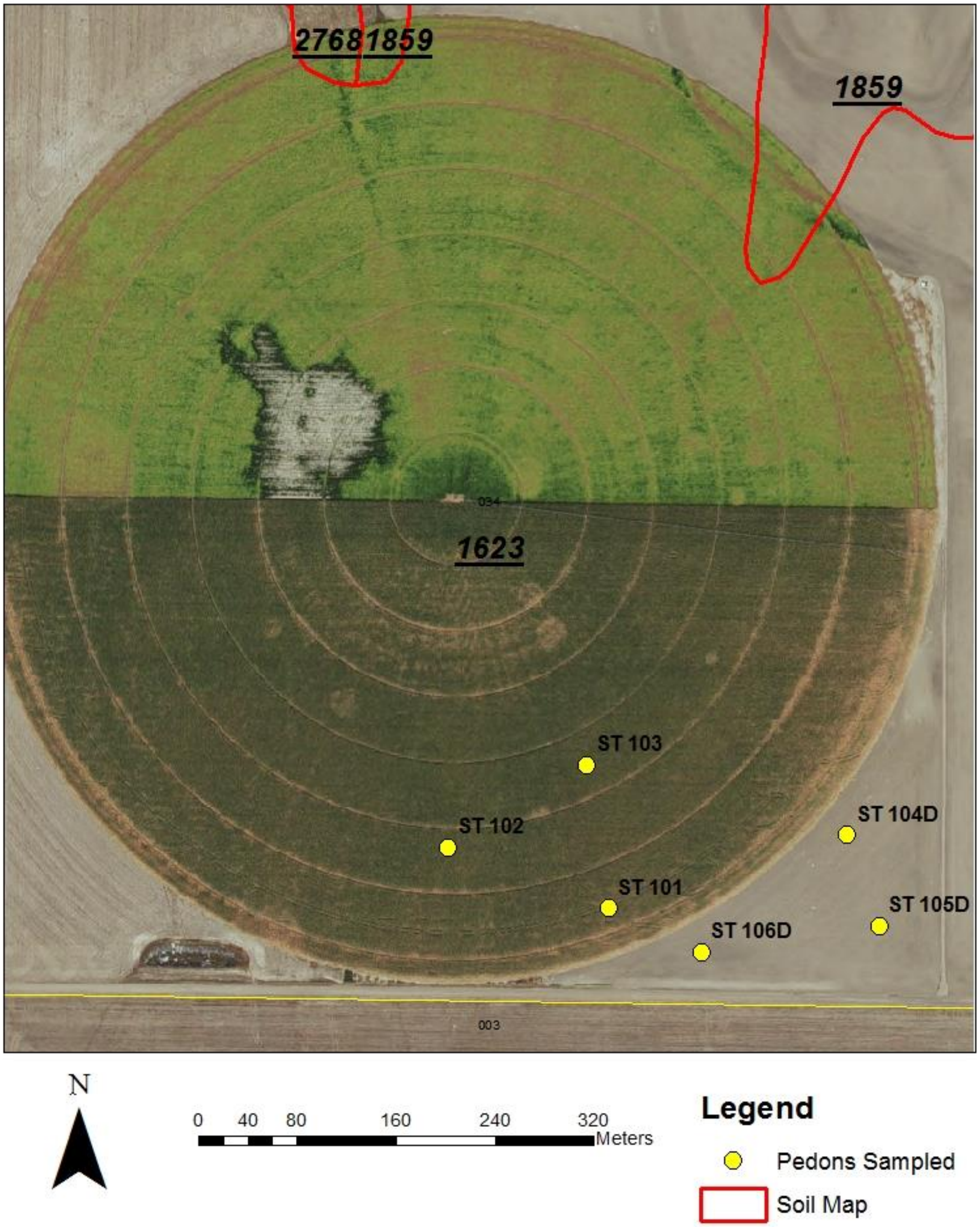
Soil Map of NT 3



Soil Map of NT 4

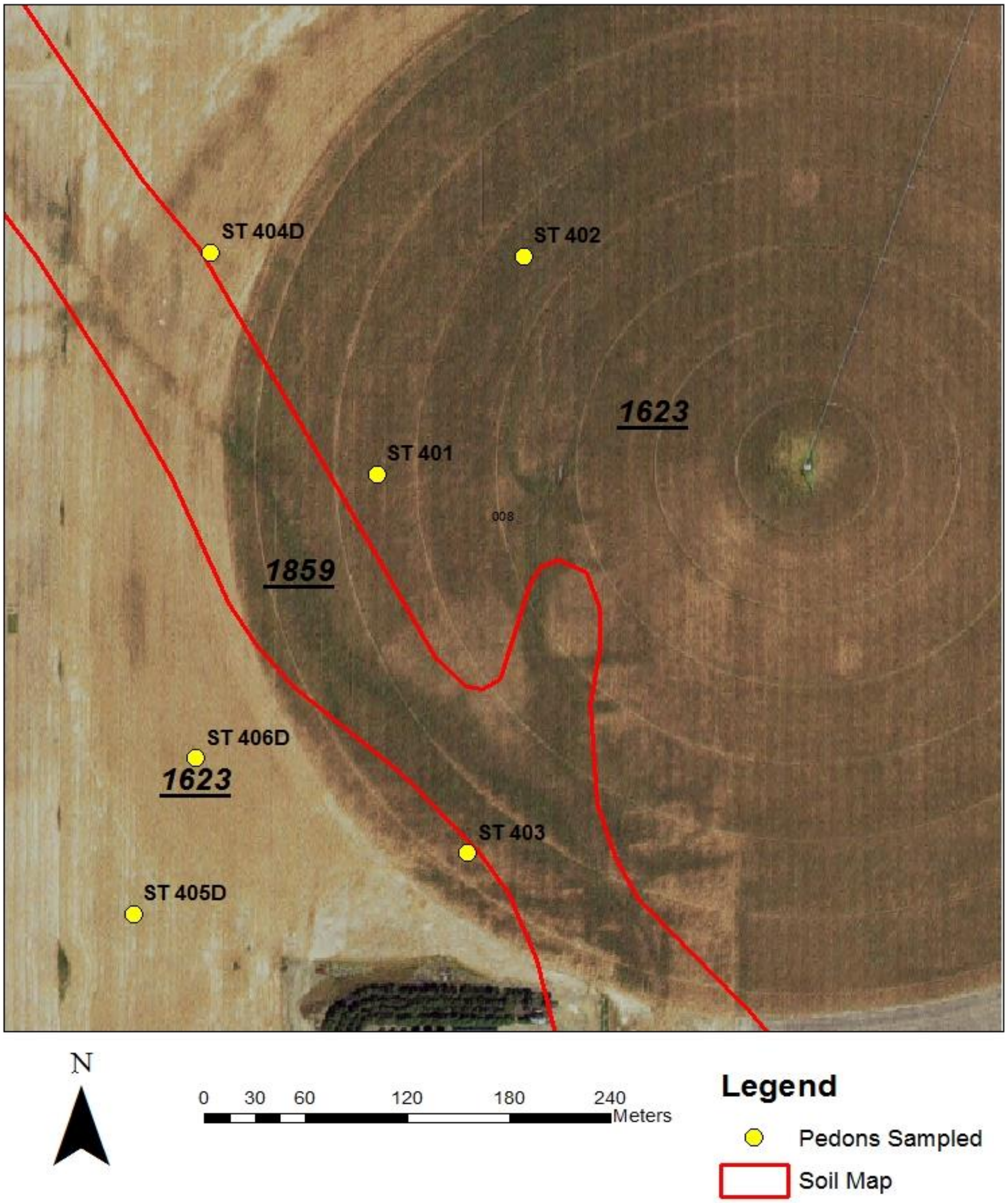


Soil Map of ST 1




Soil Map of ST 2 and ST 3
ST 202
ST 201
1859
ST 304D
ST 203
ST 205D
ST 206D
1623
ST 204D
ST 305D
005
1859
ST 301
1623
ST 306D
ST 302
1580
ST 303
1580
N
0
40
80
160
240
320
Meters
Legend
Pedons Sampled
Soil Map

