EFFECT OF LAND MANAGEMENT PRACTICES ON SOIL MOISTURE RETENTION

BY

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CAPSTONE PROJECT

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ABSTRACT

Soil sustainability will play a key role in maintaining crop production in the face of decreased precipitation due to global climate change. A field study that compared fields with similar soil types farmed with varying soil conserving practices was conducted in central Ohio to determine if practices such as no-till and cover crops can influence soil moisture through the build-up of soil organic matter. Soil moisture samples were taken 23 times throughout the season at depths of 0-20, 20-40, and 40-60 cm. Soil samples for organic matter determination were collected once at the end of the growing season. This study found that soil water content was not increased by use of reduced tillage or cover crops when compared to fields that had not used conservation practices. However, study design and the wet season, central Ohio received above average rainfall in 2015, limited the study's ability to explore relationships between SOC and moisture retention and thus prevents drawing conclusions about prospects for management to improve soil water holding capacity.

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INTRODUCTION

Maintenance and improvement of soil quality are critical for sustaining agricultural productivity (Fourie et al., 2007). Soil is a valuable resource, which must be managed in a way that can maintain its resilience in the face of climate change. “It is an elementary fact that economic activity is absolutely dependent on the goods and services supplied by the natural environment” (Ekins, 2011). To ensure continued economic prosperity and production, agriculture must contend with the fact that our natural environment is changing.

According to model predictions for the Great Lakes region of the United States, increases in precipitation of 5-30% during the spring and decreased precipitation of 5-10% in the summer will greatly affect the growing season and water availability for rain fed crops (Hayhoe et al., 2009; Particola and Cook, 2013; Fan et al., 2014). If these predictions are correct, soils in the Midwest will need to build resilience to drier summer conditions. To do so soils will need to retain greater amounts of moisture from wetter springs to support growth through drier summers. Farmers may need to adapt their management practices in order to build resilience into their soils, so as to maintain current levels of crop production. One approach for enhancing soil resilience is through the use of conservation practices.

Conservation practices, such as no-till and cover cropping, have been evaluated for their effectiveness in improving soil structure through building SOM. “Organic matter promotes aggregation of soil separates into peds, which allow for increased percolation, drainage, and water retention” (Bowles, 1990). If climate change leads to higher temperatures, SOM will be subject to greater microbial decomposition. Soil with less organic matter has lower average crop yields as it holds fewer nutrients and is more susceptible to drought (Smith and Almaraz, 2004). With less rainfall expected in the latter part of the growing season, land management practices that increase SOM may be a means of retaining more moisture and maintaining agricultural productivity. Which conservation practice builds the greatest amount of SOM? Will a combination of conservation practices have a greater impact on SOM formation? What is the relationship between SOM and soil moisture content? This study aims to address all of these questions.

LITERATURE REVIEW

The relationship between soil moisture content and soil organic matter will become increasingly important as precipitation patterns change. Conservation practices, such as no-till and cover cropping could be a way to build soil organic matter (SOM), thus increasing the soil's capacity to retain moisture (Ugarte et al., 2014). The term SOM is used to describe the organic content in soil including dead and decaying plants and animals. Soil organic carbon (SOC) is the carbon occurring in SOM. Soil organic matter contains approximately 58% carbon; therefore, SOC can be used to estimate SOM (Bianchi et al., 2008; USDA-NRCS, 2009).

Soil organic carbon (SOC) varies with depth in response to specific tillage practices. Long-term studies, in which the initial SOC pool was determined using adjacent forest soils to substitute for initial soil state, have shown that no-till often increases carbon stocks for the surface soil (0-15cm) but with no profile increase as compared to conventional tillage (Ussiri and Lal, 2008; Mishra et al., 2010). In no-till systems, SOC decreases sharply with depth, signifying that no-till systems may not sequester carbon beyond surface soil (Olson et al., 2014a; Olson et al., 2014b; Blanco-Canqui et al., 2009). Olson et al. (2014b) report that no-till is slowly losing carbon over time in relation to baseline data, therefore no-till does not fully replace SOC with residue carbon. Additionally, SOC response to tillage practices depends on baseline SOC. Clay soils low in SOC may retain carbon when under no-till management compared to conventional tillage. Conversely, soils that have high baseline levels of SOC may not retain additional carbon when using a no-till system, but conservation practices could help to mitigate carbon release from soils over conventional tillage on the same fields (VandenBygaart et al., 2003; Tan et al., 2007). Therefore, the potential to store SOC, when no-till was adopted, decreased with increasing background levels of SOC.

Cover crops such as cereal rye and rye grass when combined with no-till, add the additional biomass needed to sequester carbon in the surface and subsurface layers of soil (0-30cm) (Kuo et al., 1997; Sainju et al., 2002). No-till and cover cropping systems can increase SOM in surface and subsurface layers of soil (0-30cm) relative to soils maintained under conventional tillage and monoculture (Ugarte et al., 2014). The combined use of no-till and cover crops could decrease soil erosion and generate the increased SOM needed to support moisture retention as compared to conventional tillage or no-tillage alone.

The use of no-till and residue incorporation has long been used in arid regions to increase soil moisture retention (Jemai et al., 2010; Verhulst et al., 2011; Zhang et al., 2014). Compared to conventional tillage, Gruber et al. (2011) found slightly higher moisture content under no-till, specifically at 60-90 cm soil depth, suggesting that the no-tillage system had greater water storage capacity due to low soil disturbance. Greater gravimetric moisture contents found in no-till systems are also attributed to the presence of crop residue mulch on the soil surface, which minimizes losses to evaporation and surface run-off compared to rates occurring in conventionally tilled systems (Ussiri and Lal, 2008).

The effects of no-tillage on moisture are, however, inconsistent. In a 30-year study of loamy soils in a cool temperate region, Hugh (2014) found that no-till was ineffective for increasing soil moisture retention or SOM storage within the topsoil. In a study conducted on bare silty soils in a subtropical climate that compared tillage treatments, Liu et al. (2013) found no-till treatments had adverse effects on soil structure and reduced water-holding capacity. Similar to tillage practices, studies of soil moisture and cover cropping have shown conflicting results.

Systems that include cover crops have shown numerous soil benefits that include: reduced erosion, nitrogen retention and availability, increased microbial activity, and weed control (Liebl et al., 1992; Bodner et al., 2009; Ugarte et al., 2012; Dagel et al., 2014). Additionally, the use of cover crops as a conservation practice has been shown to increase SOM and improve soil structure (Fourie et al., 2007). Hudson (1994), found that as SOM increased from 0.5 to 3%, in soils with the sandy, silt loam, and silty clay loam textures, the volume of water held at field capacity more than doubled. However, in a two-year study using oats as cover crops for cabbage, no significant difference was found in soil moisture levels between cover crops and conventional tillage in Michigan (Haramoto and Brainard, 2012). Working in Minnesota, Krueger et al. (2011) used a rye cover crop to influence soil moisture in corn, but observed no positive impact on soil moisture conservation. Moreover, timing of kill-date for cover crops influences soil moisture retention. A late rye cover crop kill date was found to have reduced available moisture for soybeans in Urbana, Illinois (Liebl et al., 1992). Cover crops and forage crops extract water from the upper layers of soil in early spring, reducing soil water content as compared to fallow fields or fields left bare during winter (Campbell et al., 1984; Ewing et al., 1991; Alonso-Ayuso et al., 2014). The effects of cover crops on soil moisture retention are, however, complex. Soil moisture was found to be slightly higher under cover crops with higher biomass production (Ward et al., 2011). Soil moisture was higher under late killed cover crops because they produced a mat that restricted evaporation (Munawar et al., 1990; Alcantara et al., 2011). During wet/dry cycles in spring and early summer, soil water evaporative loss was lower in fields with cover crop residue (Alonso-Ayuso et al., 2014). In a recent study of loamy soils conducted in Iowa, a rye cover crop was found to either significantly increase or have no impact on soil water conservation (Daigh et al. 2014). Collectively, these results show that the influence of covers on moisture is complex and weather and time dependent. The contradictory results of these studies indicate the need for further research to determine how cover crops and no-till practices interact with soil moisture throughout the growing season.

