Short-term effects of cover crops on soil health and yield in established no-till systems

by

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Abstract

Agriculture in Kansas and the Great Plains faces many sustainability challenges. Cover cropping is a practice that can affect sustainability by improving soil health parameters in some environments, but more work is needed in the frame of no-till systems in eastern Kansas. Additionally, cash crop yield is an important consideration for production agriculture, but is only reported in less than one-third of soil health studies. Field experiments were conducted on long-term no-till (>10 years) farms in 2014-2017 near Burlington, Hutchinson, and Valley Falls, Kansas. Sites were selected in partnership with local extension, with typical cropping rotations for the area. The objectives of this study were to (i) determine the impact of cover crops on soil health (ii) quantify biomass of established cover crops (iii) quantify yield impacts of cover crops on cash crop yield by comparing single species cover crop (CS), multiple species cover crop (CM), and no cover crop (NC) treatments. In addition, a tillage (T) treatment was included at the Burlington site. Plots were arranged in a randomized complete block design with three replications. Analysis of the soil property data largely found no consistent treatment effects (alpha = 0.05), though sporadic differences were detected. For example, infiltration significantly differed among treatments at the Burlington site in fall 2016, where the T and NC plots had significantly higher rates than the CS and CM plots, but it did not repeat in the 2017 samplings. The Burlington location was the only site to have differences in soil aggregate properties. The aggregates in the tillage plots were getting smaller over time likely from the mechanical breakdown of annual tillage. A significantly smaller mean weight diameter was observed for T as opposed to the other treatments in spring 2016. In 2015 and 2016 the NC treatment also began to show higher proportions of the 0.25mm WSA and less 4.75mm and 2.00mm WSA than the cover crop plots. Very few significant differences were found in the soil biological or

chemical parameters, and those that were found lacked repeatability across years. Significantly higher dissolved organic carbon concentrations were observed in the mixed cover crop treatment at the Burlington location for the fall 2017 sampling time, and pH had sporadic instances of significance as well.

In conclusion, during the first three years of this project, cover crops have had minimal short-term effects on soil dynamic properties, or cash crop yield, in long-term no-till in eastern Kansas. These results imply that cover crops are likely not a hindrance nor an enhancement to grain corn or soybean yields in eastern Kansas. Additionally, there may be an opportunity for growers to reduce seed costs by planting a single species cover crop as there was no short-term yield or soil health benefit to planting a multi-species mix.

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Chapter 1 - Introduction

Agriculture in Kansas and the Great Plains faces many sustainability challenges due to soil erosion, limited precipitation, and declining aquifer levels (Bruinsma, 2012; Knapp and Tomlinson, 2012). Sustainability and conservation agricultural practices have been broadly defined by the National Resource Conservation Service, the Food and Agricultural Association of the United Nations, and the Soil Health Institute; however, it is not a one-size fits all paradigm. For producers in eastern Kansas, the quandary remains as to which practices will be viable and improve soil health in cropping systems of the region.

Cover crops are classified as any plant introduced during or directly after the main cropping phase of a system and terminated before the planting of the next crop (Hartwig and Ammon, 2002). A key principal of cover cropping is that it increases the cropping intensity, which has been shown to improve water use efficiency, weed control, and soil fertility (Roozeboom, 2012; Leikam, 2013; McVay et al., 1989). Cover cropping has been identified as a practice of sustainable or conservation agriculture for its ability to support soil health.

Cover crops have been a keystone practice of the conservation agriculture paradigm; however, only 5.4% of Kansas commodity crop acres were cover cropped as of 2017 (Myers, 2019). The effects of cover cropping in long-term no-till has been at the forefront of the debate for many producers. Producers have been reluctant to adopt cover cropping due to the lack of consensus about the soil health benefits that cover crops can add to an established long-term no-till system, as well as the effects that cover crops can have on cash crop yield. While many studies addressed in this review look at long-term effects of cover crops on soil health, producers are interested in the short-term effects that may have immediate implications on farm profitability and productivity.

A recent meta-analysis of 192 papers by Stewart et al., (2018) found that less than one third of soil health studies measured crop yield, which is a primary concern for many producers. Another aspect that affects profitability of cover cropping is the choice to plant a single species or mixed species cover crop. Of the 86 cover crop studies analyzed in the meta-data study, less than 10% of the studies included a species mixture. Single-species cover crop seed can cost $25/hectare less than a multi-species mix, however, it is questionable that the mix will compensate for that price difference in quantifiable soil or crop measurements. (Shoup et al. 2016).

Conservation focused agricultural practices are those which may reduce soil erosion, increase soil microbial properties, and improve water infiltration rates. (Magdoff and Van Es, 2009). Soil health is defined by the National Resource Conservation Service (1999) as “the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.” Soil health can be broken into inherent and dynamic properties.

Dynamic soil health properties are those properties that can be influenced by soil use and management over the human time scale, and therefore are typically the subject of soil health studies (NRCS, 1999). The following section will review papers on the effects of cover crops on dynamic soil properties and cash crop yield.

Review of Relevant Literature

Cash Crop Yield

Letter et al. (2003) conducted a 15-year study in southern Pennsylvania to compare organic and conventional corn (*Zea mays*) and soybean (*Glycine max*) systems. The conventional system was a corn-soybean rotation, while the organic system was a corn-soybean-wheat (*Triticum* *aestivum*) rotation with a yearly hairy vetch (*Vicia villosa)* cover crop. The conventional system received mineral fertilizers, while the organic system received organic fertilizers as well as a plow-down cover crop of hairy vetch as nutrient sources. They found the yield of organic corn in drought years, and the yield of organic corn and soybean following a cover crop, was greater than conventionally-produced corn and soybean due to higher stored soil moisture in the organic corn and soybean treatments. This increased moisture may have been due to the cover crop increasing surface residue, which increases the soil surface shading, resulting in cooler soil temperatures and decreased wind speeds over the soil surface (Hatfield et al., 2001).

A three-year study conducted in Brookings, SD examined the impact of cover crops and crop residue on soil properties and soybean yield in a no-till corn/soybean system. The treatments consisted of residue returned and residue not returned, with each also receiving a cover crop and no cover crop treatment. In this study, returning residue coupled with cover cropping had many positive impacts on the soil health and crop productivity. The researchers found that compared to the no cover treatments, the cover crop reduced the bulk density and increased infiltration rates. The cover crop treatments resulted in a 14% increase in soybean yield over the no cover treatment. (Chalise et al., 2019)

Ewing et al. (1991) found contrasting results in their evaluation of the effects of subsoiling and cover crop management on grain corn yield in Central California. The factors consisted of subsoiling, cover crop [clover (*Trifolium incarnatum*) vs. no cover], and tillage (chisel-till vs. no-till). In both years, the clover reduced soil moisture in the 0-15cm depth as compared to the no-cover treatment. The corn grain yield was reduced by 0.5 Mg ha^{-1} in 1985 and 0.9 Mg ha^{-1} in 1986. Therefore, the authors suggested that cover crop lowered soil moisture and reduced the productivity of subsequent cash crops. The authors noted that termination of the cover crop should occur seven to ten days prior to planting to reduce moisture losses for the cash crop.

Cover Crop Species and Mix Selection

Finney et al. (2016) tested nine cover crop mixtures but did not find a mixture that produced more biomass than the most productive component in monoculture. They did find a positive relationship between the number of species and the cover crop biomass where each cover crop species added 533 kg ha^{-1} to the above ground biomass on a dry weight basis. The authors noted that this relationship, while statistically significant, was only a weak indication of correlation (R^2=0.15). They also investigated if the cover crop species phenology affected biomass or soil nitrogen. They found that incorporating complementary nitrogen (N) acquisition strategies or phenologies into the mixture did not increase biomass, but it appeared to have increased soil N retention. The researchers also noted that mixes can be challenging to seed due to variations in seed size, but this can be overcome by broadcasting some and drilling others.

A study in Nebraska on legume and brassica cover crops as mixes and monocultures found that the mixes generally yielded less. However, they concluded that the mixes may have provided resiliency to environmental stress due to natural tolerances. (Wortman, et al., 2012) Cover crop species selection is important for erosion prevention as well as Locke et al., (2015) found that cover crop species with fibrous root systems were more effective at reducing soil losses.

Soil Physical Properties

Infiltration rate is influenced by inherent and dynamic soil properties such as soil structure, texture, soil organic matter, soil cover, and soil water content. Properties such as soil structure and soil cover can be improved through reduced tillage and the use of cover crops (Radke and Berry, 1993; Shukla 2014; Mohammad, 2016, no. 1; Magdoff and Van Es, 2009).

