LONG-TERM EFFECTS OF SUBSURFACE DRAIN SPACING ON SOIL PHYSICAL AND CHEMICAL PROPERTIES

by

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ABSTRACT

Subsurface tile drainage is a commonly used practice to lower the water table in poorly drained soils, and is often done to improve soil conditions for agricultural operations. Tile drainage has been shown to increase cash crop yield, allow for more timely field operations, and reduce erosion. However, few studies have evaluated the potential long-term changes in soil physical and chemical properties as a result of subsurface tile drainage. This study was conducted on a naturally poorly drained Clermont silt loam soil located at the Southeast Purdue Ag Center near Butlerville Indiana. The intent of this study was to characterize possible evolution of soil physical and chemical properties after 35 years of subsurface drainage. The field site was established in the spring of 1983 with tile drains installed in 2 blocks with tile spacings of 5, 10, 20, and 40m, with the 40-m spacing used as the undrained control. Soil samples were collected in May of 2018 to a depth of 1 meter and were analyzed for carbon and nitrogen content, aggregate stability, and fertility at depth increments of 0-5, 5-15, 15-30, 30-50, 50-75 and 75-100cm. In-field measurements were also taken in May of 2018 for vane shear resistance and in May of 2019 for cone penetration resistance. Total carbon content was found to be significantly higher in the 5-m tile spacing than the 40-m tile spacing in the 0-5cm and 5-15cm depths, with the 10-m and 20-m tile spacings being intermediate. Conversely, in the 75-100cm depth the inverse trend was observed, where the 40-m tile spacing was found to have significantly greater carbon content than narrower tile spacings. Trends observed with carbon stocks per depth increment closely followed trends observed with carbon content at the same depth. However, no significant differences were observed among treatments with the summation of carbon stocks to the 1-m depth. Tile spacing did not have a significant effect on aggregate stability at any depth. The soil fertility data showed some indication of the potential translocation of soil calcium from the soil surface to lower depths in the soil profile resulting in significantly higher soil pH in the 5-m tile spacing than the 40-m tile spacing in all depths below 30cm. No consistent differences related to treatment were found with the cone penetrometer or vane shear penetrometer measurements. After 35 years of drainage history, tile drain spacing did not have a significant effect on total carbon stocks to the 1-m depth, but rather seems to have had a significant effect on the vertical distribution of soil carbon content throughout the soil profile.

CHAPTER 1. LITERATURE REVIEW

1.1 Introduction

Subsurface tile drainage is a method commonly used to lower the water table in the soil, and is often done to improve conditions for growing crops. Subsurface tile drainage consists of burying a series perforated flexible plastic pipes in the soil at the depth of the desired water table. These pipes are installed at a predetermined grade to allow gravity flow towards an outlet, such as a ditch or a stream. Excess soil moisture must be removed to prevent a negative impact to plant root growth and development or limitations to agricultural field operations**.**

Indiana is among the top five states in the nation for corn and soybean production (State Agriculture Overview, 2018), and more than 40% of Indiana's cropland relies on subsurface drainage (tile drainage) to be productive (Sugg, 2007). Indiana averages more than 40 inches of rainfall annually (US Department of Commerce, and NOAA, 2018) and only about 60% of the rainfall can be used by crops (Neild and Newman, 1987). Abundant rainfall makes Indiana one of the leading agricultural states. However, rainfall can also be an impediment to agricultural production. When soil moisture is in excess, it can negatively impact field trafficability and prevent seed germination. In addition, soil saturated with water does not warm as quickly in the spring, thus delaying planting of cash crops. If field saturation occurs for an excessive amount of time after germination it can reduce yield potential or even terminate the stand.

Improving soil drainage, although necessary to maximize agricultural operations, can have an adverse effect environmentally. Tile drainage, especially in Indiana has led to the loss of natural wetlands. Wetlands help both sustain wildlife and improve water quality. The public also has a deeply-rooted interest in the use of tile drainage, as tile drains create a path for nutrient and pesticide leaching into the water supply, which in large concentrations affects water quality. A large hypoxic zone at the mouth of the Mississippi River has made news in recent years. A hypoxic zone is an area of water that can no longer sustain fauna due to a low dissolved oxygen content. Excessive nutrients entering water ways, such as those from agricultural operations much farther upstream, are a large part of the cause of this hypoxic zone. (NOAA, 2009). It is important to recognize that the benefits of tile drainage must be weighed against the potential issues with water quality and effects on wildlife.

Subsurface drainage systems have been used for centuries. Some of the first tile drains where made of hollowed logs cut into segments, laid end to end and buried in a shallow trench. Eventually clay tiles were used, which is where the term “tile drain” originated. Even though tile drainage has been utilized for centuries in agriculture, we are just now beginning to understand how it affects the soil and our environment. There are many studies focusing on subsurface drainage, but few studies have looked at the effect of tile drain spacing on soil physical properties or carbon content.

1.2 Total Carbon and Nitrogen Content

Poorly drained soils often experience water logged conditions for extended periods of time. Under these conditions there is insufficient oxygen present, preventing aerobic organisms from decomposing organic matter (OM). Under anaerobic conditions (low-oxygen), the rate of decomposition of OM is greatly reduced, allowing higher amounts of OM to accumulate in poorly drained soils (Brady and Weil, 2010). Kumar et al. (2014) (conducted in central Ohio on a Crosby silt loam soil) observed that tillage had a significant negative influence on SOC and that no-till had a significantly positive relationship to SOC. It was also noted that the undrained soils had greater SOC at all depths compared to the soils that had subsurface drainage. Drainage also significantly influenced total nitrogen and the carbon to nitrogen ratio (C/N) in the top 10cm of the soil. Abid and Lal. (2008) found that the organic carbon concentration was higher in undrained soils and that it decreased with depth. This was attributed to a decrease in plant biomass inputs in the lower depths. This study was conducted in central Ohio on Kokomo silty clay and Crosby silt loam soils. Similarly, Van Wesemael et al. (2010) found that from 1960 to 2006 the largest losses in carbon stocks in Belgium ranging from 11 to > 45 Mg C ha^{-1} were caused by drainage of grassland soils.

1.3 Aggregation

Soil aggregation as defined by Amezketa et al. (1999) “involves the formation of aggregates through the joining of sand, silt and clay particles, and the stabilization by organic and inorganic materials”. Soil aggregate stability is the capacity of soil aggregates to resist degradation when exposed to stress (Amezketa, 1999). Aggregate analysis of soil by wet sieving is a procedure used to evaluate the stability of soil aggregates (MWD, mean weight diameter, measured in mm) (Kladivko, 2017). This analysis is used to suggest how well a soil can resist the destructive forces of raindrop impact and water erosion. Aggregate stability is influenced by many factors and the relationships between these factors. Climate is one of the factors that influences the stability of soil aggregates. Bullock et al. (1988) found that soil aggregate stability followed a seasonal cycle where aggregate cohesion decreased during fall and into winter but tended to increase during the spring and summer months. Blackman (1992) also found that aggregate stability follows a seasonal variation, however the seasonality appeared to be inter-twined with the biological factors such as the use of cover crops, root activity, soil temperature and moisture, as well as the microbial activity in the soil. Thus, the effects of climate on soil aggregate stability appears to be closely related to the annual biological cycle. Biological factors including plant roots, soil microbes, and soil fauna have also been shown to have a significant effect on soil aggregate stability. Hudek et al. (2017) conducted a study in North West Italy on soil classified as a Skeletic Eutric Regosol with a loamy sand texture. This study evaluated the effect of the root systems of native alpine vegetation on aggregate stability. This evaluation identified significant differences in soil aggregate stability in the presence of a living root system. In addition, a positive correlation between aggregate stability and root length density was also observed. Soil aggregate stability may also be impacted by soil drainage; however, several studies have found conflicting results. Lal and Fausey. (1993) and Abid and Lal. (2008) found that undrained soils had significantly higher MWD than the drained soils. These studies took place in central Ohio on Kokomo silty clay and Crosby silt loam soils. However, Kumar et al. (2014) found in the 0-10 cm depth that soils utilizing tile drainage improved MWD by 35% compared to soils without drainage. The 10-20 cm depth showed a comparable trend but was not significant. This experiment was also conducted in central Ohio on a Crosby silt loam soil. Kumar et al. (2014) also reported that tillage resulted in low aggregate stability and poor protection of soil organic matter (SOM). SOM is an important factor influencing aggregate stability.

Blackman (1992) found that SOM content had accounted for the greatest variation in aggregate stability.

1.4 Soil Fertility

Subsurface soil drainage improves soil conditions for agricultural production, however, there are some concerns associated with it. Most studies regarding the relationship of soil drainage and soil fertility primarily focus on the increased potential for nutrients leaching into tile drain water discharge. Of the primary nutrients applied to agricultural fields as fertilizer, nitrogen and phosphorus are the primary concern. Nitrate N loss in southern Indiana is greatest in subsurface drains during the fall through winter and into early spring. Kladivko et al. (1991, 1999, and 2004) reported as much as 80% of the total nitrate losses took place between November and April. Aside from the seasonal factor subsurface drain spacing can also affect the amount of nitrate that enters a tile drain. Kladivko et al. (1991, 2004) also found that drain flow volume and nitrate (N) losses were higher for narrower drain spacings.

Phosphorus is generally considered to be rather immobile in the soil, thus it is considered that its loss is more in part due to surface run off as opposed to losses from tile drainage systems. However, Smith et al. (2015) found that 48% of the total phosphorus losses from their fields (in northeastern Indiana) were from subsurface tile drains.

Several solutions have been proposed to mitigate the environmental impact of nutrient loss in tile drainage systems. Adeuya et al. (2012) evaluated the use of controlled water drainage to reduce the nitrate loads in subsurface drains in Indiana. This study found that over a two-year period the controlled water drainage system reduced N loads ranging from 18% to 22.7%. Evans et al. (1995) in a study conducted in North Carolina, found that controlled drainage can reduce nitrate and phosphorus loss through subsurface drains by 30% to 50% over conventional drainage methods. The use of cover crops has also been shown to reduce nutrient losses to water run off through tile drains. Wyland et al. (1996) conducted a study in the Salinas Valley of California, evaluating the impacts of winter cover crops in a vegetable production system. This study observed a 65-70% reduction in nitrate load with the use of cover crops.

Soil pH greatly effects the soil nutrient availability and the plants ability to take in the needed nutrients. There has been very little research on soil pH and how drainage may affect it. Frison et al. (2009) found that after 20 years of subsurface drainage, the soil's pH in the A horizon decreased with distance to the tile. It was also noted that the pH was similar beyond 2 meters from the drain. The pH also increased with depth, with the pH in the A horizon of 7.5 to 8.0 in the Bt horizon. This study was conducted in the Yonne plateau in France on a loam Albeluvisol soil.

1.5 Cone and Vane Shear Penetrometer

A soil's strength, or its tolerance to resist displacement and penetration, is an important aspect of a soil in its function as it relates to plant growth (Byrnes et al., 1982). Penetrometers are used to determine soil strength in the field. The cone penetrometer uses a steel cone attached to a long shaft with horizontal handles and a pressure gauge on top. The cone is pushed into the soil at a constant rate, and is used to identify layers of soil compaction as well as to reflect the potential resistance a plant root may face as it grows through the soil. Soil compaction can have a significant negative impact on agricultural soils, as noted by Raney et al. (1955), who found that soil compaction reduces soil aeration, prevents moisture penetration, and can inhibit plant root growth. As soils develop a restrictive layer (layer of compaction) the rate that water can infiltrate is reduced. This creates a higher water table in the soil that reduces the flow of oxygen into the soil; creating an anaerobic environment that can suffocate existing roots or limit their growth in the soil. Soil compaction can be remedied with the use of deep tillage equipment or by implementing the use of various cover crops into a field rotation. Cover crops have also been shown to increase soil organic matter (soil carbon) over time. Stone et al. (1993) found that increasing SOM can reduce the effects of soil compaction and reduce penetration resistance. The cone penetrometer has also been used to quantify the trafficability of a soil. Kornecki and Fouss (2001) evaluated trafficability influenced by subsurface drainage and used the cone penetrometer as their primary method of measuring soil strength. This study found that subsurface drainage improved trafficability by improving field conditions, allowing the operation of farm machinery a day earlier after a 30mm rain fall than in undrained soils.

Vane shear penetrometers use a set of 4 steel fins that are set at 90-degree angles from one another. These fins are attached to a long shaft with a torque gauge on top. The vane shear penetrometer is inserted into the soil to a given depth of interest, rotated until the soil reaches its maximum stress load where the vanes rotate freely, and the amount of force (torque) is recorded on the gauge. Bachmann et al. (2006) conducted a comparison of these two penetrometers and determined that the values given from both the cone penetrometer and the vane shear penetrometer show that the horizontal stress component is the primary force affecting the vertical penetration resistance as well as the shear resistance. This study also indicates that the measurements from both penetrometers can be used to indicate the horizontal stress component of soil strength.

Drainage has also been shown to have a strong relationship with penetration resistance. Lal and Fausey (1993) found that their undrained plots had approximately 20% lower penetration resistance than their drained plots, and that overall, penetration resistance was negatively correlated with soil moisture content. This study also found that, of the variability in penetration resistance, up to 41% of it could be accounted for by the differences in soil moisture content. However, the study also stated that the influence soil moisture has on penetration resistance varies between cash crop type (corn and soybeans). Kandel et al. (2013) also found similar results to Lal and Fausey (1993), in that their undrained plots had a lower penetration resistance than the drained plots. It was also noted that 42% of the variation in penetration resistance could be accounted for by the depth to the water table below the soil surface. However, they did not directly measure soil moisture content to evaluate its effect on their penetration resistance measurements. This study also noted that penetration resistance may also have been affected by the evapotranspiration (ET) rate of different cash crops. Hundal et al. (1976) observed that the undrained treatments showed a lower surface penetration resistance than the drained treatments. This was measured using a blunt end Proctor penetrometer. It was also stated that if the soil moisture had been equal across all treatments, the difference would have been even greater.

1.6 Hypothesis and Objectives

There is little research available regarding the long-term effects of subsurface drainage on the evolution of soil physical properties and chemical properties. The goal of this study was to help fill this gap by evaluating the effects after 35 years of subsurface drainage and various drain spacings on soil physical and chemical properties. The field site used for this study was established in the spring of 1983 with tile drains installed in 2 blocks with tile spacings of 5, 10, 20, and 40m, with the 40-m spacing used as the undrained control.

The specific objectives of this study were to evaluate the effect of tile-drain spacing and depth on aggregation, total nitrogen and carbon content, penetration resistance, soil pH, and soil fertility after 35 years of drainage treatments. The hypotheses for this study include the following: (i) Aggregate stability will show a larger MWD in the 10-m and 20-m drain spacing compared to the 5m and 40m, (ii) soil carbon and nitrogen content will show a greater value in the 10m and 20m tile spacing when compared to the 5m and 40m spacings, (iii) Penetration resistance will be greater in the narrower tile spacing and less as the drain spacing increases due to differences in water content, (iv) and soil pH and fertility will be relatively unchanged regardless of drain tile spacing.

Poorly drained soils experience anaerobic conditions more frequently then well drained soils throughout the year. Under anaerobic conditions the decomposition of plant residues (organic matter) occurs at a slower rate. Thus, poorly drained soils tend to accumulate large amounts of organic matter over time. It is also known that poorly drained soils often provide less than ideal conditions for plant growth, leading to less production of biomass and lower additions of organic matter. Well drained soils have greater aeration, this increases the mineralization of soil organic matter resulting in a smaller amount of carbon (from plant residues) to be retained, thus generating very little change in soil organic carbon from one year to the next. However well drained soils provide a more favorable environment for crop growth allowing for more crop biomass to be produced, generating greater additions of organic matter to the soil.

Narrower tile spacing may allow for more crop growth resulting in greater organic matter additions due to their greater drainage intensity, but very little of this will be retained. Wider tile spacing will have less drainage which may produce less crop growth, hence less additions of organic matter. However, the wider tile spacing may be able to retain more of the organic matter. This leads to the stated hypothesis regarding aggregate stability as well as soil carbon and nitrogen content. The middle range tile spacing of 10 and 20 meters, may provide a balance between these factors by allowing for a greater quantity of added organic matter (plant residues) but also creating an environment that will allow more of the added soil carbon to be accumulated over time.

CHAPTER 2. METHODS

2.1 Site Description.

The site is located at the Southeast Purdue Agricultural Center (SEPAC) near Butlerville, Indiana. The site was established in 1983, on a poorly drained Clermont silt loam soil (fine silty, mixed, superactive, mesic Typic Glossaqualfs) that is low in organic matter (~1.3%) with approximately 1% slope and consisting of 22% sand, 66% silt and 12% clay. The soil formed in 50 to 120 cm of loess over Illinoian glacial till with shallow layers of low permeability.

In the spring of 1983, subsurface tile drains with a diameter of 10cm were installed in two blocks with tile spacing as the treatments at 5-m, 10-m, 20-m, and 40-m meter spacing at a depth of 75 cm with a slope of 0.4%. The 40-m spacing was used as the undrained control. Each plot spacing is made up of 3 drainage tiles that are 225 m long, with the outer tiles being shared with the neighboring treatment (Figure 1) as border tiles. Each plot is divided into 8 subplots along the length of the drain but for this study only the first 4 subplots were sampled. Each subplot was sampled in 2 positions, one on the east side of the middle tile drain and one on the west side, giving a total of 8 sampling positions per plot. Samples were taken at the mid-plane position between the middle tile and the border tile, representing the wettest portion of the plot for each spacing. The drain spacing treatments were randomized in the first block but were not re-randomized in the second block.

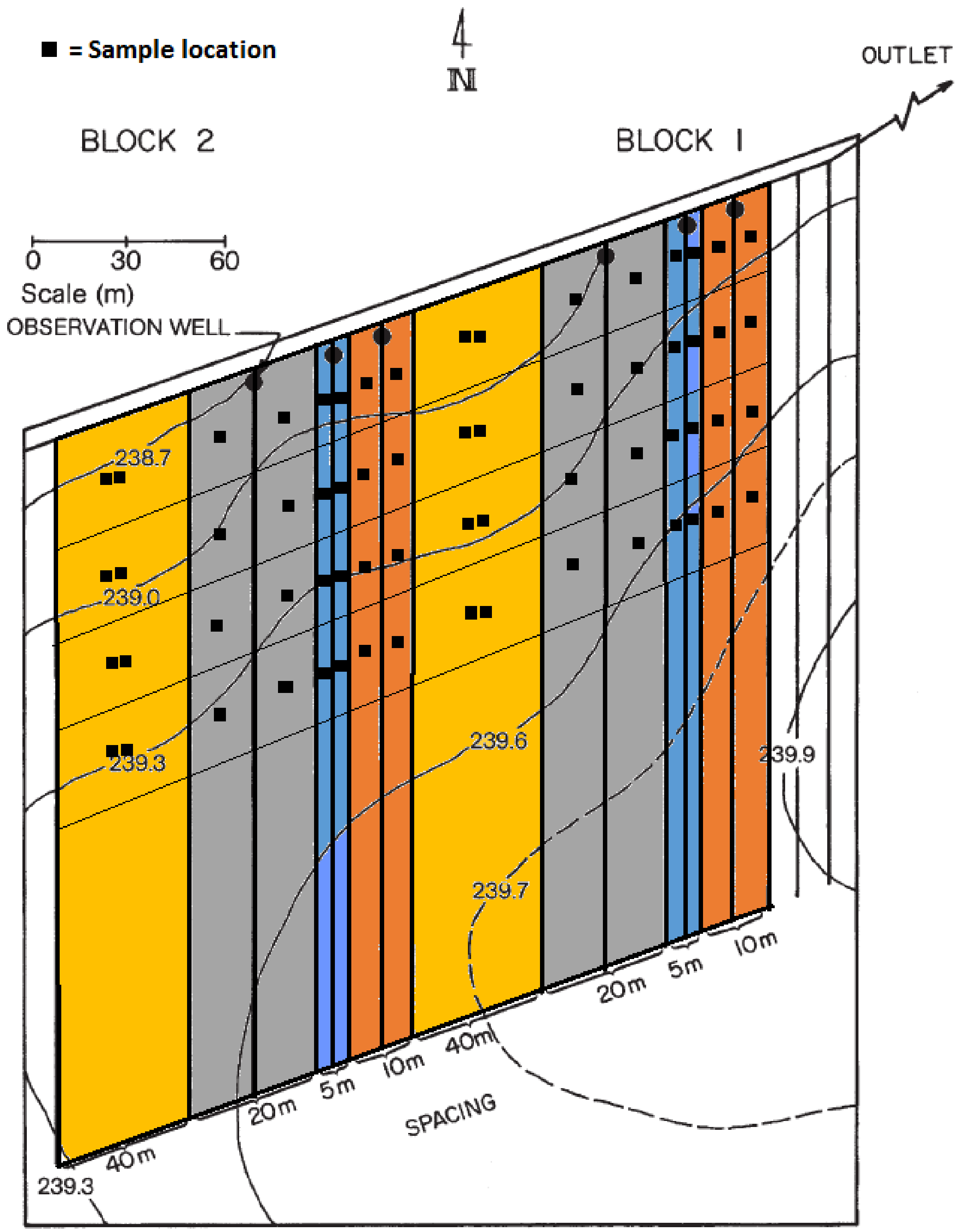

Figure 2.1. Plot diagram of SEPAC drainage experimental site.

2.2 Field Management

After the establishment of the site in 1983, corn was planted each year from 1984 to 1993. During this time conventional tillage methods were used. This included the use of a chisel plow (to ~25 cm depth) in the spring that was then followed with two passes of a finishing tool such as a disc or field cultivator. In 1994 the farming practices transitioned to a no-till, corn-soybean rotation with cover crops. Fertilizers and pesticides were used according to good agronomic practices throughout the study. Details on fertilizer and pesticide management have been given in Kladivko et al. (2004, 2005).

2.3 Sampling Methods

Samples taken for carbon and nitrogen, aggregate stability, soil pH and fertility, soil moisture and bulk density were taken in May of 2018 using a Giddings truck-mounted hydraulic probe with diameter of 5.24 cm. Samples were collected in the mid plane between the center tile and the east or west border tile. Wheel tracks from farm equipment were avoided when they were evident. Two cores each were taken from subplots 1 through 4 on both the east and west sides of the center tile, except in subplots 2E and 2W where 3 cores were taken, the third core for soil moisture. These samples were then cut into five depth increments (0 – 15, 15 – 30, 30 – 50, 50 – 75, 75-100 cm), with each segment being carefully bagged, making sure to not lose any soil, as these samples were also used to calculate bulk density at each depth except the shallowest depth. One core was used for carbon, nitrogen, pH, fertility and bulk density, and the other core was used for aggregate stability.

The samples collected with the hydraulic probe in the 0-15 cm depth were not used to measure carbon and nitrogen. For this shallower depth separate cores were taken using a hand soil probe with a 2cm diameter to a depth of 15 cm. The samples were then cut into two segments of 0-5 cm and 5-15 cm. A composite of 10 soil probes were then placed in a labeled sample bag. All samples for carbon, nitrogen, pH and fertility were air dried, hand ground to pass through a 2 mm sieve, and stored for further processing, subsampling and testing. Samples for aggregate stability were placed in a walk-in refrigerator upon return to the university and were gently sieved through an 8 mm sieve the following day. These samples were air dried and placed into labeled sample bags to be stored and later sub-sampled for analysis.

Some additional samples were collected in May of 2019, based on preliminary results from 2018. Samples for aggregate stability for the 0-5 cm depth, were collected using a golf cup cutter with diameter of 10.8 cm to a depth of 5 cm. Two samples were composited from each subplot. Field moist samples were sieved through an 8mm sieve as previously described. Samples for bulk density of the hard layer at 30cm depth were collected in May of 2019 using a typical double cylinder, hammer driven core sampler with a diameter of 5.4 cm and short brass rings with a height of 3 cm.

2.4 Carbon and Nitrogen

Samples for total carbon and nitrogen content were taken using a truck-mounted hydraulic probe and hand sampling as described above. A sub-sample of the <2mm ground soil was collected from each sample and finely ground using a mortar and pestle to pass a 150 µm sieve. A 50mg (+/- 5mg) subsample was then weighed from the finely ground subsample and was analyzed for Carbon and Nitrogen using a Flash 2000 CN Analyzer.

2.5 Carbon Stocks

Carbon stocks were calculated for each depth increment within each sub-plot. The carbon stocks from each depth were then added to find the carbon stock for the entire soil profile to the 1-m depth. The carbon stock data were then statistically analyzed for differences within each depth interval as well as for differences between the profile sums. The bulk density (g soil cm^{-3}) data used for this calculation are presented and discussed in Welage, (2020). Carbon stocks were calculated using the following equation (Equation 2.1).

$$\frac{1g\ Carbon}{100g\ soil} * \frac{g\ Soil}{cm^3} * depth\ interval\ \ (cm) * \frac{10^4 cm^2}{m^2} * \frac{10^4 cm^2}{10^3 g} * \frac{1kg}{10^3 g} * \frac{1Mg}{10^3 kg} =$$

$$\frac{Mg\ Carbon}{Hectare}\ (carbon\ stock\ for\ given\ depth\ interval$$

Equation 2.1

2.6 Aggregation

The field moist samples had been gently pushed through an 8 mm sieve and allowed to air dry, as previously described. The air-dried samples were sieved to remove the <2 mm fraction. Two 25 g subsamples of each sample were analyzed using wet-aggregate stability method (by Kemper and Rosenau, 1986), and an average mean weight diameter (MWD) was calculated for each depth, after correcting for sand and stones. The sieve sizes used for this analysis 4.76, 2.00, 1.00 and 0.21mm.

2.7 Soil pH and Fertility

The soil samples to be tested for soil fertility were collected with the hydraulic probe as described above in May of 2018. The air dried <2mm samples were mixed and sub-sampled, placing approximately 100g of soil in labeled sample bags which were stored at room temperature until they were shipped to A and L Great Lakes Laboratories.

2.8 Soil Moisture

Gravimetric water content was found for the truck mounted hydraulic probe samples from 2018 as ancillary data for penetrometer results. A subsample of each depth was placed into a numbered soil moisture can and sealed. Each moisture can was then weighed with moist soil. Next, it was placed in an oven at 105° C for 48 hours and weighed again and recorded as dry weight. The soil was then discarded, and the empty can was weighed. The following equation was used to calculate the gravimetric water content (Θg).

$$\frac{Mass\ of\ water}{Mass\ of\ oven\ dry\ soil} = \Theta_g$$

2.9 Bulk Density

Bulk density in the restrictive layer (which is thought to be an old plow pan) was measured using the short core method described by Grossman and Reinsch (2002) with samples collected in May of 2019. Samples were taken at the approximate depth where the restrictive layer began, which is about 30cm. While investigating the restrictive layer using the cone penetrometer, 2cm hand probe and a spade, it was noted that the start of the restrictive layer coincided with a noticeable color change in the soil. This color change was used to identify the restrictive layer for sampling. Each core was placed into a numbered soil moisture can and sealed. Each moisture can was opened and placed in an oven at 105° C for 48 hours and weighed. The soil was then discarded, and the empty can and brass ring was weighed. The weight of the can and the brass ring was subtracted from the initial weight and was recorded as the "Mass of Dry Soil". The volume of each core was calculated and then bulk density was calculated as a mass of dry soil per core volume.