Soil Map of ST 4

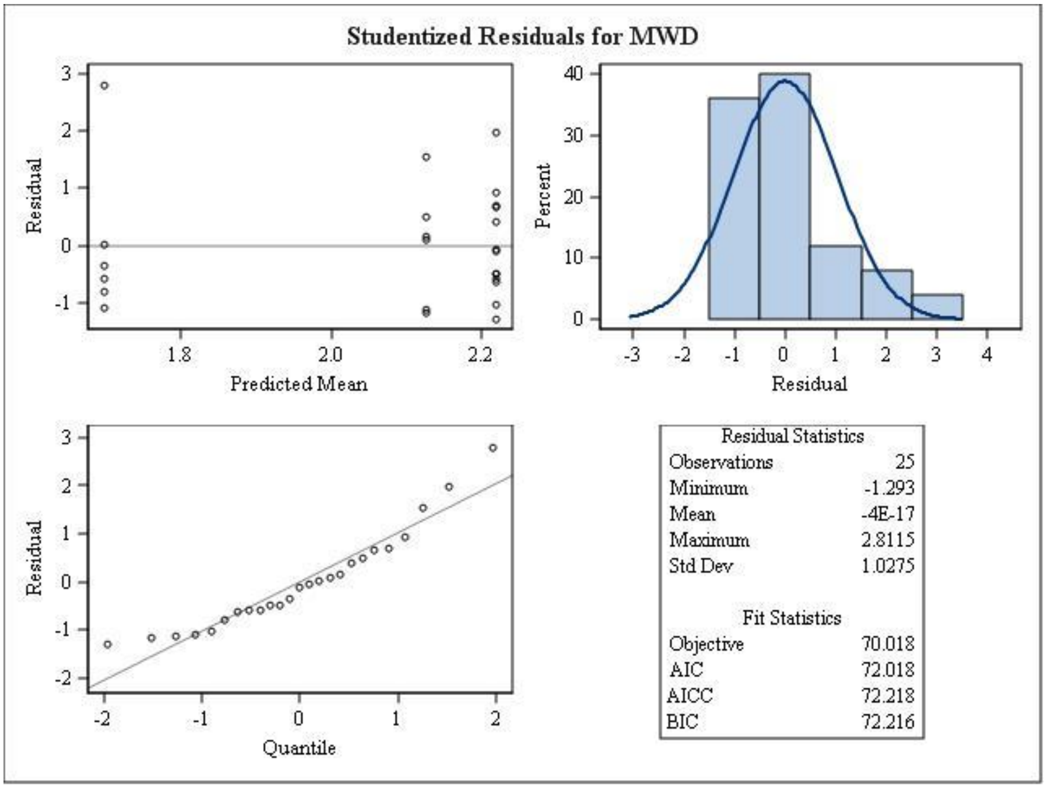


Appendix B - Statistical Analyses

ANOVA table explaining completely randomized design with subsampling

Completely Randomized Design with Subsampling

	Random/fixed	Source	Degrees of Freedom
Treatment	Fixed	Till_cover	3-1=2
Experimental Unit	Random	Site(till_cover)	(2-1)+(2-1)+(4-1+1)=6
Subsampling Unit	Random	Pit(site till_cover)	(3-1)(8)=16



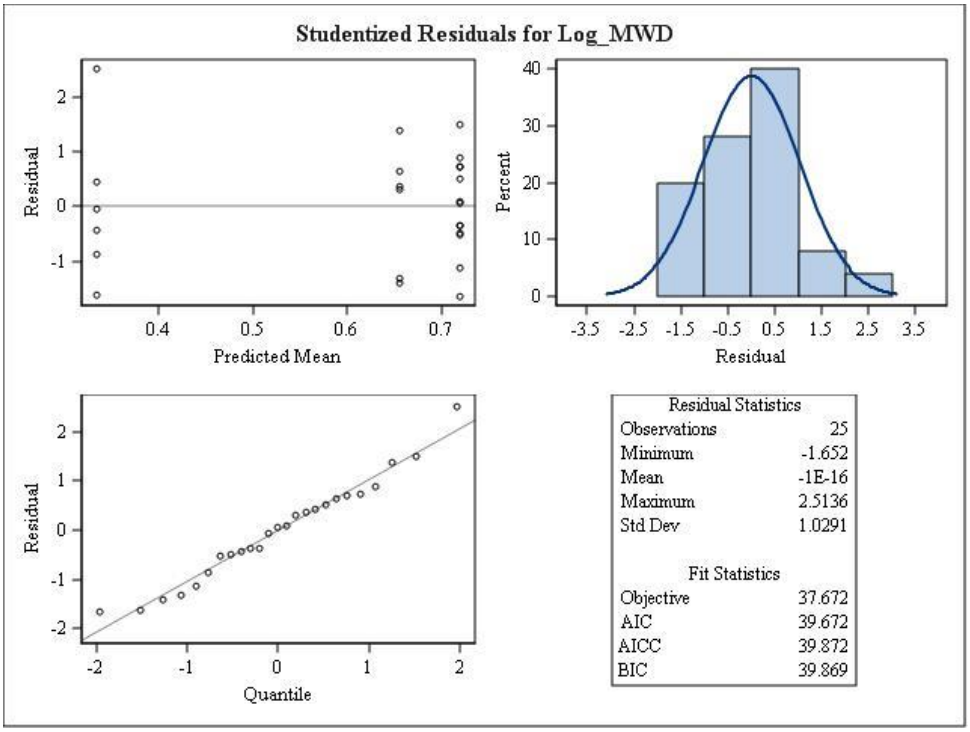
Residual Statistics

Observations	25
Minimum	-1.293
Mean	-4E-17
Maximum	2.8115
Std Dev	1.0275

Fit Statistics

Objective	70.018
AIC	72.018
AICC	72.218
BIC	72.216

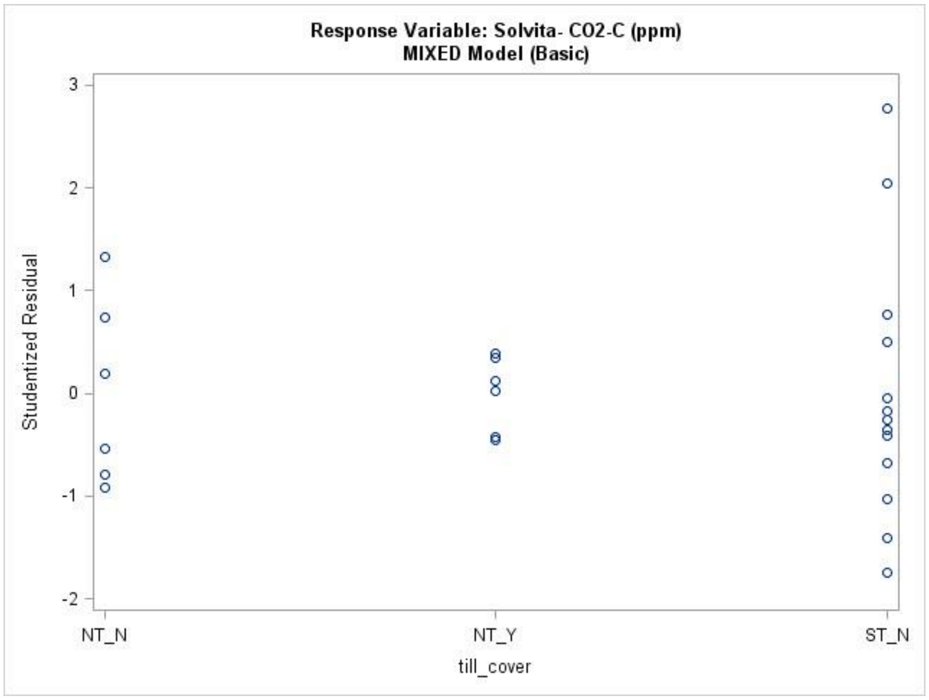
Studentized residuals for mean weight diameter reveal that the data was skewed.