The purpose of this study was to evaluate the effects of cover crops and no-till conservation practices on SOM content and the available moisture in central Ohio soils exposed to the same environmental conditions. Both SOC and soil moisture measurements, were taken from fields with various management practices, to test the hypothesis that fields under no-till or cover crop management will have higher SOM measurements and therefore hold more moisture than fields under conventional tillage.

Objectives

- Quantify total organic matter content of soils under no-tillage, conventional tillage, and cover crop practices.

- Quantify moisture content retained throughout the growing season in soils under no-tillage, conventional tillage, and cover crop practices.

- Compare conservation practices to determine soil moisture benefits of cover crops and no-till fields under the same environmental conditions.

MATERIALS AND METHODS

Site Description and Selection

Four fields in central Ohio (Madison and Pickaway counties) were chosen based on management practices and similar slope to be representative of the Midwest in soil type and texture. The assumption was made that the soil type would be similar enough to allow evaluation of soil change in dynamic soil properties that were associated with recent management practices. Fields were derived from Glacial till, which is a major parent material of the Great Lakes Region, and silt loam is a common soil texture (Daigh et al. 2014). In addition, these fields have been in agricultural production over the past thirty years, mostly in corn-soybean rotations. Ohio's agriculture is typical of the Midwest grain producing region, which relies on rain fed crop production. Mean annual precipitation is 97.92 cm; with little rainfall occurring in late summer (NOAA, 2015a).

Fields 1 and 2 were chosen for their use of cover crops and no tillage. Cover crops have been grown on field 1 for the last 5 years, and on field 2 for the past 15 years. Field 3 does not have a cover crop and was converted to a no-till operation 4 years ago. Field 4 is a conventionally tilled field; the seed bed is prepared by chisel plowing before planting corn and no-tillage before planting beans. However, in 2015 Sorghum Sudan grass was no-till planted into the previous year's soybean stubble. Field 4 was chosen because it is representative of typical management practice in this region and serves as a control for this study, see Table 1.

Table 1. Field Description and Soil Information

Field #	Tillage	Cropping History	Slope	Texture/ Soil Type	Drainage Class/Hydrologic Soil Group (HSG)
1	No-till- 11 years F-1	2015- Winter Wheat double crop Sorghum Sudan Grass 2014- Soybeans 2013- Corn 2005- Alfalfa 5 years- Cover Crops 2015-Winter Wheat 2010-2014-Red Clover	2%	Silt Loam Kendallville (KeB)	Well Drained HSG-C
2	No-till- 15 years F-2	2015-Soybeans 2014-Corn 2013- Winter Wheat 2012-Pumpkins 15 years- Cover Crops 2015- Red Clover 2014-Rye 2013-Winter Wheat 2012-Rye 2011-Red Clover	1%	Silt Loam Ross (Rs) Medway (Mk)	Well Drained permeable along flood plains HSG-B Moderately Well Drained permeable along flood plains HSG-B/ D
3	No-Till - 4 years F-3	Continuous 2 year corn/soybean rotation 2015-Soybeans 2014- Corn	1%	Silt Loam Ross (Rs)	Well Drained permeable along flood plains HSG-B
4	Conventional Tillage F-4	2015-Sorghum Sudan Grass 2014- Soybeans 2013- Corn	1%	Silt Loam Kokomo (Ko) Miami and Lewisburg (MlA)	Poorly Drained HSG-C/D Well Drained upland adjacent streams HSG-C/D

(Based on data from USDA, 1981)

Experimental Design and Field Management

Samples were taken in a random fashion from within a one-acre grid, which was created and overlaid on an aerial image of the farm field, as illustrated in Appendix A, Figures 4-7. The Farm Works® program was used to create points within each grid square and link each point to latitude and longitude coordinates. The geo-referenced points were located in the field using a handheld GPS, see Appendix A, Figures 8-11. The sample sites were chosen using Excel® to generate random numbers. Grids were then sampled based on the numbers assigned to each of the geo-referenced points.

Sample size was determined using a two tail test with a 95% confidence level.

$$\text{Sample Size} = \frac{(t*SD)^2}{d^2}$$

Where $t_{1-\frac{\alpha}{2}, n-1}$ = 1.980 (McClave et al., 2014) for α=.975 and n = number of samples taken (114 samples), SD = standard deviation (3.49% moisture), and d = absolute error (1.5% moisture content).

Twenty-one samples a week were required per field, for a total of 84 samples to be pulled per week. This resulted in seven sites in each field being sampled at three different depths, once a week, from late April to the first week in October of 2015.

Field 1 was planted in winter wheat on October 13, 2014. Nitrogen and herbicide were applied on April 12, 2015. Liquid nitrogen (28%) and Instinct® were applied at a rate of 72lbs/acre and 28oz/acre respectively. The herbicide Sterling Blue® and MCPA were applied at 4oz/acre and 16oz/acre respectively. Fungicide was applied on May 21, 2015. The winter wheat was harvested on July 6, 2015, and straw was baled on July 9, 2015. Sorghum Sudan grass was planted on July 10, 2015 and received dry urea at a rate of 137lbs/acre on July 21, 2015. August

26, 2015 Sorghum Sudan grass was mowed and baled; cows were released onto the field one week later.

Field 2 was planted to red clover on November 3, 2014. The red clover was mowed and bailed on May 5, 2015. Soybeans were planted on May 13, 2015, using a John Deere® 750 drill, 176,500 beans per acre. The red clover was allowed to continue to grow until May 14, 2015 when Roundup® was used to burn down the cover crop. Roundup® was used again on July 11, 2015 for further weed control. The soybeans were harvested September 12, 2015.

Weeds were controlled on field 3 using Roundup-2, 4-D® on April 28, 2015. The field was planted to soybeans on May 9, 2015 using a John Deere® 750 drill, 176,500 beans per acre. Roundup® was used for additional weed control on July 3, 2015. The soybeans were harvested on September 19, 2015.

Weeds were burned down on field 4, using Roundup-2, 4-D®, on May 14, 2015. Sorghum Sudan grass was no-till planted on May 23, 2015. The grass was fertilized using urea at a rate of 1lb/acre/day of nitrogen. Grass was mowed and baled on July 29, 2015, and urea was reapplied on August 1, 2015 at the rate of 1lb/acre/day. The Sorghum Sudan grass was mowed and bailed a final time on September 16, 2015.

Soil Moisture and Organic Matter Measurements

In early October, Excel® was used to randomly select two of the seven sites in each field to draw samples for soil organic carbon. The samples were taken at three different depths (0-20, 20-40, and 40-60 cm) using a regular auger (6.98 cm in diameter). Soil organic carbon was quantified using a Blue M ™ combustion analyzer oven without an acid pretreatment to decompose carbonate. Soil organic matter was determined by multiplying the SOC percentages by a factor of 1.72, which estimates 58% of SOC of the total SOM (USDA-NRCS, 2009).

$$SOM = \%SOC * 1.72$$

Bulk density (BD) was determined using an undisturbed soil core sampler (1.8 cm in diameter) from 0-20cm. Soil was weighed in the field and dried at 105^0C for 24 hours (Jemai et al., 2012).

$$\frac{Dry\ Weight}{\pi * (0.9cm)^2 * 20cm}$$

Soil moisture content was determined using the gravimetric method (Verhulst et. al, 2011; Abdullah, 2014). Soil cores were taken at depths of (0-20, 20-40, 40-60 cm) with an undisturbed soil core sampler (1.8 cm in diameter) and an auger sampler (6.98 cm). Once collected, the samples were placed in a plastic bag and then into a cooler for transportation. Samples were weighed in the lab using a digital gram scale accurate to 0.01grams. To prepare the samples for drying, the soil was mixed while in the bag to ensure uniform distribution. Samples were oven dried at 105^0C for 24 hours. Once dried, samples were weighed again to determine water content. Soil moisture percentage was calculated using:

$$\frac{Wet-Dry}{Dry}\ x\ 100.$$

Statistical Analysis

Soil moisture response to management practices was assessed for statistical significance using a t-test. The differences between the means of soil moisture, depth, field, and month were assessed by analysis of variance (ANOVA), to determine which management practice could retain more moisture throughout the growing season. All statistics were performed in JMP® (version 11) and means were separated at the $p<0.05$ level.