2.10 Vane Shear

Soil shear resistance was measured using a vane shear penetrometer in May of 2018. Eight measurements were taken for every plot in the number 2 subplots, four measurements in sub plots 2E and four in subplot 2W. Measurements were taken at depths of 10, 20, 30, and 40 cm. Several measurements taken exceeded the instrument's maximum limit (120 kPa). These values were entered as the instrument's maximum value (120 kPa) for calculating means.

2.11 Cone Penetrometer

Soil penetration resistance was measured using a CP40II digital cone penetrometer in May of 2019. A total of 16 insertions to a depth of 75 cm were randomly taken per subplot, with 8 in sub-plots 2 east and 8 in sub-plot 2 west. The penetrometer used would stop recording if it reached the maximum load measurable by the instrument (kPa). When this happened, the data was saved and an additional insertion was made. For each insertion, the penetrometer was pushed by hand at a rate of approximately 1 cm sec^{-1} and recorded in kPa. Insertions were then downloaded to our computer for analysis. Concurrently, gravimetric soil moisture (Θg) samples were taken within each of the sub-plots to determine soil moisture at each depth increment.

2.12 Data Analysis

Statistical analyses were performed using SAS version 9.4 software (SAS Institute Inc., Cary, NY.). Data were evaluated for normality and homogeneity of variance using the MIXED procedure. In addition, the Box-Cox transformation in the TRANSREG procedure was used to determine if a transformation was needed. All data that required a transformation are presented and discussed in this paper in back-transformed units. The GLIMMIX procedure and an LSMeans separation test was performed on all significant effects ($p \leq 0.10$).

CHAPTER 3. RESULTS AND DISCUSSION

In this chapter I first will present the results of the statistical analysis for each variable, and then the in-depth explanation of these results is presented at the end of this chapter in section 3.10 Summary and Discussion.

3.1 Total Soil Carbon Content

The total carbon content data in all depths except the 50-75cm and the 75-100cm depths, met the primary assumptions that the data be normally distributed, and have homogeneous distribution of variance. Thus, the data from the 50-75cm and the 75-100cm depths were transformed using ln(Y) to make the data meet the primary assumptions. The total soil carbon content data by tile spacing for each depth increment are shown in Table 3.1.

In the 0-5cm depth, the interaction of block and tile spacing had a significant effect on total carbon content (Figure 3.1). In Block 2 the 5-m tile spacing is significantly different from the 10-m tile spacing in Block 2 (plot # 210) as well as the 40-m tile spacing in Block 1 (plot # 208) but is not different from any other tile spacing in either block. Plot 210 (Block 2, 10-m tile spacing) does not follow the general trend of decreasing total carbon content with increasing tile spacing observed in Block 1 and has the lowest total carbon content. The main effect of tile spacing was also found to have a significant effect on total soil carbon content in the 0-5cm depth (Table. 3.1). The 5-m tile spacing had significantly higher total carbon content than the 10-m and the 40-m tile spacings but not significantly different from the 20-m tile spacing. The significant differences found between the 5-m tile spacing and the 10-m tile spacing can be explained by the interaction of block and tile spacing discussed above. However, the interaction of block and tile spacing does not explain the significant difference found between the 5-m spacing and the 40-m tile spacing, and the trend was similar across both blocks.

In the 5-15cm depth the interaction of block and tile spacing (shown in Figure 3.2) had a significant effect on total carbon content. At this depth, the 5-m tile spacing in Block 2 (plot 212) has a significantly greater total carbon content than all other spacings in Block 1 and in Block 2. The 40-m tile spacing in both Block 1 and Block 2 had a significantly lower total carbon content than all other tile spacings in either block, with the exception of the 20-m spacing in Block 1 which was not statistically different from either of the 40-m tile spacings. The main effect of tile spacing was also found to have a significant effect on the total carbon content in the 5-15cm depth (Table 3.1). At this depth the 5-m tile spacing had a significantly higher total carbon content than all other tile spacings, while the 40-m tile spacing had a significantly lower total carbon content than all other tile spacings. Block had a significant main effect on total carbon content in the 5-15cm depth, with Block 2 having a significantly higher carbon content than Block 1. This is explained by the interaction of block and tile spacing mentioned previously, where the carbon content of the 5-m tile spacing in Block 2 is 11.3% higher than the 5-m tile spacing in Block1.

The interaction of block and tile spacing also had a significant effect in the 15-30cm depth (Figure 3.3). At this depth the 10-m tile spacing in Block 2 had a significantly higher total carbon content than the 20-m and 40-m tile spacings in Block 2 and the 10-m tile spacing in Block 1, but was not statistically different from any other tile spacing in either block. There were no significant effects found in the 30-50cm or the 50-75cm depths for total carbon content. In the 75-100cm depth the data were transformed using a (ln(Y)) transformation and the results discussed here are shown in back transformed units. In the 75-100cm depth tile spacing had a significant main effect on total carbon content (Table 3.1). At this depth the 40-m tile spacing had a significantly higher total carbon content than the 10-m tile spacing but was not significantly different from the 5-m and the 20-m tile spacings. The general trend observed at this depth is the inverse of the trends observed in the 0-5cm and the 5-15cm depths.

Table 3.1. Total carbon content (%) by tile spacing (m) at multiple depths. Samples collected from the 0-5cm and the 5-15cm depth were composite samples collected using a hand soil probe with a 2cm diameter. Samples collected at all depths below 15cm were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Total Carbon Content (%) by Tile Spacing (m)						
* Back transformed values are shown from the 50-75cm and the 75-100cm depths						
spacing	**0-5cm**	**5-15cm**	**15-30cm**	**30-50cm**	**50-75cm**	**75-100cm**
5m	1.424 a	0.720 a	0.488 a	0.259 a	0.204 a	0.176 ab
10m	1.268 b	0.672 b	0.400 a	0.275 a	0.209 a	0.166 b
20m	1.353 ab	0.663 b	0.462 a	0.260 a	0.195 a	0.178 ab
40m	1.278 b	0.603 c	0.451 a	0.262 a	0.207 a	0.197 a

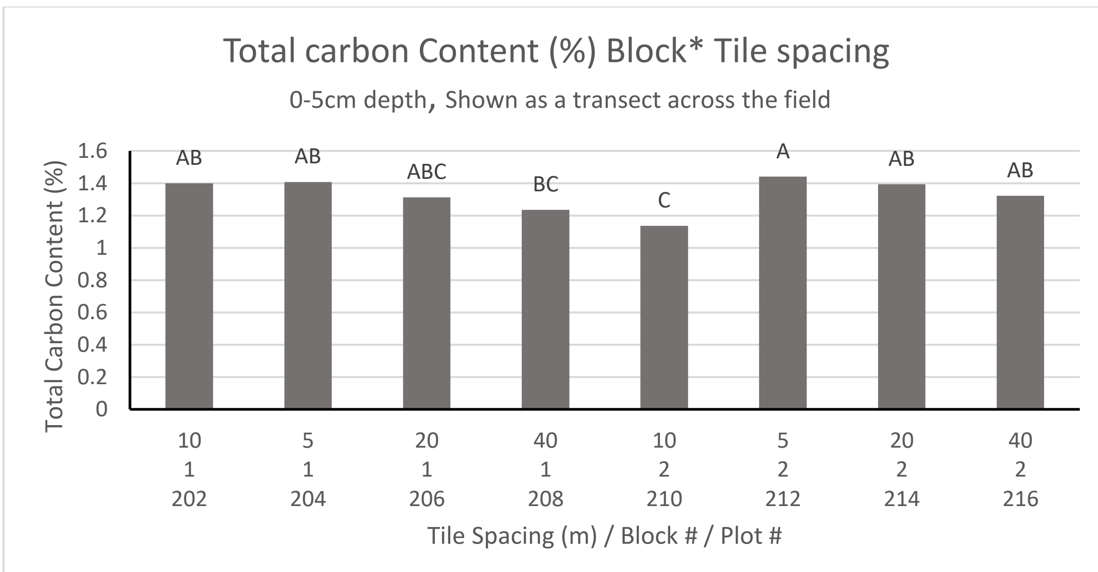

Figure 3.1 Total carbon content (%) at the 0-5cm depth. Samples were composite samples collected using a hand soil probe with a 2cm diameter. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

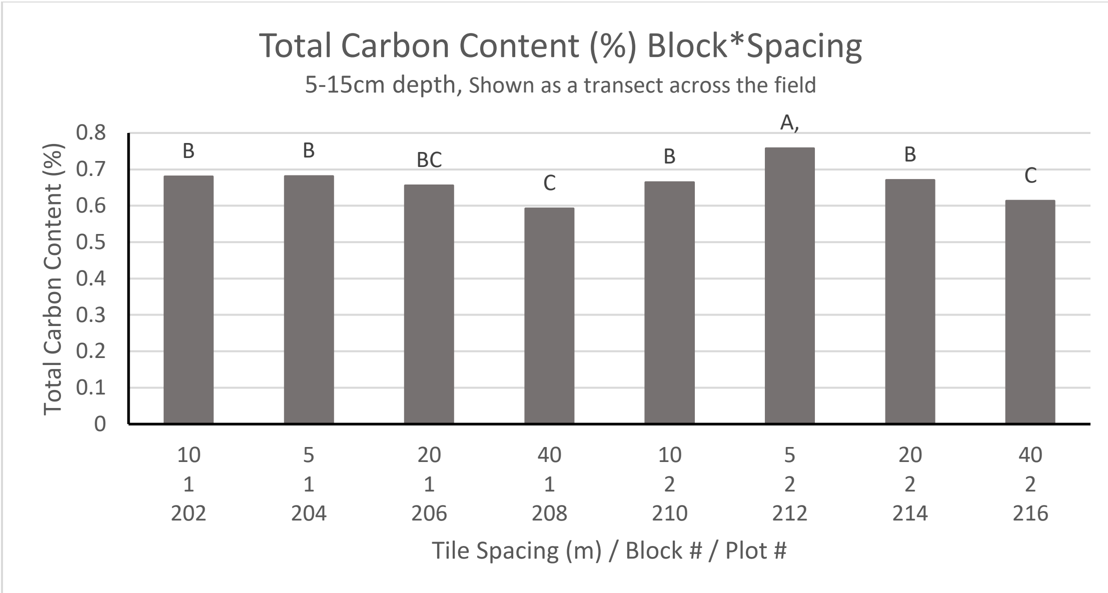

Figure 3.2. Total carbon content (%) at the 5-15cm depth. Samples were composite samples collected using a hand soil probe with a 2cm diameter. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

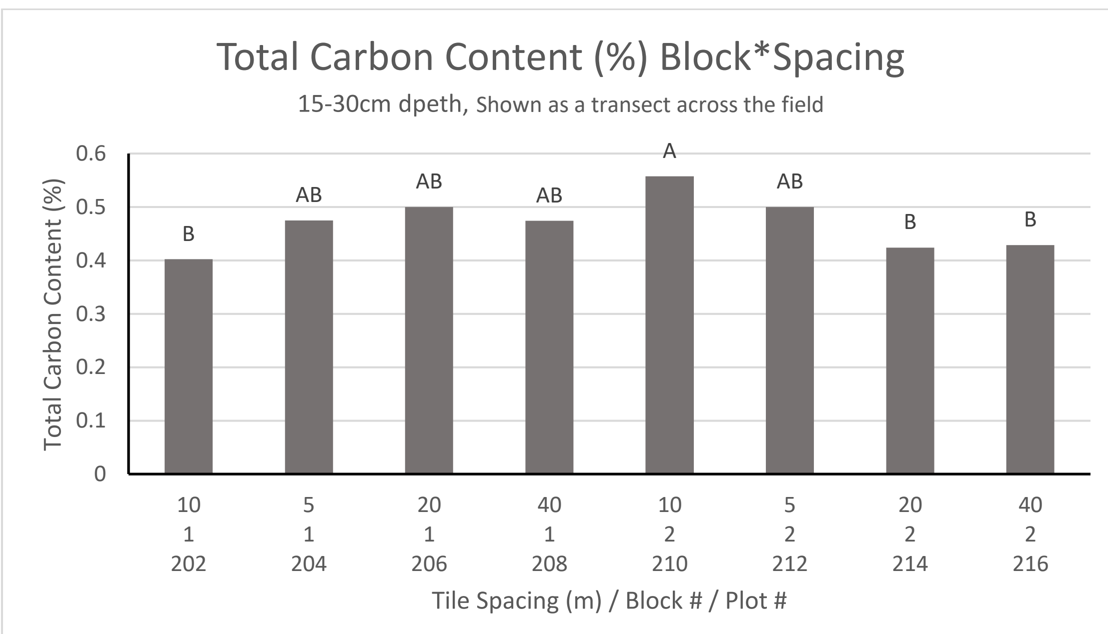

Figure 3.3 Total carbon content (%) at the 15-30cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

3.2 Carbon Stocks by Depth

No transformations were performed except in the 50-75cm depth, where the data were transformed using a ln(y) transformation. However, at this depth no significant results were found. In the 0-5cm depth the interaction of block* tile spacing was found to be significant, but after performing the means separation analysis no significant differences were identified.

The average carbon stocks by tile spacing for each depth increment are shown in Table 3.2. In the 5-15cm depth the main effect of block had a significant effect on carbon stocks. Block 2 was significantly different from Block 1, with the carbon stocks in Block 2 averaging 10.55 Mg C ha^{-1} whereas Block 1 was 10.15 Mg C ha^{-1}. Also, in the 5-15cm depth, tile spacing had a significant main effect on carbon stocks (Shown in Table 3.2). The Carbon stocks in the 5-m tile spacing were significantly greater than carbon stocks in the 20-m and 40-m tile spacings, but were not different from the 10-m tile spacing. The 20-m tile spacing was significantly different from the 5-m and 40-m tile spacings but not different from the 10-m tile spacing. The carbon stocks in the 40-m tile spacing was significantly lower than all other spacings.

In the 15-30cm depth, the interaction of block and tile spacing had a significant effect on carbon stocks. The general trend observed in Block 2 appears to be the reverse of the trend observed in Block 1(Figure 3.4). The 10-m tile spacing in Block 1 had significantly lower carbon stocks than the 20-m tile spacing also in Block 1 but was not significantly different from the 5-m or the 40-m tile spacing in the same block. Whereas, in Block 2 the 10-m tile spacing had a significantly greater carbon stocks than the 20-m and the 40-m tile spacings in the same block(Figure 3.4). In the 30-50cm and 50-75cm depths no significant results were found.

In the 75-100cm depth (Table 3.2) tile spacing was found to have a significant main effect on carbon stocks. At this depth the 5-m and 10-m tile spacings contained significantly lower carbon stocks than the 40-m tile spacing but neither was significantly different from the 20-m tile spacing.

Carbon stocks were found to be significantly higher in the narrower tile spacings than in the 40-m (control) spacing in the 5-15cm depth. However, in the 75-100cm depth the inverse trend was observed, where the 40-m tile spacing was found to have significantly greater carbon stocks than the narrower tile spacings. This trend is very similar to the trends observed with total carbon concentration for each depth. Carbon stocks are calculated using carbon concentration and bulk density (Equation 2.1). Since there were very small differences in bulk density found by Welage (2020), the carbon stocks reflect the same trends as the carbon concentration.

The carbon stocks calculated for each depth within a subplot were then added to find the carbon stock for the entire soil profile to the 1-m depth. Average carbon stocks to the 1-m depth were then calculated for each plot and tile spacing. No significant differences were detected when analyzing the summation of the carbon stocks to the 1-m depth (Table 3.2).

Table 3.2 Carbon Stocks (Mg C ha^{-1}) by tile spacing (m) at multiple depths. Samples collected from the 0-5cm and the 5-15cm depth were composite samples collected using a hand soil probe with a 2cm diameter. Samples collected at all depths below 15cm were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Soil Carbon Stocks per depth by Tile Spacing (m)							
*Data from the 50-75cm were transformed using a ln(y) transformation prior to statistical analysis. Values shown for this depth are calculated means of untransformed values							
Spacing	**0-5cm**	**5-15cm**	**15-30cm**	**30-50cm**	**50-75cm**	**75-100cm**	**1-m Sum**
5	9.92 a	11.03 a	11.75 a	8.16 a	8.18 a	7.05 b	56.09 a
10	9.45 a	10.54 ab	11.70 a	8.67 a	8.70 a	6.62 b	55.68 a
20	9.42 a	10.34 b	11.29 a	8.31 a	7.82 a	7.19 ab	54.37 a
40	9.14 a	9.50 c	11.20 a	8.42 a	8.51 a	8.11 a	54.87 a

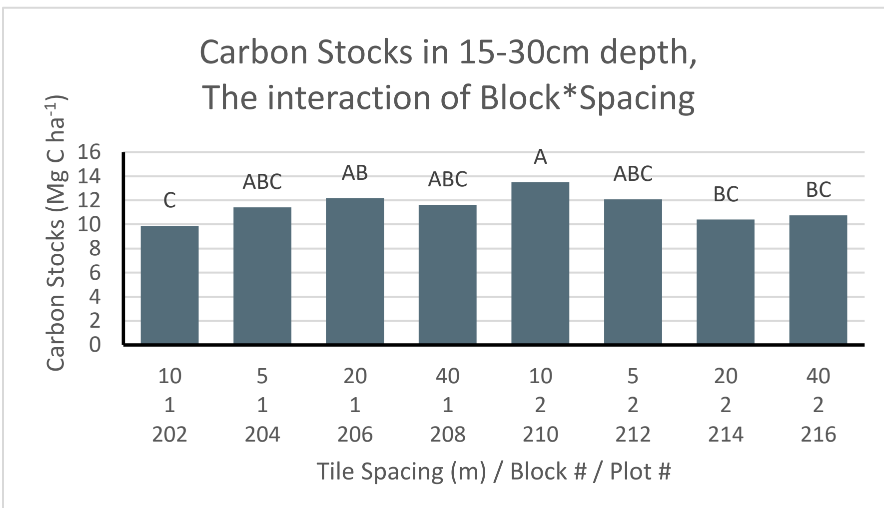

Figure 3.4 Carbon Stocks (Mg C ha^{-1}) at the 15-30cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

3.3 Nitrogen Content.

The % total Nitrogen data in all depths except the 50-75cm and the 75-100cm depths, met the primary assumptions that the data be normally distributed, and have homogeneous distribution of variance. Thus, the data from the 50-75cm and 75-100cm depths were transformed using 1/Y to make the data from these depths meet the primary assumptions. The findings presented here from these two depths are shown in back transformed units.

The total soil nitrogen content data by tile spacing for each depth increment are shown in Table 3.3. The interaction of block and tile spacing had a significant effect in all depths except the 15-30cm and the 50-75cm depths. In the 0-5cm depth the 10-m tile spacing in Block 2 had significantly lower total nitrogen content than any other tile spacing in Block 1 or in Block 2 (Figure 3.5), which is similar to what was found for carbon, while no other significant differences were identified in any other tile spacing regardless of block. The main effect of tile spacing had a significant effect on total nitrogen content in the 0-5cm depth. At this depth, the 10-m tile spacing had significantly lower total nitrogen content than any other tile spacing (Table 3.3), as explained by the interaction of block and tile spacing described above.

In the 5-15cm depth the interaction of block and tile spacing had a significant effect on total nitrogen content (Figure 3.6). At this depth no significant differences were identified among the tile spacings in Block 1. Conversely, the 5-m and the 40-m tile spacings in Block 2 had significantly higher soil nitrogen contents than the 10-m and the 20-m tile spacing in Block 2. Also, at this depth a significant main effect of tile spacing was found for total nitrogen content (Table 3.3), with the 5-m tile spacing having a significantly higher soil nitrogen content than the 10-m and 20-m tile spacings. Again, the significant interaction of block and tile spacing previously described explains the significant main effects observed with tile spacing.

In the 15-30cm depth the main effect of tile spacing had a significant effect on total soil nitrogen content (Table 3.3). The 20-m tile spacing had a significantly lower total nitrogen content than the 5-m and 10-m tile spacings but was not significantly different from the 40-m tile spacing.

In the 30-50cm depth the interaction of block and tile spacing had a significant effect on total nitrogen content (Figure 3.7). In the 30-50cm depth, the 10-m tile spacing in Block 1 had a significantly higher total nitrogen content than any other tile spacing in Block 1 or in Block 2. No other significant differences between any tile spacing in either block were found at this depth. The main effect of tile spacing had a significant effect on total nitrogen content at this depth. The 10-

m tile spacing had a significantly higher total nitrogen content than the 20-m and the 40-m tile spacings but was not significantly different from the 5-m tile spacing. Block also had a significant effect on total nitrogen content at this depth, with Block 1 having a significantly higher total nitrogen content than Block 2. However, the interaction of block and tile spacing described above explains the significant main effects of tile spacing and block observed at this depth.

In the 50-75cm depth tile spacing had a significant main effect on total nitrogen content, with the 10-m tile spacing containing significantly higher total nitrogen content than the 20-m tile spacing but was not significantly different from any other tile spacing (Table 3.3). Also, at this depth, the main effect of block was significant, with Block 1 having significantly higher total nitrogen content than Block 2.

In the 75-100cm depth the interaction of block and tile spacing had a significant effect on total nitrogen content (Figure 3.8). At this depth the 10-m tile spacing in Block 1 had a significantly higher total nitrogen content than the 20-m tile spacing in the same block and the 5-m, 10-m, and 20-m tile spacings in Block 2. No significant differences were observed among any of the tile spacings in Block 2. The main effect of block also had a significant effect on total nitrogen content. At this depth Block 1 had a significantly greater nitrogen content than Block 2. The significant effect of the interaction of block and tile spacing explains the significant main effect of block observed at this depth.

Tile spacing had a significant main effect on total nitrogen content in all depths above the 75-100cm depth. However, in the 0-5cm, 5-15cm and the 30-50cm depths the interaction of block and tile spacing explains any significant main effects observed in these depths. In the 15-30cm and the 50-75cm depths the 10-m tile spacing had greater total soil nitrogen content than the 20-m tile spacings from the same depth. However, the differences observed here were very small and mathematically significant but it is possible that these differences are not biologically significant.

Table 3.3. Total nitrogen content (%) by tile spacing (m) at multiple depths. Samples collected from the 0-5cm and the 5-15cm depth were composite samples collected using a hand soil probe with a 2cm diameter. Samples collected at all depths below 15cm were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Soil Total Nitrogen Content (%)						
*Values shown for the 50-75cm and the 75-100cm depths have been back transformed						
spacing	**0-5cm**	**5-15cm**	**15-30cm**	**30-50cm**	**50-75cm**	**75-100cm**
5	0.130 a	0.0735 a	0.0531 a	0.0334 ab	0.0279 ab	0.0269 a
10	0.113 b	0.0646 b	0.0547 a	0.0394 a	0.0313 a	0.0298 a
20	0.123 a	0.0650 b	0.0472 b	0.0319 b	0.0261 b	0.0263 a
40	0.128 a	0.0700 ab	0.0497 ab	0.0322 b	0.0267 ab	0.0280 a

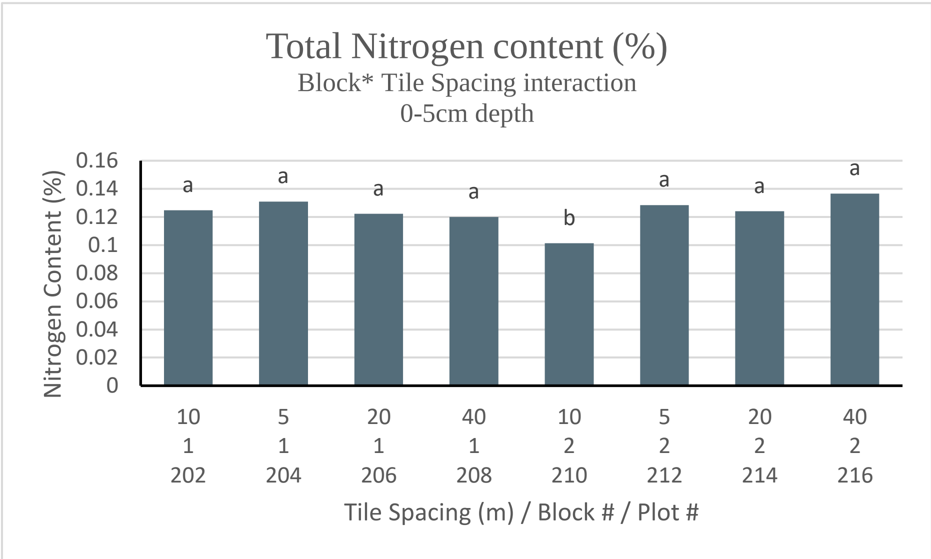

Figure 3.5. Total nitrogen content (%) at the 0-5cm depth. Samples were composite samples collected using a hand soil probe with a 2cm diameter. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

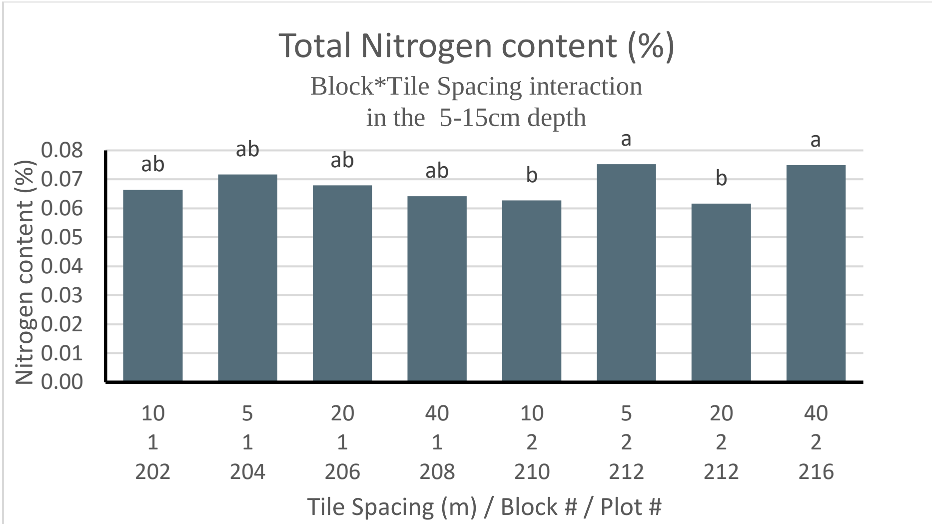

Figure 3.6. Total nitrogen content (%) at the 5-15cm depth. Samples were composite samples collected using a hand soil probe with a 2cm diameter. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

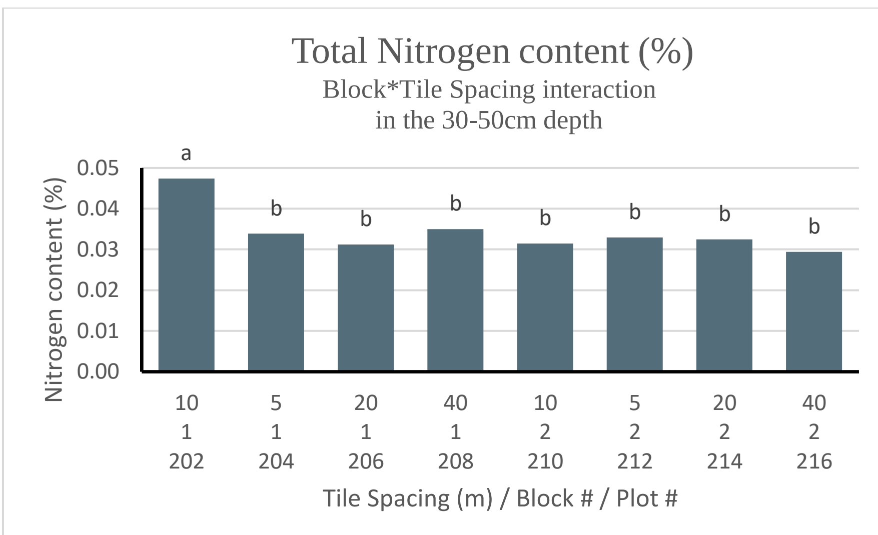

Figure 3.7. Total nitrogen content (%) at the 30-50cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

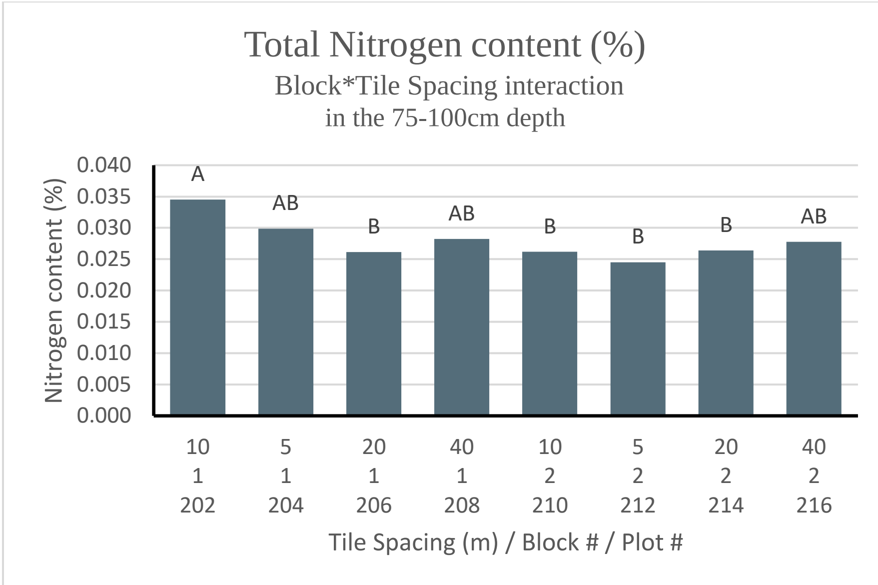

Figure 3.8. Total nitrogen content (%) at the 75-100cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

3.4 Aggregate Stability

The aggregate stability data in all depths except the 50-75cm depth, met the primary assumptions that the data be normally distributed, and have homogeneous distribution of variance. Thus, the data from the 50-75cm depth were transformed using 1/y to make the data meet the primary assumptions. Tile spacing alone was not found to have a significant main effect on aggregate stability at any depth (Table 3.4). In the 0-5cm depth no significant differences were detected. A significant main effect of block was observed in the 0-15cm depth, with Block 2 having a significantly higher mean weight diameter (MWD) than Block 1 (2.3mm and 2.0mm respectively).