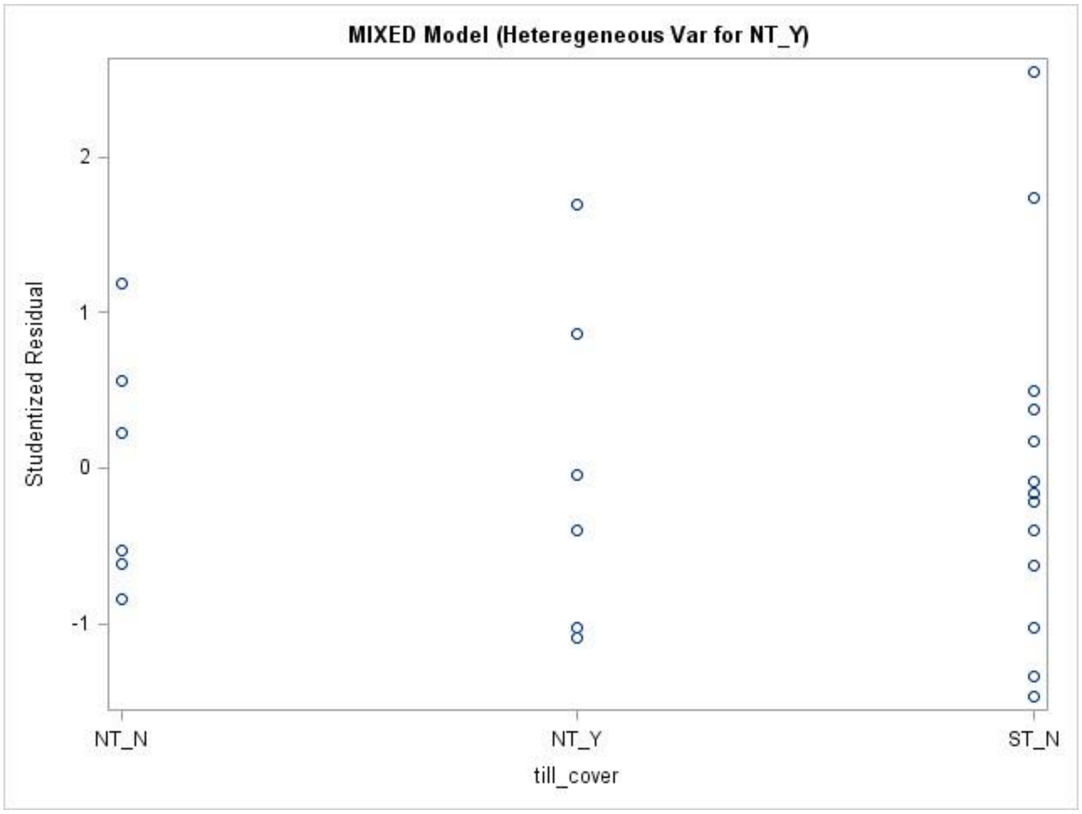
Residual Statistics	
Observations	25
Minimum	-1.652
Mean	-1E-16
Maximum	2.5136
Std Dev	1.0291

Fit Statistics	
Objective	37.672
AIC	39.672
AICC	39.872
BIC	39.869

Log transformation normalized the mean weight diameter data with a lower AIC and BIC



Original model for Solvita did not meet the assumption of homogeneity in residuals



After a follow-up analysis incorporated a heterogeneous variance for the NT_Y treatment group, a better model was created that met the assumption of homogeneity in residuals. The AIC and BIC were also lower in these models.

Appendix C - Field Descriptions

ST 1- 101 irrigated Ulysses

Depth	Horizon	Matrix Color	Structure	Ped and Void Surface Features	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-10	Ap1	10 YR 3/2	1-f-gr	#	#
10-27	Ap2	10 YR 3/2	2-f-sbk/2-f-gr	#	#
27-44	Bk1††	10 YR 4/2	2-f-pr/2-f-sbk	10% M D PRF VF	#
44-68	Bk2	10 YR 5/3	2-f-pr	1% F D PRF VF	2% F I CAM MAT
68-129	Bk3	10 YR 5/3	2-f-pr	#	2% F I CAM MAT 2% F T CAM MAT
129-174	Bk4	10 YR 5/3	1-co-pr/1-f-sbk	#	3% F T CAM MAT
174-236	Bk5	10 YR 5/4	1-co-pr/1-f-sbk	2% M D CAF VPF	1% F T CAM MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

††27-46 changed from Bw to Bk1 after micromorphology analysis

ST 1- 102 irrigated Ulysses

Depth	Horizon	Matrix Color	Structure	Ped and Void Surface Features	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-9	Ap1	10 YR 2/2	2-f-gr	#	#
9-18	Ap2	10 YR 2/2	3-vf-abk	#	#
18-28	Bt	10 YR 3/3	3-f-abk	5% D D CLF VF 2% D D CLF HF	#
28-46	Bk1	10 YR 3/3	2-f-pr	5% D D PRF VF	#
46-82	Bk3	10 YR 5/4	1-f-pr	#	2% M I CAM MAT 3% F T CAM MAT
82-151	Bk3	10 YR 5/4	1-m-pr	#	2% F I CAM MAT
151-230	Bk4	10 YR 4/4	1-co-pr	#	1% F T CAM SP 1% F I CAM MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

††28-46 changed from Bw to Bk1 after micromorphology analysis

ST 1- 103 irrigated Ulysses

Depth	Horizon	Matrix Color	Structure	Clay Coatings	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-7	Ap1	10 YR 3/2	1-f-gr	#	#
7-21	Ap2	10 YR 3/2	2-f-sbk/2-f-gr	#	#
21-40	Bw1	10 YR 3/2	2-f-pr/2-f-sbk	20% M D PRF VF	#
40-52	Bw2	10 YR 5/3	2-f-pr	20% M D PRF VF	#
52-75	Bw3	10 YR 5/3	2-f-pr	10% M D PRF VF	
75-116	Bk1	10 YR 5/3	1-co-pr/1-f-srk	#	3% F I CAM TOT
116-156	Bk2	10 YR 5/3	1-co-pr/1-f-sbk	#	5% F T CAM TOT
156-197	Bk3	10 YR 5/3	1-co-pr/1-f-sbk	2% M D CAF VF	3% M I CAM TOT
197-208	2Bk4	10 YR 5/3	2-m-pr/1-f-srk	#	3% M I CAM RPO 2% F I CAM TOT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

ST 1- 104 non-irrigated Keith

Depth	Horizon	Matrix Color	Structure	Clay Coatings	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-5	Ap1	10 YR 3/3	1-m-sbk/1-f-gr	#	#
5-23	Bt1	10 YR 3/3	2-f-pr/2-f-sbk	2% D/C CLF PF	#
23-46	Bt2	10 YR 4/3	1-f-pr	1% D/D CLF VF 2% D/D PRF VF 2% D/D PRF HF	#
46-144	Bk1	10 YR 5/4	1-m-pr/ 1-m-sbk	#	2% F I CAM MAT
144-230	Bk2	10 YR 5/4	1-f-pr/1-co-gr	#	1% F T CAM MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

ST 1- 105 non-irrigated Keith

Depth	Horizon	Matrix Color	Structure	Clay Coatings	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-8	Ap1	10 YR 3/2	1-f-gr	#	#
8-15	Ap2	10 YR 3/2	3-m-pl/2-f-gr	#	#
15-26	Bt1	10 YR 3/2	2-f-pr/2-m-sbk	2% F D CLF VF	#
26-47	Bt2	10 YR 4/3	2-f-pr	1% F D CLF VF	#
47-79	Bk1	10 YR 5/3	2-f-pr	#	2% F T CAM TOT
79-140	Bk2	10 YR 5/3	2-m-pr/2-m-sbk	#	2% F T CAM TOT 5% M I CAM TOT
140-195	Bk3	10 YR 5/3	1-co-pr/1-f-sbk	#	1% F I CAN TOT 2% F T CAM TOT 2% I CAM RPO
195-230	Bk4	10 YR 5/3	1-co-pr/1-f-sbk	#	2% F I CAM TOT 2% F I CAM RPO

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

ST 1- 106 non-irrigated Keith

Depth	Horizon	Matrix Color	Structure	Clay Coatings	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-5	Ap1	10 YR 2/2	1-co-gr/1-f-gr	#	#
5-12	Ap2	10 YR 2/2	1-f-sbk/1-co-gr	10% D C PRF HPF	#
12-46	Btk1††	10 YR 2/2	2-f-sbk	10% D C CLF APF	#
46-69	Btk2††	10 YR 4/3	2-f-pr	10% D C CLF APF	#
69-89	Bt	10 YR 5/4	1-m-pr/2-f-sbk	5% D D PRF VPF	#
89-141	Bk1	10 YR 5/4	1-f-pr	#	5% M I CAN MAT 2% F I CAM MAT
141-230	Bk2	10 YR 5/4	1-m-pr	#	1% F I CAN MAT 2% F T CAM MAT 1% F I CAM MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