Aggregate stability is also widely regarded as a dynamic soil health indicator that can be impacted by management practices. "Desirable aggregates are stable against rainfall and water movement. Aggregates that break down in water or fall apart when struck by raindrops release individual soil particles that can seal the soil surface and clog pores. This breakdown creates crusts that close pores and other pathways for water and air entry into a soil and also restrict emergence of seedlings from a soil." (NRCS, 1996)

Haruna et al., (2018) examined the effects of tillage and cover cropping on a selection of dynamic soil properties in Missouri. For fifty years previous to the start of the study, the land had been in a corn/soybean rotation with annual moldboard tillage. The factors included two levels of tillage (tillage versus no-tillage) and two levels of cereal rye (*Secale cereale*) cover crop (cover crop versus no cover). This two year study found that cover crops increased ponded infiltration rates and improved infiltration parameters of saturated hydraulic conductivity (K_s) and sorptivity (S) in both tillage and no-tillage treatments. The no-till K_s was increased by about 54% over the till, and the cover crop S was increased by about 90% over the no cover treatment. The researchers also found there was no difference in antecedent soil moisture or bulk density between any of the treatments.

This result was contrasted by Blanco-Canqui et al. (2011). The 15-year study examined the use of cover crops in a no-till wheat-grain sorghum (*Sorghum bicolor*) rotation in central Kansas.

The researchers found that cover crops decreased surface bulk density, increased water stable aggregates, and increased infiltration rates. The researchers attributed these improvements in soil properties to soil organic carbon (SOC) accumulation. Notably, the early spring sampling found cover crops decreased the soil temperature by 4 degrees C at the 5cm depth, and increased the soil water content by 35%.

Haruna and Nkongolo (2015) examined the effects of tillage, rotation, and cover crops on soil physical properties in a three-year study based outside of Jefferson City, Missouri. The factors were tillage (no-till vs. till), cover crop (rye vs. no cover), and rotation (corn/soybean, soybean/corn, continuous soybean, and continuous corn). Sampling was conducted after the cash crop harvest, and after the cover crop termination. The results found that no-till management with the rye cover crop decreased bulk density by 3%, as compared to the no-till no-cover treatment. They found a cover crop x crop rotation interaction, which suggested that soil physical properties were more likely to improve in rotations than in monoculture. Soil gravimetric water content (GWC) was increased with rye in the continuous corn and soybean/corn rotation. A 16% increase in GWC in the soybean/corn rotation was observed in the cover crop treatment over the no-cover treatment. The researchers noted that the interactions between management and treatment are “complex in nature and their effects on soil properties may not be easily predictable” (Haruna, S. and Nkongolo, N. 2015).

Nouwakpo et al., (2018) in West Lafayette, Indiana on silt loam soils found that long-term no-till improved aggregate stability in the 0-15cm layer for all crop rotations of continuous corn, continuous soybean, corn then soybean, soybean then corn. In the 0-15cm layer, no-till samples had an average of 51.5% (-/+6.1) of water stable macroaggregates compared to conventional tillage with 29.9% (+/- 5.9%). In the 15-30cm layer, there was not a significant tillage effect on water stable macroaggregates.

Liu et al. (2005) found results that contrasted this tillage effect. The study in Vancouver, CA and found that soil aggregates under annual ryegrass and fall rye grass had greater mean weight diameter (MWD) than bare ground. After one year of winter cover cropping, they observed an increase in soil aggregate stability in soils with intensive cultivation.

Soil Chemical and Biological Properties

Yield is an important consideration for production agriculture, as well as any nutrient credits that may be gained or lost. Cover crops have been shown to increase the soil available nitrogen to subsequent crops, and specifically legume cover crops have been shown to contribute enough nitrogen to reduce the amount of N fertilizer required (Decker et al., 1994; McVay et al., 1989; Shipley et al., 1992). The availability of nitrogen from crop residue as fertilizer to subsequent crops is affected by several factors including precipitation, tillage, temperature, length of growing season, and soil texture (Decker et al., 1994; Vyn et al., 2000). Nitrogen must be mineralized from the cover crop residue prior to planting the following grain crop in order for the N to be utilized. In a 1984 study, Rice and Smith concluded that an increase in surface residue might result in decreased nitrogen availability due to lower N mineralization rates and greater N immobilization.

Janke et al., (2002) found contrasting results in a South Central Kansas study. They observed that in years of adequate rainfall, cover crops could provide all or part of the nitrogen required for the subsequent sorghum crop. In dry years however, the sorghum yields were less in the cover crop treatment. The authors suggested that long-term cover cropping may improve available water storage and thereby minimize yield reductions.

The additional organic matter that is provided by the cover crop residue also provides a benefit to aggregate stability. “Additions of organic matter increase aggregate stability, primarily after decomposition begins and microorganisms have produced chemical breakdown products or mycelia have formed.” (NRCS, 1996)

A 2006 study in Urbana, IL by Villamil et al., (2006) examined the effects of cropping sequence and cover crop species sequencing on physical and chemical soil properties. The study evaluated a no-till corn/soybean rotation with various sequencing of cereal rye and hairy vetch preceding each cash crop. The researchers found that soil organic matter was significantly increased in the profile when the cover crop species were alternated, as compared to only using cereal rye or no covers. The researchers hypothesized that while rye provided a large amount of biomass, it has a higher C/N ratio as compared to the hairy vetch, which prevented its transformation into SOM. The study also found that the corn-rye/soybean-rye and the corn-rye/soybean-vetch treatments had significantly lower soil phosphorus than the no-cover corn/soybean treatment. This reduction in soil phosphorus with the use of a legume cover crop was also reported by McVay et. al., (1989). Ackroyd et al., (2019) hypothesized that this effect is due to the legume crop maximizing cash crop growth, thereby increasing its uptake of soil phosphorus.

Soil microbial activity may also play a role in increasing aggregate stability. Nouwakpo et al., (2018) found soils with low C/N ratios had higher aggregate stability. The authors concluded that as a low C/N ratio is favored by soil microbes, this ratio could be “an indication that aggregate-forming agents in the soil might depend on soil microbial activity.”

Soil microbial biomass carbon (MBC) is commonly used to quantify the biomass of the fungi and bacteria present in the soil. Dissolved organic carbon (DOC) and MBC are two pools of labile soil carbon that are regarded as early indicators of changes in soil health due to their rapid responses in changes to carbon supply (Liu, et al, 2005). Blanco-Canqui and Lal (2009) found that soil organic carbon concentration in no-till was 19.2 g kg^{-1} and 11.4 g kg^{-1} in plow tillage, indicating no-till had higher SOC in the top 0-5cm. Below the 5cm depth, however, plow tillage had 1.5 times greater SOC concentrations than no-till.

Cover crops were seen to increase microbial biomass carbon over no cover crops, in a no-till sorghum study based in Argentina. (Fraiser, et al, 2016) This result was corroborated by Dinesh et al, (2009) who found more than a 50% increase in MBC from leguminous cover cropped plots to no cover crops.

Justification and Objectives

Common no-till cropping systems in eastern Kansas include winter wheat, corn, grain sorghum, and soybean. Due to the high temperatures and variable precipitation that occurs during critical periods of the growing season, the sustainability and profitability of incorporating cover crops into current no-till cropping systems in still debated. A common concern from producers is that a cover crop will negatively affect cash crop yields by reducing soil profile water. Yield effects aside, profitability of cover cropping is often questioned due to the additional expenses of cover crop seed, operation, and termination.

Producers often cite sustainability, improved soil health, and reduced erosion as reasons for cover cropping. Once the choice to cover crop has been made, the next choice the producer is faced with is which species to plant. The literature has shown a lack of consensus about the benefits of a single versus a multi-species cover crop. There is a significant difference in the cost between a single species and a mixed species cover crop, but the benefits of mixtures have not been thoroughly evaluated.

Demonstrations and research are needed to illustrate to producers of the region how crop rotations respond when including cover crops with respect to soil health, soil water dynamics, nutrient cycling, and cash crop yield.