The interaction of block and tile spacing had a significant effect on MWD in the 15-30cm and the 30-50cm depths. In the 15-30cm depth the interaction of block and tile spacing showed the 5-m tile spacing in Block 2 having a significantly higher MWD than all other tile spacings in both blocks except the 10-m tile spacing in Block 1 and the 20-m tile spacing in Block 2 (Figure 3.9). Also, in this depth a significant main effect of block was observed. Block 2 had a significantly higher MWD than Block 1 (0.58mm, 0.50mm respectively) . The interaction of block and tile spacing described above explains the significant main effects observed in block.

In the 30-50cm depth the interaction of block and tile spacing had a significant effect on MWD. At this depth the 5-m tile spacing in Block 2 was significantly greater than the 40-meter tile spacing in Block 2, but neither was significantly different from any other tile spacing in both Block 1 or Block 2 (Figure 3.10). Block was found to have a significant main effect in the 50-75cm depth. At this depth Block 1 had a significantly greater MWD than Block 2 (0.45mm, 0.37mm respectively).

Table 3.4. Aggregate stability measured by MWD (mm) by tile spacing (m) at multiple depths. Samples collected in the 0-5cm depth were composite samples collected in May of 2019 using a golf cup cutter with a diameter 10.8cm to a depth of 5cm. Samples from the 0-15cm depth and below were collected using a truck mounted hydraulic probe in May of 2018. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Mean Weight Diameter (MWD) by Tile spacing					
*Values shown for the 50-75cm depth have been back transformed					
Tile spacing	**0-5cm**	**0-15cm**	**15-30cm**	**30-50cm**	**50-75cm**
5m	3.1 a	2.2 a	0.6 a	0.5 a	0.4 a
10m	2.9 a	1.9 a	0.5 a	0.4 a	0.5 a
20m	2.9 a	2.3 a	0.5 a	0.4 a	0.4 a
40m	3.1 a	2.2 a	0.5 a	0.4 a	0.4 a

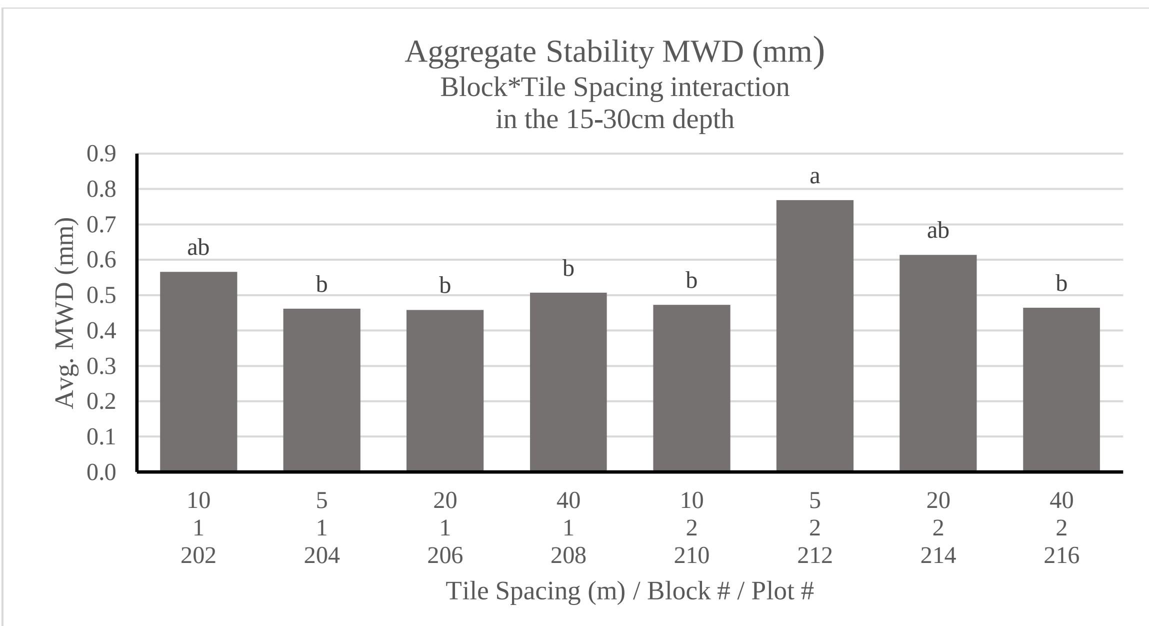

Figure 3.9. Aggregate stability measured by MWD (mm) at the 15-30cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

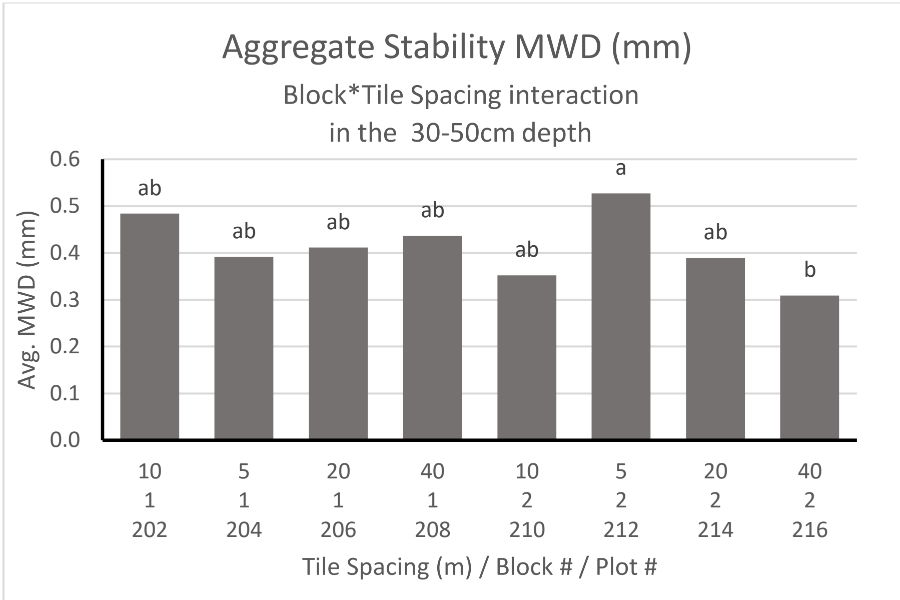

Figure 3.10. Aggregate stability measured by MWD (mm) at the 30-50cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

3.5 Soil Fertility

3.5.1 Soil organic matter content

The % soil organic matter (%OM) data were found to be normally distributed and had a homogeneous distribution of variance. Consequently, the data did not need a transformation prior to analysis. No significant effects were found in 0-15cm and 15-30cm depths. Tile spacing did not have significant effect on %OM at any depth (Table 3.5). In the 30-50cm depth Block had a significant main effect on the %OM, with Block 1 having significantly higher %OM than Block 2.

In the 50-75cm depth the interaction of block and tile spacing had a significant main effect on % organic matter (Figure 3.11). At this depth the 10-meter tile spacing in Block 1 contained a significantly higher % organic matter than the 20-meter tile spacing in Block 1 and the 10-meter tile spacing in Block 2. The 10-meter tile spacing in Block 1 was not significantly different from any other tile spacing in Block 1 or Block 2.

The interaction of block and tile spacing was also found to be of significance in the 75-100cm depth (Figure 3.12). At this depth the 10-meter tile spacing in Block 1 had a significantly higher %OM than the 10-meter and the 5-meter tile spacings in Block 2 but was not significantly different from any other tile spacing in Block 1 or in Block 2.

Table 3.5. Organic matter content (%) by tile spacing (m) at multiple depths. Samples were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Soil Organic Matter Content (%)					
Tile spacing	**0-15cm**	**15-30cm**	**30-50cm**	**50-75cm**	**75-100cm**
5m	1.7 a	1.0 a	0.8 a	0.7 a	0.9 a
10m	1.7 a	0.9 a	0.9 a	0.9 a	1.0 a
20m	1.7 a	1.1 a	0.7 a	0.7 a	0.9 a
40m	1.6 a	1.0 a	0.8 a	0.8 a	1.0 a

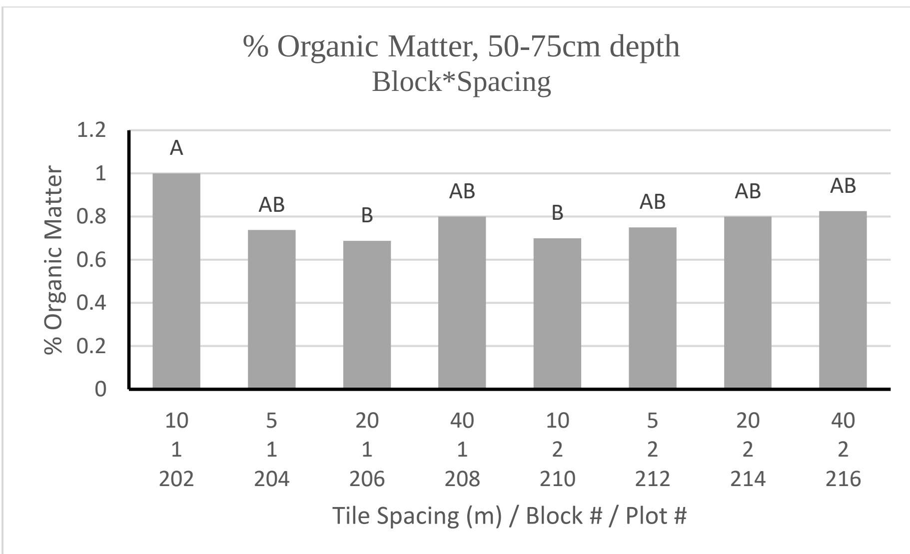

Figure 3.11. Organic matter content (%) at the 50-75cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

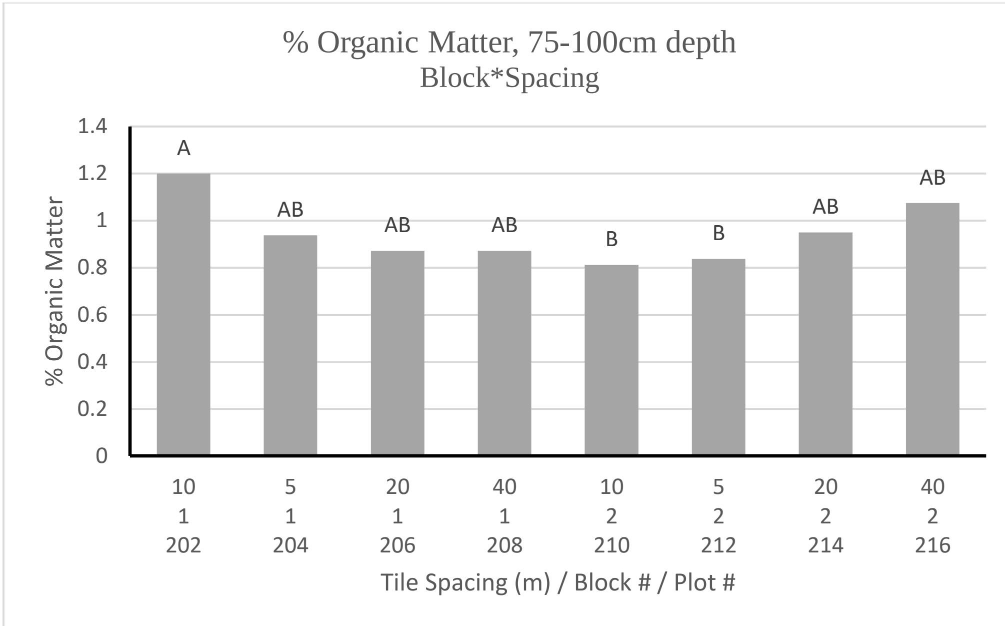

Figure 3.12. Organic matter content (%) at the 75-100cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

3.5.2 Soil phosphorus content

The phosphorus content data in the 0-15cm depth did not meet the primary assumptions that the data be normally distributed, and have homogenous distribution of variance; thus, were transformed using the log(Y). The data collected from the 15-30cm depth met all the needed assumptions and were not transformed. All other depths could not meet the needed assumptions regardless of the transformation applied due to their low values and duplicate values in each depth. Thus, statistical analysis was performed on the untransformed data. Block by itself did not have a significant effect on phosphorus content at any depth. The soil phosphorus content data by tile spacing for each depth increment are shown in Table 3.6.

In the 0-15cm depth the interaction of block and tile spacing had a significant effect on soil phosphorus content (Figure 3.13). The 40-meter tile spacing in Block 2 contained significantly greater phosphorus values than the 20-meter tile spacing in Block 1 and the 5-meter tile spacing in Block 2 but was not significantly different from any other tile spacing in Block 1 or Block 2 . The 20-meter tile spacing in Block 2 was also found to have a significantly higher soil phosphorus content than the 20-meter tile spacing in Block 1, but was not significantly different from any other tile spacing in both Block 1 and Block 2. Tile spacing also had a significant main effect on soil phosphorus content at this depth (Table 3.6). At this depth the 40-meter tile spacing had a significantly higher soil phosphorus content than the 5-meter tile spacing but was not significantly different from any other tile spacing.

In the 15-30cm depth the interaction of block and tile spacing had a significant effect on soil phosphorus content (Figure 3.14). At this depth no significant differences were found among the tile spacings in Block 1. However, the 10-m tile spacing in Block 2 had a significantly higher soil phosphorus content than the 20-m and the 40-m tile spacings in the same block and was different than the 10-m and 20-m tile spacings in Block1.

Table 3.6. Soil phosphorus content (ppm) by tile spacing (m) at multiple depths. Samples were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Soil Phosphorus Content (ppm) by Tile Spacing					
**Back transformed values shown for the 0-15cm*					
spacing	**0-15cm**	**15-30cm**	**30-50cm**	**50-75cm**	**75-100cm**
5m	15 b	4 a	1 a	1 a	1 a
10m	16 ab	4 a	2 a	1 a	1 a
20m	16 ab	3 a	2 a	1 a	1 a
40m	20 a	3 a	2 a	1 a	1 a

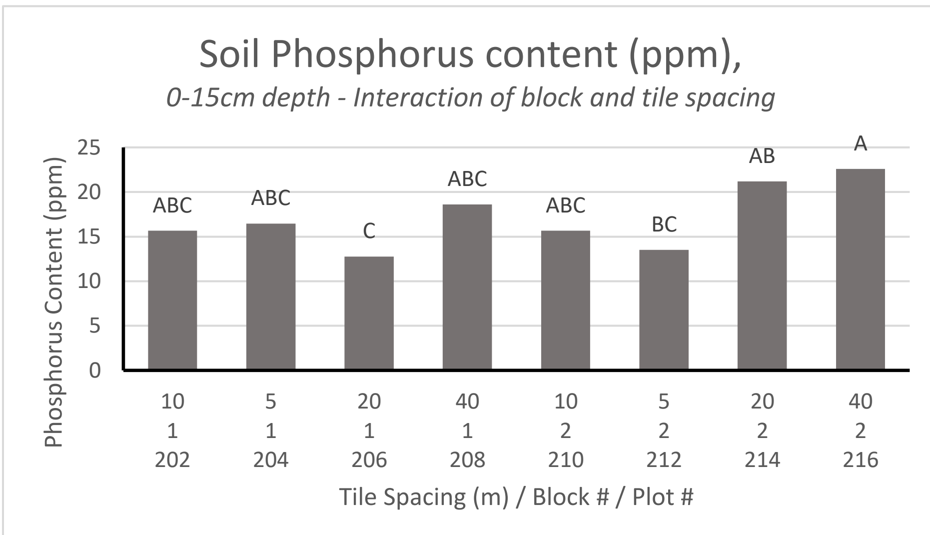

Figure 3.13. Soil phosphorus content (ppm) at the 0-15cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

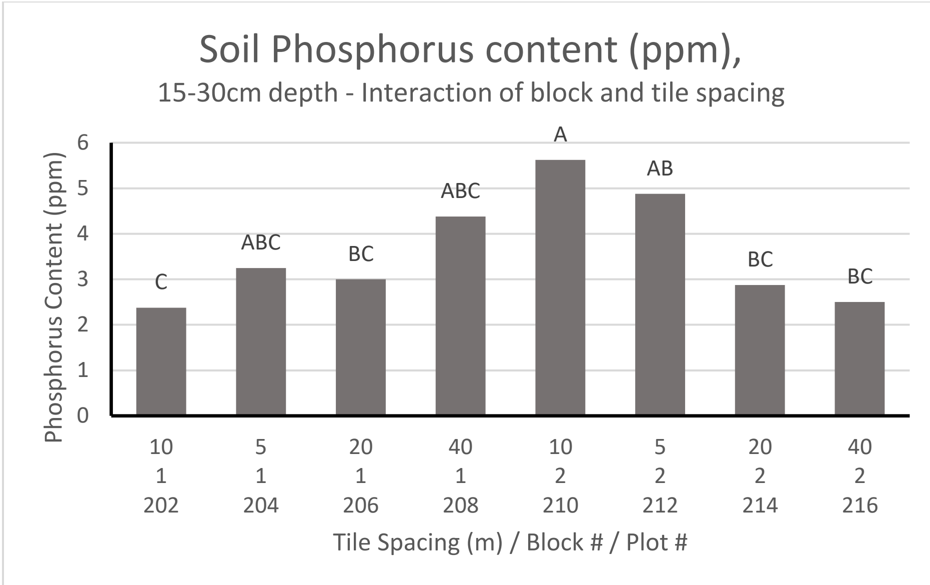

Figure 3.14. Soil phosphorus content (ppm) at the 15-30cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

3.5.3 Soil potassium content

The Potassium (K) content data in the 0-15 and the 15-30cm depth did not meet the primary assumptions that the data be normally distributed, and have homogenous distribution of variance. Thus, the data from these depths were transformed using the Ln(Y), and 1 /-(Y) respectively. All values discussed and presented here from these depths have been back transformed. All other depths met the needed assumptions hence, no transformation was performed.

In the 0-15cm depth tile spacing was found to have a significant main effect on soil potassium content. The 5-m tile spacing had a significantly higher soil potassium content than all other tile spacings (Table 3.7). At this depth block also had a significant effect on soil potassium content, with Block 1 having significantly higher soil potassium content than Block 2.

In the 15-30cm depth, the interaction of block and tile spacing was found to have a significant effect on soil potassium content. The soil potassium content in the 5-m tile spacing in both Block 1 and Block 2 was significantly higher than the 20-m tile spacing in Block 1 and the 40-m tile spacing in Block 2. The 40-m tile spacing in Block 2 had significantly lower soil potassium content than the 10-m, 5-m and 40-m tile spacings in Block 1 and the 10-m, and 5-m tile spacing in Block 2 (Figure 3.15). Tile spacing also had a significant main effect on soil potassium content in the 15-30cm depth (Table 3.7). The soil potassium content in the 5-m tile spacing was significantly greater than all other tile spacings. The soil potassium content in the 10-m tile spacing was significantly higher than the 40-m tile spacing but was not significantly different from the 20-m tile spacing. However, the significant difference observed between the 10-m and 40-m tile spacing can be explained by the interaction of block and tile spacing previously described. No significant effects were identified in the 30-50cm or the 50-75cm depths.

In the 75-100cm depth, the interaction of block and tile spacing had a significant effect on soil potassium content. But after performing the means separation analysis, no significant differences could be distinguished (Figure 3.16).

Table 3.7. Soil potassium content (ppm) by tile spacing (m) at multiple depths. Samples were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Soil Potassium content (ppm) by Tile Spacing (m)					
** Back transformed Values shown for the 0-15cm and 15-30cm depths*					
spacing	**0-15**	**15-30**	**30-50**	**50-75**	**75-100**
5m	81 a	48 a	46 a	50 a	63 a
10m	66 b	41 b	42 a	50 a	61 a
20m	60 b	38 bc	42 a	52 a	66 a
40m	60 b	36 c	41 a	48 a	60 a

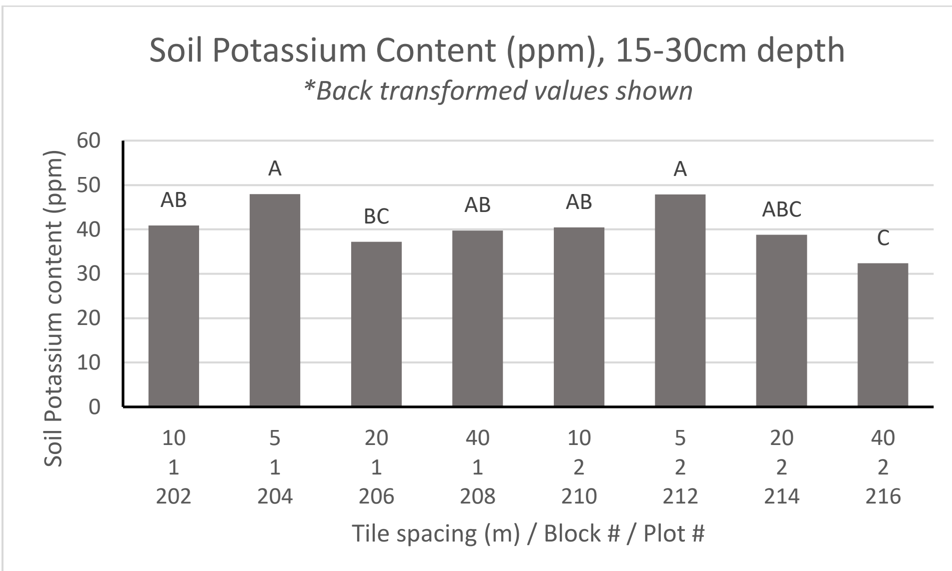

Figure 3.15. Soil potassium content (ppm) at the 15-30cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

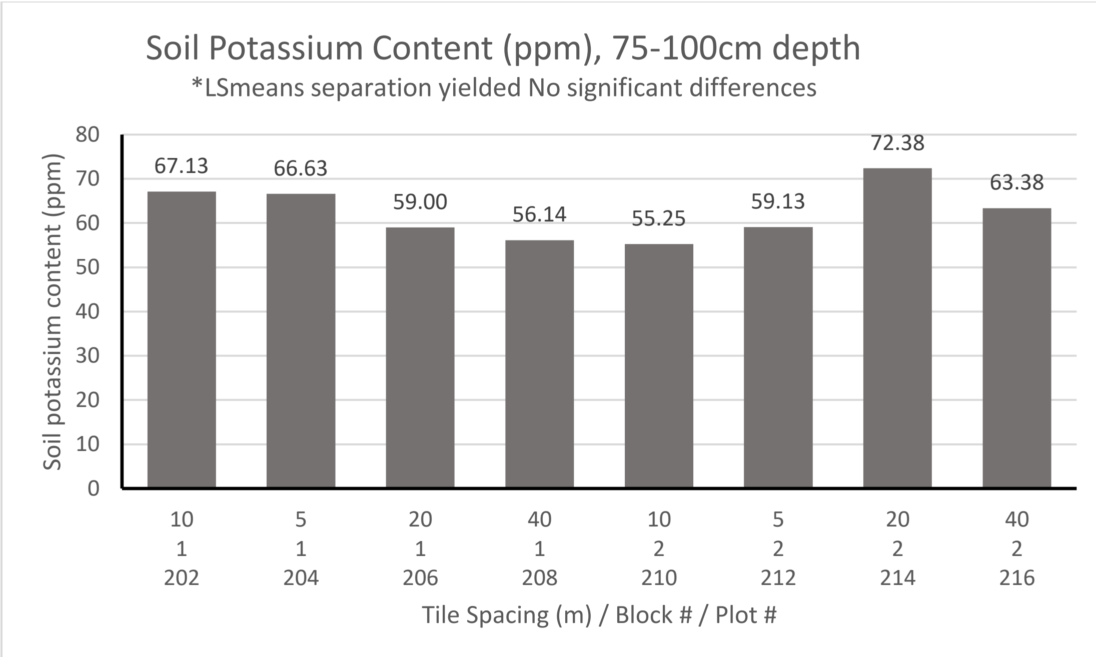

Figure 3.16. Soil potassium content (ppm) at the 75-100cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

3.5.4 Soil calcium content

The soil calcium content data (ppm) in the 30-50cm depth did not meet the primary assumptions that the data be normally distributed and have homogeneous distribution of variance. Thus, the data from this depth were transformed using a ln(Y) transformation. The data presented here from the 30-50cm depth have been back transformed. The data from all other depths met the primary assumptions and did not require a transformation.