††12-69 changed from Bt1 and Bt2 to Btk1 and Btk2 after morphological analysis

ST 2 201 irrigated Keith

Depth	Horizon	Matrix Color	Structure	Clay Coatings	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-4	Ap	10 YR 3/2	1-m-pl/1-m-gr	#	#
4-28	Btk1††	10 YR 2/2	2-f-pr/2-f-sbk	5% F D CLF VPF 2% F P CLF HPF	#
28-44	Btk2††	10 YR 4/3	1-m-pr/2-f-sbk	2% F P CLF VPF 2% D D PRF VPF 1% F P CLF HPF	#
44-116	Bk1	10 YR 6/4	1-m-pr	#	1% F IR CAM MAT
116-168	Bk2	10 YR 5/4	1-m-pr	#	3% M IR CAM VPF 1% F IR CAM MAT
168-230	Bk3	10 YR 5/4	1-co-pr/1-f-sbk	#	3% F TH CAM MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

††4-28 changed from Bt1 and Bt2 to Btk1 and Btk2 after morphological analysis

ST 2 202 irrigated Ulysses

Depth	Horizon	Matrix Color	Structure	Clay Coatings	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-11	Ap1	10 YR 3/2	2-m-pl/2-f-gr	#	#
11-21	Ap2	10 YR 3/2	2-m-sbk/2-f-gr	#	#
21-38	Bw††	10 YR 4/3	2-f-pr	1% D CLF VPF	#
38-60	Bk1	10 YR 5/3	2-f-pr/2-m-sbk	#	1% F T CAM TOT
60-93	Bk2	10 YR 5/3	2-f-pr/2-m-sbk	#	1% F T CAM TOT 1% F I CAM TOT
93-138	Bk3	10 YR 5/3	2-f-pr	#	2% F I CAM APF 2% F T CAM TOT
138-190	Bk4	10 YR 5/3	1-m-pr	#	2% F T CAM TOT 1% F I CAM RPO

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

††Not enough clay films for a Bt

ST 2 203 irrigated Keith

Depth	Horizon	Matrix Color	Structure	Clay Coatings	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-5	Ap1	10 YR 2/2	2-f-pl/1-f-gr	#	#
5-12	Ap2	10 YR 2/2	2-co-gr	#	#
12-34	Btk††	10 YR 2/1	1-m-pr/1-f-sbk	2% D D CLF APF	#
34-59	Bt2	10 YR 3/4	2-f-pr/1-f-sbk	1% F P CLF APF 5% F D PRF VPF	#
59-115	Bk1	10 YR 5/4	1-f-pr	#	1% F T CAM MAT 2% F I CAM MAT
115-230	Bk2	10 YR 5/4	1-co-pr	#	2% F I CAM MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

††12-34 cm changed from Bt to Btk after Micromorphological analysis

ST 2 204 non-irrigated Keith

Depth	Horizon	Matrix Color	Structure	Clay Coatings	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-11	Ap1	10 YR 3/2	2-f-gr	#	#
11-15	Ap2	10 YR 3/2	2-m-pl/2-f-gr	#	#
15-29	Bt1	10 YR 3/3	2-f-pl	10% CLF PF	#
29-44	Bt2	10 YR 5/3	2-f-pl/2-f-sbk	5% CLF VPF	#
44-87	Bk1	10 YR 5/3	2-m-sbk	#	4% F I CAM TOT 2% F I CAM RPO 3% M I CAM TOT 1% F T CAM TOT
87-130	Bk2	10 YR 5/3	1-m-sbk	#	3% F T CAM TOT 1% M I CAM TOT
130-165	Bk3	10 YR 5/3	1-m-sbk	#	1% F T CAM TOT
165-204	Bk4	10 YR 5/3	1-m-sbk	#	1% F CAM TOT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

ST 2 205 non-irrigated Kuma

Depth	Horizon	Matrix Color	Structure	Clay Coatings	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-8	Ap1	10 YR 3/2	1-f-gr	#	#
8-25	Ap2	10 YR 2/2	2-f-sbk	#	#
25-50	Bt1††	10 YR 3/2	2-f-pr	10% D D PRF APF	#
50-70	Bt2	10 YR 4/3	2-m-pr/2-f-sbk	5% D C CLF APF	#
70-99	Bk1	10 YR 4/4	1-m-pr/1-f-sbk	#	1% F I CAM MAT
99-230	Bk2	10 YR 5/4	1-co-pr	#	2% F I CAM MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

††25-50 cm changed from Bw to Bt after Micromorphological analysis

ST 2 206 non-irrigated Richfield

Depth	Horizon	Matrix Color	Structure	Clay Coatings	$CaCO_3$ Conc.
cm		†	Grade-Size-Type‡	Kind, Amount, Continuity, Distinctness, Location§	Kind, Amount, Size, Shape, Location¶
0-5	Ap1	10 YR 3/2	1-f-gr	#	#
5-19	Ap2	10 YR 3/2	2-f-sbk/2-m-gr	#	#
19-33	Bt1	10 YR 4/3	2-f-pr/1-f-sbk	5% D D CLF APF	#
33-51	Bt2	10 YR 5/3	3-f-pr/2-f-abk	10% D C CLF APF 1% D P SKF VPF	#
51-97	Bk1	10 YR 5/4	1-m-pr	#	3% F I CAM MAT 1% M I CAM MAT
97-230	Bk2	10 YR 5/4	1-co-pr	#	1% F T CAM MAT 2% F I CAM MAT

†Matrix colors are Munsell colors of moist peds

‡Grade: 1=weak, 2=moderate, 3=strong; Size: vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse; Type: gr=granular, abk=angular block, sbk=subangular blocky, pr=prismatic

§Kind: CLF=clay films (argillans), PRF=pressure faces; Continuity: C=Continuous, D=Discontinuous, P=Patchy; Distinctness: F=Faint, D=Distinct, P=Prominent; Location: PF=All ped faces, VF=Vertical ped faces, HF=Horizontal ped faces

¶Kind: CAM=carbonate masses, CAN=carbonate nodules; Size: F=fine, M=medium, C=coarse; Shape: I=irregular, T=threadlike; Location: MAT=in the matrix, TOT=throughout, SPO=on surfaces along pores

#None present

Appendix D - Micromorphology Descriptions

ST 101 irrigated Ulysses							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bk1	27-44	None	Very few, thin grain argillans	Granostriated	Few masses, 25-75µm	Common quasi and masses ranges from 100µm-2000µm	Common
Bk2	44-68	None	Very few, thin grain argillans, but more than previous horizon	Granostriated	None	Frequent quasi and masses ranges from 100µm-2000µm	Common
Bk3	68-129	Very few, thin, discontinuous illuvial argillans along voids	Few, thin grain argillans	Monostriated	None	Frequent quasi and masses ranges from 100µm-2000µm	Common

† Used to describe oriented clay and stress feature: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

ST 102 irrigated Keith							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt	18-28	Very few clay infillings within matrix 50µm-100µm long	Thin, frequent grain argillans	Granostriated	Common Masses 100-150µm	Quasi Masses and nodules, dominant ranges from 250µm- 1000µm	Common crystals from 50-375µm
Bk1	28-46	None	Very thin, frequent grain argillans, less than horizon above	Granostriated and stipple specked	Few Masses 75µm-150µm	Quasi Masses, Common ranges from 250µm to 1000µm. Less than horizons above	Common crystals from 50-375µm
Bk2	46-82	None	Thin, frequent grain agrillians	Granostriated.		Very Dominant Quasi, hypocoatings, and nodules ranges from 250µm-2000µm	Common crystals from 50-375µm

† Used to describe oriented clay and stress feature: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