The project objectives are as follows:

1. Determine the short-term effects of cover crops in long-term no-till systems in Eastern Kansas.
    - (i) Determine the impact of cover crops on soil health
    - (ii) Quantify biomass of established cover crops
    - (iii) Quantify yield impacts of cover crops on cash crop yield

Chapter 2 - Materials and Methods

Field experiments were conducted on farmer owned fields in 2014-2017 near the towns of Burlington, Valley Falls, and Hutchinson, Kansas (Figure 2-1). Cover crops were evaluated in no-tillage, farm-practice crop rotations. Sites were selected based on having >10 years no-tillage history, and cropping rotations that were typical practices for the site area. Plots were arranged in randomized complete block design with three replications. The plots were arranged within a larger field, and therefore all were planted to the same crop within a year within a site. The crop rotation at Hutchinson and Valley Falls was as follows starting in 2014; soybean, fall cover crop, corn, fall cover crop. The crop rotation at Burlington was as follows; soybean (2014), fall cover crop, corn (2015), fall cover crop, soybean (2016), fall cover crop, soybean (2017), fall cover crop. The treatments of one-species cover crop, multi-species cover crop, and no-cover crop were randomized in the fall of 2014 and remained fixed throughout the study. The Burlington site was the only location to receive an additional treatment of tillage. The tillage was post-harvest and pre-plant disk tillage.

The cover crop treatments were established in the fall after the cash crop harvest. The species were chosen by the farmers based on ease of obtaining seed, and low seed cost. The goal for the species in the mixes was to include at least three species in the mix and ideally would meet the criteria of including a grass, a brassica, and a legume. Chemical fallow was used for a control, no-cover, treatment.

Plot dimensions were unique at each location due to producer equipment widths, field shape, and soil type distribution. The study was strategically placed within a larger field with the aim of predominately aligning over one soil type. Plots were designed in strips for ease of working with field scale implements (figure 2-2). At the Burlington, Hutchinson, and Valley Falls, plots were 12.2m x 800m, 12.2m x 61m, and 24.4m x 45.7m, respectively.

Soil physical, chemical, and biological measurements were conducted 2-3 weeks after cash crop planting, and 2-3 weeks after cash crop harvest each year. Crop yield was taken from the entire plot at harvest each year, and cover crop biomass was measured prior to termination.

Description of Sites and Their Management

The site locations were comprised of three long-term no-till farms strategically located across eastern Kansas. Each site was selected to represent typical farmer practices for the area. The cropping rotations and sequences varied by location, as did the selected cover crop species (Table 2-1, 2-2, 2-3).

The Burlington location had two different CM treatments planted instead of a CS and a CM in 2014. This was a producer decision based on the availability of seed at the time. The two mixes that were planted were CM (22 kg ha^{-1} rye, 22 kg ha^{-1} winter pea, and 2 kg ha^{-1} rapeseed), and CM2 (6 kg ha^{-1} hairy vetch, 22 kg ha^{-1} winter pea, 2.2 kg ha^{-1} rapeseed, and 22 kg ha^{-1} triticale). After this first year, the producer planted the CS treatment of 104 kg ha^{-1} rye and the CM treatment of 35 kg ha^{-1} rye, 4 kg ha^{-1} radish, 14 kg ha^{-1} winter pea. (Table 2-2)

The Hutchinson location was able to plant the same CS treatment (70 kg ha^{-1} rye) and CM treatment [70 kg ha^{-1} rye, 4 kg ha^{-1} common vetch (*Vicia sativa*), and 4 kg ha^{-1} rapeseed] all years of the trial. (Table 2-2)

The Valley Falls location planted a CS treatment of radish at 12 kg ha^{-1}, and a CM treatment of 70 kg ha^{-1} wheat, and 3 kg ha^{-1} radish in 2014 and 2015. As the CS radish poorly established in 2014-15, and failed to establish in 2015-16, the decision was made to change the CS treatment to wheat at 70 kg ha^{-1} in the fall of 2016. (Table 2-2)

Plant Related Properties

Grain yield

Grain yield was collected using the cooperating producer's combine. The producer harvested the entire plot and then measured the grain weight with weigh wagons. Yield was calculated using the following equation:

$$\text{Yield (Mg ha}^{-1}\text{)} = [(GMg/A_1)*A_2]*2.471$$

Where:

GMg=weight of grain harvested in Mg

A_1=area harvested in ft^2

A_2=area of 1 acre in ft^2

2.471= number of acres in one ha

The total weight of grain was converted to Mg ha^{-1} and normalized to 15.5% for data analysis and reporting.

Cover Crop Seed Cost

Cover crop seed cost was calculated using prices from Hoorman (2016). The calculation was as follows:

Cost (\$ ha^{-1}) = component seed rate (lbs ac^{-1}) x component cost (\$ ac^{-1}) x 2.47 acre $hectare^{-1}$

Plant Biomass

Total biomass was measured in the spring before termination for cover crops. For the cover crop, biomass was collected from a 1 m^2 area in three points within each treatment. All plants were cut at the stem base, weighed, and dried for to constant moisture at 60°C. Dry weight was recorded.

Soil Physical Properties

Bulk Density

Bulk density was measured 2-3 weeks after planting, and again at harvest time each year. Samples were collected using 5 cm diameter 5-cm long increments sampled by pushing thin-walled metal tubing into the soil surface by hand.

Dry bulk density was determined using the core method (Blake and Hartge, 1986). Samples were collected at depths of 0-5, and 5-10 cm. Soil cores obtained were placed in paper bags and the wet weight was determined within 48 hours of collection. Samples were then oven dried at 105°C for a minimum of 48 hours. Once a constant mass was reached, bulk density was calculated as shown:

Pb = Wods/Vs

where

Pb = dry bulk density (g cm^{-3})

Wods = weight of oven-dry soil (g)

Vs = total volume of soil (cm^3)

Infiltration

Infiltration rate was measured using the Cornell Sprinkle Infiltrometer method (Ogden et al., 1997). Measurements were taken 2-3 weeks after planting, and again at harvest time each year. The bottom of the air entry tube was set 2.0 cm from the bottom of the graduated scale on the sprinkle cylinder; this was equivalent to a head of 2.0 cm. The infiltrometer ring was typically placed in between the corn rows avoiding the mid row fertilizer disk opening. We chose reasonably flat, level ground and avoided cracks, wheel tracks or artificial disturbances in the soil. Surface residue, such as leaves or corn stalks from the previous year, were gently removed. The ring was driven into the ground to a depth of 7.5 cm until the lower edge of the outflow hole was level with the ground surface. This was done using a hammer and a square piece of wood at least 30 cm length to buffer blows from the hammer.

The height of the water level in the cylinder of the Cornell sprinkle infiltrometer at the start of each experiment (Hs) was measured. A stopwatch was started at the time of removing the stopper on the air-entry tube. When runoff started to flow out of the tube, the time was recorded as time to runoff (Tro). The water volume (Vw) collected in the outflow beaker was measured periodically by taking the volume using a graduated cylinder and recording the time t(min) at which the measurement was taken. Care was taken to avoid spills during volume measurement. The initial volumes were weighed at intervals of 30 seconds for the first 3 to 9 minutes, then the interval was increased to 3 minutes. After 30 minutes of running the experiment, the interval for collecting volumes was further increased to 5 minutes until the experiment had run for 60 min. When an infiltration test was run and no runoff was observed, the experiment was repeated at a new location within the same plot with a much higher application rate achieved by raising the head to between 4 cm to 5 cm.

At the end of the experiment, the final water level (Hf) was recorded together with the time T (min) at which it was taken. The application rate R (cm min-1) was determined by:

$R = Hs - Hf/T$

The runoff rate, Ro (cm min^{-1}) is based on the relationship:

$Ro = \mathrm{Vw}(457.3 \times ti)$

where Vw is the volume (cm^3) collected in time ti (min) and 457.3 is the area (cm^2) of the ring. The infiltration rate It (cm min^{-1}) for a given time interval was determined as the difference between the application rate and runoff rate for that time interval,

$$It = R - Ro$$

where It (cm min^{-1}) is the infiltration rate, R (cm min^{-1}) is the application rate and Ro (cm min^{-1}) is the runoff rate. For the Cornell sprinkle infiltrometer, the final infiltration rate was calculated by taking the average of infiltration rate for the final 20 min of the experiment. The sorptivity in the Cornell sprinkle infiltrometer is given by:

$$S = (2Tro\ )0.5 \times \mathrm{R}$$

where S is sorptivity and Tro (min) is time to runoff (Ogden et al., 1997).

Water Stable Aggregates

Wet sieving procedures were used to determine water stable aggregate (WSA) distributions of the 0-5 cm soil depth. Samples were collected twice each year of the project, 2-3 weeks after cash crop planting and again post-harvest. Approximately 2 kg of soil were collected from the surface 5 cm depth from three random areas in each plot and placed into cloth bags and allowed to air dry. Once air dried, the soil was sieved to collect aggregates 4.75 mm in size to determine the percent WSA. A sub sample containing a minimum of 40 g of >4.75 mm aggregates was oven dried for a minimum of 48 hours at 105°C to determine gravimetric water content. Size distribution of WSA was determined using a 50 g subsample of air-dried soil and a wet sieving method by Kemper and Rosenau (1986). This was accomplished using a machine (Grainger, Inc., Lake Forest, IL) that moved four nests of sieves, each set in a separate compartment, through vertical displacement of 35 mm at 30 cycles min^{-1}. Each nest of sieves contained five sieves of 127 mm diameter and 40 mm depth with the following screen openings: 4.75; 2.00; 1.00; 0.50; and 0.25 mm (Newark Wire Cloth Company, Clifton, NJ).