RESULTS AND DISCUSSION

Soil Carbon Response to Depth

Soils sampled in this study generally reflect the characteristic depth-based decline in SOC. Many studies suggest SOC stratification is more strongly expressed in soils under no-tillage management (Blanco-Canqui and Lal, 2007; Mitchell et al., 2015). In fields 2 and 3, which are both mapped as the Ross soil series, carbon decreased with depth (Table 2). Relatively high SOC levels in the 20-40 cm depth are consistent with the fact that this series is a lowland soil with an A horizon reported to 74 cm. One might have expected SOC to be less stratified in field 2 than 3 due to the root-contributions made by the cover crops but this is not suggested by the data.

In field 1, which is a no-till field, like field 2 which also includes cover crops, SOC increased at the depth of 40-60cm. The SOC response is contrary to the expected outcomes for no-till fields but this is likely explained by the soil type as the mapped series, Kendallville, has a silty clay (1Bt) over a clay loam (2Bt horizon), so differences in clay may account for observed trends in SOC. Kahle et al. (2003) and Sausen et al. (2014) report that more carbon is found in soils with smaller particles such as clay due to the binding of carbon to the clay particle protecting it from decomposition. Additionally, field 1 was cropped in alfalfa from 2005-2012. “Perennial forages, such as alfalfa, can increase soil C sequestration compared with annual cropping systems due to greater below-ground biomass C input and continuous root growth” (Sainju and Lenssen, 2011). However, the SOC retention in below ground biomass should also accumulate from 0-40cm. The data are not consistent with the findings of Zendonadi dos Santos et al. (2011) who found that deposition of cover crop roots increased with depth.

Field 4 had an increased amount of SOC at the depth of 20-40cm over the 0-20cm depth. This response may also be attributed to the Miami/Lewisburg soil profile which consists of a silt loam (Ap) over a clay loam (2Bt horizon) so the differences in the SOC are possibly accounted for in the clay content of the soil. Additionally, the differences between 0-20cm and 20-40cm may not be significant due to the small sample size and standard deviation of ±3.67 and ±4.5 g C/kg soil respectively for each depth.

Furthermore, the soils are derived from glacial till which is calcareous in nature. An acid pretreatment to decompose the calcium carbonate was not performed on these soils before SOC was quantified by loss on ignition. Therefore, the amount of reported SOC may be overestimated.

Soil Organic Matter Response to Management Practice

At a depth of 0-20cm: field 2 had the highest percentage of SOM at 3.5%, followed by field 3 with 3.05%, field 4 with 2.95%, and field 1 with 1.25%, see Table 2. Field 2 is mapped as having Ross and Medway soil types and one would expect to find around 4% SOM in fields with those soil types (USDA, 2016). Therefore, the buildup of biomass on the surface and subsurface soil layers that results in accumulation of organic matter as Kuo et al. (1997) and Sainju et al. (2002) have described in a combined no-till cover crop system, such as field 1, is not expressed by the data. The SOM that was measured reflects underlying soil properties. Additionally, fields 2 and 3 are located in the flood plain of Deer Creek. Fresh deposits of alluvium each year have provided additional organic matter besides the residue left by the practice of no-till (USDA, 1981). Therefore, baseline measurements would need to be established in conjunction with long term studies to determine SOM response to cover crops.

Field 4 is mapped as having Kokomo and Miami-Lewisburg soils which from 0-20cm would have about 4.5% and 2% SOM respectively (USDA, 2016). The average of two samples taken for field 4 was 2.95%, indicating that one sample is representative of each soil type and the results lie within the expected SOM content for those soils. Field 1 SOM data are unexpectedly low given the soil type and the use of cover crops on this field. Field1 had 1.25% SOM and is mapped as Kendallville soils, the expected SOM content for the soils series is about 2.5% (USDA, 2016). This field sits on the largest slope of any other field, which may impact SOM results due to losses from past erosion.

Bulk Density

The bulk density for 0-20 cm was 1.49 g/cm³, 1.11 g/cm³, 1.49 g/cm³, and 1.61 g/cm³ for fields 1, 2, 3, and 4 respectively, see Table 2. The conventionally tilled field, field 4, had the greatest bulk density at the depth of 0-20 cm. The effects of tillage on bulk density are variable due to the amount of compaction incurred by a particular management practice (Crittenden, et al., 2015; Yang et al., 2013). It should be noted, that soils in tillage systems typically have lower bulk density than soils in no-till systems due to breaking up soil into smaller particles. The 1.61 g/cm³ reported for field 4 in the study would have impacted root growth. This value could have been inflated due to compaction induced by the use of a 1.8 cm diameter undisturbed soil corer. One would expect lower bulk density values for fields with no-till and cover crops combined (Blanco-Canqui et al., 2011). However, the bulk density value for field 1 is greater than the ideal bulk density of less than 1.4 g/cm³ for silty soil. This may be due to the periodic presence of cattle on the field.

It should be noted that bulk density values reported here do not reflect typical patterns. Generally, bulk density increases with depth (NRCS, 2008). Bulk density data in this study decreases with depth in all fields, indicating a potential sampling error may have occurred. Samples were difficult to pull at the depth of 40-60 cm and the full 20 cm for each depth increment may not have been collected for each sample, affecting the volume of soil. Incorrect volume measurements could explain the low measurements of bulk density. Additionally, field 2 at the depth of 20-40cm is comprised of small pebbles mixed with sand, which may have fallen out of the soil corer as samples were taken making the volume of the sample incorrect.

Table 2: SOM, SOC, and Bulk Density results for fields 1-4 at all depths.

Field	Depth (cm)	SOM%	SOC (g C/kg soil)	Bulk Density (g/cm³)
1	0-20	1.25±0.07	7.3±0.28	1.49
1	20-40	1.25±0.21	7.2±1.2	1.34
1	40-60	1.45±0.21	8.4±1.27	1.75
2	0-20	3.5±0.98	20.3±5.79	1.11
2	20-40	2.45±0.63	14.2±3.67	0.83
2	40-60	1.25±0.91	7.2±5.23	1.3
3	0-20	3.05±0.63	17.7±3.67	1.49
3	20-40	2.90±0.98	16.8±5.72	1.28
3	40-60	2.70±0.42	15.6±2.47	1.16
4	0-20	2.95±.063	17.1±3.67	1.61
4	20-40	3.35±0.77	19.4±4.5	1.39
4	40-60	2.20±1.13	12.7±6.5	1.34

Sample Size for SOM and SOC n=2, Sample Size for Db n=7.

Precipitation throughout the Growing Season

During the 2015 growing season, the observed average monthly precipitation was above the 30-year monthly average for 6 of the 7 months; see Figure 1 (NOAA, 2015b). June and July were the wettest months of the growing season, with June getting approximately 7 cm of additional precipitation over the 30-year average. Due to the increased precipitation, Deer Creek rose out of its banks and flooded the lower portions of field 3. Four of the 7 sampling sites on field 3 were under water during 3 separate sampling dates. The water on the field made the samples saturated or too difficult to pull. On July 15, 2015, 2 of the 7 sample sites were unable to be sampled due to the 76.2 cm of water standing in the field. Thus, any conclusions made from this study are representative of wet years.