ST 104 Non-irrigated Keith							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	5-23	Very few, thin, discontinuous illuvial argillans along voids	Frequent, thin grain argillans	Monostriated	Very few nodules (30-100μm) and masses (100-400μm)	None	Common- Not intact
Bt2	23-46	Very few, thin, discontinuous illuvial argillans along voids; hypocoatings associated with voids	Frequent, thin grain argillans.	Granostriated	None	None	Common- not intact
Bk1	46-144	None	Common, thin grain argillans.	Granostriated	Very few nodules and masses 100-400μm	None	Common- not intact
Bk2	144-230	None	Very few, thin grain argillans	Granostriated	None	Quasi-carbonate coatings	Common- intact

† Used to describe oriented clay and stress feature: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20μm), medium (20-200μm), thick (>200μm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

ST 106 Non-irrigated Keith							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Btk1	12-46	None	Thin, frequent, continuous grain argillians	Granostriated	Common, nodules, 30-50µm in diameter. Mainly located surrounding a void	Masses, Nodules, Hypocoating, and Quasi very dominant	Frequent and intact
Btk2	46-69	None	Thin, very frequent, continuous grain argillans	Granostriated	Common Noduels, 30-50µm in diameter.	Masses, hypocoatings, and quasi dominant. Carbonate looks different than others	Frequent and intact
Bw	69-89	Thin illuvial clay coatings along voids, common, discontinuous	Thin very frequent, continuous grain argillans	Granostriated	Common nodules and masses 30-50µm	None	Frequent- less intact than pervious horizons

† Used to describe oriented clay and stress feature: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

ST 201 Irrigated Keith							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Btk1	4-28	None	Dominant, thin grain argillians	Granostriated	Common nodules 20-50µm	Common masses and nodules typically located along void	Frequent
Btk2	28-44	None	Dominant, thin grain agrillans	Granostriated	Common nodules 20-50µm	Common very large masses and nodules; frequent hypocoatings and quasi associated with voids.	Frequent
Bk1	44-116	None	Frequent, thin grain argillans	Granostriated	Few nodules 20-50µm	Dominant coatings and hypocoatings associated with voids.	Frequent
Bk2	116-168	None	Frequent, thin grain argillans	Granostriated	Very few nodules 20-50µm	Frequent fine disseminated carbonate material	Frequent
Bk3	168-230	None	Frequent, thin grain argillans	Granostriated	None	Frequent hypocoatings, nodules, masses and quasi associated with voids.	Frequent

†Used to describe oriented clay and stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

ST 203 Irrigated Keith							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Btk*	12-34	Hypocoatings around void	Thin grain agrillans, that are present in hypocoatings may not be illuvial but seem to be affected by irrigations	Granostriated	Frequent nodules, 30-50µm in size	Masses, nodules, quasi and hypocoatings.	Common, not as prominent as Bk horizons from other pedons
Bt	34-59	Thin illuvial argillans along voids Hypocoatings around void	Thin grain argillans, same as previous horizon	Granostriated	Frequent nodules, 30-50µm in size	None- Really weird compared to Bt1	Common, not as prominent as Bk horizons from other pedons
Bk1	59-115	Thin illuvial argillans very few	Thin grain argillans, very frequent	Granostriated	Frequent nodules, 30-50µm in size	Quasi and hypocoatings but not very prominent.	Frequent
Bk2	115-230	None	Thin grain agrillans very frequent	Stipple Speckled	Common nodules 30-50µmin size	Dominant quasi, hypocoatings, masses and nodules; Carbonate is also in fine mass that is spread all over bfabric and is over the grain argillans	Frequent

†Used to describe oriented clay and stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness-thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); *Changed from Bt to Btk based off micrmorphology

ST 204 Non-irrigated Keith							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	15-29	Thin, common illuvial argillans; hypocoatings associated with voids.	Thin, dominant grain argillans.	Granostriated	Few concentrations 30-50µm	None	Frequent
Bt2	29-44	Thin, common illuvial argillans; dominant hypocoatings associated with voids	Thin, dominant grain argillans. Grain argillans are thicker and easier to see around voids.	Granostriated	Few concentrations 30-50µm	None	Frequent
Bk1	44-87	None	Thin, common grain argillans	Granostriated	Few Concentrations 30-50µm	Common nodules hypocoatings, and fine disseminated carbonate material	Frequent

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%)

ST 205 Non-irrigated Kuma							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt	25-50	Thin illuvial argillans located along voids	Thin grain argillans	Granostriated	Common nodules 30-50µm	None	Very frequent
Btk	50-70	Prominent thin illuvial argillans present along voids discontinuous	Thin grain argillans	Monostriated	Common nodules 30-50µm	Few Nodules and Masses between 150-300µm	Very frequent
Bk1	70-99	Prominent Thin illuvial discontinuous argillans. Located more along thin voids compared to large voids/pore spaces.	Thin grain argillans. Prominent.	Granostriated	Common nodules 30-50µm	Few quasi, fine micrite that is unorganized. Normally associated with voids, One nodule 200µm.	Very Frequent

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%)

ST 206 Non-irrigated Richfield							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	19-33	Illuvial argillans range in thickness from 10-25µm. Discontinuous, but they are the thickest yet. Dominant hypocoatings and quasi.	Thin grain argillans <25µm	Granostriated and monostriated	Common nodules 30-50µm	None	Very Frequent
Bt2	33-51	Illuvial argillans, discontinuous, <20µm thick. Less argillans than previous horizon. Dominant hypocoatings and quasi	Thin grain argillans 25-30µm thick. Very prominent	Granostriated and monostriated	Common nodules 30- 100µm	None	Very frequent
Bk1	51-97	No argillans, but quasi are present and associated with voids	Thin grain argillans <20µm thick. Not as prominent as previous horizon	Granostriated	Common nodules 30-100µm	Masses and nodules present along voids and in groundmass range from 100µm-1000µm Also fine organized micrite over grains	Very frequent, more than previous horizon

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%)

ST 301 Irrigated Keith

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt	23-38	Common, thin, discontinuous illuvial argillans; common hypocoatings associated with voids.	Dominant, thin grain argillans	Granostriated	Common nodules 30-50µm	None	Frequent
Btk*	38-61	Few, thin, discontinuous illuvial argillans; common hypocoatings associated with voids	Dominant, thin grain argillans.	Granostriated	Common nodules 30-50µm	Common nodules 30-100µm, masses 50-200µm and quasi 50-100µm associated with voids.	Frequent
Bk1	61-87	None	Frequent, thin grain argillans.	Granostriated	Common nodules 30-50µm	Frequent quasi 50-100µm associated with voids; few Nodules 50-100µm	Frequent

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%)

*Changed from Bt2 to Btk based off of micromorphology

ST 302 Irrigated Keith							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt	5-24 cm	Few thin discontinuous illuvial argillans	Very dominant grain argillans. Thin <20µm, continuous	Granostriated	Fe Nodules< 50µm Frequent. Fine masses that cover grain and illuvial argillans and are associated with voids	None	Common
Bt2	24-40	Few thin	Very dominant grain argillans. Thin <20µm continuous	Granostriated	Nodules common <50µm. Fine masses that cover grains, associated with voids	None	Common
Bk1	40-72	None	Very dominant grain argillans. Thin <10µm continuous	granostriated	Nodules 30-50µm Frequent. Fine masses scattered with no pattern.	Very Few Concentrations about 100µm. Masses of carbonate found along voids. Masses were frequent between 250µm-300µm. Also fine carbonate material is present all over b-fabric to cover grains	Common

Bk2	72-197	None	Dominant-Frequent, around 50% of grain argillans. Thin<10µm continuous	Granostriated	Large mass of Fe, maybe larger than 1mm in some parts. Concentrations frequent 20-75µm	Few nodules 100-200µm. Masses 150-300µm associated with voids, frequent. Fine carbonate material is unorganized and present in b-fabric	Common
Bk3	197-230	None	Frequent (less than previous horizon) thin <10µm grain argillans. Mostly covered by carbonate material	granostriated	Nodules Frequent, 20-50µm	Frequent Hypocoatings and quasi of carbonate material in masses. Few nodules. Quasi and hypocoatings associated with voids. Carbonate material is also present in fine unorganized material within ground mass	Frequent

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%)