A significant effect of tile spacing was observed in the 0-15cm depth (Table 3.8). At this depth the 40-m tile spacing contained significantly higher soil calcium content than the 5-m tile spacing but was not significantly different from the 10-m or 20-m tile spacing.

In the 30-50cm depth the interaction of block and tile spacing had a significant effect on soil calcium content (Figure 3.17). There were no significant differences found among tile spacings in Block 1. However, the calcium content in the 10-m tile spacing in Block 2 was significantly lower than the 5-m, 10-m and 20-m tile spacings in Block 1 and the 20-m tile spacing in Block 2. Similarly, the 5-m tile spacing in Block 2 had a significantly lower soil calcium content than the 10-m and 20-m tile spacing in Block 1 and the 20-m tile spacing in Block 2. Also, in this depth block had a significant main effect on soil calcium content, with Block 1 having significantly higher soil calcium content than Block 2. It should be noted that the interaction of block and tile spacing described above explains the significant main effect of block.

Table 3.8. Soil Calcium content (ppm) by tile spacing (m) at multiple depths. Samples were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Soil Calcium Content (ppm) By Tile Spacing					
*30-50cm depth values shown have been back transformed					
spacing	**0-15cm**	**15-30cm**	**30-50cm**	**50-75cm**	**75-100cm**
5	719 b	678 a	492 a	500 a	509 a
10	741 ab	663 a	504 a	431 a	438 a
20	753 ab	706 a	588 a	484 a	530 a
40	819 a	759 a	541 a	441 a	479 a

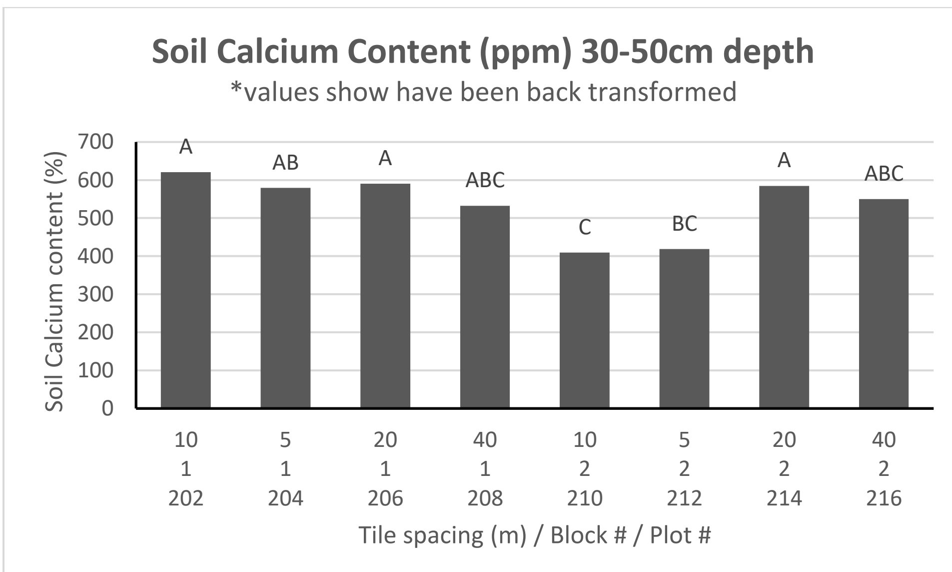

Figure 3.17. Soil calcium content (ppm) at the 30-50cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

3.5.5 Soil magnesium content

The soil magnesium (Mg) content data met all the primary assumptions that the data be normally distributed and have homogeneous distribution of variance. Thus, a transformation was not required prior to analyzing the data. The soil magnesium content data by tile spacing for each depth increment are shown in Table 3.9.

The interaction of block and tile spacing had a significant effect on soil Mg content at all soil depth increments. In the 0-15cm depth the soil Mg content was significantly higher in the 40-m tile spacing in Block 2 and the 10-m tile spacing in Block 1 than the 10-m tile spacing in Block 2 but was not significantly different from any other tile spacing in either Block 1 or Block 2. There were no significant differences found between any tile spacings in Block 1 (Figure 3.18).

In the 15-30cm depth the interaction of block and tile spacing had a significant effect on soil Mg content. The 10-m tile spacing in Block 1 had a significantly higher soil Mg content than the 5-m and the 40-m tile spacing also in Block 1. But no significant differences were observed among the tile spacings in Block 2 (Figure 3.19). This interaction also explains the significant main effect of block, with Block 1 having a significantly higher soil Mg content than Block 2.

The interaction of block and tile spacing also had a significant effect on the soil Mg content in the 30-50cm depth. At this depth the 10-m and the 5-m tile spacing in Block 1 had a significantly higher soil Mg content than the 40-m tile spacing in the same block, while there were no significant differences found between any of the tile spacings in Block 2 (Figure 3.20). This interaction explains the significant main effect of block that was observed at this depth, with Block 1 having a significantly higher soil Mg content than Block 2.

In the 50-75cm and the 75-100cm depth the interaction of block and tile spacing had a significant effect on soil Mg content. There were no significant differences between any tile spacings in Block 1 at either depth. However, the 40-m tile spacing in Block 2 in both depths, had significantly higher soil Mg contents then the 10-m and the 5-m tile spacing in Block 2 in the same depths (Figure 3.21 and Figure 3.22). Tile spacing had significant main effect in both the 50-75cm and the 75-100cm depths. In both depths the 40-m tile spacing had significantly higher soil Mg content than the 5-m and 20-m tile spacings, with the 10-m tile spacing intermediate (Table3.9). The interaction of block and tile spacing previously described explains the significant main effect of tile spacing observed in the 50-75cmn and the 75-100cm depths.

Table 3.9. Soil Magnesium content (ppm) by tile spacing (m) at multiple depths. Samples were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Soil Magnesium Content (ppm) by Tile Spacing (m)					
spacing	**0-15**	**15-30**	**30-50**	**50-75**	**75-100**
5	123 a	13 a	119 a	84 b	122 b
10	128 a	147 a	121 a	88 ab	138 ab
20	127 a	140 a	121 a	87 b	133 b
40	138 a	138 a	105 a	105 a	164 a

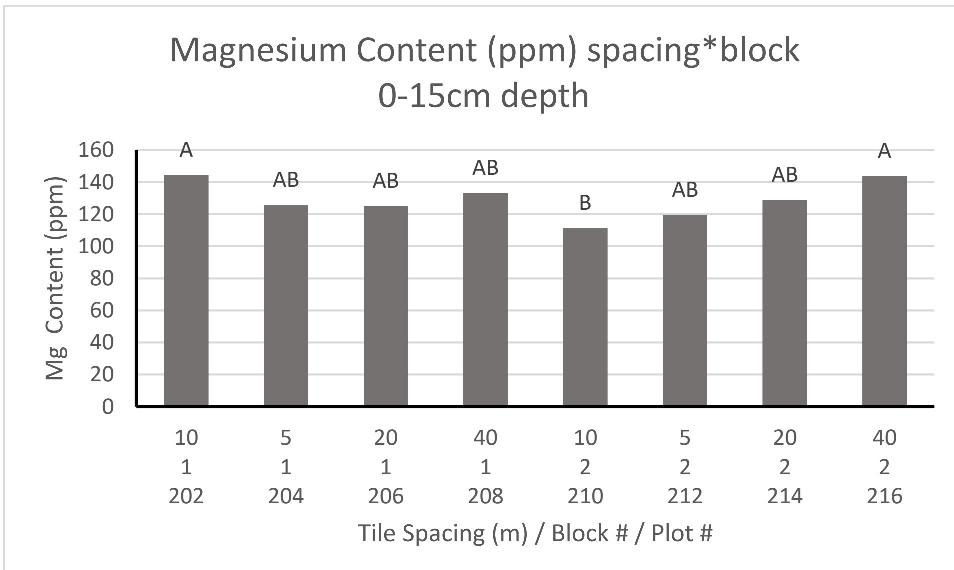

Figure 3.18. Soil magnesium content (ppm) at the 0-15cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

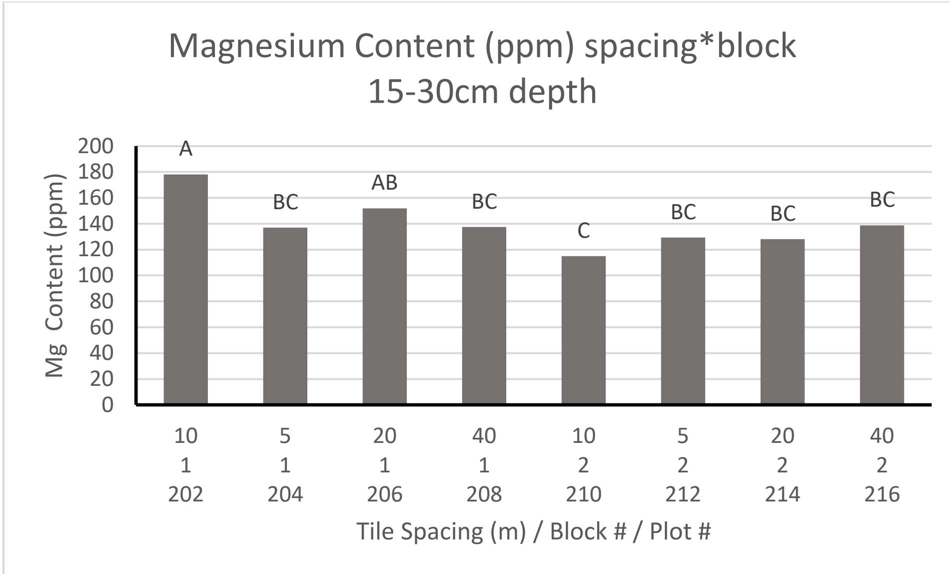

Figure 3.19. Soil magnesium content (ppm) at the 15-30cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

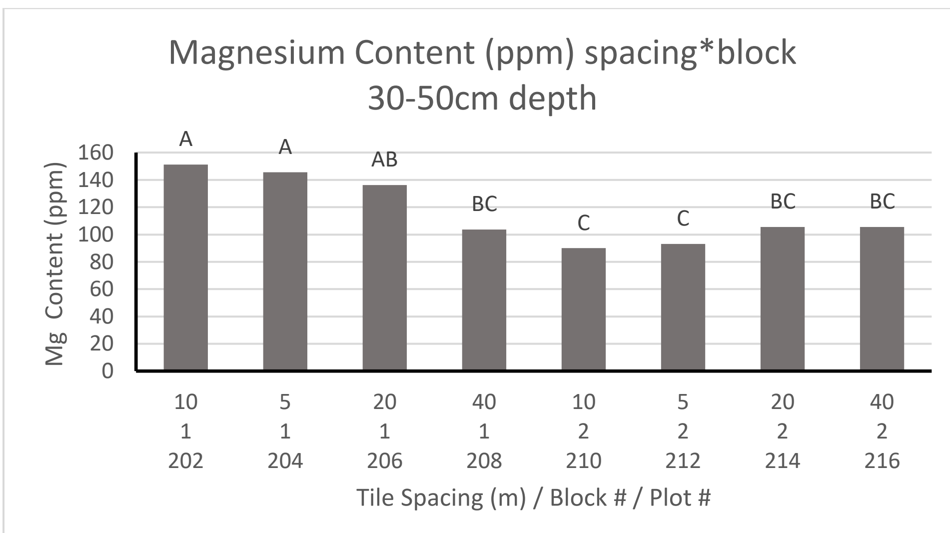

Figure 3.20. Soil magnesium content (ppm) at the 30-50cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

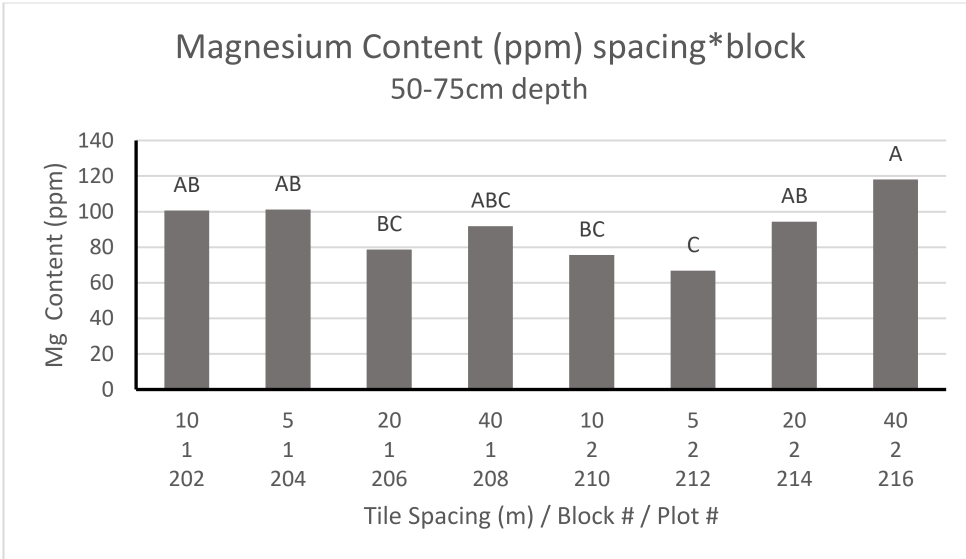

Figure 3.21. Soil magnesium content (ppm) at the 50-75cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

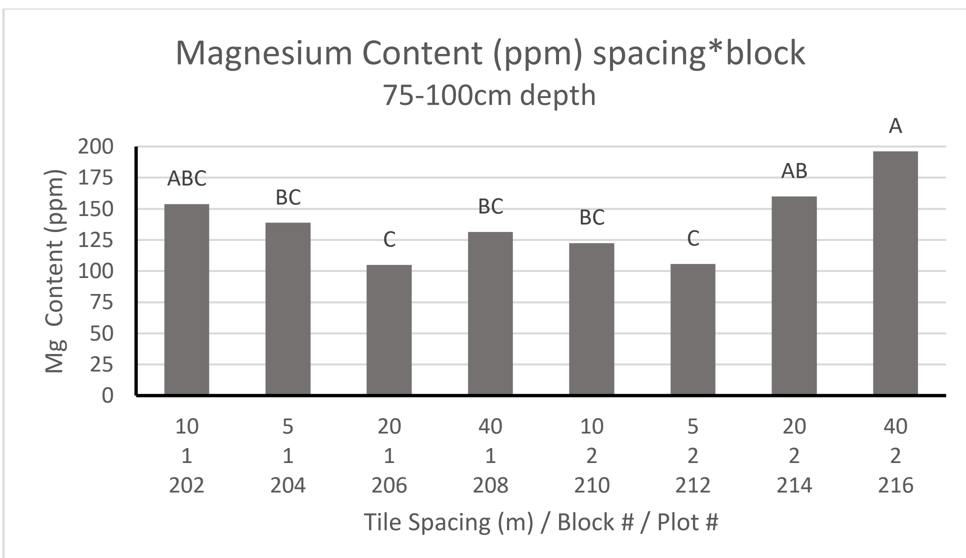

Figure 3.22. Soil magnesium content (ppm) at the 75-100cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

3.5.6 Soil sodium content

The soil sodium content data met all the primary assumptions that the data be normally distributed and have homogeneous distribution of variance. Thus, a transformation was not required prior to analyzing the data.

In the 0-15cm depth tile spacing had a significant main effect on soil sodium (Na) content (Table 3.10). At this depth the 40-m tile spacing had a significantly higher soil Na content than the 20-m tile spacing but was not significantly different from either the 5-m or the 10-m tile spacings. Also, at this depth block had a significant main effect on soil Na content, with Block 1 having a significantly higher soil Na content than Block 2.

The interaction of block and tile spacing had a significant effect on soil Na content in the 15-30cm, 30-50cm, 50-75cm and the 75-100cm depth (Figure 3.23 through Figure 3.26) In each of these depths the 40-m tile spacing in Block 2 had a significantly higher soil Na content than all other tile spacings in Block 2. In the 15-30cm depth the 10-m tile spacing was found to have a significantly higher Na content than the 20-m spacing in Block 1 but neither was significantly different from any other tile spacing in Block 1 at this depth. In the 30-50cm depth the 10-m tile spacing had significantly greater soil Na content than the 20-m tile spacing in the same block. However, in the 50-75cm, and the 75-100cm depths no significant differences were observed between any of the tile spacings in Block 1.

In the 15-30cm, 30-50cm, 50-75cm and the 75-100cm depths tile spacing was found to have a main effect on soil Na content (Table 3.10). At each of these depths the 40-m tile spacing was significantly higher in soil Na content than all other tile spacings. However, the interaction of block and tile spacing previously described explained the observed significant effects of tile spacing (Table 3.10). Block also had a significant effect on soil Na content in the 75-100cm depth, with Block 2 having a significantly higher soil Na content than Block 1.

Table 3.10. Soil Sodium content (ppm) by tile spacing (m) at multiple depths. Samples were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Soil Sodium Content (ppm) by Tile Spacing (m)					
Spacing (m)	**0-15cm**	**15-30cm**	**30-50cm**	**50-75cm**	**75-100cm**
5	12 ab	12 b	13 b	13 b	16 b
10	11 ab	13 b	13 b	14 b	16 b
20	10 b	12 b	13 b	14 b	17 b
40	12 a	15 a	16 a	18 a	22 a

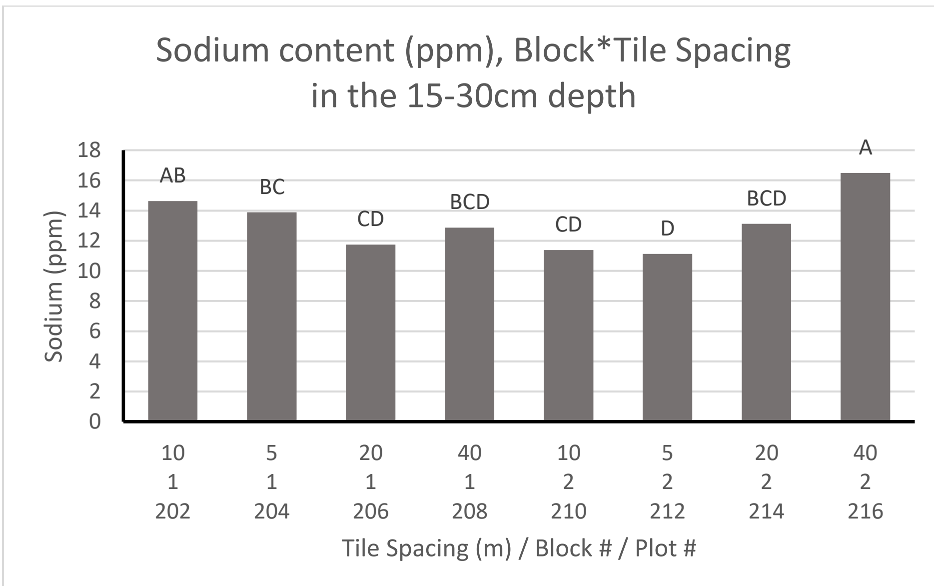

Figure 3.23. Soil sodium content (ppm) at the 15-30cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

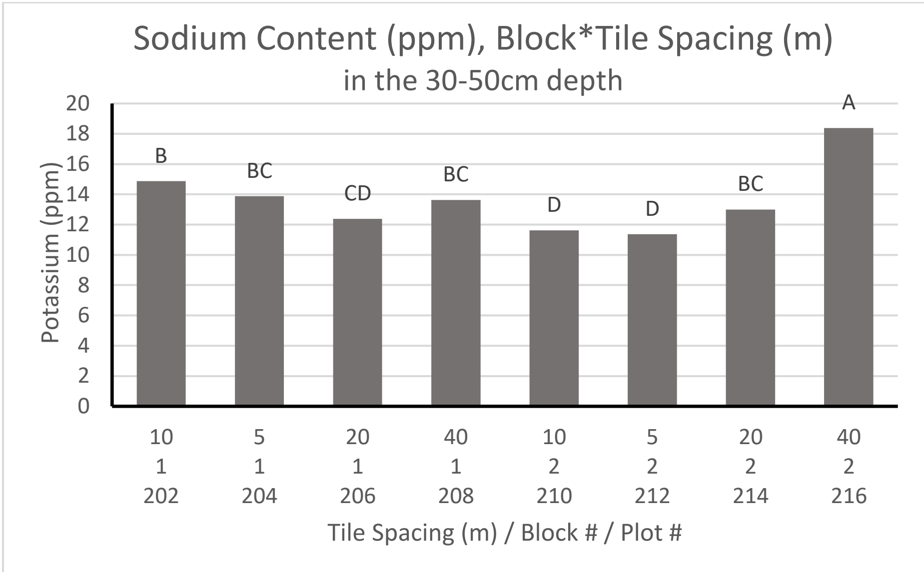

Figure 3.24. Soil sodium content (ppm) at the 30-50cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

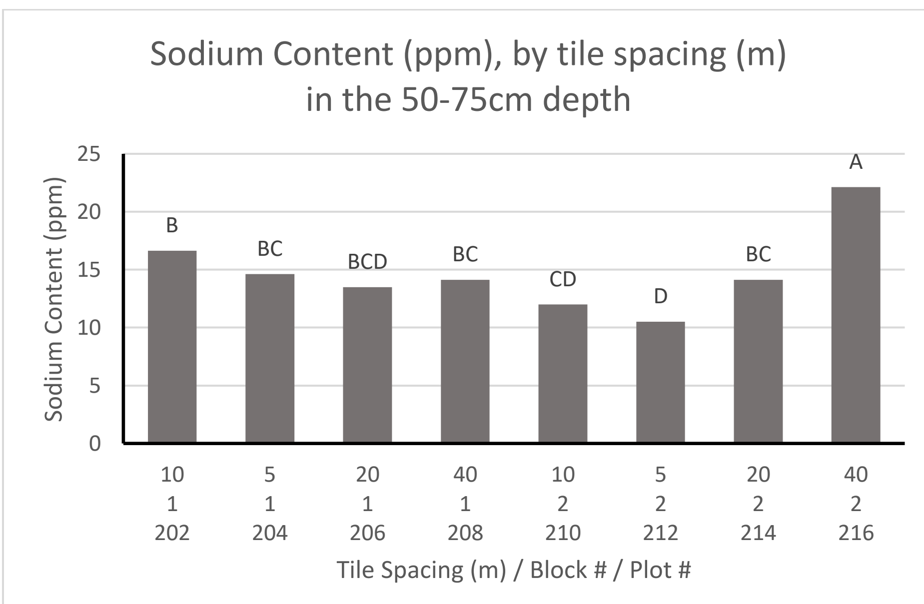

Figure 3.25. Soil sodium content (ppm) at the 50-75cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

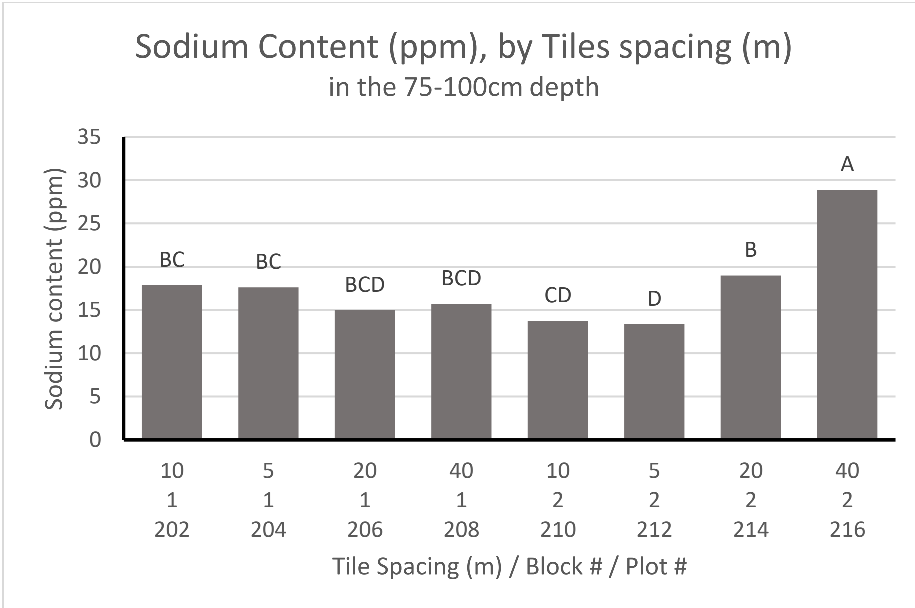

Figure 3.26. Soil sodium content (ppm) at the 75-100cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

3.5.7 Soil cation exchange capacity

The soil CEC data from the 0-15cm and 15-30cm depths did not meet the primary assumptions that the data be normally distributed and have homogeneous distribution of variance. Thus, the data from these depths were transformed using a ln(Y) transformation. The data presented here from the 30-50cm depth are shown having been back transformed. The data from all other depths met the primary assumptions and did not require a transformation. The soil CEC data by tile spacing for each depth increment are shown in Table 3.11. No significant results were found for the 0-15cm depth.

In the 15-30cm depth, the interaction of block and tile spacing had a significant effect on soil CEC. However, upon performing the means separation analysis no significant differences were able to be identified.

In the 30-50cm depth the interaction of block and tile spacing had a significant effect on soil CEC (Figure 3.27). At this depth the 40-m tile spacing in Block 2 was significantly greater than the 10-m tile spacing in Block 2 and the 5-m in Block 1 but was not significantly different from any other tile spacing in either Block 1 or Block 2. This interaction also explains the significant main effect of block that was also identified at this depth, with Block 2 having a significantly higher CEC than Block 1.

In the 50-75cm depth tile spacing had a significant main effect on soil CEC (Table 3.11). At this depth the 5-m and 20-m tile spacings were significantly higher than the 10-m tile spacing but neither was significantly different from the 40-m tile spacing. Block had a significant effect on CEC at the 50-75cm depth and the 75-100cm depth, with Block 2 was having a significantly higher CEC than block 1. Soil CEC generally increased with depth. This general trend is a result of an increase in clay content with depth (Kladivko 2005).