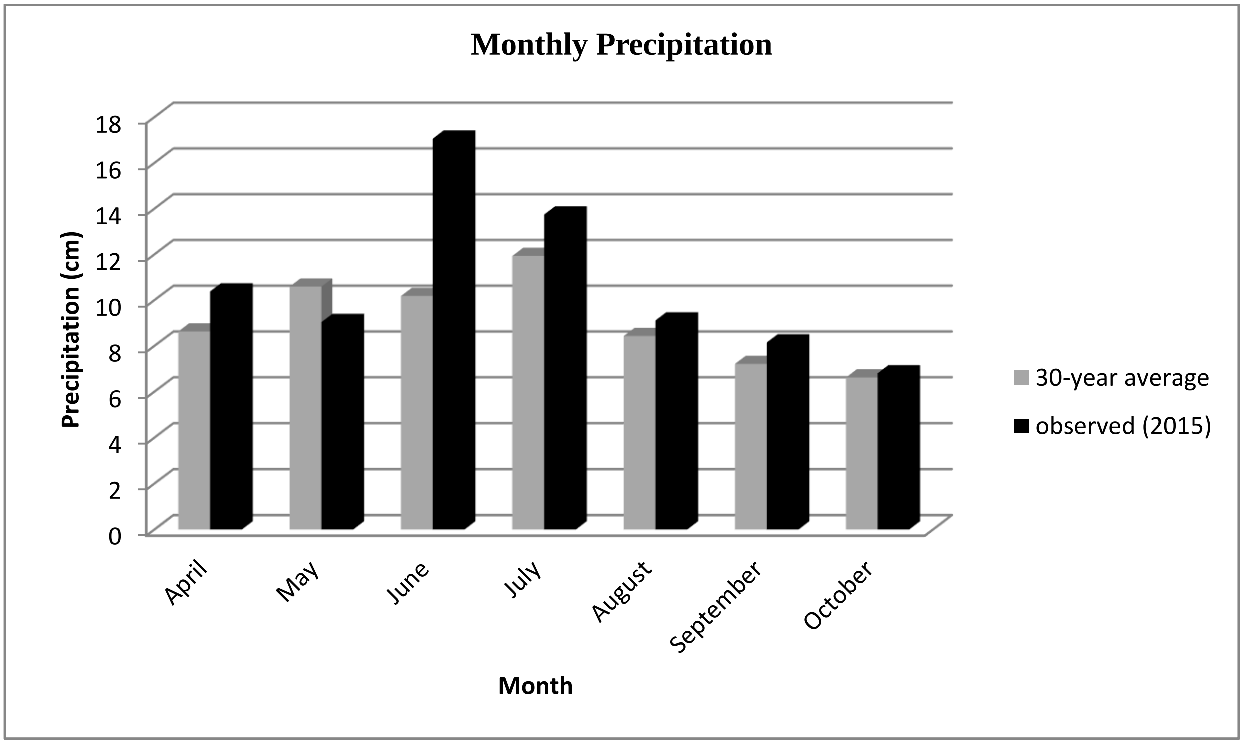


Figure 1: Observed and 30-year monthly averages of precipitation for central Ohio. Based on data from NOAA, 2015.

Moisture Retention by Field

With an alpha of 0.05, the resulting p value 0.0001 from the ANOVA indicates statistical differences in soil moisture content between the 4 fields, see Table 4 in Appendix B. Normality was assessed using a Shapiro-Wilk test in order to determine the validity of the ANOVA for average moisture content including all depths. The Shapiro-Wilk Test resulted in a p-value of 0.0001 rejecting the assumption of normal distribution, see Table 5 in Appendix B. However, based on visual inspection of the distribution it appears to be a robust deviation from normality, and therefore this underlying condition necessary for the ANOVA is met. Mean moisture content for the entire growing season, and for all depths in fields 1, 2, 3, and 4, was 14.21%, 15.97%, 18.38%, and 18.42% respectively, see Figure 2. With a correlation of determination equaling 46%, nearly half of the moisture variance can be explained by field differences. However, due to underlying differences in soil type, the moisture contents of individual fields cannot be attributed to management practices.

Soil classification influences the drainage capabilities of the soils in each field. Fields 1 and 4 are in hydrologic soil group (HSG) C, which is defined as soils with slow infiltration rates when thoroughly wet, and have a slow rate of water transmission (NRCS, 2016). Field 4 contains about 50% Kokomo soils with a drainage class of very poorly drained, which in combination with the wet year in 2015 may explain why this field retained the greatest amount of mean moisture at all depths. Additionally, field 4 is the only field in this study that contains tile. The tile line is an old clay tile and likely broken rendering it inadequate; the farmer indicated that he will be re-tiling the field this winter. Despite being in HSG C, field 1 retained the least amount of mean moisture for all depths; this may be due to the Kendallville soil found in field 1 which is considered well-drained soils. Field 2 is in HSG B which is defined as soils with moderate infiltration when thoroughly wet and has a moderate rate of water transmission (NRCS, 2016). The field is composed of Ross and Medway soils which have a drainage classification of well-drained. In addition, this field has gravel at 20-60cm, increasing the infiltration rate of water through this field.

Field 1 and 2 were planted in winter wheat and red clover cover crops respectively. Campbell et al. (1984) and Ewing et al. (1991) found that cover crops can deplete the moisture in the upper layer of soil as compared to fields left fallow during the winter. In 2015, the month of May was drier than the 30-year average, which may have influenced overall soil moisture retention percentages for cover cropped fields, fields 1 and 2, during the spring, see Figure 1.

There was no statistical difference in moisture content between fields 3 and 4. T-tests revealed the remaining pairs to be statistically different, see Table 6 in Appendix B. Although these fields were statistically different moisture content is not likely due to the differences in management practices. There are many confounding factors such as soil types, drainage class, HSG, management practices, and the above average rainfall. The opportunistic nature of this field study could not address all the variation in the fields. Therefore, future studies should focus on management practices that are applied to fields with greater similarity in order to control variance.

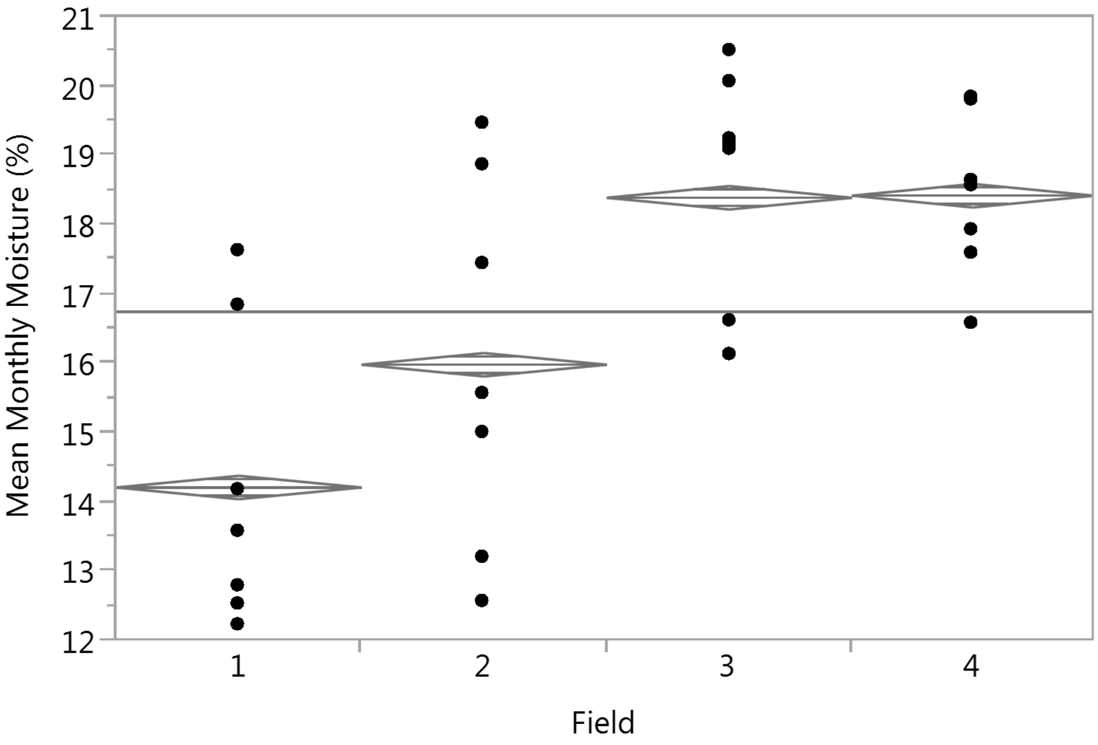


Figure 2: One-way Analysis of Mean Moisture Content (%) by Field for all depths combined for the entire growing season.