ST 304 Non-irrigated Keith							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt	23-38	Common, thin, discontinuous illuvial argillans; common hypocoatings associated with voids.	Dominant, thin grain argillans	Granostriated	Nodules 30-50µm	None	Frequent
Btk*	38-61	Few; thin, discontinuous illuvial argillans; common hypocoatings associated with voids	Dominant, thin grain argillans	Granostriated	Nodules 30-50µm	Common nodules 30-100µm, masses 50-200µm and quasi 50-100µm associated with voids.	Frequent
Bk1	61-87	None	Frequent, thin grain argillans	Granostriated	Nodules 30-50µm	Frequent quasi 50-100µm associated with voids; few Nodules 50-100µm	Frequent

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

*Changed from Bt2 to Btk based off micromorphology

ST 305 Non-irrigated Richfield

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
B**t1**	18-34	Frequent thin illuvial argillans <10µm Hypocoatings and quasi associated with voids	Dominant thin grain argillans<10µm. Associated with voids	Granostriated	Quasi and hypocoatings associated with voids. Nodules frequent 20-50µm	None	Dominant
Bt**2**	34-45	Few thin illuvial argillans <10µm; Few hypocoatings and quasi associated with voids	Dominant thin grain argillans <10µm. Associated with voids	Granostriated	Frequent nodules 20-50µm. Few quasi and hypocoatings	None	Dominant
Bk1	45-148	None	Frequent grain argillans <10µm thick. Associated with voids	Granostriated	Frequent nodules 20-50µm . Few quasi and hypocoatings	Common nodules 50-200µm. Frequent quasi and hypocoatings	Dominant

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

ST 401 irrigated Keith

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	15-29	Very few, thin, discontinuous illuvial argillans. Few hypocoatings associated with voids	Thin, dominant grain argillans. Abundance higher when associated with voids	Granostriated	Frequent hypocoatings associated with voids; common nodules 20-50µm	None	Common –not intact
B**t**2	29-39	Very few, thin, discontinuous, illuvial argillans. Very few hypocoatings associated with voids	Thin, frequent grain argillans.	Monostriated	Frequent hypocoatings associated with voids; Frequent nodules 20-50µm	None	Common- not intact
Bk1	39-80	None	Thin, common grain argillans.	Granostriated	Common nodules 20-50µm	Common Nodules 50-200µm; Dominant quasi and masses. Dominant- fine dismantled carbonate material in ground mass	Common intact minerals

† Used to describe oriented clay and stress feature: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

ST 402 Irrigated Richfield

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	25-48	Very few, thin, discontinuous illuvial argillans associated with voids; few hypocoatings associated with voids	Dominant grain argillans; abundance higher when associated with voids	Granostriated	Dominant hypocoatings associated with voids; frequent nodules 20-50µm	None	Frequent-not intact
Bt2	48-83	Few, thin, discontinuous illuvial argillans associated with voids; few hypocoatings associated with voids	Very dominant grain argillans.	Monostriated	Few hypocoatings associated with voids; common nodules 20-50µm.	None	Frequent-not intact
Bk1	83-165	None	Few grain argillans; very thin and very hard to see	Granostriated	Common nodules 20-50µm	Frequent quasi associated with voids; common nodules 100-200µm	Frequent-intact minerals
Bk2	165-230	None	Few grain argillans; very thin and very difficult to see	Granostriated	Common nodules 20-50µm	Frequent quasi associated with voids; few nodules 50-100µm; other carbonate was fine disseminated carbonate material.	Frequent-intact minerals

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness-thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

ST 404 Non-irrigated Keith							
Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	28-47	Frequent, discontinuous, thin <30µm illuvial argillans. Also hypocoatings and quasi associated with voids	Dominant thin grain argillans stronger when associated with voids	Granostriated	Frequent Fe-Mn nodules 20-50µm. Common Fe-Mn hypocoats and quasi associated with voids	None	Dominant
Bt2	47-64	Frequent, but less than previous horizon, thin <20µm illuvial argillans. Hypocoatings and quasi associated with voids.	Dominant thin grain argillans strong with associated with voids	Monostriated	Common Fe-Mn nodules 20-50µm. Few hypocoats and quasi associated with voids	None	Dominant
Btk	64-118	Very few thin, discontinuous illuvial argillans	Frequent thin grain argillans	Granostriated	Common Fe-Mn nodules 20-50µm.	Dominant Hypocoatings and Quasi associated with voids. Few nodules 50-100µm. also carbonate present in unorganized material within the groundmass	Dominant

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%); Thickness-thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

ST 405 Non-irrigated Keith

Horizon	Depth	Oriented Clay†	Stress Features†	b-fabric‡	Fe-Mn Features‡	Carbonate Forms‡	Mica§
	cm						
Bt1	15-32	Frequent, thin-medium, illuvial argillans. About 60% are discontinuous, 40% are continuous; common hypocoats associated with voids	Dominant, thin, grain argillans	Granostriated	Common Fe-Mn nodules 20-50 µm; few hypocoats associated with voids	Few nodules 20-100µm; fine disseminated carbonate material	Frequent-not intact
Bt2	32-46	Frequent thin-medium illuvial argillans. 50% continuous, 50% discontinuous; frequent hypocoats associated with voids	Dominant, thin, grain argillans	Monostriated	Common Fe-Mn nodules 20-50µm; very few hypocoats associated with voids	None	Frequent-not intact
Btk	46-64	Few thin, discontinuous illuvial argillans	Frequent, thin grain argillans	Granostriated	Few Fe-Mn nodules 20-50µm	Frequent quasi and masses associated with voids; few nodules 50-100µm; fine disseminated carbonate material	Frequent-not intact

†Used to describe oriented clay, stress features: Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);Thickness- thin(<20µm), medium (20-200µm), thick (>200µm); Continuity: continuous, discontinuous

‡Described using terminology from (Stoops, 2003)

§Abundance: very dominant (>70%), dominant (50-70%), frequent (30-50%), common (15-30%), few (5-15%), very few (<5%);

Appendix E - Full Characterization Data for Keith Pedon

Source: National Cooperative Soil Survey. 2016. National Cooperative Soil Survey Characterization Database.

http://ncsslabdatamart.sc.egov.usda.gov/ Accessed Monday, April 25, 2016

*** Primary Characterization Data ***

Pedon ID: 90KS023001
(Cheyenne, Kansas)
Print Date: Apr 25 2016 9:34AM

Sampled as on Jul 1, 1990: Keith ; Fine-silty, mixed, mesic Aridic Argiustoll
Revised to correlated: Keith ; Fine-silty, mixed, superactive, mesic Aridic Argiustolls

SSL - Project CP90NE215 SOUTHWEST
- Site ID S1990KS023001 Lat: 39° 37' 50.00" north Long: 101° 27' 6.99" west MLRA: 72
- Pedon No. 90P0794
- General Methods 1B1A, 2A1, 2B

United States Department of Agriculture
Natural Resources Conservation Service
National Soil Survey Center
Soil Survey Laboratory
Lincoln, Nebraska 68508-3866

Layer	Horizon	Orig Hzn	Depth (cm)	Field Label 1	Field Label 2	Field Label 3	Field Texture	Lab Texture
90P04651	Ap1	AP1	0-11				SIL	SIL
90P04652	Ap2	AP2	11-18				SIL	SIL
90P04653	Bt	BT	18-41				SICL	CL
90P04654	Btk	BTK	41-62				SICL	L
90P04655	Bk	BK	62-84				SIL	L
90P04656	C1	C1	84-115				SIL	SIL
90P04657	C2	C2	115-155				SIL	L
90P04658	C3	C3	155-187				SIL	SIL
90P04659	C4	C4	187-213				SIL	SIL
90P04660	C5	C5	213-288				SIL	SIL
90P04661	C6	C6	288-367				SIL	L
90P04662	C7	C7	367-492				SIL	SIL
90P04663	C8	C8	492-596				FSL	SIL
90P04664	C9	C9	596-716				FSL	SIL
90P04665	2C	2C	716-795				CL	CL

Pedon Calculations

Calculation Name	Result	Units of Measure
Weighted Particles, 0.1-75mm, 75 mm Base	2	% wt
Volume, >2mm, Weighted Average	0	% vol
CEC Activity, CEC7/Clay, Weighted Average	0.86	(NA)
Clay, total, Weighted Average	27	% wt
Clay, carbonate free, Weighted Average	25	% wt