Table 3.11. Soil cation exchange capacity (meq/100g) by tile spacing (m) at multiple depths. Samples were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Soil CEC (meq/100g) by Tile Spacing					
Spacing (m)	**0-15cm**	**15-30cm**	**30-50cm**	**50-75cm**	**75-100cm**
5	6.0 a	6.3 a	8.3 a	13.5 a	18.5 a
10	6.3 a	6.0 a	7.0 a	10.2 b	17.4 a
20	6.2 a	6.4 a	8.1 a	13.2 a	18.5 a
40	6.2 a	6.1 a	7.1 a	12.2 ab	17.4 a

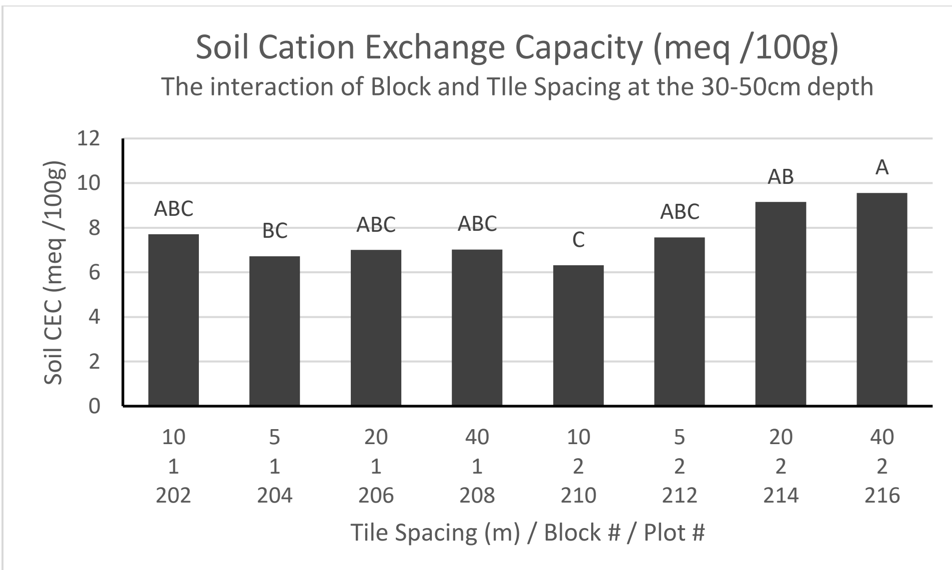

Figure 3.27. Soil cation exchange capacity (meq/100g) at the 75-100cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

3.5.8 Soil pH

The soil pH data met all of the necessary assumptions that the data be normally distributed and have homogeneous distribution of variance. Thus, none of the soil pH data were transformed. The soil pH data by tile spacing for each depth increment are shown in Table 3.12. Block was found to have a significant effect on soil pH in all depths except in the 0-15cm depth. In the depths where block had a significant main effect, Block 2 had a significantly higher soil pH than Block 1.

In the 0-15cm depth the interaction of block and tile spacing had a significant effect on soil pH (Figure 3.28). At this depth the 40-m tile spacing in Block 2 had a significantly higher soil pH than the 10-m and 20-m tile spacings in the same block. However, in Block 1 no significant differences were found.

In the 30-50cm depth, tile spacing had a significant effect on soil pH. At this depth the 40-m tile spacing had a significantly lower soil pH than all other tile spacings (Table 3.12).

In the 50-75cm depth tile spacing had a significant main effect on soil pH. At this depth the 40-m tile spacing had a significantly lower soil pH than the 5-m and 10-m tile spacings. The soil pH in 20-m tile spacing was significantly lower than the 5-m tile spacing but was not significantly different from the 10-m or the 40-m tile spacing (Table 3.12).

In the 75-100cm depth the interaction of block and tile spacing had a significant effect on soil pH (Figure 3.29). At this depth the 5-m tile spacing in Block 1 had a significantly higher soil pH than the 40-m tile spacing in Block 1 and the 5-m, 20-m, and the 40-m tile spacings in Block 2. Tile spacing also had a significant main effect on soil pH at the 75-100cm depth (Table 3.12). At this depth, the 40-m tile spacing was significantly lower than 5-m and 10-m tile spacings but not significantly different from the 20-m spacing. However, the interaction of block and tile spacing previously described, did not explain the significant effects of block or tile spacing that were also observed at this depth.

The 30-50cm, 50-75cm and the 75-100cm depths all display the same trend in regards to tile spacing, where the narrower tiles spacings have significantly higher soil pH values than the wider tiles spacing. In these depths, soil pH values generally decline as tile spacings increase.

Table 3.12. Soil pH by tile spacing (m) at multiple depths. Samples were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

Soil pH by tile spacing (m)					
Spacing (m)	**0-15cm**	**15-30cm**	**30-50cm**	**50-75cm**	**75-100cm**
5	6.1 a	5.9 a	5.3 a	4.8 a	4.7 a
10	6.2 a	6.1 a	5.2 a	4.7 ab	4.6 ab
20	6.2 a	6.1 a	5.4 a	4.7 bc	4.5 bc
40	6.5 a	6.2 a	4.9 b	4.6 c	4.5 c

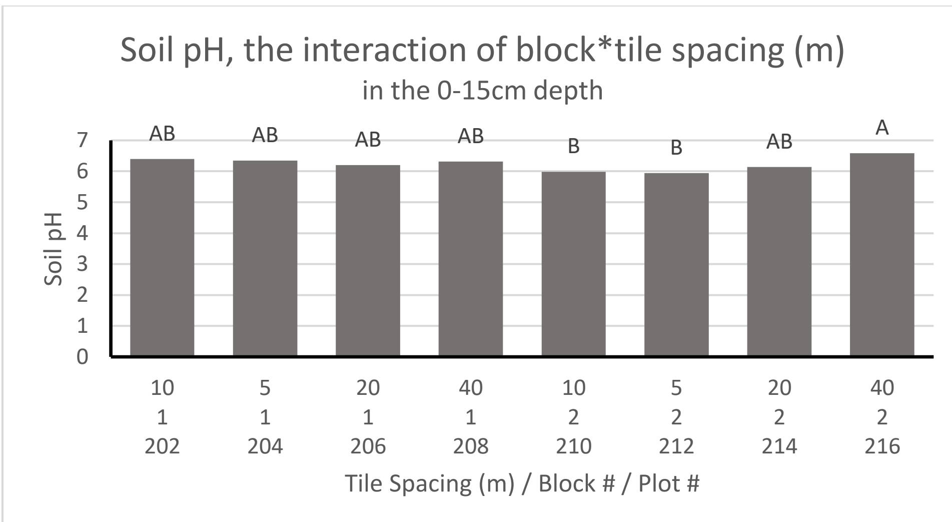

Figure 3.28. Soil pH at the 0-15cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

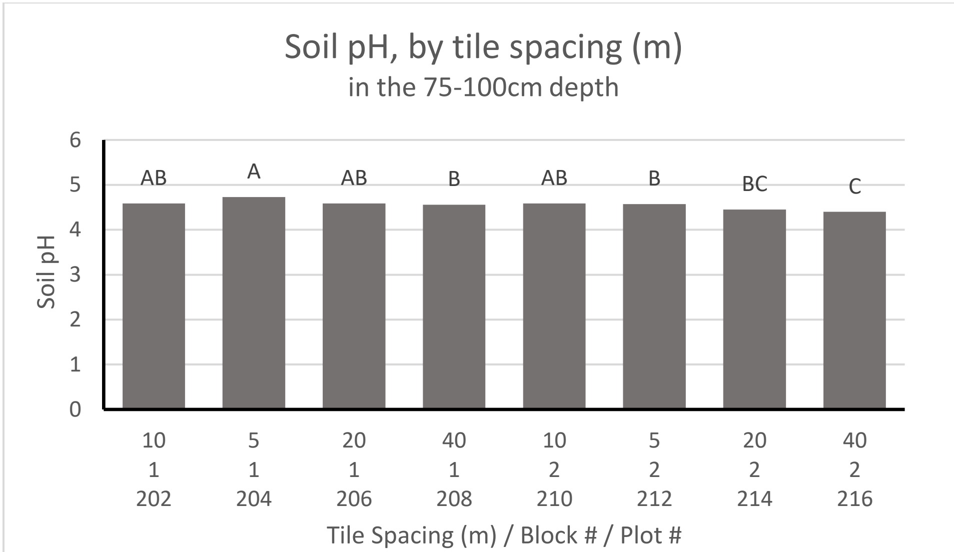

Figure 3.29. Soil pH at the 75-100cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

3.6 Bulk Density of Plow Pan

Tile spacing had a significant effect on the bulk density of the restrictive layer. The bulk density of the restrictive layer in the 40-m tile spacing was significantly greater than that of the 10-m tile spacing, but was not significantly different from any other tile spacing (Figure 3.30). Block also had a significant effect on the bulk density of the restrictive layer, with the restrictive layer in Block 2 having a significantly higher bulk density than that in Block 1 (1.64g cm^{-3} and 1.60g cm^{-3} respectively).

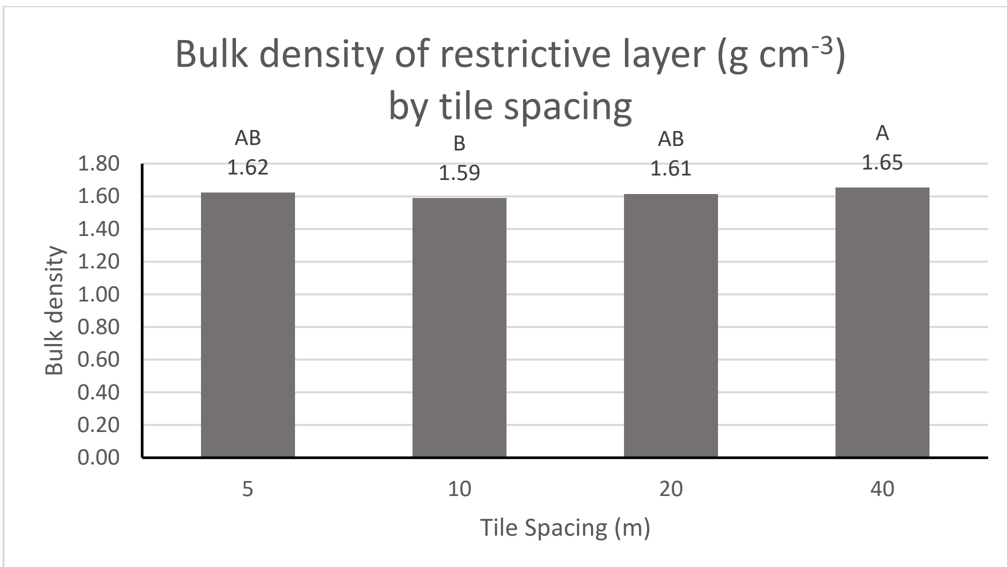

Figure 3.30. Bulk density of restrictive layer (g cm^{-3}). Samples were collected at approximate depth of restrictive layer with each subplot, using the short core method. Depth to restrictive layer varied across the field from with an average depth of 27.5cm. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

3.7 Soil Moisture Content - Gravimetric Water Content (g g^{-1})

Soil moisture was measured primarily to support the cone penetrometer and the vane shear penetrometer data. The soil moisture data in all depths met the primary assumptions that the data be normally distributed, and have homogeneous distribution of variance. Thus, no transformation was needed. Tile spacing alone was not found to have a significant effect on soil moisture at any depth. The average soil moisture content by tile spacing is shown in Table 3.13.

In the 0-15cm depth the interaction of block and tile spacing was found to have a significant effect on soil moisture content (Figure 3.31). At this depth the 10-m tile spacing in block 1 and the 20-m tile spacing in Block 2 had significantly higher soil moisture contents than the 20-m tile spacing in Block 1. However, neither was significantly different from any other tile spacing in either block.

In the 15-30cm depth the interaction of block and tile spacing was found to have a significant effect on soil moisture content (Figure 3.32). At this depth the 40-m spacing in Block 2 had a significantly greater soil moisture content than all other tile spacings in both blocks except it was not significantly different from the 5-m tile spacing in Block 1. Block was also found to have a significant main effect on soil moisture content in the 15-30cm and the 30-50cm depths, with Block 2 having a significantly higher soil moisture content than Block 1 in both depths. In the 15-30cm depth Block 2 had a moisture content of 0.191g $g^{-1,}$whereas Block 1 had a moisture content of 0.185g g^{-1}. In 30-50cm depth Block 2 had a moisture content of 0.222g g^{-1} and Block 1 had a moisture content of 0.211g g^{-1}.

Table 3.13. Soil gravimetric water content (g g^{-1}) by tile spacing (m) at multiple depths. Samples were collected using a truck mounted hydraulic probe. Each value represents the mean of both blocks and 8 subplots (n=16). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

Gravimetric water content (g g^{-1})				
Tile Spacing	**0-15cm**	**15-30cm**	**30-50cm**	**50-75cm**
5m	0.186 a	0.188 a	0.213 a	0.221 a
10m	0.188 a	0.186 a	0.215 a	0.236 a
20m	0.184 a	0.186 a	0.217 a	0.229 a
40m	0.188 a	0.192 a	0.222 a	0.258 a

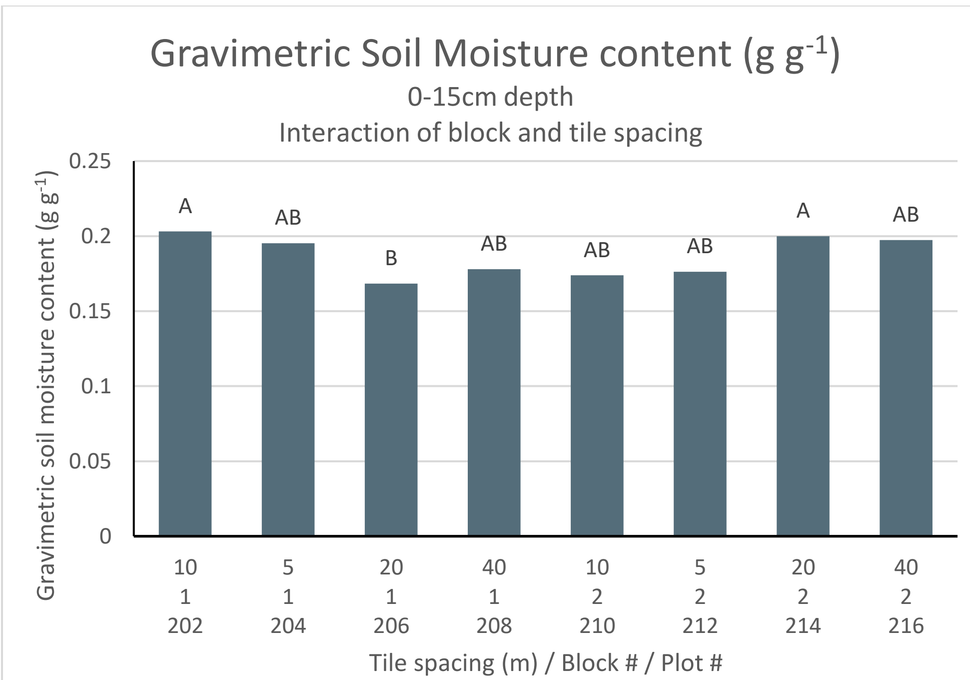

Figure 3.31. Soil gravimetric water content (g g^{-1}) at the 0-15cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

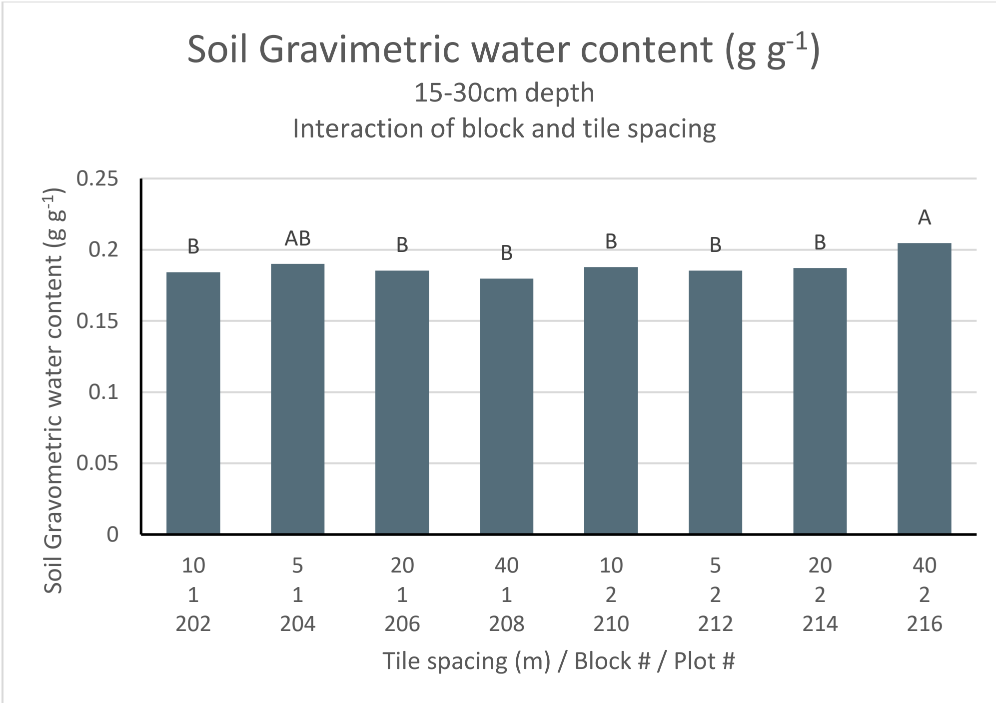

Figure 3.32. Soil gravimetric water content (g g^{-1}) at the 0-15cm depth. Samples were collected using a truck mounted hydraulic probe. Each column represents the mean of 8 subplots. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

3.8 Vane Shear Resistance (VSR)

The data from the vane shear penetrometer met all the primary assumptions that the data be normally distributed, and have homogeneous distribution of variance, thus the data set did not need to be transformed. No formal statistical analysis was performed on the data from the 30cm depth. At the 30cm depth, 71% of the measurements taken exceeded the instruments maximum measurable limit (Table 3.14). These values were recorded as the instruments maximum limit of 120 kPa, however these values were actually greater than 120 kPa.

At the 10cm depth, tile spacing had a significant effect (Table 3.15). The 20-m tile spacing had a significantly greater VSR measurement than the 5-m and 40-m tile spacings. However, the 20-m tile spacing was not significantly different from the 10-m tile spacing.

In the 20cm depth the interaction of block and tile spacing had a significant effect on VSR measurements (Figure 3.33). At this depth the 40-m tile spacing in Block 2 had significantly greater VSR measurement than all tile spacings in Block 1 except for the 20-m spacing in Block 1. The 40-m tile spacing in Block 2 also had significantly greater VSR measurement than the 5-m tile spacing in Block 2. In addition, the 40-m tile spacing in Block 1 also had a significantly lower VSR than the 20-m and 40-m tile spacing in Block 2 but was not significantly different from any other tile spacing in either block.

Also, at the 20cm depth tile spacing had a significant main effect on VSR measurements (Table 3.15). The 20-m and the 40-m tile spacings had a significantly greater VSR measurements than the 5-m tile spacing but neither was significantly different from the 10-m tile spacing. It should be noted that the differences found between the 40-m tile spacing and the 5-m tile spacing can be explained by the interaction of block and tile spacing, as previously described. However, the interaction of block and tile spacing does not explain the significant differences found between the 20-m tile spacing and the 5-m tile spacing (Table 3.15). Block also had a significant effect in the 20cm depth, with Block 2 having significantly greater VSR values than Block 1. This is also explained by the interaction of block and tile spacing as previously discussed and shown in Figure 3.33. There were no significant results found in the 40cm depth.

Table 3.14. Vane shear resistance (kPa) by tile spacing (m) at multiple depths. Samples were collected using a handheld vane shear penetrometer. Measurements were taken only in subplot number 2 in each of the 8 plots, with 4 measurements taken in both the east and west positions. Each value represents the mean of both blocks (n=16). Number of measurements taken in each spacing and depth that exceeded the maximum limit of the device (120 kPa) that were entered as maximum measurable value the device.

Tile spacing (m)	**Depth (cm)**	**Avg. VSR (kPa)**	**Contain values >120 kPa but entered as 120**
5	10	85	
5	20	88	
5	30	108	6 values >120
5	40	101	
10	10	94	
10	20	94	
10	30	111	5 values >120
10	40	94	
20	10	105	1 value >120
20	20	101	1 value >120
20	30	106	6 value >120
20	40	98	3 values >120
40	10	88	
40	20	99	3 values >120
40	30	109	6 values >120
40	40	102	3 values >120

Table 3.15. Vane shear resistance (kPa) by tile spacing (m) at multiple depths. Samples were collected using a handheld vane shear penetrometer. Measurements were taken only in subplot number 2 in each of the 8 plots, with 4 measurements taken in both the east and west positions. Each value represents the mean of both blocks (n=16). No statistical analysis was able to be performed on the data from 30cm depth. Values within the same column that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

VSR (kPa) by tile spacing per depth (cm)				
Spacing	**10cm**	**20cm**	**30cm**	**40cm**
5m	85 b	88 b	108	101 a
10m	94 ab	94 ab	111	94 a
20m	105 a	101 a	106	98 a
40m	88 b	99 a	109	102 a

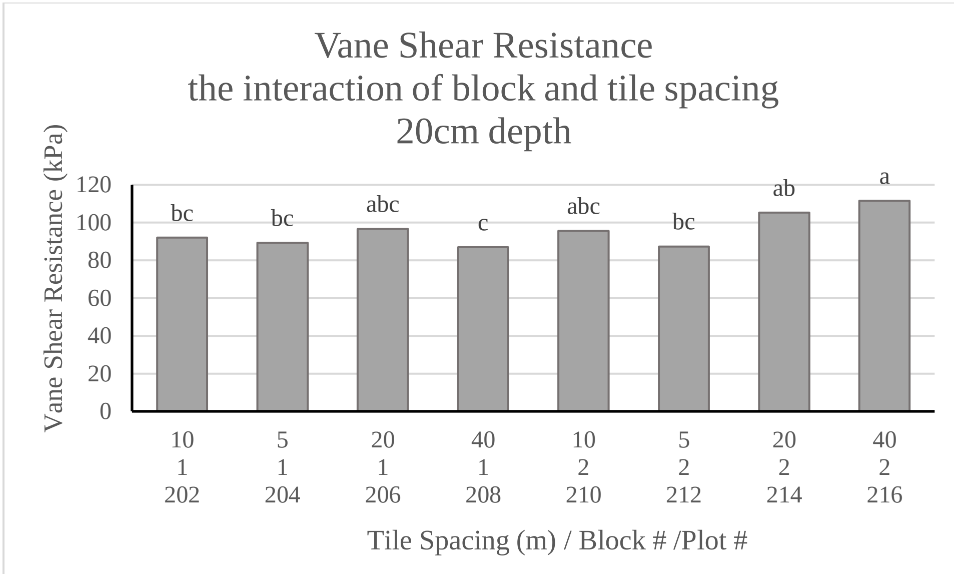

Figure 3.33. Vane shear resistance (kPa) at the 20cm depth. Samples were collected using a handheld vane shear penetrometer. Measurements were taken only in subplot number 2 in each of the 8 plots, with 4 measurements taken in both the east and west positions. Each column represents the mean of 8 measurements taken in each plot. Columns that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

3.9 Cone Penetrometer – Cone Penetration Resistance (CPR).

The cone penetrometer data from the soil depth increments of 2.5cm through 25cm met all the primary assumptions that the data be normally distributed, and have homogeneous distribution of variance, thus this portion of the data set did not need to be transformed. However, all data from the soil depth increments of 27.5cm through 75cm did not meet the necessary primary assumptions and were transformed using a log(y) transformation. The data from these depths presented here, have been back-transformed. The CPR data by tile spacing for each depth increment are shown in Table 3.16, Table 3.17, Table 3.18 and Figure 3.34.

The interaction of block and tile spacing had a significant effect on the CPR values at all soil depths from 2.5cm through 25cm (Figure 3.35 and Figure 3.36 through Figure 3.45). At all depths from 2.5cm through 17.5cm, the 40-m tile spacing in Block1 (plot 208) had significantly higher CPR values than all other tile spacings in Block 1 and Block 2. At the 20cm and the 22.5cm depths, there were no significant differences observed among tile spacings in Block 2 but the 40-m tile spacing in Block 1 had significantly higher CPR values than the 5-m and the 10-m tile spacings also in Block 1. In the 25cm depth the interaction of block and tile spacing had a significant effect on VSR. However, after performing the LS-means separation analysis no significant differences were observed (Figure 3.45).

Tile spacing had a significant main effect on CPR in all depths from 2.5cm through 20cm (Figure 3.34 and Table 3.16). At soil depths 2.5cm through 10cm the 40-m tile spacing had significantly higher CPR than all other tile spacings. At the 12.5cm and 15cm soil depths the 40-m tile spacing had significantly CPR than all other tile spacings. Also, at these depths the 10-m tile spacing had significantly higher CPR than the 5-m tile spacing but was not significantly different from the 20-m tile spacing. In the 17.5cm depth the 40-m tile spacing had significantly higher CPR than the 20-m and the 5-m tile spacings, but was not significantly different from the 10-m tile spacing. In the 20cm depth the 5-m tile spacing had significantly lower CPR than all other tile spacings. Block also had a significant effect on CPR in all depths from 2.5cm through 20cm. At all of these depths Block 1 had significantly higher CPR values than Block2. The significant primary effects of block and tile spacing observed at all depths from 2.5cm through 20cm is explained by the interaction of block and tile spacing described above.

The data from soil depth increments 27.5 through 75cm were transformed using a log(y) transformation prior to performing statistical analysis. The data discussed here have been back transformed. The interaction of block and tile spacing also had a significant effect on CPR at all depths from 27.5cm through 40cm (Figure 3.35 and Figure 3.46 through Figure 3.51). In each of these depths the 10-m tile spacing in Block 1 (plot 202) generally had significantly lower CPR than all other tile spacings in both Block 1 and Block 2, while there were no significant differences found between all other tile spacings in both Block 1 and Block 2.

A significant main effect of tile spacing was found on CPR in all depth increments from 27.5cm through 50cm (Table 3.17). At soil depths of 27.5cm through 40cm the 10-m tile spacing had significantly lower CPR than the 5-m and the 40-m tile spacings. It should be noted that the interaction of block and tile spacing described above explains the significant main effects of tile spacing observed at these soil depths. However, in the soil depths from 42.5cm through 50cm, the main effect of tile spacing was also found to be significant. In each of these depths the 10-m tile spacing had significantly lower CPR than the 40-m tile spacing, while the 5-m and the 20-m tile spacing were generally not significantly different from any other tile spacing. Block had a significant effect on CPR at the 32.5cm, 35cm and the 50cm depths. In the 32.5cm and the 35cm depths Block 2 had significantly greater CPR than Block 1, while in the 50cm depth Block 1 had significantly greater CPR than Block 2

At soil depths 52.5cm and 62.5cm through 75cm, tile spacing had a significant effect on CPR (Table 3.18 and Figure 3.34). In the 52.5cm depth the 10-m tile spacing had significantly lower CPR than the 40-m spacing. At soil depths from 62.5cm through 75cm a similar trend was observed with the 10-m tile spacing being found to have significantly lower CPR than 5-m and the 40-m tile spacings. A significant effect of block was also observed in all soil depths from 52.5cm through 75cm. At each of these depths Block 1 had significantly greater CPR than Block 2.