Moisture at Depth

An ANOVA was conducted on moisture content for 0-20cm, 20-40cm, and 40-60cm depths for all fields. The ANOVA resulted in a p-value of 0.6160 which is greater than 0.05, therefore the analysis of moisture changes by depth revealed no overall depth-based differences in moisture when averaged over the season, see Table 7 in Appendix B. This finding may be due to the wet year central Ohio experienced in 2015.

Depth alone is not predictive of moisture. However, when a two-way ANOVA is conducted on field and depth, the resulting p value for field by depth is 0.001, indicating that moisture at depth varies among fields, see Table 8 in Appendix B. The change in moisture by depth per field may be due to the presence of clay loam in the 20-40 cm depth of Miami-

Lewisburg and Kendallville soil types. Additionally, the depth to the water table in field 4 reported by USDA web soil survey is 15 cm (USDA, 2016). Therefore, soil at 20-60 cm depths will naturally retain greater amounts of moisture than the 0-20 cm depth for that field.

Moisture changed by depth in the months of August and October. With a p value of 0.0074 and 0.001 in August and October respectively, there is a statistical difference in soil moisture content by depth, see Tables 9 and 10 in Appendix B. Precipitation during the months of August and October were similar to the 30-year average for those months, indicating that they may be representative of average field conditions and moisture retention by depth during dry years could be more pronounced.

SOC and Moisture

A linear regression of moisture and SOC resulted in a p-value of less than 0.0001, see Table 3. This regression analysis suggests that there is a statistical relationship between moisture content and the amount of SOC present in fields. However, the accompanying coefficient of determination is very low, 0.192, indicating a large amount of variance that cannot be explained by the model. Additionally, there are many overlapping data points and very small differences between fields for mean moisture content at all depths, see Figure 3. Therefore, no practical relationship between SOC and moisture retention can be determined from the data.

Table 3: Linear regression of mean moisture content (%) by SOC.

RSquare	0.192311
RSquare Adj	0.191897
Root Mean Square Error	3.530942
Mean of Response	16.73724
Observations (or Sum Wgts)	1956

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	11.639296	0.249469	46.66	<.0001*
SOC g C/kg soil	0.3792195	0.017581	21.57	<.0001*

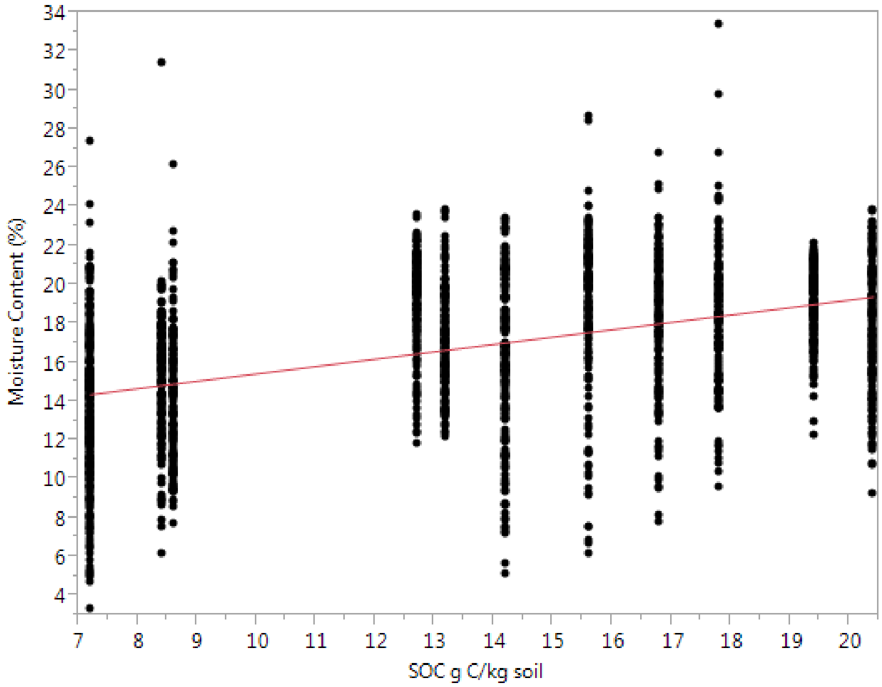


Figure 3: Linear Regression of Mean Moisture Content for all fields and depths over the entire growing season as compared with SOC.

CONCLUSION

This study is representative of the variability farmers experience as they seek to mitigate their risk by purchasing land in geographically separate locations to account for weather variability and soil differences. Fields 1, 2, 3, and 4 are within a 10 mile radius and have slightly different soil types. This field study presents conflicting results about the influence of management practice on organic content in soils and therefore is not conclusive. The research hypothesis that soil organic carbon influences moisture retention is supported in this research. However, management practices do not statistically correspond directly with SOC or moisture findings. Therefore, moisture retention cannot be attributed to any particular farm practice due to the number of variables unaccounted for such as HSG, soil type, and soil drainage classification. Future studies could address these constraints by placing all treatments into a split block design or more carefully controlling soil type of farms compared, to reduce the possible soil variations. Additionally, there is a need for greater accuracy in soil moisture, precipitation, and bulk density measurements that could be achieved through the use of continuous data recording devices such as a soil probe that can record information hourly throughout the growing season.

Future climate change will impact the precipitation pattern in the Midwest, making studies such as this crucial to maintaining crop production at current levels. Future studies should seek to include long term monitoring of fields under varying management practices for SOM and SOC concentrations, being sure to include field variability into the study. Additionally, long term soil moisture studies should accompany the SOC and SOM studies. Future SOC studies have implications beyond moisture retention, as they may influence policy decisions about the effectiveness of cover crops for carbon sequestration and carbon credits, as well as other ecosystem services. Long term studies completed on moisture, SOC, and SOM will aid farmers in determining best practices for their farming operations to maintain crop production.

REFERENCES

Abdullah, A.S. 2014. Minimum tillage and residue management increase soil water content, soil organic matter and canola seed yield and seed oil content in the semiarid areas of Northern Iraq. Soil and Tillage Research 144:150-155.

Alcantaraa C., A. Pujadasb, and M. Saavedraa. 2011. Management of cruciferous cover crops by mowing for soil and water conservation in southern Spain. Agriculture Water Management 98:1071-1080.

Alonso-Ayuso M., J.L. Gabriel, and M. Quemada. 2014. The kill date as a management tool for cover cropping success. Plos ONE. doi:10.1371/journal.pone.0109587.

Bianchi, S.R., M. Miyazawa, E.L. de Oliveira, and M.A. Pavan. 2008. Relationship between the mass in organic matter and carbon in soil. Brazilian Archives of Biology and Technology 51:263-269.

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

Blanco-Canqui, H., L.R. Stone, A.J. Schiegel, D.J. Lyon, M.F. Vigil, M.M. Mikha, P.W. Stahlman, and C.W. Rice. 2009. No-till induced increase in organic carbon reduces maximum bulk density of soils. *Soil Science Society of America Journal* 73: 1871-1879.

Blanco-Conqui, H., and R. Lal. 2007. No-tillage and soil-profile carbon sequestration: an on farm assessment. *Soil Science Society of America Journal* 72:693-701.

Bodner, G., M. Himmelbauer, W. Loiskandl, and H.P. Kaul. 2009. Improved evaluation of cover crop species by growth and root factors. Agronomy for Sustainable Development 30:455-464.

Bowles, J.P. 1990. Soils. Brooklyn Botanic Gardens, Brooklyn, New York.

Campbell, R.B., D.L. Karlen, and R.E. Sojka. 1984. Conservation tillage for maize production in the U.S. Southeastern Coastal Plain. Soil and Tillage Research 4:511-529.

Crittenden, S.J., N. Poot, M. Heinen, D.J. van Balen, and M.M. Pulleman. 2015. Soil physical quality in contrasting tillage systems in organic and conventional farming. Soil and Tillage Research 154: 136-144.

Dagel, K. J., S.L. Osborne, and T.E. Schumacher. 2014. Improving soybean performance in the Northern Great Plains through the use of cover crops. Communications in Soil Science & Plant Analysis 45:1369-1384.

Daigh, A.L., M.J. Helmers, E. Kladivko, X. Zhou, R. Goeken, J. Cavidini, D. Baker, and J. Sawyer. 2014. Soil water during the drought of 2012 as affected by rye cover crops in field in Iowa and Indiana. *Journal of Soil and Water Conservation* 69:564-573.