The air-dry aggregates were placed on the top sieve (4.75 mm), saturated with water for 10 min, and then mechanically sieved in water for 10 min. The soil remaining on each sieve after wet sieving was washed into pre-weighed glass jars and oven dried for a minimum of 48 hours at 105°C to obtain soil mass. The oven-dry soil was soaked for a minimum of 24 hours in a 13.9 g L^{-1} sodium hexametaphosphate solution to facilitate the separation of coarse fragments from soil particles. The dispersed samples were then washed through the corresponding sieves in order to collect and account for coarse fragment content. Using the equation from Stone and Schlegel (2010), MWD was calculated as shown:

MWD = Σ (i=1, to 6) (wi/ma)xi

Where i represents the oven-dry mass of aggregates (w1 through w5) determined for each of the five sieve sizes (aggregates and fragments after sieving [mm] minus fragments on the same sieve after dispersion [mf]) and dry mass (w6) of material passing through the sieve with 0.25 mm openings during sieving (Kemper and Rosenau, 1986), xi represents the mean diameter of each of the six size fractions (size of smallest fraction [x6] was calculated as 0.25 mm/2) ma is the total dry mass of aggregates (sum of w1 through w6).

Total percent aggregation is the sum of the aggregates retained on the 4.75mm through 0.25mm sieves.

Dynamic Soil Water Measurements

Em-50 Soil moisture sensors made by Meter were placed at depths of 20, 35, 50, 90, and 120 cm below the soil surface. One array was placed per treatment at each location ie. one array was installed in no-till, one array in the single species cover, and one array in the multi species cover portion of the field. Precipitation was measured using a rain gauge. All devices were connected to a datalogger in order to capture data continuously. Data loggers were moved as needed to allow for field operations, and then immediately replaced.

Soil Chemical and Biological Properties

Soil Fertility

Soil samples were collected from the 0 to 15 cm depth [15 soil cores (2-cm diameter) were composited into one sample] in the spring (pre-cover crop termination), and in the fall (pre-cover crop planting).

Soil Fertility, Microbial Biomass Carbon, and Dissolved Organic Carbon

Samples were collected 2-3 weeks after planting, and again at harvest time each year. Samples were collected using a 1.59 cm diameter sterilized soil probe. Fifteen 0-15 cm soil cores were randomly collected within the plot area (samples are not to be taken within 10m of the end of each plot). Samples were transferred from the probe to a plastic zip lock bag using sterile procedures. The soil probe was cleaned between plots using alcohol, and one core in the proceeding plot was taken and discarded before collection began. Samples were transported from the field on cold packs and then transferred to a cold room where they were stored at 4 °C. Samples were processed within 28 days of collection. Samples were dried at 55°C to constant weight, and submitted to the Kansas State University Soil Testing Lab and tested for total soil carbon, N, P (Melich-3), K (exchangeable K), calcium, magnesium, and sodium concentrations in the soil at each of the farm-locations. Composite samples (used for fertility testing) were also used to test microbial biomass (chloroform fumigation extraction) analysis using a single 0.5M K_2SO_4 extraction method to estimate the size of the microbial community (Vance et al. 1987).

This method fumigates a soil sample to kill the existing soil microorganisms, resulting in a flush of C, and N that results from the destruction of the cells. This flush is then compared to an unfumigated sample to determine the difference and estimate the mass of the microbial community. Two 8 g samples of moist soil were weighed into 100 mL Erlenmeyer flasks. One of the samples was fumigated in a desiccator using chloroform vapors for 24 h. Both the fumigated and non-fumigated samples were then extracted by adding 40 mL 0.5 M K_2SO_4 solution to the flasks and shaking the samples for 30 min. The samples were filtered through Whatman 42 or equivalent filter paper (11 cm diameter) into 40 mL borosilicate vials. Samples were analyzed for non-purgable organic carbon (NPOC) on a Total Organic Carbon (TOC) analyzer (Shimadzu, Columbia, MD). An aliquot sample extractant was assayed using the potassium persulfate oxidation method (Cabrera and Beare, 1982) to determine dissolved total nitrogen (DTN) and NO_3^- and NH_4^+. Samples were added to the $K_2S_2O_8$ reagent and autoclaved for 30 min at 120°C. Samples were cooled and the digest was analyzed for nitrogen by colorimetric procedure using the Rapid Flow Analyzer, Model RFA-300 (Alpkem Corporation, Clackamas, OR). Dissolved organic nitrogen was calculated by the difference between DTN and NO_3^- and NH_4^+. In both cases, the MB-C and N are determined as the difference between fumigated and unfumigated samples, corrected for extraction blank samples.

Dissolved Organic Carbon (DOC) was determined from the unfumigated microbial biomass samples. Briefly, the 8 g of unfumigated samples were extracted with 40 mL of 0.5 M K_2SO_4.

DOC was measured by analyzing for non-purgable organic carbon (NPOC) with a Total Organic Carbon (TOC) analyzer (Shimadzu, Kyoto, Japan) (Jones and Willett, 2006).

Statistical Analysis

All data was analyzed by sampling date within location using one-way analysis of variance (ANOVA). It was a randomized complete block design with cover crop treatments as the factor and rep as a random variable. The Proc Mixed procedure of SAS 9.4 (SAS Institute, 2008) was used of separation of means and ANOVA. Results are considered significantly different at P=0.05. Treatment comparisons were only made within each location and year due to various management practices, soils, and climate (Table 2-3).

Figure 2-1. Map of Kansas with site locations

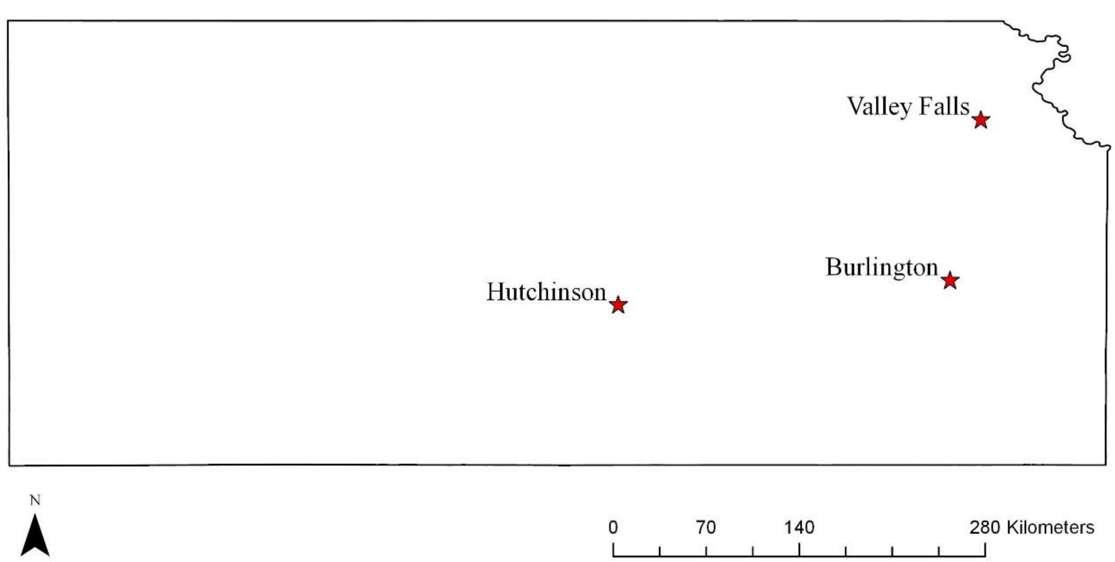
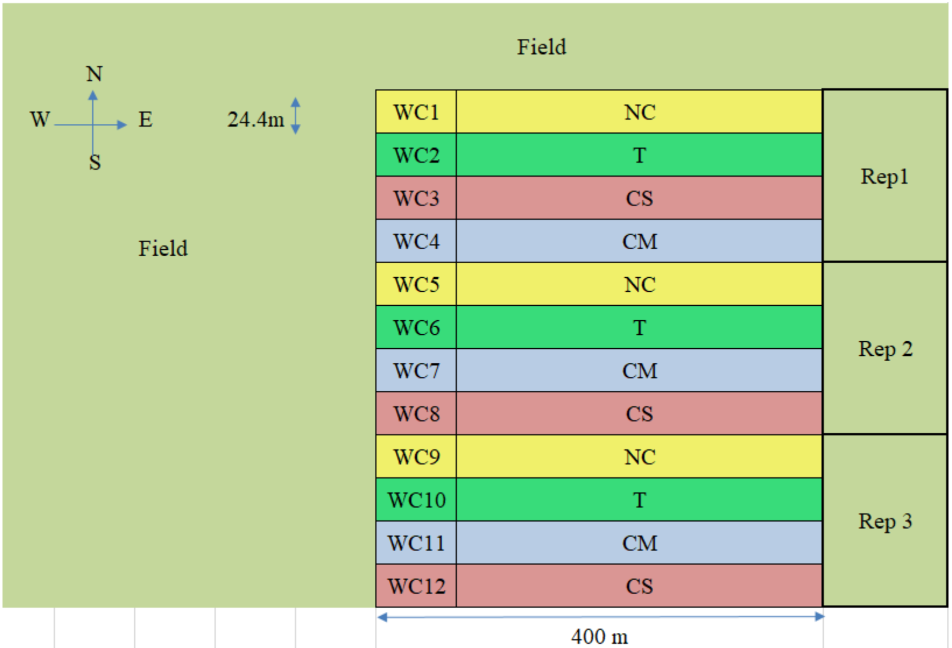