Table 3.16. Cone penetration resistance (kPa) by tile spacing (m) at multiple depths. Measurements were taken only in subplot number 2 in each of the 8 plots, with 8 measurements taken in both the east and west positions. Each value represents the mean of both blocks (n=32). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Cone Penetration Resistance (kPa) by Tile Spacing depth increments 2.5cm to 25cm										
Tile Spacing (m)	**2.5 cm**	**5 cm**	**7.5 cm**	**10 cm**	**12.5 cm**	**15 cm**	**17.5 cm**	**20 cm**	**22.5 cm**	**25 cm**
5m	1185 b	1366 b	1506 b	1627 b	1741 c	1843 c	1905 c	1996 b	2332 a	2607 a
10m	1278 b	1536 b	1659 b	1816 ab	1969 b	2119 b	2218 ab	2341 a	2411 a	2506 a
20m	1279 b	1399 b	1543 b	1679 b	1862 bc	2048 bc	2209 b	2360 a	2516 a	2527 a
40m	1577 a	1795 a	1894 a	1998 a	2218 a	2389 a	2460 a	2583 a	2607 a	2798 a

Table 3.17. Cone penetration resistance (kPa) by tile spacing (m) at multiple depths. Measurements were taken only in subplot number 2 in each of the 8 plots, with 8 measurements taken in both the east and west positions. Each value represents the mean of both blocks (n=32). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

Cone Penetration Resistance (kPa) by Tile Spacing depth increments 27.5cm through 50cm										
*Values shown have been back Transformed										
Tile Spacing (m)	**27.5cm**	**30cm**	**32.5cm**	**35cm**	**37.5cm**	**40cm**	**42.5cm**	**45cm**	**47.5cm**	**50cm**
5	2647 a	2539 a	2464 a	2265 a	2071 a	2055 a	2126 a	2081 a	2012 ab	1914 ab
10	2197 b	1950 b	1866 b	1759 b	1582 b	1537 b	1501 b	1590 b	1664 b	1633 b
20	2463 ab	2369 a	2198 ab	2104 ab	1968 a	1976 a	2011 a	1945 ab	1837 ab	1827 ab
40	2804 a	2660 a	2376 a	2235 a	2197 a	2189 a	2204 a	2152 a	2154 a	2146 a

Table 3.18. Cone penetration resistance (kPa) by tile spacing (m) at multiple depths. Measurements were taken only in subplot number 2 in each of the 8 plots, with 8 measurements taken in both the east and west positions. Each value represents the mean of both blocks (n=32). Values within the same column that have the same letter are not significantly different as determined by an LSMeans test ($p \leq 0.10$).

Cone Penetration Resistance (kPa) by Tile Spacing depth increments 52.5cm through 75cm										
*Values shown have been back Transformed										
Tile Spacing (m)	**52.5cm**	**55cm**	**57.5cm**	**60cm**	**62.5cm**	**65cm**	**67.5cm**	**70cm**	**72.5cm**	**75cm**
5	1843 ab	1902 a	1922 a	1877 a	1917 a	1974 a	2059 a	2037 a	1978 a	1846 a
10	1562 b	1597 a	1649 a	1655 a	1552 b	1439 b	1437 c	1452 c	1395 b	1417 b
20	1777 ab	1754 a	1721 a	1749 a	1720 ab	1664 ab	1605 bc	1635 bc	1683 ab	1585 ab
40	2083 a	1979 a	1864 a	1924 a	1981 a	1975 a	1961 ab	1908 ab	1900 a	1905 a

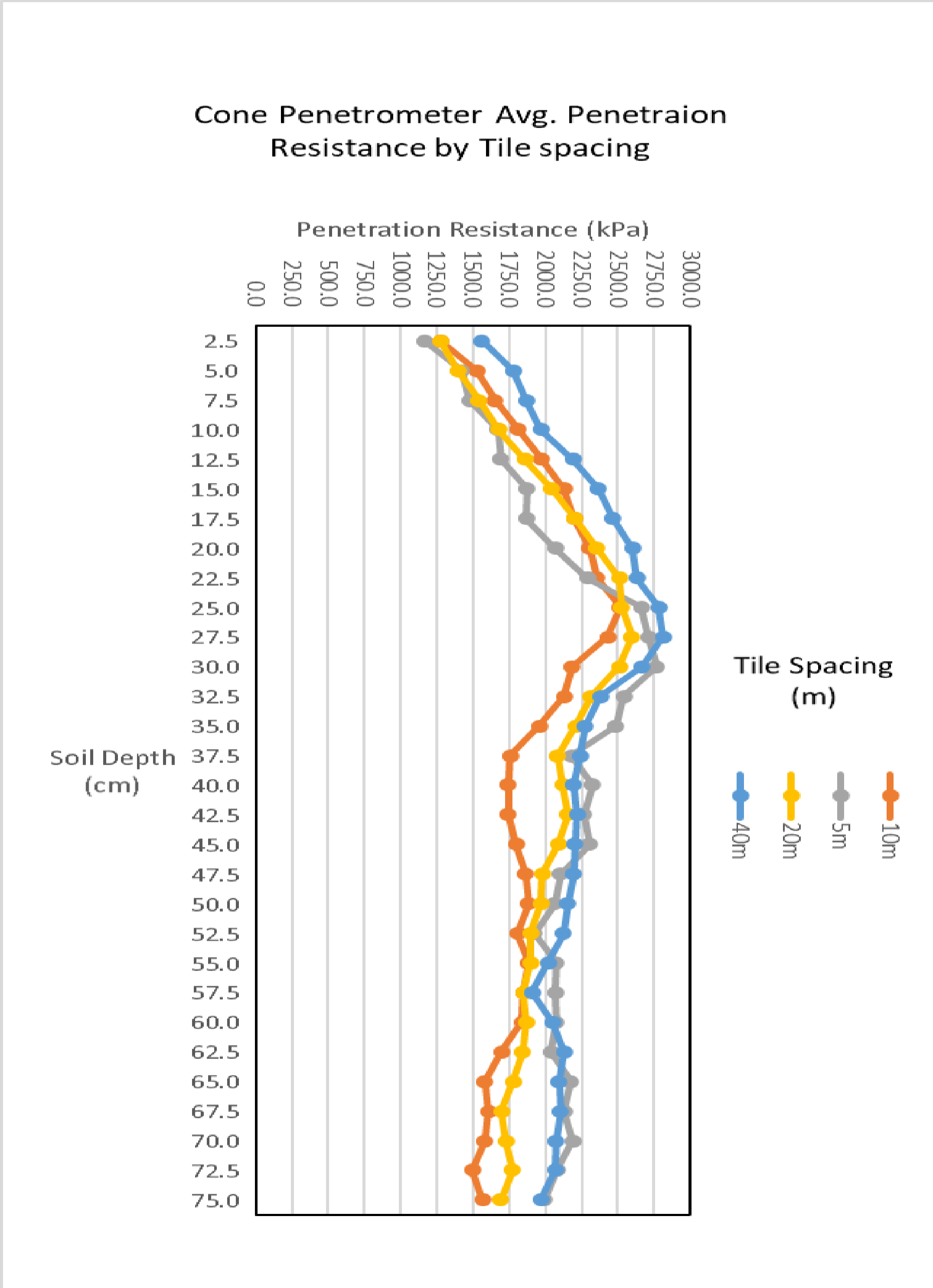

Figure 3.34. Cone penetration resistance (kPa) by tile spacing (m) at multiple depths. Measurements were taken only in subplot number 2 in each of the 8 plots, with 8 measurements taken in both the east and west positions. Each data point represents the mean of both blocks (n=32).

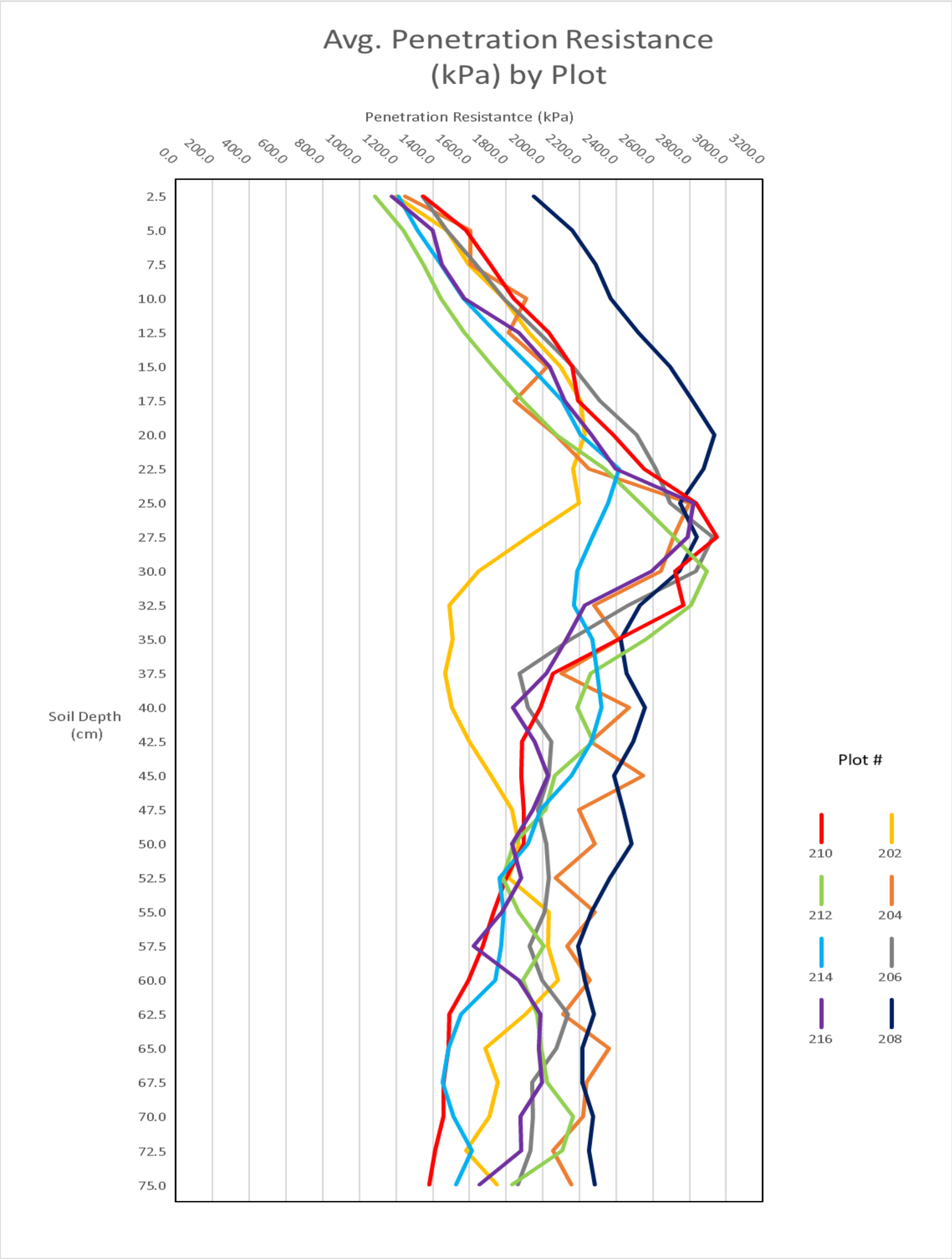

Figure 3.35. Cone penetration resistance (kPa) by plot (m) at multiple depths. Measurements were taken only in subplot number 2 in each of the 8 plots, with 8 measurements taken in both the east and west positions. Each data point represents the mean of each plot (n=16).

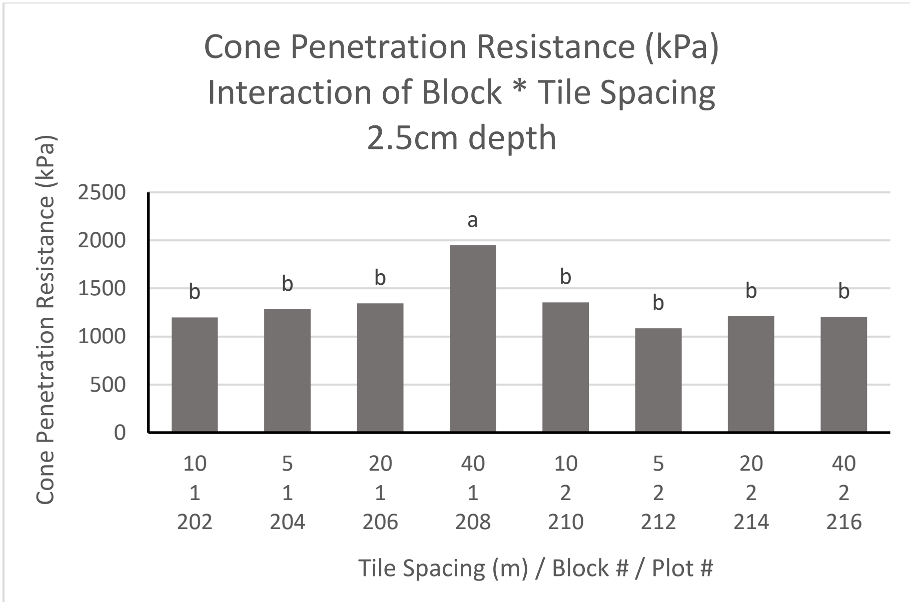

Figure 3.36. Cone penetration resistance (kPa) by tile spacing (m) at the 2.5cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

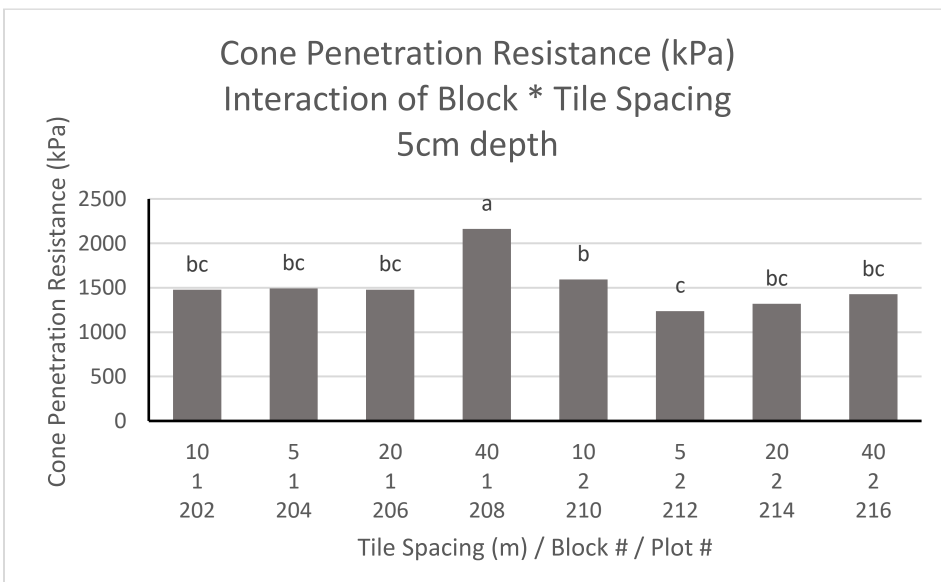

Figure 3.37. Cone penetration resistance (kPa) by tile spacing (m) at the 5cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

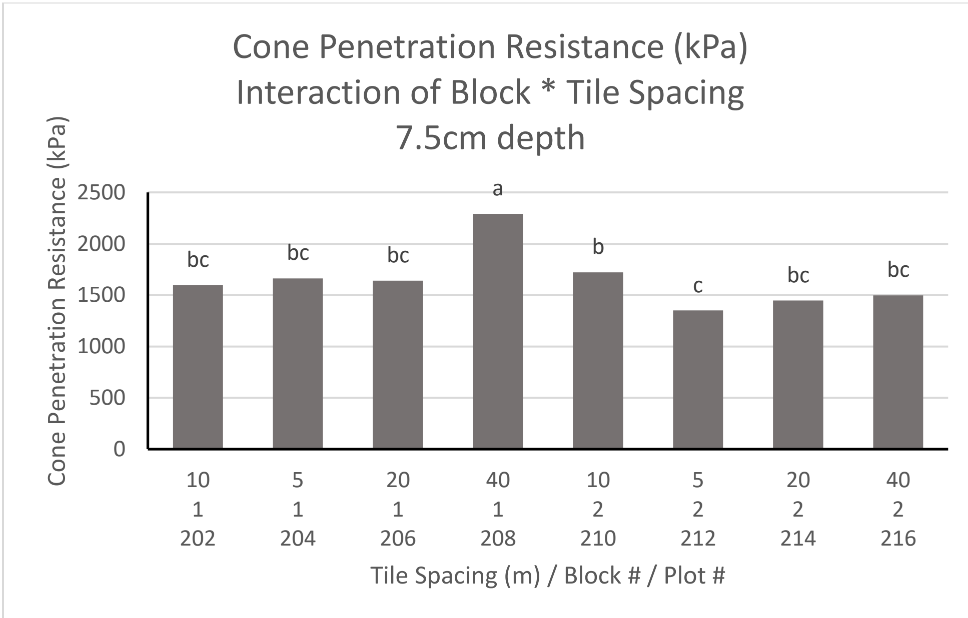

Figure 3.38. Cone penetration resistance (kPa) by tile spacing (m) at the 7.5cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

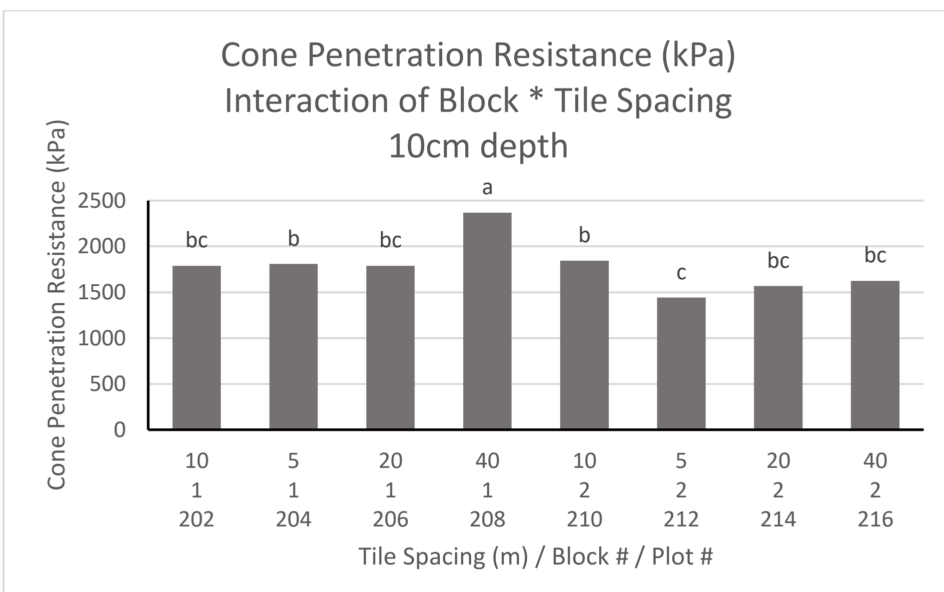

Figure 3.39. Cone penetration resistance (kPa) by tile spacing (m) at the 10cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

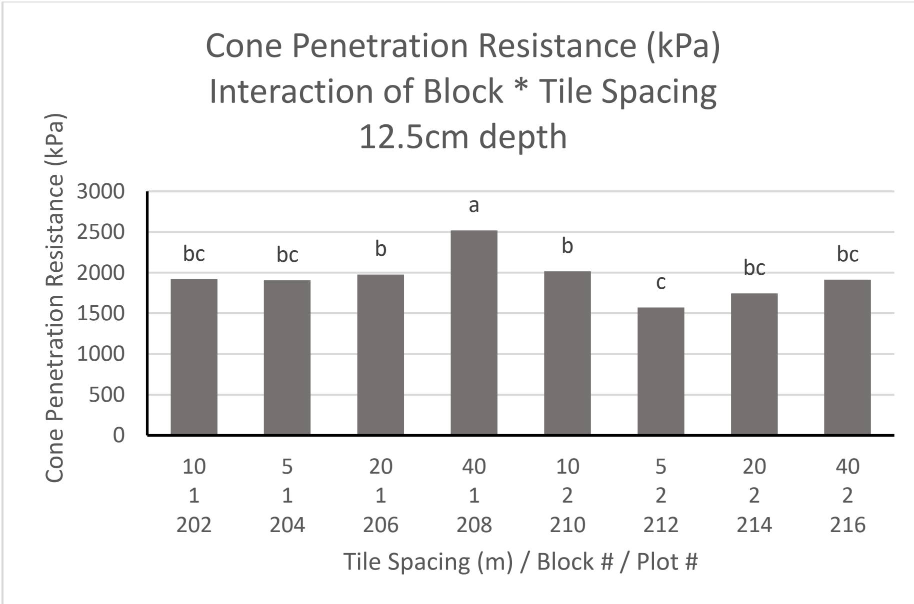

Figure 3.40. Cone penetration resistance (kPa) by tile spacing (m) at the 12.5cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

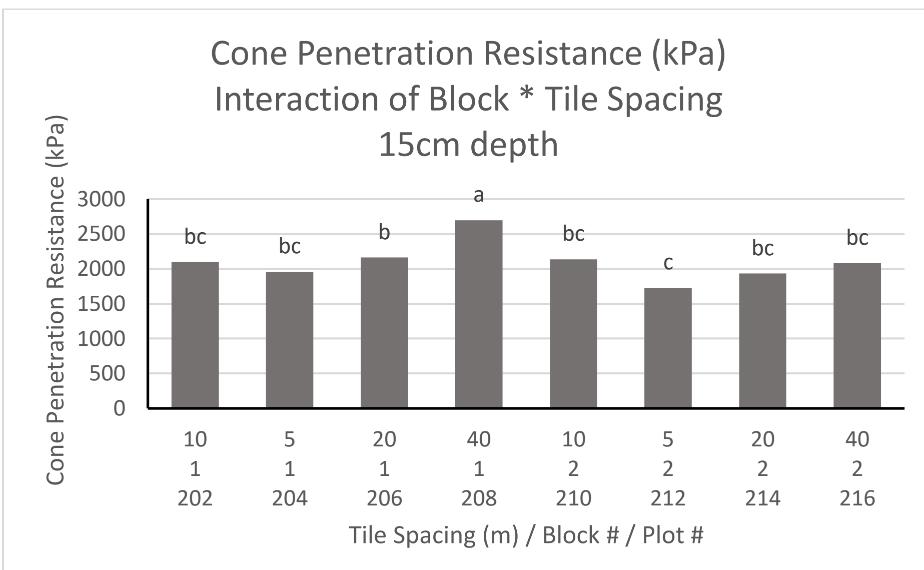

Figure 3.41 Cone penetration resistance (kPa) by tile spacing (m) at the 15cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

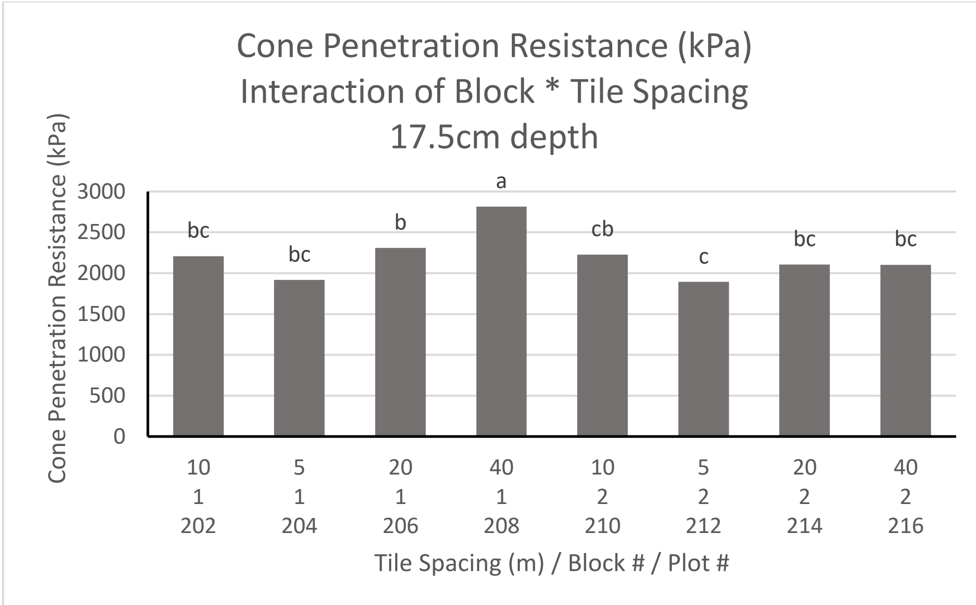

Figure 3.42. Cone penetration resistance (kPa) by tile spacing (m) at the 17.5cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

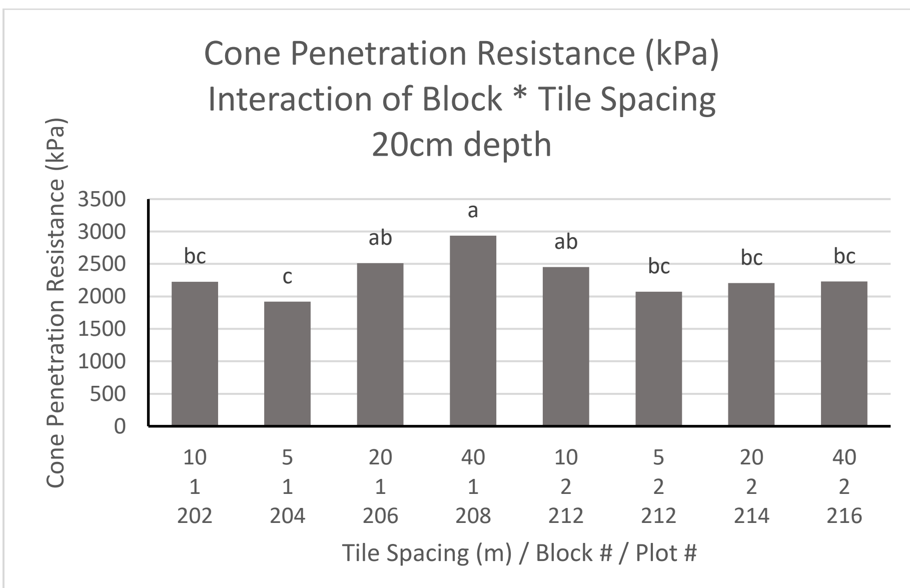

Figure 3.43. Cone penetration resistance (kPa) by tile spacing (m) at the 20cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

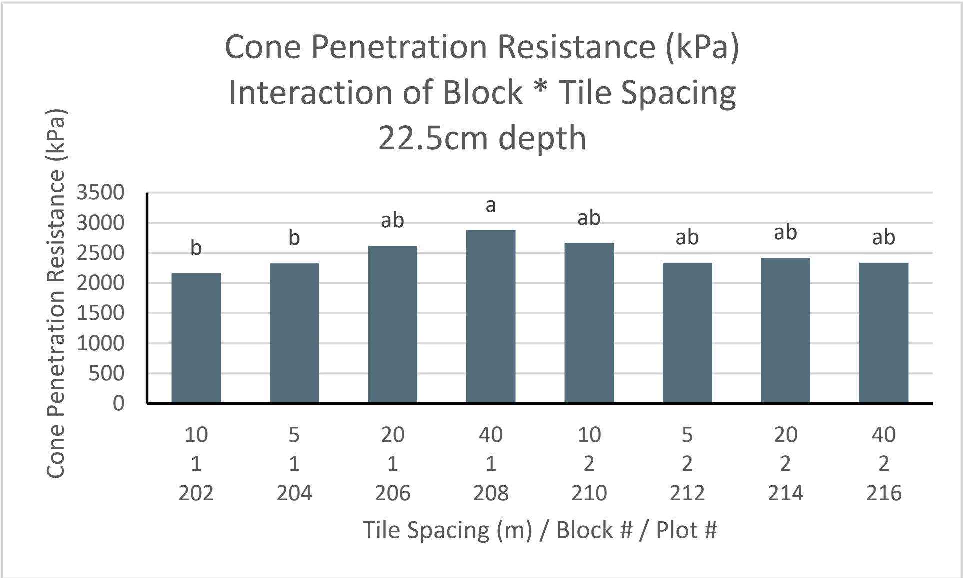

Figure 3.44 . Cone penetration resistance (kPa) by tile spacing (m) at the 22.5cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