Ekins, P. 2011. Environmental sustainability: From environmental valuation to the sustainability gap. Progress in Physical Geography 35:629-651.

Ewing, R.P., M.G. Wagger, and H.P. Denton. 1991. Tillage and cover crop management effects on soil water and corn yield. *Soil Science Society of America Journal* 55:1081-1085.

Fan, F., R. Bradley, and M. Rawlins. 2014. Climate change in the Northeastern US: regional climate model validation and climate change projections. Climate Dynamics 43:145-161.

Fourie, J. C., G.A. Agenbag, and P.E. Louw. 2007. Cover crop management in a Sauvignon Blanc/Ramsey Vineyard in the semi-arid Olifants River Valley, South Africa. *South African Journal of Enology & Viticulture* 28:92-100.

Gruber, S., J. Mohring, and W. Claupein. 2011. On the way towards conservation tillage-soil moisture and mineral nitrogen in a long-term field experiment in Germany. Soil and Tillage Research 115-116:80-87.

Haramoto, E. R., and D.C. Brainard. 2012. Strip tillage and oat cover crops increase soil moisture and influence N mineralization patterns in cabbage. Hortscience 47:1596-1602.

Hayhoe, K., J. VanDorn, T. Croley, N. Schlegal, and D. Wuebbles. 2009. Regional climate change projections for Chicago and the US Great Lakes. *Journal of Great Lakes Research* 36:7-21.

Hudson, B.D. 1994. Soil organic matter and available water capacity. *Journal of Soil and Water Conservation* 49:189-194.

Hugh, R. 2014. Grain yields and soil properties on loam soil after three decades with conservation tillage in southeast Norway. Soil and Plant Science 64:185-202.

Jemai, I., B.A. Nadhira, S.B. Guirat, M.B. Hammouda, and T. Gallali. 2012. Impact of three and seven years of no-tillage on the soil water storage, in the plant root zone, under a dry sub-humid Tunisian climate. Soil and Tillage Research 126:26-33.

Kahle, M., M. Kleber, M.S. Torn, and R. Jahn. 2003. Carbon storage in coarse and fine clay fractions of illitic soils. *Soil Science Society of America Journal* 67:1732:1739.

Krueger, E.S., T.E. Ochsner, P.M. Porter, and J.M. Baker. 2011. Winter rye cover crop management influences on soil water, soil nitrate, and corn development. *Agronomy Journal* 103:316-323.

Kuo, S., U.M. Sainju, and E.J. Jellum. 1997. Winter cover crop effects on soil organic carbon and carbohydrate in soil. *Soil Science Society of America Journal* 61:145-152.

Liebl, R., F.W. Simmons, L.M. Wax, and E.W.Stoller. 1992. Effect of rye (*Secale cereale*) mulch on weed control and soil moisture in soybean (Glycine max). Weed Technology 6:838-846.

Liu, Y., M. Gao, W. Wu, S.K. Tanveer, X. Wen, and Y. Liao. 2013. The effects of conservation tillage on the soil water-holding capacity of a non-irrigated apple orchard in the Loess Plateau, China. Soil and Tillage Research 130:7-12.

McClave, J.T., G.P. Benson, and T. Sincich. 2014. Statistics for business and economics. 12th ed. Pearson, Boston.

Mishra, U., D. Ussiri, and R. Lal. 2010. Tillage effects on soil organic carbon storage and dynamics in Corn Belt of Ohio USA. Soil and Tillage Research 107:88-96.

Mitchell, J.P., A. Shrestha. W.R. Horwath, R.J. Southard, N. Madden, J. Veenstra, and D.S. Munk. 2015. Tillage and cover cropping affect crop yields and soil carbon in the San Joaquin Valley, California. *Agronomy Journal* 107: 588-596.

Munawar, A., R. L. Blevins, W. W. Frye, and M. R. Saul. 1990. Tillage and cover crop management for soil water conservation. *Agronomy Journal* 82:773-777.

NRCS (Natural Resource Conservation Service). 2008. Soil quality indicators. United States Department of Agriculture. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053256.pdf (accessed 13 January 2015).

NRCS (Natural Resource Conservation Service). 2016. Web Soil Survey. United States Department of Agriculture. http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (accessed 6 March 2016).

NOAA (National Oceanic and Atmospheric Administration). 2015a. NOWData. NOAA online weather data. Ames, IA: National Atmospheric Administration. http://www.ncdc.noaa.gov/cag/time-series/us (accessed 21 March 2015).

NOAA (National Oceanic and Atmospheric Administration). 2015b. Observed Weather. National weather forecast office: Wilmington, Ohio. http://w2.weather.gov/climate/index.php?wfo=iln (accessed 12 January 2015).

Olson K.R., M. Al-Kaisi, R. Lal, and B. Lowery. 2014a. Examining the paired comparison method approach for determining soil organic carbon sequestration rates. *Journal of Soil and Water Conservation* 69:193-197.

Olson K.R., M. Al-Kaisi, R. Lal, and B. Lowery. 2014b. Experimental consideration, treatments, and methods in determining soil organic carbon sequestration rates. *Soil Science Society of America Journal* 78:348-360.

Particola, C.M., and K.H. Cook. 2013. Mid-twenty-first century warm season climate change in the Central United States, Part I: Regional and global model predictions. Climate Dynamics 40:551-568.

Sainju, U.M., and A.W. Lenssen. 2011. Dryland soil carbon dynamics under alfalfa and durum-forage cropping sequences. Soil and Tillage Research 113:30-37.

Sainju, U.M., B.P. Singh, and W.F. Whitehead. 2002. Long-term effects of tillage, cover crops, and nitrogen fertilization on organic carbon and nitrogen concentrations in sandy loam soils in Georgia, USA. Soil and Tillage Research 63:167-179.

Sausen T.L., G.F. de Paula Schaefer, M. Tomazi, L. Scheunemann dos Santos, C. Bayer, and M. Goncalves Rosa. 2014. Clay content drives carbon stocks in soils under a plantation of *Eucalyptus saligna* Labill in southern Brazil. Acta Botanic Brasilica 28:266-273.

Smith, D.L., and J.J. Almaraz. 2004. Climate change and crop production: contributions, impacts, and adaptations. Canadian Journal Plant Pathology 26:253-266.

Tan Z., S. Liu, Z. Li, and T. Loveland. 2007. Simulated responses of soil organic stock to tillage management scenarios in the Northwest Great Plains. Carbon Balance and Management 2:7.

Ugarte, C.M., H. Kwon, S.S. Andrews, and M.M. Wander. 2014. A meta-analysis of soil organic matter responses to soil management practices: An approach to evaluate conservation indicators. Journal of Soil and Water Conservation 69:422-430.

Ugarte, C.M., E.R. Zaborski, and M.M. Wander. 2012. Nematode indicators as integrative measures of soil condition in organic cropping systems. Soil Biology and Biochemistry 64:103-113.

United States Department of Agriculture. 2016. Web Soil Survey. USDA-NRCS. http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx (accessed 3 Feb. 2016).

United States Department of Agriculture Soil Conservation Service in cooperation with Ohio Department of Natural Resources Division of Lands and Soils and Ohio Agricultural Research and Development Center. 1981. Soil Survey of Madison and Pickaway County Ohio.

USDA-NRCS. 2009. Soil Quality Indicators. USDA-NRCS. http://soilquality.org/indicators/total_organic_carbon.html (accessed 17 Nov. 2015).

Ussiri, D. and R. Lal. 2008. Long-term tillage effects on soil carbon storage and carbon dioxide emissions in continuous corn cropping system from an alfisol in Ohio. Soil and Tillage Research 104:39-47.

VandenBygaart, A.J., E.G. Gregorich, and D.A. Angers. 2003. Influence on agricultural management on soil organic carbon: A compendium and assessment of Canadian studies. *Canadian Journal of soil Science* 83:363-380.