Figure 2-2. Burlington plot map



1-NC (no-cover), T (tillage), CS (single species cover crop), CM (mixed-species cover crop)

Table 2-1. Field operations by site and year

Site	Year	Cover Crop Dates Planting	Cover Crop Dates Termination	Cash Crop	Cash Crop Seeding Rate seeds ha^{-1}	Cash Crop Planting Date
Hutchinson	2014	10/31/14	NA		NA	
	2015	10/8/15	4/16/15	Corn	45,720	4/15/15
	2016	12/6/16	6/26/16	Soybean	304,800	6/28/16
	2017	NA	5/20/17	Corn	45,720	5/20/17
Valley Falls	2014	10/21/14	NA		NA	
	2015	10/2/2015	4/22/15	Corn	69,850	4/22/15
	2016	11/11/2016	5/19/16	Soybean	368,300	6/6/16
	2017	NA	4/12/17	Corn	69,850	4/12/17
Wolf Creek	2014	12/4/14	NA		NA	
	2015	10/10/15	4/7/15	Corn	57,150	4/6/15
	2016	11/7/16	5/6/16	Soybean	368,300	6/5/16
	2017	NA	5/20/17	Soybean	368,300	5/20/17

NA: Not applicable for the experiment.

Table 2-2. Cover crop seeding rates

Site	Trt[1]	Seeding Rates kg ha^{-1}						
		Rye	Wheat	Radish	Vetch	Pea	Rape	Triticale
Burlington	CS	104	-	-	-	-	-	-
	CM (2014)	22	-	-	-	22	2	-
	CM (2015-2017)	35	-	4	-	14	-	-
	CM2	-	-	-	6	22	2	22
Hutchin-son	CS	69	-	-	-	-	-	-
	CM	69	-	-	3	-	3	-
Valley Falls	CS (2014-2016)	-	-	12	-	-	-	-
	CS (2017)	-	69	-	-	-	-	-
	CM	-	69	3	-	-	-	-

1- Trt (treatment) CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2)

Table 2-3. Site Descriptions. Date from NRCS Soil Survey and NOAA regional climate centers

Site	Rotation[1]	Soil Type	1981-2010 Mean Annual Precipitation (cm)
Valley Falls	C-CC-SB-CC	Martin silty clay loam	96.5
Burlington	C-CC-SB-CC	Kenoma silt loam	101.6
Hutchinson	C-CC-SB-CC	Avans loam	76.2

1 - C (corn), CC (cover crop), SB (soybean)

Chapter 3 - Results

Hutchinson

Plant Parameters

There was not a significant difference in cash crop yield between treatments in 2015, 2016, or 2017 at any of the sites (Table 3-1). At Hutchinson, in 2015, the mean corn yields ranged from 4221 kg ha^{-1} in the NC treatments to 6815 kg ha^{-1} in the CS treatments. Notably, this site location had a coefficient of variance percentage (CV) of 29%, indicating a larger than expected experimental error.

The 2016 mean soybean yields ranged from 3696 kg ha^{-1} in the CS treatment, and 3899 kg ha^{-1} in the NC treatment. The 2017 mean corn yields ranged from 10091 kg ha^{-1} in the CM treatment to 12586 kg ha^{-1} in the CS treatment. The CV for both 2016 and 2017 were less than 20%. (Table 3-1)

There was not a significant difference in cover crop dry matter biomass between the cover crop treatments in 2015, 2016, 2017 (alpha = 0.05). The 2015 mean for CS was 2.06 Mg ha^{-1} and the mean for CM was 1.95 Mg ha^{-1}. The 2016 mean biomass was 2.14 Mg ha^{-1} for CS and 2.64 Mg ha^{-1} for the CM treatments. The 2017 mean biomass was 3.41 Mg ha^{-1} for CS and 2.85 Mg ha^{-1} for the CM treatments. (Table 3-2)

Soil Parameters

There was not a significant difference for the majority of soil physical, biological, or chemical properties between treatments in 2014, 2015, 2016, or 2017 (alpha = 0.05) (Table 3-3 – Table 3-6). In the spring of 2015 pH was significantly higher in CS (6.94) than in NC (6.39), but neither were significantly different from CM (6.52) (Table3-5). In the same sampling period total nitrogen percent was significantly higher in the CM (0.115%) than in the NC (0.100%), but neither were significantly different from CS (0.107%) (Table 3-7).

Valley Falls

Plant Parameters

There was not a significant difference in cash crop yield between treatments in 2014, 2015, or 2016 (alpha = 0.05) (Table 3-1). In 2015 mean corn yields ranged from 8061 kg ha^{-1}in the CM treatment to 10264 kg ha^{-1} in the CS treatment. The 2016 mean soybean yields ranged from 5041 kg ha^{-1}in the CM treatment to 5171 kg ha^{-1} in the CS treatment. The 2017 mean corn yields ranged from 6912 kg $ha^{-1}$to 8163 kg ha^{-1}in the CS and CM treatments, respectively. (Table 3-1)

The cover crop dry matter biomass was not significantly different at the alpha 0.05 level in 2016 or in 2017 (Table 3-2). There was insufficient data collected in 2015 as the CS treatment did not establish, and the CM was the only cover crop treatment that established. The 2016 mean biomass for CS was 1.16 Mg ha^{-1} and 0.43 Mg ha^{-1} for the CM treatments. The 2017 mean biomass for CS was 0.22 Mg ha^{-1} and 0.39 Mg ha^{-1} for the CM treatments.

Soil Parameters

There was not a significant difference between treatments in bulk density, total aggregation percent, infiltration, MWD, or WSA class between treatments in 2014, 2015, 2016, or 2017 (alpha = 0.05) (Table 3-7, Table 3-8). There also was no significant differences for any soil biological or chemical parameter in any site or year (Table 3-9 – Table 3-11).

Burlington

Plant Parameters

There was not a significant difference in cash crop yield between treatments within year in 2014, 2015, or 2016 (alpha = 0.05) (Table 3-1). The 2015 mean corn yields ranged from 5210 kg ha^{-1} to 6037 kg ha^{-1} in the NC and T treatments respectively. In 2016, the soybean yields ranged from 3091 kg ha^{-1} to 3392 kg ha^{-1} in the CS and T treatments respectively. The 2017 soybean yields ranged from 1480 kg ha^{-1} (CS, CM, T) to 1547 kg ha^{-1} (NC).

The cover crop dry matter biomass was not significantly different between cover crop treatments in 2015, 2016, or in 2017 (alpha = 0.05) (Table 3-2). In 2015 the mean biomass for CM was 0.37 Mg ha^{-1} and 0.50 Mg ha^{-1} for the CM2 treatments. The 2016 mean biomass for CS was 2.13 Mg ha^{-1} and 1.45 Mg ha^{-1} for the CM treatments. The 2017 mean biomass for CS was 1.77 Mg ha^{-1} and 1.25 Mg ha^{-1} for the CM treatments. (Table 3-2)

Soil Parameters

Very few soil parameters showed significant differences. There was not a significant difference in bulk density or total aggregation between treatments in 2014, 2015, 2016, or 2017 (alpha = 0.05) (Table 3-12, Table 3-13). Infiltration was significantly different between treatments in the fall 2016 sampling where NC had a significantly higher rate (3.0 cm hr^{-1}) than the CS (0.9 cm hr^{-1}) and CM (1.1 cm hr^{-1}) treatments (Table 3-13).