Weighted averages based on control section: 18-61 cm

*** Primary Characterization Data ***

Pedon ID: 90KS023001 (Cheyenne, Kansas) Print Date: Apr 25 2016 9:34AM

Sampled As : Keith Fine-silty, mixed, mesic Aridic Argiustoll

USDA-NRCS-NSSC-Soil Survey Laboratory ; Pedon No. 90P0794

PSDA & Rock Fragments

				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-
					(- - - - - Total - - - - - -)			(- - Clay - - -)		(- - - - Silt - - - - -)		(- - - - - - - - - - - - - Sand - - - - - - - - - - - - -)					(Rock Fragments (mm))				
				Lab	Clay	Silt	Sand	Fine	CO_3	Fine	Coarse	VF	F	M	C	VC	(- - - - - - - - Weight - - - - - - - -)				>2 mm
				Text-	<	.002	.05	<	<	.002	.02	.05	.10	.25	.5	1	2	5	20	.1-	wt %
	Depth			ure	.002	-.05	-2	.0002	.002	-.02	-.05	-.10	-.25	-.50	-1	-2	-5	-20	-75	75	whole
Layer	(cm)	Horz	Prep		(- % of <2mm Mineral Soil -)												(- - - - - - - % of <75mm - - - - - -)				soil
				3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a	3A1a1a	3B1	3B1	3B1		
90P04651	0-11	Ap1	S	sil	20.9	50.3	28.8	12.8		17.2	33.1	26.7	1.2	0.6	0.3	tr	--	--	--	2	--
90P04652	11-18	Ap2	S	sil	26.7	50.1	23.2	18.3		14.6	35.5	21.8	0.9	0.4	0.1	--	--	--	--	1	--
90P04653	18-41	Bt	S	cl	27.7	41.1	31.2	15.4		13.9	27.2	29.2	1.0	0.7	0.3	tr	--	--	--	2	--
90P04654	41-62	Btk	S	l	26.8	49.7	23.5	6.8	4.6	19.1	30.6	22.6	0.6	0.2	0.1	tr	--	--	--	1	--
90P04655	62-84	Bk	S	l	21.2	48.1	30.7	4.2	4.0	19.4	28.7	29.7	0.7	0.2	0.1	tr	--	--	--	1	--
90P04656	84-115	C1	S	sil	16.5	52.1	31.4	3.6	2.2	17.7	34.4	30.4	0.7	0.2	0.1	tr	--	--	--	1	--
90P04657	115-155	C2	S	l	14.8	46.6	38.6	3.1	1.2	17.1	29.5	37.5	0.8	0.2	0.1	--	--	--	--	1	--
90P04658	155-187	C3	S	sil	13.7	50.7	35.6	3.2	0.9	16.8	33.9	34.5	0.7	0.3	0.1	--	--	--	--	1	--
90P04659	187-213	C4	S	sil	13.2	50.9	35.9	2.8		16.9	34.0	34.5	0.9	0.3	0.1	0.1	--	--	--	1	--
90P04660	213-288	C5	S	sil	12.5	58.0	29.5		0.9	14.4	43.6	28.3	0.9	0.2	0.1	tr	--	--	--	1	--
90P04661	288-367	C6	S	l	12.9	41.1	46.0		0.9	13.8	27.3	43.0	1.9	0.6	0.4	0.1	--	--	--	3	--
90P04662	367-492	C7	S	sil	12.9	54.5	32.6			16.2	38.3	31.7	0.7	0.1	0.1	tr	--	--	--	1	--
90P04663	492-596	C8	S	sil	12.3	55.1	32.6		1.2	17.5	37.6	31.3	0.7	0.4	0.1	0.1	--	--	--	1	--
90P04664	596-716	C9	S	sil	12.6	56.3	31.1			17.5	38.8	30.1	0.7	0.2	0.1	tr	--	--	--	1	--
90P04665	716-795	2C	S	cl	29.6	26.3	44.1		14.7	13.0	13.3	33.3	5.2	3.8	1.2	0.6	tr	1	--	12	1

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Pedon ID: 90KS023001 (Cheyenne, Kansas) Print Date: Apr 25 2016 9:34AM

Sampled As : Keith Fine-silty, mixed, mesic Aridic Argiustoll

USDA-NRCS-NSSC-Soil Survey Laboratory ; Pedon No. 90P0794

Bulk Density & Moisture				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-
				(Bulk Density)		Cole	(- - - - - - - - - - - Water Content - - - - - - - - - - -)						WRD	Aggst		
				33	Oven	Whole	6	10	33	1500	1500 kPa	Ratio	Whole	Stabl	(- - Ratio/Clay - -)	
	Depth			kPa	Dry	Soil	kPa	kPa	kPa	kPa	Moist	AD/OD	Soil	2-0.5mm	CEC7	1500 kPa
Layer	(cm)	Horz	Prep	(- - - g cm^{-3} - - -)			(- - - - - - - - - - - - % of < 2mm - - - - - - - - - - - -)						cm^3 cm^{-3}	%		
				4A1d	4A1h				4B1c	3C2a1a		3D1	4C1	3F1a1a	8D1	8D1
90P04651	0-11	Ap1	S							11.2		1.020		7	0.88	0.54
90P04652	11-18	Ap2	S	1.31	1.53	0.053			28.8	14.4		1.026	0.19		0.80	0.54
90P04653	18-41	Bt	S	1.27	1.46	0.048			26.7	14.9		1.027	0.15		0.88	0.54
90P04654	41-62	Btk	S	1.36	1.45	0.022			26.4	14.9		1.027	0.16		0.83	0.56
90P04655	62-84	Bk	S	1.29	1.36	0.018			25.7	12.4		1.024	0.17		0.94	0.58
90P04656	84-115	C1	S	1.25	1.35	0.026			25.4	10.6		1.022	0.19		1.13	0.64
90P04657	115-155	C2	S	1.25	1.34	0.023			27.8	9.6		1.021	0.23		1.21	0.65
90P04658	155-187	C3	S							9.4		1.019			1.28	0.69
90P04659	187-213	C4	S	1.29	1.34	0.013			23.5	9.1		1.019	0.19		1.33	0.69
90P04660	213-288	C5	S							8.5		1.020			1.35	0.68
90P04661	288-367	C6	S							9.2		1.022			1.39	0.71
90P04662	367-492	C7	S							9.3		1.023			1.39	0.72
90P04663	492-596	C8	S							9.3		1.023			1.51	0.76
90P04664	596-716	C9	S							9.5		1.023			1.44	0.75
90P04665	716-795	2C	S							9.9		1.015			0.38	0.33

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Pedon ID: 90KS023001
(Cheyenne, Kansas)
Print Date: Apr 25 2016 9:34AM

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Fine-silty, mixed, mesic Aridic Argiustoll

USDA-NRCS-NSSC-Soil Survey Laboratory ; Pedon No. 90P0794

Water Content

Layer	Depth (cm)	Horz	Prep	-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-
				(- - Atterberg - -)		(- - - - - Bulk Density - - - - -)			(- Water Content -)							
				(- - - Limits - - -)		Field	Recon	Recon	Field	Recon	(- - - - - - - - - - - - - - - Sieved Samples - - - - - - - - - - - - -)					
				LL	PI		33 kPa	Oven Dry		33 kPa	6 kPa	10 kPa	33 kPa	100 kPa	200 kPa	500 kPa
				pct <0.4mm		(- - - - - - - - g cm^{-3} - - - - - - -)			(- % of < 2mm -)							
				4F1	4F										3C1e1a	
90P04651	0-11	Ap1	S	36	15										15.9	
90P04652	11-18	Ap2	S												20.1	
90P04653	18-41	Bt	S	42	25										21.0	
90P04654	41-62	Btk	S												19.8	
90P04655	62-84	Bk	S												16.6	
90P04656	84-115	C1	S	32	10										13.9	
90P04657	115-155	C2	S												12.4	
90P04658	155-187	C3	S												11.9	
90P04659	187-213	C4	S												11.5	
90P04660	213-288	C5	S												10.5	
90P04661	288-367	C6	S												11.5	
90P04662	367-492	C7	S												11.1	
90P04663	492-596	C8	S												11.5	
90P04664	596-716	C9	S												11.5	
90P04665	716-795	2C	S												13.4	

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Pedon ID: 90KS023001 (Cheyenne, Kansas) Print Date: Apr 25 2016 9:34AM

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USDA-NRCS-NSSC-Soil Survey Laboratory ; Pedon No. 90P0794