Verhulst, N., V. Nelissen, N. Jespers, H. Haven, K.D. Sayre, D. Rales, J. Deckers, and B. Govaerts. 2011. Soil water content, maize yield and its stability as affected by tillage and crop residue management in rain fed semi-arid highlands. Plant Soil 344:73-85.

Ward, P.R., K.C. Flower, N. Cordingley, C. Weeks, and S.F. Micin. 2011. Soil water balance with cover crops and conservation agriculture in a Mediterranean climate. Field Crops Research 132:33-39.

Yang, X., C. Drury, and M. Wander. 2013. A wide view of no-tillage practices and soil organic carbon sequestration. Soil and Plant Sciences 63: 523-530.

Zendonadi dos Santos, N., J. Dieckow, C. Bayer, R. Molin, N. Favaretto, V. Pauletti, and J.T. Piva. 2011. Forages, cover crops and related shoot and root additions in no-till rotations to C sequestration in a subtropical Ferralsol. Soil and Tillage Research 111: 208-218.

Zhang, P., T. Wei, Z. Jia, Q. Han, X. Ren, and Y. Li. 2014. Effects of straw incorporation on organic matter and soil water-stable aggregates content in semiarid regions of Northwest China. PloS ONE. doi:10.1371/journal.pone.009283.

Appendix A: FIGURES

One-acre grid on an aerial outline image of fields 1-4

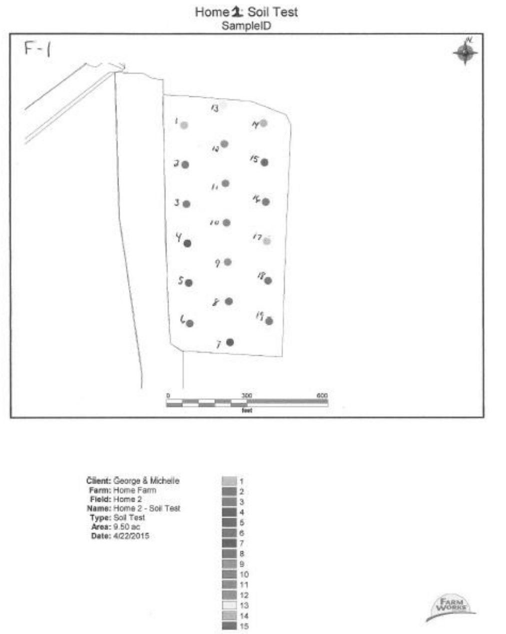


Figure 4: Field 1-1 acre grid on 10 acre field

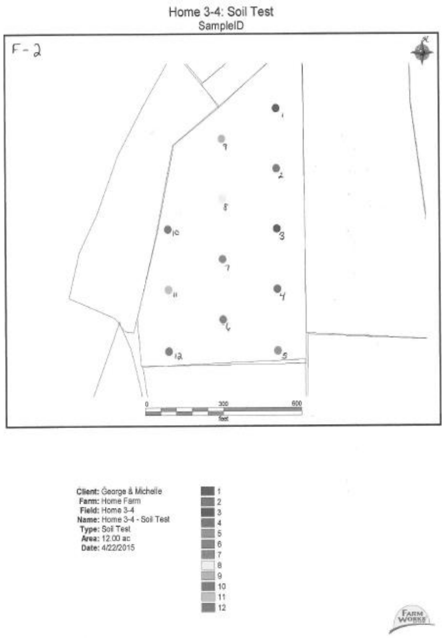


Figure 5: Field 2-1 acre grid on a 9 acre field

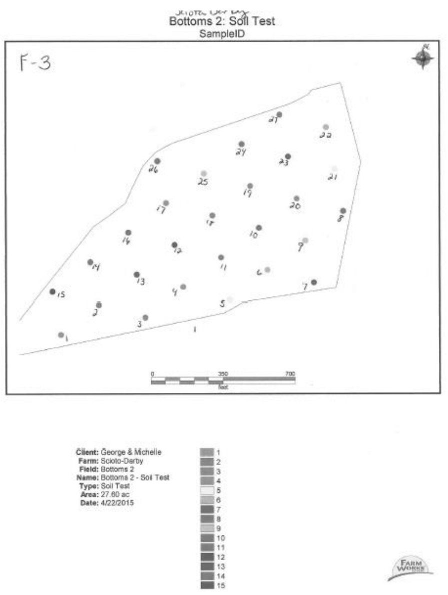


Figure 6: Field 3-1 acre grid on a 13 acre field

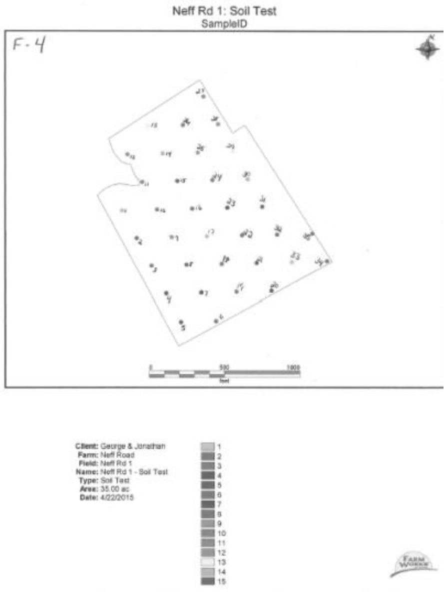
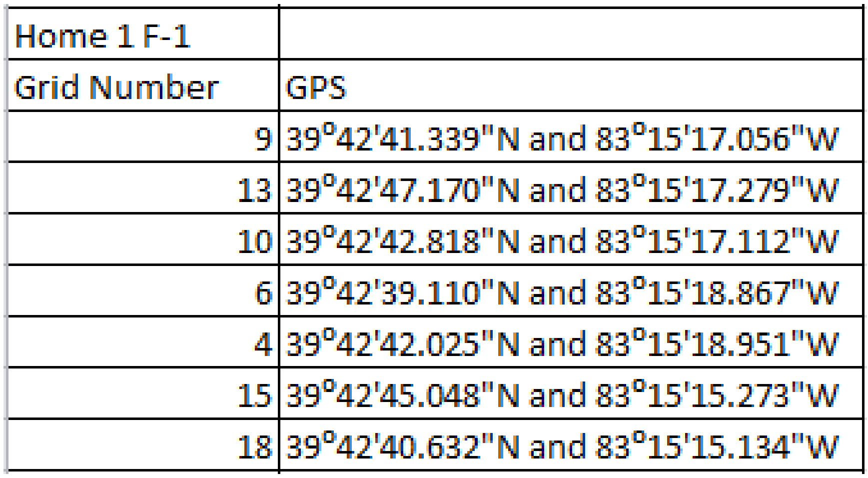
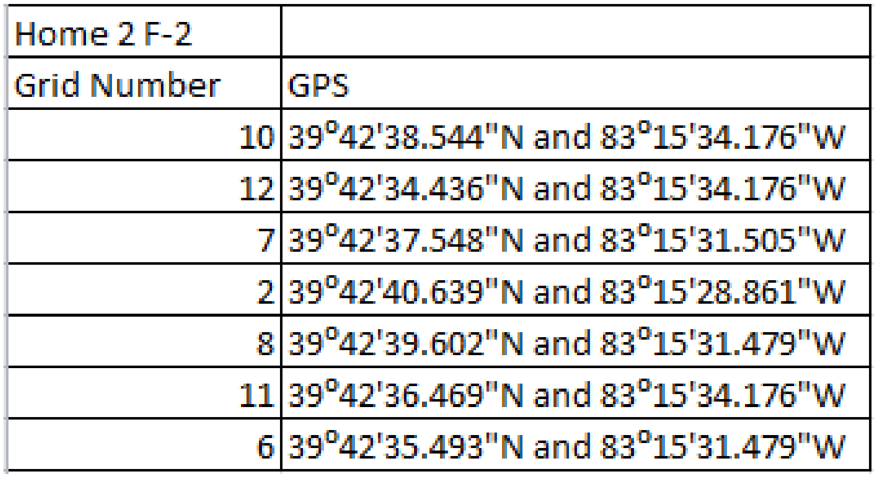