Soil aggregate data did not show any instances of significance that held across time (Table 3-14 – 3-15). In the spring 2015 the T treatment had significantly more 1.00 mm WSA (9.85%) than the NC (6.39%), CS (5.92%), and CM (4.73%) treatments. In the fall 2015 sampling the T treatment had significantly more 0.50 mm WSA than the other treatments, and also had significantly more 0.25 mm WSA than the CS and CM treatments. (Table 3-14)

In the spring of 2016, a significantly smaller mean weight diameter for T (1.93mm) as opposed to the CS (2.56mm) and CM (2.53mm) treatments was observed (Table 3-13). In the same sampling, T and NC treatments had significantly less 4.75mm and 2.00 mm WSA than the CS and CM treatments (Table 3-15).

Soil biological parameters resulted in one instance of significance (Table 3-17). The DOC was significantly different among the treatments in the fall 2017 sampling where CM was significantly higher than all the other treatments with a mean value of 39.2 ugC g^{-1}. The CS treatment was not significantly different from the NC or the T, but the NC and T were significantly different from each other.

Soil chemical parameters were generally not affected by treatments (Table 3-17 – Table 3-21). In the spring of 2016 pH was significantly higher in the CM treatment than in the CS and NC treatments, but it was not significantly different from the T treatment, and in the fall of 2016 pH was significantly higher (6.30) in CM than all other treatments (Table 3-17).

The dynamic soil measurement for Burlington 2015 in the months of April (cover crop termination and cash crop planting) and July were included for demonstrative purposes in the differences in volumetric water content at various depths by treatment (Figure 3-1, Figure 3-2). Visually it appears that the cover crops and no-till treatments had approximately the same soil moisture content as the tillage plots in the month of April. In the month of July, the NC plot provided the most soil moisture at the 15.2 cm depth as compared to the other treatments. Overall, the CM treatment appeared to generate the most consistent soil moisture, around 0.50 m^3/m^3 across time and depths. (Figure 3-1, Figure 3-2)

Table 3-1. Cash crop mean yields by site and year

Site	Year	Crop	NC	CS	CM	CM 2	T	P[2]	CV[3]
			Treatment[1] Mean Yield kg ha^{-1}						
Hutchinson	2015	Corn	4221	6815	6103			0.19	29
	2016	Soybean	3899	3696	3831			0.80	11
	2017	Corn	12261	12586	10091			0.22	16
Valley Falls	2015	Corn	8596	10264	8061			0.18	16
	2016	Soybean	5160	5171	5041			0.91	7
	2017	Corn	8084	6912	8163			0.45	17
Burlington	2015	Corn	5210	-	5289	5410	6037	0.10	6
	2016	Soybean	3147	3091	3117	-	3392	0.37	4
	2017	Soybean	1547	1480	1480	-	1480	0.18	2

1- NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2), T (Till)
2-P = mean separations calculated on p=0.05
3-CV= coefficient of variance percent

Table 3-2. Cover crop mean dry matter biomass by site and year

Site	Season	Date	Trt[1]	Dry Mass (Mg ha^{-1}) Mean	CV[2]	P[3]
Hutchinson	Spring 2015	4/18/15	CS	2.06	17	0.63
		4/18/15	CM	1.95		
	Spring 2016	5/12/16	CS	2.14	39	0.20
		5/12/16	CM	2.64		
	Spring 2017	5/16/17	CS	3.41	34	0.59
		5/16/17	CM	2.85		
Valley Falls	Spring 2015	4/22/15	CM	0.42	18	nd
		4/25/15	CS	nd		
	Spring 2016	5/3/16	CM	1.16a	66	0.09
		5/3/16	CS	0.43b		
	Spring 2017	4/11/17	CM	0.22	54	0.33
		4/12/17	CS	0.39		
Burlington	Spring 2015	4/16/15	CM	0.37	40	0.58
		4/16/15	CM2	0.50		
	Spring 2016	5/5/16	CS	2.13	34	0.20
		5/5/16	CM	1.45		
	Spring 2017	5/5/16	CS	1.77	29	0.18
		5/5/16	CM	1.25		

nd: no data measured at this sampling date
1- NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2), T (Till)
2- CV (coefficient of variance percent)
3- P = mean separations calculated on p=0.05, one-way analysis of variance within site year

Table 3-3. Cover crop seed costs

Site	Treatment[1]	Seed Cost \$ ha^{-1}
Burlington	CS	53.35
	CM (2014)	74.52
	CM (2015-2017)	84.97
	CM2	85.22
Hutchinson	CS	35.57
	CM	54.09
Valley Falls	CS (2014-2016)	88.92
	CS (2017)	14.82
	CM	37.05

1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2)

Table 3-4. Hutchinson physical soil property means

Date	Trt[1]	Mean Weight Diameter (mm)			Total Aggregation (%)			Bulk Density 0-5cm g cm^{-3}			Bulk Density 5-10cm			Infiltration cm hr^{-1}		
		Mean	CV[2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P	Mean	CV	P
Fall 2014	CM	2.81	20	0.24	69.52	9	0.14	nd	nd	nd	nd	nd	nd	nd	nd	nd
	CS	3.78			80.48			nd			nd			nd		
	NC	3.40			73.29			nd			nd			nd		
Spring 2015	CM	3.82	25	0.57	78.80	15	0.29	1.11	13	0.22	1.57	3	0.10	1.0	38	0.87
	CS	3.10			64.75			1.16			1.64			1.0		
	NC	3.84			76.94			1.25			1.62			1.2		
Fall 2015	CM	4.40	16	0.47	86.81	6	0.68	1.45	15	0.29	1.57	7	0.57	11.2	105	0.19
	CS	5.09			90.68			1.40			1.48			3.5		
	NC	4.39			87.96			1.20			1.51			3.0		
Spring 2016	CM	2.60	16	0.06	45.03	58	0.05	1.22	10	0.96	1.52	3	0.63	2.2	72	0.63
	CS	2.86			71.91			1.24			1.51			1.3		
	NC	2.04			39.85			1.25			1.55			2.5		
Fall 2016	CM	4.39	22	0.46	83.23	10	0.77	1.01	21	0.35	1.50	10	0.83	1.9	36	0.74
	CS	3.63			79.92			1.23			1.44			2.3		
	NC	4.11			84.29			0.99			1.53			2.5		
Spring 2017	CM	nd	nd	nd	nd	nd	nd	1.43	5	0.62	1.60	5	0.81	1.3	54	0.55
	CS	nd			nd			1.36			1.57			1.3		
	NC	nd			nd			1.39			1.56			0.8		
Fall 2017	CM	3.53	27	0.94	74.94	9	0.99	1.38	9	0.38	1.59	3	0.37	3.0	34	0.89
	CS	3.31			74.83			1.28			1.56			2.7		
	NC	3.36			73.96			1.24			1.59			3.3		

1- Trt (Treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-5. Hutchinson water stable aggregate mean values

Date	Trt[1]	4.75 WSA			2.00 WSA			1.00 WSA (g sand-free 100 g^{-1} soil)			0.50 WSA			0.25 WSA		
		Mean	CV [2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P	Mean	CV	P
Fall 2014	CM	32.30	28	0.24	12.60	20	0.15	4.35	24	0.42	5.06	20	0.63	15.20	24	0.52
	CS	49.31			9.05			3.58			5.65			12.89		
	NC	42.04			10.82			3.43			4.74			12.27		
Spring 2015	CM	51.31	32	0.73	12.05	48	0.66	3.64	43	0.72	5.22	36	0.82	6.58	33	0.69
	CS	41.70			8.32			3.65			4.25			6.83		
	NC	51.75			12.12			2.71			5.06			5.29		
Fall 2015	CM	61.71	21	0.47	8.57	50	0.46	7.36	134	0.50	3.54	60	0.33	5.64	50	0.48
	CS	73.82			9.56			1.59			1.98			3.74		
	NC	59.31			14.31			3.38			4.32			6.65		
Spring 2016	CM	28.95	21	0.11	16.01	11	0.34	5.04	13	0.54	7.39	12	0.52	10.16	9	0.12
	CS	33.16			15.79			5.91			7.49			9.56		
	NC	21.08			13.39			5.70			8.52			11.10		
Fall 2016	CM	61.94	29	0.34	7.07	42	0.17	2.17	51	0.28	3.52	53	0.24	8.53	60	0.73
	CS	45.66			11.42			3.85			6.84			12.16		
	NC	53.13			14.46			4.69			3.95			8.05		
Spring 2017	CM	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	CS	nd			nd			nd			nd			nd		
	NC	nd			nd			nd			nd			nd		
Fall 2017	CM	46.76	38	0.97	11.70	28	0.37	3.97	58	0.89	5.60	51	0.97	6.91	56	0.78
	CS	41.21			14.83			4.73			6.44			7.62		
	NC	41.44			16.71			4.06			5.60			6.15		