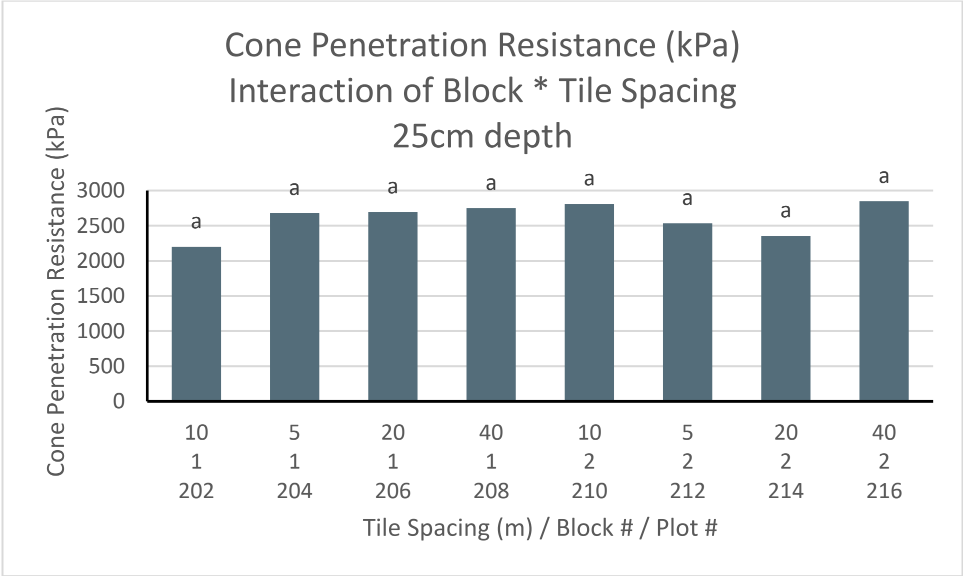

Figure 3.45. Cone penetration resistance (kPa) by tile spacing (m) at the 25cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

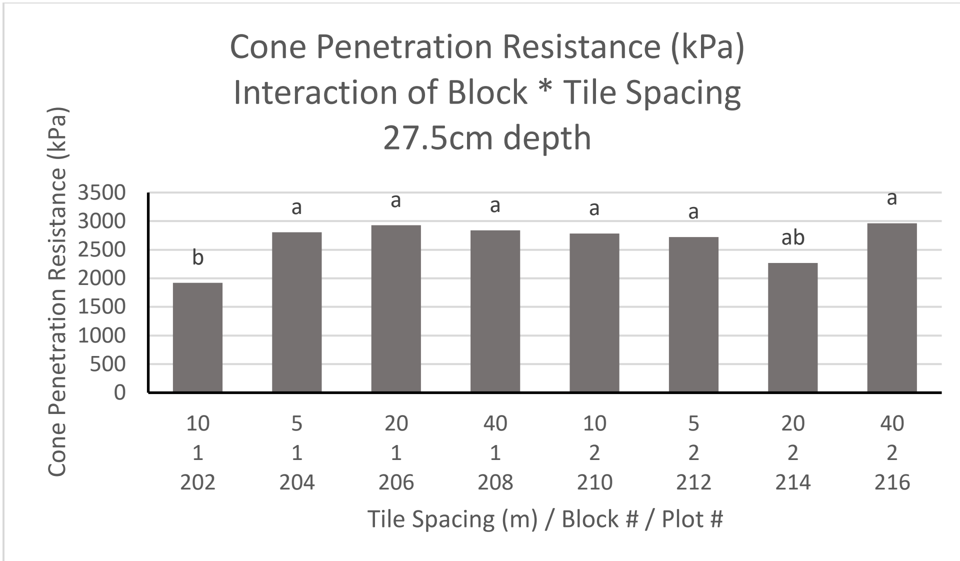

Figure 3.46. Cone penetration resistance (kPa) by tile spacing (m) at the 27.5cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

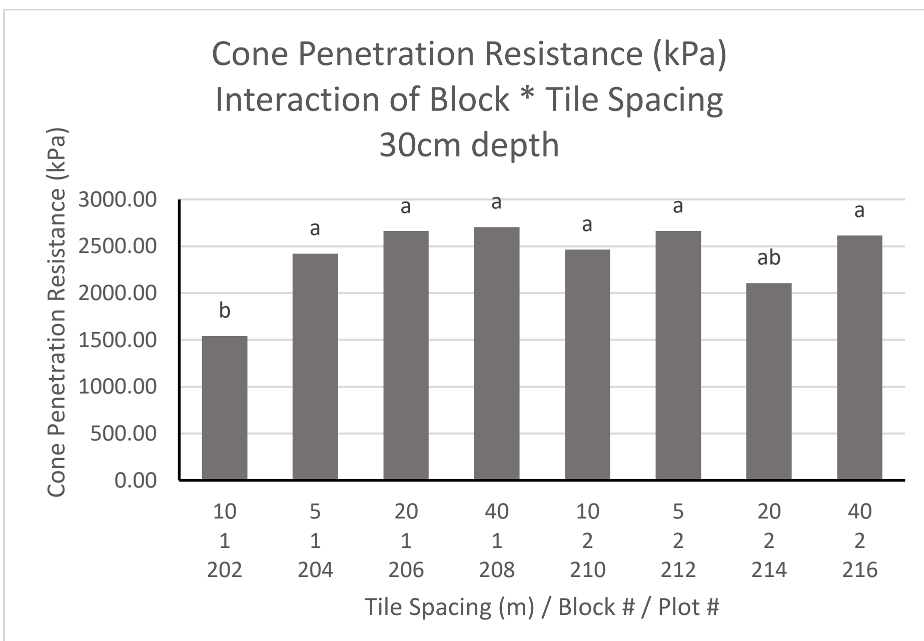

Figure 3.47. Cone penetration resistance (kPa) by tile spacing (m) at the 30cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

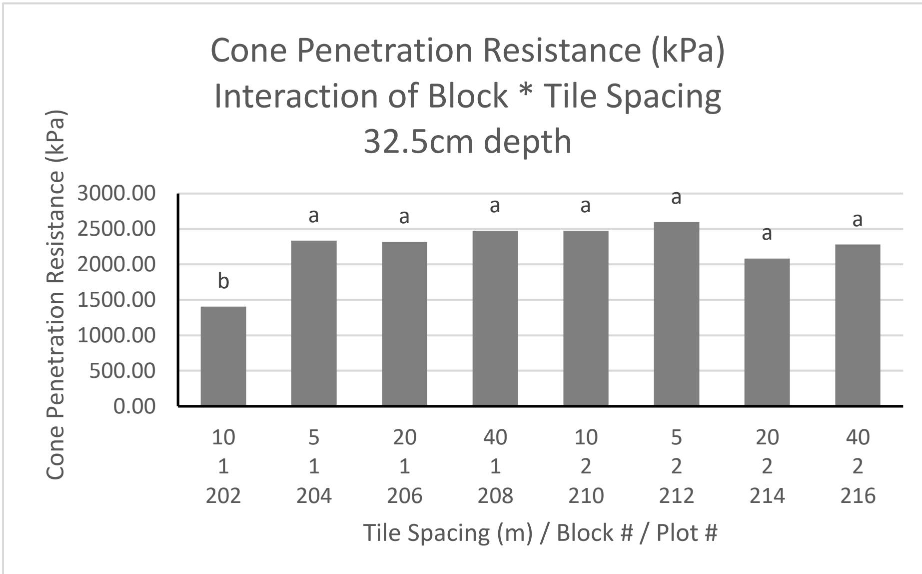

Figure 3.48. Cone penetration resistance (kPa) by tile spacing (m) at the 32.5cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

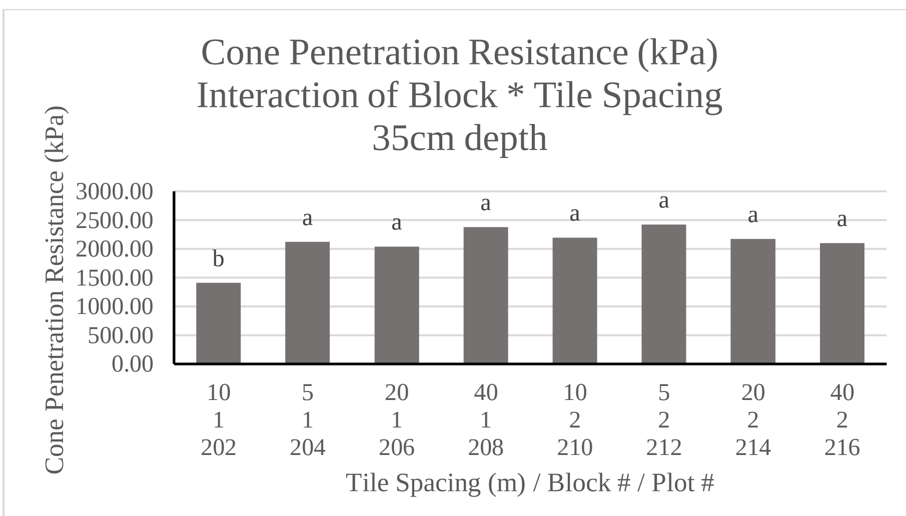

Figure 3.49. Cone penetration resistance (kPa) by tile spacing (m) at the 35cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

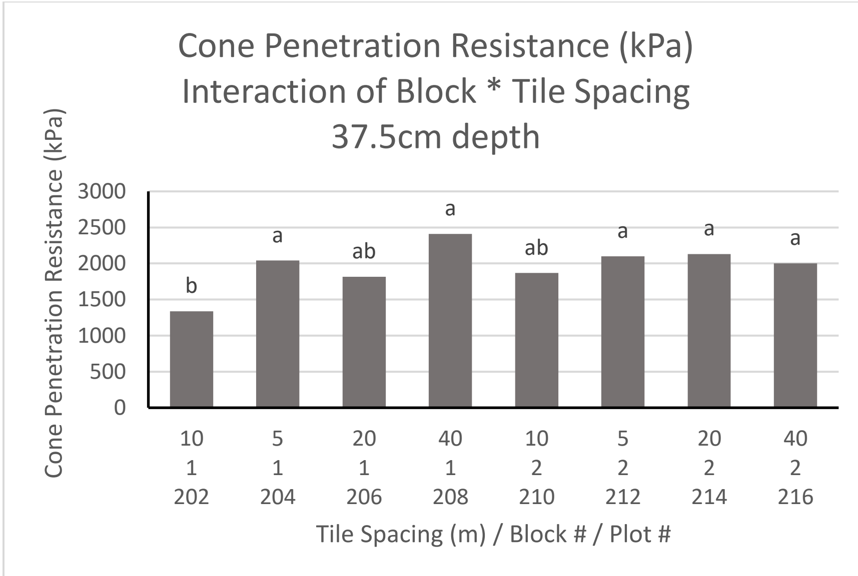

Figure 3.50. Cone penetration resistance (kPa) by tile spacing (m) at the 37.5cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

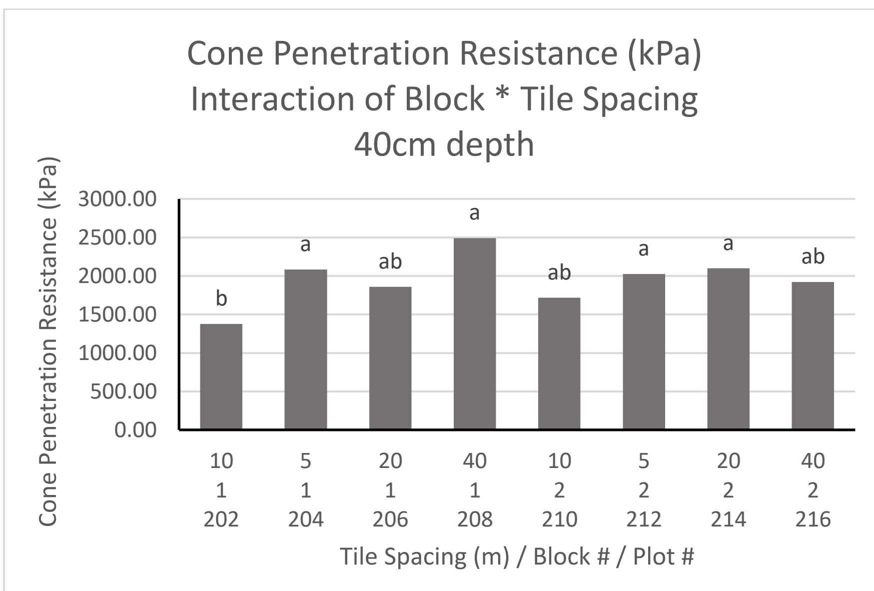

Figure 3.51. Cone penetration resistance (kPa) by tile spacing (m) at the 40cm depth. Measurements were taken only in subplot number 2, with 8 measurements taken in both the east and west positions . Each column represents the mean of 16 measurements. Columns that have the same letter are not significantly different as determined by an LSMeans test (p≤0.10).

3.10 Summary and Discussion

In general, the 5-m tile spacing had a significantly higher total carbon content than the 40-m tile spacing in the 0-5cm and 5-15cm depths, with the 10-m and 20-m tile spacing being intermediate. This is likely attributed to increased carbon inputs in the upper depths as a result of greater cover crop growth (Kladivko, 2020b) and higher cash crop yields in the 5-m tile spacing as compared to the 40-m tile spacing. Corn yields over the 24 years of corn in the 35-yr project averaged 10.5 Mg ha^{-1} for the 5-m spacing and 9.0 Mg ha^{-1} for the 40-m spacing (Kladivko, 2020a). However, the general trend observed in the upper depths was found to be the inverse of the trend observed in the 75-100cm depth, where the 10-m tile spacing had significantly less total carbon content than the 40-m tile spacing (considered the control). This is likely due to the excess soil moisture in the 40-m tile spacing subjecting the 40-m tile spacing to longer periods of time under anaerobic or near anaerobic conditions that slows the decomposition of organic matter. When subsurface tile drainage is applied to a poorly drained soil, the removal of the excess soil moisture improves the soils aeration and increases the time that the soil is exposed to aerobic conditions, allowing the decomposition of OM to occur at a faster rate. Thus, in the 75-100cm depth the increased rate at which soil carbon is mineralized in the narrower tile spacings, such as the 10-m tile spacing, may have been greater than the increased carbon inputs in the narrower tile spacings as previously described. In summary, the increased carbon inputs seem to be the main driver in differences found in total carbon content in the shallower soil depths, in contrast to the lower soil depths, where the main driver in carbon concentration would seem to be carbon loss associated with the mineralization process. Kumar et al. (2014) (conducted in central Ohio on a Crosby silt loam soil) reported that undrained plots contained greater SOC by 12.5%, 13.8% and 28.2% compared to plots that utilized tile drainage in the 0-10cm, 10-20cm and 40-60cm depths. However, only the 40-60cm depth was found to be statistically significant. David et al. (2009) conducted a study in Illinois on Mollic soils. This study used archived samples for carbon content, bulk density, nitrogen content and carbon stocks. These samples were collected from 19 locations, including 6 that had previously been sampled between 1901 to 1904, 10 locations that were previously sampled in 1957, and 3 locations that were paired with adjacent prairie remnants that were not previously sampled. Each of these locations were then resampled to the same depths in 2001 and 2002. All fields except the remnant prairies were tile drained and have been cultivated for approximately 100 plus years. This study observed a reduction of carbon and nitrogen in the upper soil profile from 1957 to 2002, but a significant increase in concentrations in the 50-100cm depth over the same time period. This study attributed this to the translocation of carbon and nitrogen to lower depths as a result of tillage and tile drainage.

The trends observed with soil carbon stocks per depth closely follow the trends observed with total soil carbon content per depth. The factors attributed to the significant differences in total carbon content previously mentioned also explain the significant differences observed with carbon stocks per depth. After summing the soil carbon stocks to the 1-m depth, no significant differences were observed despite finding significant effects in shallower depths as well as in the 75-100cm depth. This is explained in that the narrower tile spacings experienced an increase in carbon stocks at the upper depths and decrease in carbon stocks in the lower depths compared to the undrained control. Thus, when the carbon stocks for each depth was added up to find the carbon stocks to the 1-m depth the changes in the upper depth offset the changes in lower depths. Soil carbon stocks were calculated using equation 2.1. In this equation the total carbon content is multiplied by the soil bulk density and the length of the depth interval being assessed and then converting to Mg C ha^{-1}. The soil bulk density data used to calculate soil carbon stocks were presented in Welage (2020). The thesis presented by Welage (2020) found that tile spacing had a significant effect on soil bulk density in the 0-5cm, 5-15cm and the 75-100cm depths. However, the differences in bulk density among tile spacings at all depths were rather small. The differences observed in carbon stocks are not a result of the bulk density and are a result of the higher total carbon content.

It is generally accepted that soil organic matter contains approximately 58% carbon (Nelson and Sommers, 1996). Therefore, it would be expected to see a similar trend in the %OM data as what was observed in the total carbon content data described above. However, tile spacing was not found to have a significant effect on %OM at any depth yet tile spacing was found to have a significant effect on total carbon content in the 0-5cm, 5-15cm and the 75-100cm depths as described above. In addition, the %OM appears to be fairly constant for all depths below 15cm, whereas SOC showed a decrease with depth. Nor does %OM data seem to follow the standard conversion estimation (the Van Bemmelen factor) of 1.724 for all depths below 15cm. For example, the average %OM across all tile spacings in the 75-100cm depth is 0.9%OM with average total carbon content across all tile spacings of 0.1792%. Using the conversion factor of 1.724 to convert SOC to %OM yields an approximate %OM of 0.3082%. The discrepancy between the %OM data and the total carbon data may be due to the method used to measure %OM. Samples for soil fertility including %OM were sent to A and L Great Lakes Laboratories for analysis. The %OM was measured using the Loss on Ignition method (LOI) which involves combustion at high temperatures and measuring the weight loss after combustion. LOI is commonly used to determine %OM as it is more cost effective and less labor intensive than other methods. However, LOI has been shown to overestimate %OM particularly in soils with low organic carbon or with higher clay contents (Chatterjee et al., 2009; Szava-Kovats, 2009). The total carbon content measures are more accurate, as each sample was finely-ground using a mortar and pestle exposing any carbon that may have been encased in soil aggregates.

Tile spacing had a significant main effect on total nitrogen content in all depths above 75cm. However, the interaction of block and tile spacing explained any main effects observed in the 0-5cm, 5-15cm, and the 30-50cm depths. In the 0-5cm and the 30-50cm depths one tile spacing in one block was found to be significantly different from all other tile spacing in both blocks and this difference caused the spacing effect. In the 5-15cm depth no significant differences were identified among the tile spacings in Block 1, whereas in Block 2 the 5-m and the 40-m tile spacings had significantly higher soil nitrogen contents than the 10-m and the 20-m tile spacing in Block 2, but none of the tile spacings in Block 2 were different from any tile spacing in Block 1. These differences among tile spacings in Block 2 caused the spacing effect observed in this depth. In the 15-30cm depth the 5-m and 10-m spacings had higher total nitrogen content than the 20-m spacing with the 40-m being intermediate. In the 50-75cm depth the 10-m tile spacing was found to have a significantly higher total nitrogen content than the 20-m tile spacing but neither was significantly different from the 5-m and 40-m tile spacing. The values observed with total nitrogen content in the 50-75cm and the 75-100cm depths were very low ranging from 0.0313% to 0.0260% in the 50-75cm depth and 0.0298% to 0.0263% in the 75-100cm depth. Although the differences found among tile spacings were statistically significant they may not be biologically significant.

Tile spacing was not found to have significant effect on aggregate stability at any depth. The results of the aggregate stability analysis presented above do not support my original hypothesis regarding aggregate stability. I hypothesized that the 10-m and 20-m tile spacings would have a greater MWD than in the 5-m and 40-m tile spacing. This hypothesis was based on the idea that the narrow tile spacing would have less organic matter and thus less carbon because the organic matter inputs would be more susceptible to oxidation and that the 40-m tile spacing would have a lower MWD as it would have less organic matter inputs as a result of its wetter soil profile limiting plant growth. But no significant differences in organic matter were found among tile spacings at any depth, nor did the organic matter follow the trends observed with total carbon content (as discussed above). However, in the near surface depths, the carbon content of the 5-m tile spacing was significantly higher than that of the 40-m spacing with the 10-m and 20-m tile spacing being intermediate, yet no differences were found among tile spacings with regard to aggregate stability. Perhaps the significant differences in total carbon content were not enough of a difference to affect aggregate stability. It may also be, that the differences in aggregate stability may have been more pronounced if the samples would have been collected while a growing crop was present. Kladivko et al. (1986) (conducted in south eastern Indiana on Clermont silt loam soils) found aggregate stability to be greater in midsummer than April and concluded that this was due to greater microbial decomposition of crop residues. Other studies such as Nevins et al. (2018) (conducted in Tippecanoe County, Indiana) have evaluated the impact of cover crop residue management practices on soil microbial activity. This study concluded that the rate of cover crop decomposition peaked after 39 days after the termination of the cover crop and that soil microbial activity peaked 14 days later (53 days from cover crop termination). The trends observed with carbon, or the lack thereof with organic matter content, do not seem to support my initial reasoning that led me to my hypothesis concerning aggregate stability. Even though there have been greater inputs in organic matter in the narrower tile spacing in the form of crop residues and cover crop biomass since 1994, we found no differences in aggregate stability. Other studies such as Rorick and Kladivko (2017) found that aggregate stability increased by 55% in the 0-10cm depth and 29% increase in the 10-20cm depth after 4 years of cereal rye compared to no-cover crop.

Tile spacing was only found to have a significant effect on soil phosphorus content in the 0-15cm depth. At this depth the soil phosphorus content was higher in the 40-m tile spacing than the 5-m tile spacing in the 0-15cm depth, with the 10-m and 20-m tile spacing being intermediate. This trend may be a result of greater cover crop growth and cash crop yields in the 5-m tile spacing as compared to the wider tile spacings (Kladivko, 2020a, b). The narrower tile spacings have improved soil conditions for more plant growth to take place. The increase in plant growth requires more soil nutrients such as phosphorus. Thus, more soil phosphorus is removed from the soil in the narrower tile spacing by the growing crop as compared to the wider tile spacing as a result of increased demand for nutrients to accommodate more plant growth. The soil phosphorus data from all depths below 15cm did not meet the needed assumptions that the data have a normal distribution and have homogenous distribution of variance despite any transformation that was applied. Thus, the statistical analysis was performed on the un-transformed data. This may have prevented us from identifying any additional significant effects or lack thereof below the15cm depth. However, the soil phosphorus values from depths below 15cm were exceedingly low and there may not have been any differences among tile spacing.

The soil potassium content followed the general trend of increasing as tile spacing decreases. This may be in part a result of the use of cereal rye as a cover crop. Cereal rye has been found to increase the exchangeable potassium content near the soil surface (Eckert, 1991). The deep fibrous roots of cereal rye are able access potassium from lower in the soil profile that is normally not accessible to other crops. The potassium is then redeposited on the soil surface after the cover crop is terminated and the plant residue is decomposed. Thus, the greater cover crop growth in the narrower tile spacings may explain the higher soil potassium content observed with the narrower tile spacings as well.

Tile spacing also had a significant effect on soil calcium content in the 0-15cm depth. At this depth soil calcium content increased with tile spacing, with the 5-m tile spacing having a significantly lower soil calcium content than the 40-m tile spacing, with the 10-m and 20-m tile spacing being intermediate. This may be attributed to the greater translocation of calcium from the upper depths to deeper in the soil profile, as tile spacing decreases and there is greater water movement through the soil profile. Although there were no significant differences in calcium content found among tile spacings in the lower depths, significant differences among tile spacings were observed with soil pH in the 50-75cm and the 75-100cm depths (Table 3.12). This may be a result of the translocation of soil calcium from near surface depths to 50-75cm and 75-100cm depth. Application of lime (Calcium carbonate) was made to the field site as needed accordance with good agronomic practices since 1983. The soil conditions in the narrower tile spacings allow for more rapid movement of water through the soil profile and in doing so facilitate the movement of various elements such as calcium in soil solution from the soil surface to lower soil depths. Similar findings were found by Li et al. (2019) who conducted a study in south east Australia, on Typic Fragiochrept soil. This study evaluated how long-term surface application of lime in various cropping systems affected subsurface soil acidity over time. They concluded that over time subsurface soil pH increased as a result of surface applied lime.

Tile spacing had a significant effect on soil magnesium content in the 50-75cm and the 75-100cm depths. However, the interaction of block and tile spacing explains any main effects of tile spacing observed within these depths. In both depths the relationships among tile spacings were inconsistent between blocks and caused the significant main effect of tile spacing in these depths. Conversely, Mathew et al. (2001) (conducted in south west India on highly acidic soils) found tile drained soils had a lower soil magnesium content than undrained (at the 50cm depth). This study attributed the lower magnesium content in drained soils to losses through the tile drain.

The bulk density of the plow pan in the 40-m tile spacing was found to be significantly higher than that of the 10m tile spacing (1.65g cm^{-3} ,1.59g cm^{-3} respectively) with the 5-m and 20-m tile spacing being intermediate (1.62g cm^{-3}, 1.61g cm^{-3} respectively). Although these values are statistically significant, they may not be physically significant. Soil bulk densities above 1.65 are known to restrict root growth in silty soils (USDA, 2008). The bulk densities of the plow pan ranged from 1.59g cm^{-3} to 1.65g cm^{-3}. The bulk densities of the plow pan for all tile spacings were at or just below the general guideline value of 1.65g cm^{-3}. Thus, any negative effects on root growth as a result of the plow pan are similarly expressed across all tile spacings. Other studies such as Hundal et al. (1976) (conducted in Ohio on a Toledo silty clay soil) found similar results, where undrained plots had a slightly higher bulk density than tile drained plots in the 0-15cm and 15-30cm depths. Conversely, Jia et al. (2008) found no significant differences in soil bulk density among drained and undrained plots.

The VSR in the 10cm depth was significantly lower in the 5-m and 40-m tile spacings than the 20-m tile spacing, with the 10-m tile spacing being intermediate. In the 20cm depth the VSR in the 5-m tile spacing was found to be significantly lower than the 20-m and 40-m tile spacing. Perhaps this is due to the improved aeration of the soil provided by the narrower tile spacings. The improved aeration of the soil allows for increased plant growth. This is demonstrated by the cover crop yield data reported by Kladivko (2020a, b) where the 5-m, 10-m and the 20-m tile spacings on average had a greater amount of above ground cover crop biomass and higher cash crop yields when compared to the 40-m tile spacing. The increase in above ground plant growth also indicates that more roots are present below ground. The growth of the roots may have increased the porosity and improved the structure of the soil. This is supported by the findings of Welage (2020) who observed that in the 15-30cm depth, the bulk density of the 5-m tile spacing was significantly lower than that of the 40-m tile spacing, with the 10-m and 20-m tile spacing being intermediate. In addition, as the cover crops are terminated and the biomass is broken down by soil microbes, it is adding more carbon to the soil in the form of organic matter. This is also supported by the total carbon content data previously discussed. In the 0-5cm and 5-15cm depths, tile spacing was found to have a significant main effect on total carbon content (Table 3.1). At these depths the 5-m tile spacing was found to have a significantly higher total carbon content than the 40-m tile spacing. The lower VSR, the increase in cover crop growth, and the increase in total soil carbon in the 5-m tile spacing all demonstrate improved soil conditions that favor agronomic operations. In the 30cm depth, no formal statistical analysis was able to be performed on the data collected from this depth. However, the fact that three quarters of the measurements taken from all tile spacings in the 30cm depth exceeded the instrument's maximum measurable limit demonstrate the extent that this restrictive layer may affect the movement of air and water through the soil as well as its impact on root growth (Table 3.14).