Figure 7: Field 4-1 acre grid on a 35 acre field



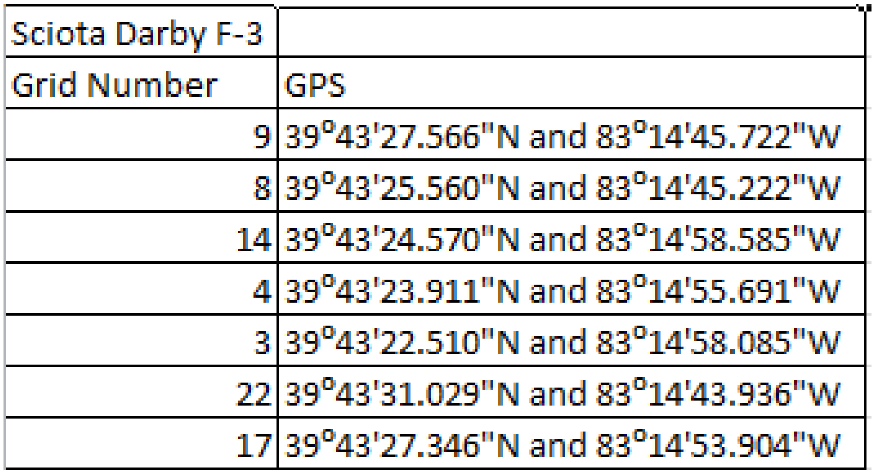
Home 1 F-1	
Grid Number	GPS
9	39°42'41.339"N and 83°15'17.056"W
13	39°42'47.170"N and 83°15'17.279"W
10	39°42'42.818"N and 83°15'17.112"W
6	39°42'39.110"N and 83°15'18.867"W
4	39°42'42.025"N and 83°15'18.951"W
15	39°42'45.048"N and 83°15'15.273"W
18	39°42'40.632"N and 83°15'15.134"W

Figure 8: Geo-referenced points for field 1



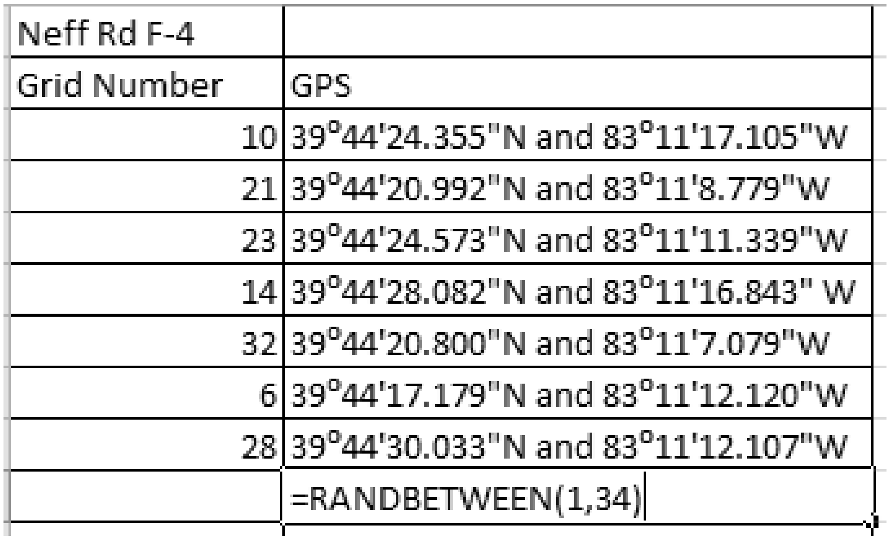
Home 2 F-2	
Grid Number	GPS
10	39°42'38.544"N and 83°15'34.176"W
12	39°42'34.436"N and 83°15'34.176"W
7	39°42'37.548"N and 83°15'31.505"W
2	39°42'40.639"N and 83°15'28.861"W
8	39°42'39.602"N and 83°15'31.479"W
11	39°42'36.469"N and 83°15'34.176"W
6	39°42'35.493"N and 83°15'31.479"W

Figure 9: Geo-referenced points for field 2



Sciota Darby F-3	
Grid Number	GPS
9	39°43'27.566"N and 83°14'45.722"W
8	39°43'25.560"N and 83°14'45.222"W
14	39°43'24.570"N and 83°14'58.585"W
4	39°43'23.911"N and 83°14'55.691"W
3	39°43'22.510"N and 83°14'58.085"W
22	39°43'31.029"N and 83°14'43.936"W
17	39°43'27.346"N and 83°14'53.904"W

Figure 10: Geo-referenced points for field 3



Neff Rd F-4	
Grid Number	GPS
10	39°44'24.355"N and 83°11'17.105"W
21	39°44'20.992"N and 83°11'8.779"W
23	39°44'24.573"N and 83°11'11.339"W
14	39°44'28.082"N and 83°11'16.843" W
32	39°44'20.800"N and 83°11'7.079"W
6	39°44'17.179"N and 83°11'12.120"W
28	39°44'30.033"N and 83°11'12.107"W
	=RANDBETWEEN(1,34)

Figure 11: Geo-referenced points for field 4

Appendix B: Tables

Table 4: One-way Analysis of Moisture Content (%) By Field

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Field	3	6116.662	2038.89	165.5162	<.0001*
Error	1952	24045.435	12.32		
C. Total	1955	30162.097			

Rsquare	0.462385
Adj Rsquare	0.461561
Root Mean Square Error	1.910452
Mean of Response	16.74564
Observations (or Sum Wgts)	1962

Table 5: Residual Distribution for Shapiro-Wilk Test of Normality

Goodness-of-Fit Test

Shapiro-Wilk W Test Shapiro-Wilk W Test

W	**Prob<W**
0.979861	<.0001*

Table 6: T-test Analysis of Mean Moisture Content (%) Throughout the Growing Season for Field Pairings

Field Pairing	p value
1 and 2	8.4E-13
1 and 3	1.21E-67
1 and 4	4.22E-94
2 and 3	1.44E-19
2 and 4	3.29E-25
3 and 4	0.851063

Table 7: One-way ANOVA of Moisture and Depth.

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**	**Prob > F**
Depth	2	14.961	7.4807	0.4846	0.6160
Error	1953	30147.136	15.4363		
C. Total	1955	30162.097			

Table 8:Two-way ANOVA Field by Depth in Response to Moisture Content (%)

RSquare	0.271372
RSquare Adj	0.26725
Root Mean Square Error	3.362292
Mean of Response	16.73724
Observations (or Sum Wgts)	1956

Analysis of Variance

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	11	8185.163	744.106	65.8209
Error	1944	21976.935	11.305	**Prob > F**
C. Total	1955	30162.097		<.0001*

Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
Field	3	3	6116.6624	180.3526	<.0001*
Depth	2	2	14.3829	0.6361	0.5294
Field*Depth	6	6	2053.5393	30.2748	<.0001*

Table 9: Two-way ANOVA Moisture Content (%) Response to Field and Depth for the Month of August

RSquare	0.440656
RSquare Adj	0.421665
Root Mean Square Error	2.679907
Mean of Response	15.25548
Observations (or Sum Wgts)	336

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	11	1833.1766	166.652	23.2045
Error	324	2326.9359	7.182	**Prob > F**
C. Total	335	4160.1125		<.0001*

Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
Field	3	3	1199.9655	55.6940	<.0001*
Depth	2	2	71.5502	4.9813	0.0074*
Field*Depth	6	6	561.6610	13.0342	<.0001*

Table 10: Two-way ANOVA Moisture Content Response to Field and Depth for the Month of October

RSquare	0.60992
RSquare Adj	0.550324
Root Mean Square Error	2.679856
Mean of Response	16.79286
Observations (or Sum Wgts)	84

Source	**DF**	**Sum of Squares**	**Mean Square**	**F Ratio**
Model	11	808.4895	73.4990	10.2343
Error	72	517.0772	7.1816	**Prob > F**
C. Total	83	1325.5667		<.0001*

Effect Tests

Source	**Nparm**	**DF**	**Sum of Squares**	**F Ratio**	**Prob > F**
Field	3	3	460.45212	21.3718	<.0001*
Depth	2	2	109.43403	7.6190	0.0010*
Field*Depth	6	6	238.60339	5.5374	<.0001*