1- Trt (Treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-6. Hutchinson soil biological and chemical mean values

			Soil Water Content (g g^{-1})			Microbial Biomass Carbon (ug C g^{-1} soil)			Dissolved Organic Carbon (ug C g^{-1} soil)			pH		
Year	**Season**	**Trt[1]**	**Mean**	**CV[2]**	**P[3]**	**Mean**	**CV**	**P**	**Mean**	**CV**	**P**	**Mean**	**CV**	**P**
2014	Fall	NC	nd	nd	nd	nd	nd	nd	nd	nd	nd	6.76	6	0.85
		CS	nd			nd			nd			6.57		
		CM	nd			nd			nd			6.59		
2015	Spring	NC	0.14	9	0.29	150.44	31	0.68	55.41	52	0.34	6.39b	5	0.049
		CS	0.15			145.88			35.04			6.94a		
		CM	0.15			157.96			39.84			6.52ab		
	Fall	NC	0.10	13	0.48	60.92	50	0.60	24.33	22	0.55	6.16	5	0.13
		CS	0.10			95.18			22.67			6.62		
		CM	0.11			70.66			19.64			6.54		
2016	Spring	NC	0.13	11	0.16	9.15	44	0.26	17.22	21	0.86	6.35	4	0.64
		CS	0.15			16.37			17.28			6.55		
		CM	0.14			11.62			18.93			6.52		
	Fall	NC	0.13ab	10	0.095	33.69	70	0.16	19.40	17	0.58	6.00	6	0.40
		CS	0.13b			35.35			21.92			6.07		
		CM	0.14b			85.38			21.63			6.40		
2017	Spring	NC	0.10	20	0.14	nd	nd	nd	52.40	15	0.72	6.07	6	0.79
		CS	0.12			nd			48.21			6.07		
		CM	0.13			nd			51.74			5.87		
	Fall	NC	0.13	9	0.16	134.53	20	0.21	41.51	7	0.24	5.70	5	0.71
		CS	0.13			180.58			40.15			5.83		
		CM	0.14			177.30			43.90			5.67		

1- Trt (Treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-7. Hutchinson soil chemical parameter means part 1

Yr	Seas.	Trt[1]	Phosphorus (ppm) Mean	CV[2]	P[3]	Potassium (ppm) Mean	CV	P	Calcium (ppm) Mean	CV	P	Magnesium (ppm) Mean	CV	P	Sodium (ppm) Mean	CV	P
2014	Fall	NC	20.17	60	0.55	204.9	26	0.48	1736	17	0.79	160.2	9	0.66	4.71	40	0.66
		CS	27.03			249.9			1774			149.5			6.49		
		CM	18.03			213.6			1602			152.0			6.30		
2015	Spring	NC	19.80	56	0.75	189.1	20	0.63	1357	20	0.87	133.7	9	0.46	15.42	25	0.69
		CS	23.63			212.4			1386			120.8			15.10		
		CM	21.70			200.7			1295			125.9			12.66		
	Fall	NC	19.40	49	0.38	187.0	25	0.36	1537	16	0.58	162.6	11	0.69	4.94	37	0.97
		CS	22.27			228.2			1713			149.8			4.52		
		CM	14.33			191.6			1525			158.5			4.75		
2016	Spring	NC	16.25	62	0.61	170.5	27	0.50	1429	14	0.87	151.4	12	0.54	5.89	33	0.29
		CS	19.37			207.1			1487			147.3			6.17		
		CM	12.77			175.4			1392			134.6			3.96		
	Fall	NC	nd	nd	nd	176.7	26	0.69	1309	17	0.91	137.7	7	0.20	7.20	22	0.75
		CS	nd			198.6			1377			124.1			7.53		
		CM	nd			190.8			1372			126.5			8.37		
2017	Spring	NC	nd	nd	nd	173.9	18	0.22	1492	13	0.64	144.4	7	0.26	8.13	51	0.40
		CS	nd			210.5			1537			135.3			5.33		
		CM	nd			186.8			1379			148.8			4.57		
	Fall	NC	22.00	45	0.99	221.0	42	0.51	1608	18	0.87	162.3	12	0.63	3.67	34	0.14
		CS	22.67			273.3			1639			146.3			6.67		
		CM	20.00			203.7			1528			151.3			5.33		

1- Trt (Treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-7. Hutchinson soil chemical parameter means part 2

			NO_3 (ppm)			NH_4 (ppm)			Total N %			Total C %			Electrical Conductivity $S\ m^{-1}$		
Yr.	**Seas.**	**Trt[1]**	**Mean**	**CV[2]**	**P[3]**	**Mean**	**CV**	**P**	**Mean**	**CV**	**P**	**Mean**	**CV**	**P**	**Mean**	**CV**	**P**
2014	Fall	NC	6.73			5.17			0.08			0.99			0.23		
		CS	8.99	27	0.22	5.51	9	0.58	0.08	10	0.71	1.06	10	0.66	0.24	32	0.93
		CM	6.28			5.17			0.08			0.98			0.25		
2015	Spring	NC	19.61			7.74			0.100b			0.99			nd		
		CS	10.68	80	0.46	8.69	50	0.10	0.107ab	7	0.03	1.04	13	0.19	nd	nd	nd
		CM	27.01			16.51			0.115a			1.13			nd		
	Fall	NC	24.89a			3.60			0.08			0.99			nd		
		CS	7.81b	63	0.08	3.68	27	0.20	0.09	13	0.86	1.07	10	0.66	nd	nd	nd
		CM	13.43ab			4.54			0.09			1.00			nd		
2016	Spring	NC	13.48			3.52b			0.06			0.95			nd		
		CS	14.39	24	0.94	4.15b	10	0.06	0.06	25	0.83	1.07	10	0.38	nd	nd	nd
		CM	14.45			4.24b			0.06			1.01			nd		
	Fall	NC	1.40			30.10			nd			nd			nd		
		CS	1.60	46	0.94	33.73	18	0.51	nd	nd	nd	nd	nd	nd	nd	nd	nd
		CM	1.60			27.87			nd			nd			nd		
2017	Spring	NC	1.40			48.53			nd			nd			nd		
		CS	1.10	28	0.61	41.07	27	0.59	nd	nd	nd	nd	nd	nd	nd	nd	nd
		CM	1.37			39.87			nd			nd			nd		
	Fall	NC	35.20			7.37			0.13			1.04			nd		
		CS	32.57	30	0.87	6.97	15	0.68	0.14	8	0.20	1.12	8	0.62	nd	nd	nd
		CM	33.83			7.73			0.13			1.06			nd		

1- Trt (Treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year 3- CV= coefficient of variance percent

Table 3-8. Valley Falls soil physical parameter means

Date	Trt[1]	Mean Weight Diameter (mm)			Total Aggregation (%)			Bulk Density 0-5cm g cm^{-3}			Bulk Density 5-10cm g cm^{-3}			Infiltration cm hr^{-1}		
		Mean	CV[2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P	Mean	CV	P
Fall 2014	CM	2.21	23	0.72	77.52	7	0.74	nd	nd	nd	nd	nd	nd	nd	nd	nd
	CS	2.42			79.48			nd			nd			nd		
	NC	2.42			80.20			nd			nd			nd		
Spring 2015	CM	1.94	31	0.49	72.23	13	0.54	0.89	27	0.36	1.35	8	0.56	1.4	63	0.27
	CS	1.53			64.64			0.66			1.38			2.0		
	NC	1.43			64.66			0.90			1.45			1.0		
Fall 2015	CM	4.37	10	0.58	92.78	2	0.70	1.28	12	0.17	1.45	4	0.73	7.1	77	0.38
	CS	4.70			93.69			1.30			1.42			3.4		
	NC	4.28			91.97			1.10			1.43			9.8		
Spring 2016	CM	2.82	18	0.57	83.23	4	0.60	1.33	15	0.66	1.40	5	0.58	4.6	43	0.30
	CS	2.72			81.37			1.20			1.37			3.3		
	NC	2.38			84.70			1.19			1.33			5.9		
Fall 2016	CM	2.80	17	0.50	77.09	12	0.82	0.59	8	0.47	1.36	6	0.80	1.4	40	0.56
	CS	2.39			73.17			0.56			1.35			1.5		
	NC	2.82			78.08			0.62			1.40			2.0		
Spring 2017	CM	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	2.1	36	nd
	CS	nd			nd			nd			nd			nd		
	NC	nd			nd			nd			nd			1.2		
Fall 2017	CM	1.67	24	0.93	76.52	8	0.35	0.75	10	0.67	1.30	8	0.96	3.3	8	0.82
	CS	1.78			76.24			0.72			1.33			3.4		
	NC	1.65			69.71			0.77			1.34			3.4		