Carbon & Extractions				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-	-19-
				(- - - - - Total - - - - -)			Est	OC	C/N	(- - - Dith-Cit Ext - - -)			(- - - - - - Ammonium Oxalate Extraction - - - - - -)						(- - - Na Pyro-Phosphate - - -)			
	Depth			C	N	S	OC	(WB)	Ratio	Fe	Al	Mn	Al+½Fe	ODOE	Fe	Al	Si	Mn	C	Fe	Al	Mn
Layer	(cm)	Horz	Prep	(- - - - - - - - - - % of <2 mm - - - - - - - - - -)						(- - - - - - - - - - - - - - - - - - - % of < 2mm - - - - - - - - - - - - - - - - - -)								mg kg^{-1}	(- - - - - - % of < 2mm - - - - -)			
					6B3a			6A1c														
90P04651	0-11	Ap1	S		0.116			1.31	11													
90P04652	11-18	Ap2	S		0.109			0.93	9													
90P04653	18-41	Bt	S		0.073			0.59	8													
90P04654	41-62	Btk	S					0.50														
90P04655	62-84	Bk	S					0.32														
90P04656	84-115	C1	S					0.19														
90P04657	115-155	C2	S					0.15														
90P04658	155-187	C3	S					0.12														
90P04659	187-213	C4	S					0.10														
90P04660	213-288	C5	S					0.09														
90P04661	288-367	C6	S					0.09														
90P04662	367-492	C7	S					0.10														
90P04663	492-596	C8	S					0.11														
90P04664	596-716	C9	S					0.12														
90P04665	716-795	2C	S					0.07														

CEC & Bases				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-
				(- - - - - - NH$_4$OAC Extractable Bases - - - - -)								CEC8	CEC7	ECEC		(- - - - Base - - - -)	
								Sum	Acid-	Extr	KCl	Sum	NH$_4$	Bases	Al	(- Saturation -)	
	Depth			Ca	Mg	Na	K	Bases	ity	Al	Mn	Cats	OAC	+Al	Sat	Sum	NH$_4$OAC
Layer	(cm)	Horz	Prep	(- - - - - - - - - - - - - - - - - - cmol(+) kg^{-1} - - - - - - - - - - - - - - - - - - -)							mg kg^{-1}	(- - - - cmol(+) kg^{-1} - - -)			(- - - - - - - - % - - - - - - - -)		
				6N2e	6O2d	6P2b	6Q2b		6H5a			5A3a	5A8b			5C3	5C1
90P04651	0-11	Ap1	S	12.8*	3.7	tr	2.2	18.7	3.5			22.2	18.4			84	100
90P04652	11-18	Ap2	S	15.2*	4.6	0.1	1.9	21.8	8.9			30.7	21.4			71	100
90P04653	18-41	Bt	S	26.7*	6.0	0.2	1.9		0.3				24.3			99	100
90P04654	41-62	Btk	S	53.1*	7.5	0.2	1.9						22.3			100	100
90P04655	62-84	Bk	S	48.9*	8.0	0.4	2.4						20.0			100	100
90P04656	84-115	C1	S	51.0*	7.2	0.2	2.6						18.7			100	100
90P04657	115-155	C2	S	44.8*	6.0	0.5	2.6						17.9			100	100
90P04658	155-187	C3	S	38.7*	4.4	1.2	2.3						17.5			100	100
90P04659	187-213	C4	S	44.0*	4.2	1.5	2.1						17.5			100	100
90P04660	213-288	C5	S	48.1*	3.9	1.1	1.7						16.9			100	100
90P04661	288-367	C6	S	45.1*	3.7	1.1	1.6						17.9			100	100
90P04662	367-492	C7	S	48.2*	3.7	1.0	1.4						17.9			100	100
90P04663	492-596	C8	S	45.4*	3.7	1.0	1.4						18.6			100	100
90P04664	596-716	C9	S	51.8*	3.7	0.7	1.2						18.1			100	100
90P04665	716-795	2C	S	47.6*	3.2	0.5	0.8						11.1			100	100

*Extractable Ca may contain Ca from calcium carbonate or gypsum., CEC7 base saturation set to 100.

Salt	-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-	-19-	-20-

				(- - - Water Extracted From Saturated Paste - - -)																	1:2		
	Depth			Ca	Mg	Na	K	CO_3	HCO_3	F	Cl	PO_4	Br	OAC	SO_4	NO_2	NO_3	H_2O	Total Salts	Elec Cond	Elec Cond	Exch Na	SAR
Layer	(cm)	Horz	Prep	(- - - - - mmol(+) L^{-1} - - - - -)				(- mmol(-) L^{-1} -)										(- - - - % - - - -)		(- - dS m^{-1} - -)		%	
																					4F1a1a1		
90P04651	0-11	Ap1	S																		0.27	--	
90P04652	11-18	Ap2	S																		0.12	tr	
90P04653	18-41	Bt	S																		0.26	1	
90P04654	41-62	Btk	S																		0.26	1	
90P04655	62-84	Bk	S																		0.26	2	
90P04656	84-115	C1	S																		0.24	1	
90P04657	115-155	C2	S																		0.24	3	
90P04658	155-187	C3	S																		0.28	7	
90P04659	187-213	C4	S																		0.27	9	
90P04660	213-288	C5	S																		0.23	7	
90P04661	288-367	C6	S																		0.24	6	
90P04662	367-492	C7	S																		0.22	6	
90P04663	492-596	C8	S																		0.22	5	
90P04664	596-716	C9	S																		0.24	4	
90P04665	716-795	2C	S																		0.32	5	

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pH & Carbonates				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-
				(- - - - - - - - - - - - - - - - - - pH - - - - - - - - - - - - - - - - - -)						(- - Carbonate - -) As $CaCO_3$		(- - Gypsum - - -) As $CaSO_4*2H_2O$		Resist
	Depth				$CaCl_2$ 0.01M	H_2O	Sat			<2mm	<20mm	<2mm	<20mm	ohms
Layer	(cm)	Horz	Prep	KCl	1:2	1:1	Paste	Oxid	NaF	(- - - - - - - - - - - - %			- - - - - - - - - - - -)	cm^{-1}
					4C1a2a	4C1a2a				6E1g				
90P04651	0-11	Ap1	S		6.4	7.0								
90P04652	11-18	Ap2	S		6.3	7.1								
90P04653	18-41	Bt	S		7.4	8.0				1				
90P04654	41-62	Btk	S		7.6	8.3				8				
90P04655	62-84	Bk	S		7.7	8.3				8				
90P04656	84-115	C1	S		7.7	8.3				8				
90P04657	115-155	C2	S		7.7	8.5				6				
90P04658	155-187	C3	S		7.8	8.6				6				
90P04659	187-213	C4	S		7.8	8.6				6				
90P04660	213-288	C5	S		7.8	8.5				6				
90P04661	288-367	C6	S		7.7	8.5				5				
90P04662	367-492	C7	S		7.7	8.4				6				
90P04663	492-596	C8	S		7.7	8.5				6				
90P04664	596-716	C9	S		7.7	8.4				6				
90P04665	716-795	2C	S		7.6	8.2				21				

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Clay Mineralogy (<.002 mm)				-1-	-2-	-3-	-4-	-5-	-6-	-7-	-8-	-9-	-10-	-11-	-12-	-13-	-14-	-15-	-16-	-17-	-18-
				X-Ray				Thermal					Elemental							EGME	Inter preta tion
													SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O	Retn	
	Depth		Fract	7A2i									7C3								
Layer	(cm)	Horz	ion	(- - - peak size - - -)				(- - - % - - -)					(- - - % - - -)							mg g^{-1}	
90P04651	0.0-11.0	Ap1	tcly	MT 3	MI 3	KK 2	QZ 1							16	6.4			2.4			
90P04653	18.0-41.0	Bt	tcly	MT 3	MI 2	KK 2	QZ 1							18	6.3			2.1			

FRACTION INTERPRETATION:
tcly - Total Clay <0.002 mm

MINERAL INTERPRETATION:

KK Kaolinite	MI Mica	MT Montmorillonite	QZ Quartz

RELATIVE PEAK SIZE:						
	5 Very Large	4 Large	3 Medium	2 Small	1 Very Small	6 No Peaks