Tile spacing had a significant main effect on CPR at all depths except 22.5cm, 25cm and 55cm through 60cm (Table 3.16, Table 3.17 and Table 3.18). A significant interaction of block and tile spacing was also observed in all depths from 2.5cm to 40cm and explains any main effect that may have been found for these depths. For example, the CPR was greater in the 40m tile spacing than all other spacings from the 2.5cm to 20cm depth. However, the differences in CPR among tile spacing are explained by the interaction of block and tile spacing, whereby the 40-m spacing in Block 1 (plot 208) has higher CPR than all other tile spacings in both blocks to a depth of 20cm (Figure 3.35). The CPR was lower in the 10-m tile spacing than in all other spacings from the 27.5cm depth to the 42.5cm depth. Again, the interaction of block and tile spacing explains the differences observed in these depths, in that between the 27.5cm and the 40cm depths the CPR of the 10-m tile spacing in block 1 (Plot 202) was significantly lower than all other tile spacings in both blocks (Figure 3.35). The interaction of block and tile spacing was not significant below the 40cm depth. In all depths below 40cm the 10-m tile spacing had a significantly lower CPR than the 40-m tile spacing and had significantly lower CPR than the 5-m tile spacing in all depths below 60cm. Many studies have reported that drained plots have higher CPR than undrained plots near the soil surface (Lal and Fausey, 1993; Kandel et al. 2013). Lal and Fausey. (1993) also found that differences in soil moisture content accounted for up to 41% of the variability in penetration resistance. Similarly, Kandel et al, (2013) observed that 42% of the variation in penetration resistance was accounted for by depth to the water table from the soil surface. However, we did not find any differences in CPR among tile spacings to a depth of 40cm that was not a explained by an interaction effect. In all depths below 40cm the 40-m tile spacing (considered our undrained control) had the highest CPR resistance, and closely followed the same trend as the 5-m tile spacing (Figure 3.34). Other studies such as Kandel et al. (1993) observed that the difference in CPR between drained and undrained plots increased with depth.

Across all tile spacings CPR in the 2.5cm depth ranged from 1185kPa to 1577kPa and generally increased in all subsequent depths until CPR peaked in the 10-m and 20-m tile spacings at the 25cm depth with CPR peaking at 2506kPa and 2527kPa respectively (Figure 3.50). The 5-m and 40-m tile spacing peaked at the 27.5cm depth with CPR peaking at 2647kPa and 2804kPa. CPR generally declined in all tile spacing from the 30cm depth to the 37.5cm where CPR ranged from 1582kPa to 2197kPa. CPR in all tile spacings showed a very gradual decreasing trend from the 37.5cm depth to the 75cm depth. The peak observed in the CPR at the 27.5cm and 30cm depth corresponds to the high VSR values observed at the 30cm depth as described above. Bachmann et al, (2006) compared the vane shear penetrometer and cone penetrometer and found that horizontal stress component was the dominant component for vertical penetration resistance as well as shear resistance and that both penetrometers produced very similar results.

3.11 Conclusions and Future Work

Soil total carbon content was higher in the 5-m tile spacing compared to the 40-m tile spacing in the 0-5 and 5-15cm depth, where carbon inputs from crop residues are greatest. However, in the 75-100cm depth the 40-m tile spacing had a higher total carbon content than the 10-m tile spacing with the 5-m and 20-m spacings being intermediate. At this depth the rate at which soil carbon is mineralized seems to have increased in the narrower tile spacings as a result of the narrower tile spacings experiencing longer time periods under aerobic conditions. Carbon stocks per depth closely follow the trends observed with total soil carbon content. The factors attributed to the significant differences in total carbon content described above, also explain the significant differences observed with carbon stocks per depth. Although, significant differences were observed among tile spacings with total carbon content and carbon stocks per depth, no significant differences were found among tile spacings in the summed carbon stocks to the 1-m depth. Thus, in this study subsurface tile drainage did not have a significant effect on total carbon stocks to the 1-m depth. However, tile drainage does seem to have had a significant effect on the vertical distribution of soil carbon content within the soil profile.

Tile spacing did not have a significant effect on aggregate stability at any depth, regardless of the increased carbon inputs in the narrower tile spacings. Aggregate stability is greatly influenced by many factors including soil texture, soil microbial activity, whether or not an actively growing crop is present and what type of crop. More research should be conducted in regards to how aggregate stability is affected at various stages of crop growth. It would also be helpful to evaluate how the decomposition of organic matter effects aggregate stability temporally. More research in these areas may help future research identify if there is an ideal window of time within a growing season to measure aggregate stability for detecting differences among treatments.

Tile drain spacing was found to have a significant effect on some measures of soil fertility. Soil organic matter was not significantly affected by tile drain spacing at any depth, despite the greater additions of plant residues over the course of this study. The soil texture at the site of this study may have been a more limiting factor restricting the accumulation of soil organic matter in the upper soil depths. Soil potassium content was generally higher in narrower tile spacings than the 40-m tile spacing. This was likely not a direct result of tile drainage but more of a secondary effect, in that the narrower tile spacings allowed for greater growth of the cereal rye cover crop than the 40-m tile spacing and the documented ability of cereal rye to move potassium that was normally not accessible to cash crops from deeper in the soil profile and redeposit it near the soil surface as the cover crop residue is decomposed. Soil calcium content near the surface was higher in the 40-m tile spacing and generally decreased with narrower tile spacing. In this study we also found some indication of the translocation of soil calcium from the soil surface to lower in the soil profile within the narrower tile spacings as compared to the 40-m tile spacing, resulting in the significantly higher soil pH in the narrower tile spacings than the 40-m tile spacings in depths below 30cm.

Tile drain spacing did not have a significant effect on total carbon stocks to the 1-m depth, but rather seems to have had a significant effect on the vertical distribution of soil carbon content throughout the soil profile. Observed significant effects of tile drain spacing on soil fertility measurements may in part be a result of the long-term use of cover-crops and no-till management practices at this site in addition to the use of tile drainage. The soils as we know them today are a product of many thousands of years of evolution. Research regarding subsurface drainage should include longer periods of time. Although in this study we were able to find some differences among various tile spacings after 35 years of drainage, more time may be needed to observe the entirety of these changes in soil physical and chemical properties.

REFERENCES

Abid, M., and Lal, R. (2008). Tillage and drainage impact on soil quality: I. Aggregate stability, carbon and nitrogen pools. *Soil and Tillage research*, *100*(1-2), 89-98.

Adeuya, R., Utt, N., Frankenberger, J., Bowling, L., Kladivko, E., Brouder, S., and Carter, B. (2012). Impacts of drainage water management on subsurface drain flow, nitrate concentration, and nitrate loads in Indiana. *Journal of Soil and Water Conservation*, *67*(6), 474-484.

Amézketa, E. (1999) Soil Aggregate Stability: A Review, Journal of Sustainable Agriculture, 14:2-3, 83-151, DOI: 10.1300/J064v14n02_08

Bachmann, J., Contreras, K., Hartge, K. H., and MacDonald, R. (2006). Comparison of soil strength data obtained in situ with penetrometer and with vane shear test. *Soil and Tillage Research*, *87*(1), 112-118.

Blackman, J. (1992). Seasonal variation in the aggregate stability of downland soils. *Soil Use and Management*, *8*(4), 142-150.

Brady, N. C., and Weil, R. R. (2010). *Elements of the nature and properties of soils*. Boston: Pearson.

Bullock, M. S., Nelson, S. D., and Kemper, W. D. (1988). Soil cohesion as affected by freezing, water content, time and tillage. *Soil Science Society of America Journal*, *52*(3), 770-776.

Byrnes, W. R., McFee, W. W., and Steinhardt, G. C. (1982). *Soil Compaction Related to Agricultural and Construction Operations: State-of-the-art Review and Annotated Bibliography with Interpretations for Transmission Rights-of-way*. Department of Forestry and Natural Resources, Department of Agronomy, Purdue University.

Carter, C. E., and Camp, C. R. (1983). Subsurface drainage of an alluvial soil increased sugarcane yields. *Transactions of the ASAE*, *26*(2), 426-0429.

David, M. B., McIsaac, G. F., Darmody, R. G., and Omonode, R. A. (2009). Long-term changes in Mollisol organic carbon and nitrogen. *Journal of environmental quality*, *38*(1), 200-211.

Ebinger, M. H., Chatterjee, A., Lal, R., Wielopolski, L., and Martin, M. (2008). *Evaluation of different soil carbon determination methods* (No. LA-UR-08-05870; LA-UR-08-5870). Los Alamos National Lab.(LANL), Los Alamos, NM (United States).

Eckert, D. J. (1991). Chemical attributes of soils subjected to no-till cropping with rye cover crops. *Soil Science Society of America Journal*, *55*(2), 405-409.

Evans, R. O., Skaggs, R.W, and Gilliam, J.W. (1995). Controlled versus conventional drainage effects on water quality. *Journal of Irrigation and Drainage Engineering*, *121*(4), 271-276.

Frison, A., Cousin, I., Montagne, D., and Cornu, S. (2009). Soil hydraulic properties in relation to local rapid soil changes induced by field drainage: a case study. *European Journal of Soil Science*, *60*(4), 662-670.

Hudek, C., Stanchi, S., D'Amico, M., and Freppaz, M. (2017). Quantifying the contribution of the root system of alpine vegetation in the soil aggregate stability of moraine. *International Soil and Water Conservation Research*, *5*(1), 36-42.

Hundal, S. S., Schwab, G. O., and Taylor, G. S. (1976). Drainage System Effects on Physical Properties of a Lakebed Clay Soil 1. *Soil Science Society of America Journal*, *40*(2), 300-305.

Jia, X., Scherer, T. F., DeSutter, T. M., and Steele, D. D. (2008). Change of soil hardness and soil properties due to tile drainage in the Red River Valley of the North. Presented at the 2008 ASABE Annual International Meeting, Providence, Rhode Island, June 29–July 2, 2008.

Kandel, H. J., Brodshaug, J. A., Steele, D. D., Ransom, J. K., DeSutter, T. M., and Sands, G. R. (2013). Subsurface drainage effects on soil penetration resistance and water table depth on a clay soil in the Red River of the North Valley, USA. *Agricultural Engineering International: CIGR Journal*, *15*(1), 1-10

Kladivko, E.J. 2020.a Soil drainage and crop yields: Insights from long-term SEPAC study. West Lafayette, IN: Purdue University Cooperative Extension Service; Agronomy AY-397-W.

Kladivko, E.J. 2020.b Soil drainage impacts on cover crop growth and soil improvement: Insights from long-term SEPAC study. West Lafayette, IN: Purdue University Cooperative Extension Service; Agronomy AY-398-W

Kladivko, E.J. 2017. Soil physics laboratory manual. Purdue University, N1-N4

Kladivko, E. J., Frankenberger, J. R., Jaynes, D. B., Meek, D. W., Jenkinson, B. J., and Fausey, N. R. (2004). Nitrate leaching to subsurface drains as affected by drain spacing and changes in crop production system. *Journal of Environmental Quality*, *33*(5), 1803-1813

Kladivko, E. J., Griffith, D. R., and Mannering, J. V. (1986). Conservation tillage effects on soil properties and yield of corn and soya beans in Indiana. *Soil and Tillage Research, 8*, 277-287.

Kladivko, E. J., Grochulska, J., Turco, R. F., Van Scoyoc, G. E., and Eigel, J. D. (1999). Pesticide and nitrate transport into subsurface tile drains of different spacings. *Journal of Environmental Quality*, *28*(3), 997-1004.

Kladivko, E. J., Van Scoyoc, G. E., Monke, E. J., Oates, K. M., and Pask, W. (1991). Pesticide and nutrient movement into subsurface tile drains on a silt loam soil in Indiana. *Journal of Environmental Quality*, *20*(1), 264-270.

Kladivko, E. J., Willoughby, G. L., and Santini, J. B. (2005). Corn growth and yield response to subsurface drain spacing on Clermont silt loam soil. *Agronomy Journal*, *97*(5), 1419-1428.

Kornecki, T. S., and Fouss, J. L. (2001). Quantifying soil trafficability improvements provided by subsurface drainage for field crop operations in Louisiana. *Applied Engineering in Agriculture*, *17*(6), 777.

Kumar, S., Nakajima, T., Mbonimpa, E. G., Gaugtam, S., Somireddy, U. R., Kadono, A. and Fausey, N. (2014). Long-term tillage and drainage influences on soil organic carbon dynamics, aggregate stability and corn yield. *Soil Acience and Plant Nutrition*, *60*(1), 108-118.

Lal, R., and Fausey, N. R. (1993). Drainage and tillage effects on a Crosby-Kokomo soil association in Ohio IV. Soil physical properties. *Soil Technology*, *6*(2), 123-135.

Li, G. D., Conyers, M. K., Helyar, K. R., Lisle, C. J., Poile, G. J., and Cullis, B. R. (2019). Long-term surface application of lime ameliorates subsurface soil acidity in the mixed farming zone of south-eastern Australia. *Geoderma*, *338*, 236-246.

Mathew, E. K., Panda, R. K., and Nair, M. (2001). Influence of subsurface drainage on crop production and soil quality in a low-lying acid sulphate soil. *Agricultural Water Management*, *47*(3), 191-209.

Neild, R. E., and Newman, J. E. (1987). *Growing season characteristics and requirements in the Corn Belt*. Cooperative Extension Service, Iowa State University.

Nelson, D. W., and Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. *Methods of soil analysis: Part 3 Chemical methods*, *5*, 961-1010.

Nevins, C. J., Nakatsu, C., and Armstrong, S. (2018). Characterization of microbial community response to cover crop residue decomposition. *Soil Biology and Biochemistry*, *127*, 39-49.

NOAA. (2009, August 2). Gulf of Mexico 'dead zone' is the largest ever measured. Retrieved from https://www.noaa.gov/media-release/gulf-of-mexico-dead-zone-is-largest-ever-measured

Raney, W. A., Edminster, T. W., and Allaway, W. H. (1955). Current status of research in soil compaction. *Soil Science Society of America Journal*, *19*(4), 423-428.

Rorick, J. D., and Kladivko, E. J. (2017). Cereal rye cover crop effects on soil carbon and physical properties in southeastern Indiana. *Journal of Soil and Water Conservation*, *72*(3), 260-265.

Smith, D. R., King, K. W., Johnson, L., Francesconi, W., Richards, P., Baker, D., and Sharpley, A. N. (2015). Surface runoff and tile drainage transport of phosphorus in the midwestern United States. *Journal of Environmental Quality*, *44*(2), 495-502.

State Agriculture Overview. (2018). Retrieved November 1, 2018, from https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=INDIANA

Stone, R. J., and Ekwue, E. I. (1993). Maximum bulk density achieved during soil compaction as affected by the incorporation of three organic materials. *Transactions of the ASAE*, *36*(6), 1713-1719.

Sugg, Z. (2007). Assessing US farm drainage: Can GIS lead to better estimates of subsurface drainage extent. *World Resources Institute, Washington, DC, 20002*.

Szava-Kovats, R. (2009). Re-analysis of the relationship between organic carbon and loss-on-ignition in soil. *Communications in Soil Science and Plant Analysis*, *40*(17-18), 2712-2724

US Department of Commerce, and NOAA. (2018, September 09). Central Indiana Local Climate Info. Retrieved from https://www.weather.gov/ind/localcli

USDA Natural Resources Conservation Service. (2008). *Soil quality indicators: Bulk density.* Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053256.pdf

Van Wesemael, B., Paustian, K., Meersmans, J., Goidts, E., Barancikova, G., and Easter, M. (2010). Agricultural management explains historic changes in regional soil carbon stocks. *Proceedings of the National Academy of Sciences*, *107*(33), 14926-14930.

Welage, D. 2020. Long-Term subsurface drainage effects on soil physical and hydraulic properties. M.S. Thesis, Purdue University, West Lafayette, IN.

APPENDIX

Table A.1. Arithmetic mean, standard deviation (SD), and inter-quartile range (IQR) of Total carbon content (%) for Block 1 by plot number at multiple depths. Samples collected from the 0-5cm and the 5-15cm depth were composite samples collected using a hand soil probe with a 2cm diameter. Samples collected at all depths below 15cm were collected using a truck mounted hydraulic probe. Each value represents the mean of 8 subplots (n=8).

Carbon Content % Block 1						
Plot	**Block**	**Spacing**	**Depth**	**Mean**	**SD**	**IQR**
202	1	10	5	1.4002	0.1106	0.1658
202	1	10	15	0.6802	0.0319	0.0558
202	1	10	30	0.4020	0.1086	0.0911
202	1	10	50	0.2764	0.1107	0.1555
202	1	10	75	0.2329	0.1013	0.1389
202	1	10	100	0.1589	0.0348	0.0237
204	1	5	5	1.4074	0.1005	0.1700
204	1	5	15	0.6810	0.0528	0.0533
204	1	5	30	0.4748	0.0539	0.1045
204	1	5	50	0.2508	0.0589	0.1021
204	1	5	75	0.2052	0.0568	0.0966
204	1	5	100	0.1773	0.0370	0.0650
206	1	20	5	1.3125	0.2002	0.3365
206	1	20	15	0.6552	0.0608	0.1072
206	1	20	30	0.4999	0.0734	0.0789
206	1	20	50	0.2650	0.0675	0.1286
206	1	20	75	0.1963	0.0402	0.0684
206	1	20	100	0.1791	0.0302	0.0603
208	1	40	5	1.2344	0.1344	0.2317
208	1	40	15	0.5921	0.0315	0.0346
208	1	40	30	0.4742	0.0633	0.0962
208	1	40	50	0.2814	0.0805	0.1653
208	1	40	75	0.2295	0.0822	0.0810
208	1	40	100	0.1940	0.0214	0.0167

Table A.2. Arithmetic mean, standard deviation (SD), and inter-quartile range (IQR) of Total carbon content (%) for Block 2 by plot number at multiple depths. Samples collected from the 0-5cm and the 5-15cm depth were composite samples collected using a hand soil probe with a 2cm diameter. Samples collected at all depths below 15cm were collected using a truck mounted hydraulic probe. Each value represents the mean of 8 subplots (n=8).

Carbon Content (%) Block 2						
Plot	**Block**	**Spacing**	**Depth**	**Mean**	**SD**	**IQR**
210	2	10	5	1.1366	0.1253	0.2409
210	2	10	15	0.6645	0.0420	0.0836
210	2	10	30	0.5574	0.0747	0.1416
210	2	10	50	0.2730	0.0529	0.1013
210	2	10	75	0.2099	0.0436	0.0716
210	2	10	100	0.1793	0.0306	0.0614
212	2	5	5	1.4402	0.0827	0.1348
212	2	5	15	0.7580	0.0534	0.0996
212	2	5	30	0.5001	0.0486	0.0783
212	2	5	50	0.2665	0.0771	0.1216
212	2	5	75	0.2143	0.0377	0.0344
212	2	5	100	0.1788	0.0233	0.0297
214	2	20	5	1.3940	0.1146	0.1621
214	2	20	15	0.6703	0.0279	0.0361
214	2	20	30	0.4241	0.0562	0.0888
214	2	20	50	0.2557	0.0541	0.1016
214	2	20	75	0.2032	0.0585	0.0630
214	2	20	100	0.1843	0.0528	0.0242
216	2	40	5	1.3223	0.0876	0.1302
216	2	40	15	0.6135	0.0636	0.1172
216	2	40	30	0.4286	0.0523	0.0734
216	2	40	50	0.2423	0.0667	0.0709
216	2	40	75	0.1981	0.0311	0.0494
216	2	40	100	0.2035	0.0284	0.0491

Table A.3. Arithmetic mean, standard deviation (SD), and inter-quartile range (IQR) of Total nitrogen content (%) for Block 1 by plot number at multiple depths. Samples collected from the 0-5cm and the 5-15cm depth were composite samples collected using a hand soil probe with a 2cm diameter. Samples collected at all depths below 15cm were collected using a truck mounted hydraulic probe. Each value represents the mean of 8 subplots (n=8).

Nitrogen Content (%) Block 1						
Plot	**Block**	**Spacing**	**Depth**	**Mean**	**SD**	**IQR**
202	1	10	100	0.0369	0.0111	0.0192
202	1	10	75	0.0416	0.0121	0.0242
202	1	10	50	0.0474	0.0121	0.0214
202	1	10	30	0.0565	0.0117	0.0222
202	1	10	15	0.0664	0.0025	0.0047
202	1	10	5	0.1248	0.0084	0.0102
204	1	5	75	0.0304	0.0058	0.0092
204	1	5	100	0.0305	0.0046	0.0063
204	1	5	50	0.0339	0.0052	0.0087
204	1	5	30	0.0498	0.0045	0.0079
204	1	5	15	0.0717	0.0106	0.0075
204	1	5	5	0.1310	0.0134	0.0128
206	1	20	75	0.0264	0.0038	0.0078
206	1	20	100	0.0264	0.0033	0.0056
206	1	20	50	0.0312	0.0069	0.0135
206	1	20	30	0.0479	0.0062	0.0083
206	1	20	15	0.0679	0.0044	0.0086
206	1	20	5	0.1223	0.0151	0.0257
208	1	40	100	0.0286	0.0039	0.0028
208	1	40	75	0.0296	0.0076	0.0061
208	1	40	50	0.0350	0.0084	0.0141
208	1	40	30	0.0522	0.0081	0.0102
208	1	40	15	0.0642	0.0030	0.0057
208	1	40	5	0.1200	0.0105	0.0193

Table A.4. Arithmetic mean, standard deviation (SD), and inter-quartile range (IQR) of Total nitrogen content (%) for Block 2 by plot number at multiple depths. Samples collected from the 0-5cm and the 5-15cm depth were composite samples collected using a hand soil probe with a 2cm diameter. Samples collected at all depths below 15cm were collected using a truck mounted hydraulic probe. Each value represents the mean of 8 subplots (n=8).

Nitrogen Content (%) Block 2						
Plot	**Block**	**Spacing**	**Depth**	**Mean**	**SD**	**IQR**
210	2	10	100	0.0268	0.0042	0.0086
210	2	10	75	0.0273	0.0051	0.0080
210	2	10	50	0.0315	0.0055	0.0094
210	2	10	30	0.0530	0.0065	0.0123
210	2	10	15	0.0627	0.0042	0.0074
210	2	10	5	0.1013	0.0092	0.0173
212	2	5	100	0.0251	0.0040	0.0073
212	2	5	75	0.0276	0.0051	0.0073
212	2	5	50	0.0330	0.0092	0.0153
212	2	5	30	0.0565	0.0064	0.0107
212	2	5	15	0.0753	0.0110	0.0102
212	2	5	5	0.1285	0.0107	0.0163
214	2	20	100	0.0272	0.0058	0.0028
214	2	20	75	0.0279	0.0078	0.0106
214	2	20	50	0.0325	0.0062	0.0122
214	2	20	30	0.0464	0.0047	0.0083
214	2	20	15	0.0617	0.0039	0.0062
214	2	20	5	0.1241	0.0091	0.0153
216	2	40	75	0.0258	0.0043	0.0079
216	2	40	100	0.0284	0.0043	0.0077
216	2	40	50	0.0294	0.0073	0.0091
216	2	40	30	0.0473	0.0058	0.0058
216	2	40	15	0.0749	0.0141	0.0268
216	2	40	5	0.1366	0.0179	0.0337

Table A.5. Arithmetic mean, standard deviation (SD), and inter-quartile range (IQR) of aggregate stability measured by MWD (mm) for Block 1 by plot number at multiple depths. Samples collected in the 0-5cm depth were composite samples collected in May of 2019 using a golf cup cutter with a diameter 10.8cm to a depth of 5cm. Samples from the 0-15cm depth and below were collected using a truck mounted hydraulic probe in May of 2018. Each value represents the mean of 8 subplots (n=8).

Aggregate stability Block 1 - Mean Weight Diameter (mm)						
Plot	**Block**	**Spacing**	**Depth**	**Mean**	**SD**	**IQR**
202	1	10	5	2.88	0.57	1.1553
202	1	10	15	1.93	0.48	0.9700
202	1	10	30	0.57	0.20	0.3834
202	1	10	50	0.48	0.22	0.3232
202	1	5	75	0.51	0.16	0.3047
204	1	5	5	3.15	0.66	0.9278
204	1	5	15	1.98	0.50	0.9918
204	1	5	30	0.46	0.15	0.2101
204	1	5	50	0.39	0.10	0.1766
204	1	5	75	0.41	0.15	0.2326
206	1	20	5	3.01	0.81	1.3907
206	1	20	15	2.13	0.64	0.9206
206	1	20	30	0.46	0.12	0.2040
206	1	20	50	0.41	0.14	0.1332
206	1	20	75	0.44	0.25	0.1978
208	1	40	5	2.81	0.60	1.0993
208	1	40	15	2.00	0.72	1.3712
208	1	40	30	0.51	0.11	0.1884
208	1	40	50	0.44	0.14	0.1830
208	1	40	75	0.45	0.15	0.2656

Table A.6. Arithmetic mean, standard deviation (SD), and inter-quartile range (IQR) of aggregate stability measured by MWD (mm) for Block 2 by plot number at multiple depths. Samples collected in the 0-5cm depth were composite samples collected in May of 2019 using a golf cup cutter with a diameter 10.8cm to a depth of 5cm. Samples from the 0-15cm depth and below were collected using a truck mounted hydraulic probe in May of 2018. Each value represents the mean of 8 subplots (n=8).

Aggregate stability Block 2 - Mean Weight Diameter (mm)						
Plot	**Block**	**Spacing**	**Depth**	**Mean**	**SD**	**IQR**
210	2	10	5	2.84	0.67	0.9267
210	2	10	15	1.91	0.50	0.8962
210	2	10	30	0.47	0.15	0.2221
210	2	10	50	0.35	0.07	0.1048
210	2	10	75	0.39	0.07	0.1259
212	2	5	5	3.12	0.54	1.0668
212	2	5	15	2.46	0.55	0.5296
212	2	5	30	0.77	0.31	0.4868
212	2	5	50	0.53	0.11	0.1560
212	2	5	75	0.40	0.12	0.1493
214	2	20	5	2.83	0.71	0.8211
214	2	20	15	2.52	0.64	0.2746
214	2	20	30	0.61	0.12	0.2107
214	2	20	50	0.39	0.16	0.1743
214	2	20	75	0.38	0.09	0.1841
216	2	40	5	3.37	0.70	1.3376
216	2	40	15	2.37	0.68	0.9048
216	2	40	30	0.46	0.20	0.1123
216	2	40	50	0.31	0.08	0.1475
216	2	40	75	0.30	0.06	0.1060