1- Trt (Treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-9. Valley Falls water stable aggregate means

Date	Trt[1]	4.75 WSA			2.00 WSA			1.00 WSA			0.50 WSA			0.25 WSA		
		g sand-free 100 g^{-1} soil														
		Mean	CV[2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P	Mean	CV	P
Fall 2014	CM	19.95	35	0.65	13.46	9	0.87	11.18	14	0.97	15.21	10	0.83	17.72	16	0.95
	CS	23.66			13.06			11.01			14.60			17.15		
	NC	23.57			12.94			10.82			15.13			17.73		
Spring 2015	CM	19.27	54	0.51	10.25	14	0.86	9.99	27	0.94	15.97	25	0.91	16.74	11	0.70
	CS	13.20			9.64			9.13			14.59			18.08		
	NC	11.23			10.13			9.41			16.04			17.85		
Fall 2015	CM	58.14	16	0.51	13.77	30	0.19	7.16	22	0.34	7.96	22	0.73	5.75	25	0.89
	CS	66.37			8.69			5.79			7.49			5.35		
	NC	57.42			12.12			7.70			8.76			5.97		
Spring 2016	CM	30.94	34	0.52	14.47	19	0.63	12.62	22	0.72	13.82	29	0.49	11.38	34	0.26
	CS	28.29			15.75			14.72			14.34			8.28		
	NC	21.73			16.81			14.53			18.37			13.25		
Fall 2016	CM	31.18	23	0.37	15.40	17	0.25	9.97	18	0.82	10.00	16	0.53	10.53	25	0.63
	CS	24.84			14.53			9.99			11.70			12.11		
	NC	33.18			12.10			9.12			10.58			13.11		
Spring 2017	CM	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	CS	nd			nd			nd			nd			nd		
	NC	nd			nd			nd			nd			nd		
Fall 2017	CM	8.50	59	0.69	19.91	27	0.16	16.38	23	0.56	17.56	21	0.99	14.17	25	0.70
	CS	12.36			17.17			13.23			17.03			16.45		
	NC	12.70			12.65			13.31			17.13			13.92		

1- Trt (Treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-10. Valley Falls soil biological and chemical means

			Soil Water Content ($g\ g^{-1}$)			Microbial Biomass Carbon (ug C g^{-1} soil)			Dissolved Organic Carbon (ug C g^{-1} soil)			pH		
Year	**Season**	**Trt[1]**	**Mean**	**CV[2]**	**P[3]**	**Mean**	**CV**	**P**	**Mean**	**CV**	**P**	**Mean**	**CV**	**P**
2014	Fall	NC	nd	nd	nd	nd	nd	nd	nd	nd	nd	6.8	6	0.94
		CS	nd			nd			nd			6.8		
		CM	nd			nd			nd			6.9		
2015	Spring	NC	0.20	8	0.55	288.7	15	0.40	25.7	7	0.66	6.8	6	0.91
		CS	0.19			276.3			24.2			6.9		
		CM	0.20			249.3			25.1			6.9		
	Fall	NC	0.19	5	0.61	168.7	76	0.77	36.3	5	0.96	6.6	6	0.93
		CS	0.20			224.3			35.9			6.8		
		CM	0.19			139.3			36.0			6.7		
2016	Spring	NC	0.16	9	0.55	15.6	39	0.67	36.6	10	0.85	6.7	6	0.94
		CS	0.17			19.6			38.5			6.6		
		CM	0.16			17.5			37.8			6.6		
	Fall	NC	0.21	8	0.26	50.9	76	0.65	37.9	15	0.47	6.6	5	0.83
		CS	0.19			57.5			41.2			6.8		
		CM	0.19			31.9			34.7			6.6		
2017	Spring	NC	0.24	8	0.82	19.8	101	0.12	37.0	19	0.70	6.8	4	0.56
		CS	0.25			113.4			33.8			7.0		
		CM	0.24			40.4			33.4			6.7		
	Fall	NC	0.20b	5	0.09	319.7	10	0.19	25.1	26	0.67	6.7	5	0.91
		CS	0.21ab			354.0			22.4			6.7		
		CM	0.22a			372.3			27.8			6.6		

1- Trt (Treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-11. Valley Falls soil chemical means part 1

Yr	Seas	Trt[1]	Phosphorus (ppm) Mean	CV[2]	P[3]	Potassium (ppm) Mean	CV	P	Calcium (ppm) Mean	CV	P	Magnesium (ppm) Mean	CV	P	Sodium (ppm) Mean	CV	P
2014	Fall	NC	13.4	33	0.41	190.2	7	0.90	3556	19	0.38	412.2	22	0.68	11.3	28	0.97
		CS	19.0			195.0			3351			395.1			11.4		
		CM	15.3			191.9			2955			350.4			10.8		
2015	Spring	NC	16.8	26	0.93	149.2	10	0.89	1757	4	0.89	245.1	11	0.99	10.4	12	0.32
		CS	18.4			150.8			1731			243.3			11.9		
		CM	17.7			155.5			1754			243.1			10.7		
	Fall	NC	13.6	28	0.27	159.7	10	0.39	3057	5	0.72	352.2	9	0.86	11.9	17	0.74
		CS	17.6			170.4			3102			355.5			13.4		
		CM	17.8			175.0			3155			368.0			12.8		
2016	Spring	NC	10.9	36	0.72	137.8	8	0.76	2765	6	0.85	334.7	10	0.73	9.3	22	0.86
		CS	10.6			135.6			2683			324.8			9.4		
		CM	12.9			142.9			2711			348.6			10.3		
	Fall	NC	nd	nd	nd	134.4	12	0.65	2650	9	0.56	303.9	13	0.71	5.9	55	0.27
		CS	nd			147.5			2861			336.3			10.9		
		CM	nd			145.6			2711			315.6			9.0		
2017	Spring	NC	nd	nd	nd	143.0	10	0.60	2834	5	0.68	310.8	10	0.79	9.9	21	0.46
		CS	nd			154.2			2947			324.7			12.6		
		CM	nd			150.7			2847			330.5			11.3		
	Fall	NC	12.0	48	0.64	234.0	10	0.37	3445	4	0.84	383.7	12	0.76	9.0	38	0.96
		CS	15.3			250.3			3515			410.3			10.0		
		CM	16.0			267.0			3448			413.0			9.7		

1- Trt (Treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-12. Valley Falls soil chemical means part 2

			NO_3-N (ppm)			NH_4 (ppm)			Total N %			Total C %			Electrical Conductivity S m^{-1}		
Yr	Seas	Trt[1]	Mean	CV[2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P	Mean	CV	P
		NC	10.1			10.0			0.16			2.08			0.39		
2014	Fall	CS	9.0	35	0.94	9.8	10	0.66	0.15	8	0.31	1.99	5	0.21	0.35	20	0.79
		CM	9.8			9.2			0.14			1.93			0.38		
		NC	9.0			10.9			0.17			2.03			nd		
	Spring	CS	8.1	63	0.77	11.3	15	0.89	0.17	5	0.89	2.02	6	0.79	nd	nd	nd
		CM	10.5			11.5			0.17			2.05			nd		
2015		NC	13.3			7.7			0.18			2.10a			nd		
	Fall	CS	12.7	21	0.96	7.8	14	0.98	0.18	4	0.33	2.02b	2	0.06	nd	nd	nd
		CM	13.3			7.9			0.18			2.02b			nd		
		NC	18.4a			5.7			0.17			2.00			nd		
	Spring	CS	15.6ab	20	0.07	5.3	10	0.77	0.17	6	0.78	1.97	5	0.80	nd	nd	nd
		CM	12.7b			5.4			0.18			1.96			nd		
2016		NC	4.1			17.6			nd			nd			nd		
	Fall	CS	2.6	29	0.18	16.6	12	0.44	nd	nd	nd	nd	nd	nd	nd	nd	nd
		CM	3.9			19.1			nd			nd			nd		
		NC	5.1			24.0			nd			nd			nd		
	Spring	CS	5.3	22	0.94	23.0	21	0.86	nd	nd	nd	nd	nd	nd	nd	nd	nd
		CM	4.9			21.6			nd			nd			nd		
2017		NC	15.0			8.5			0.19			2.08			nd		
	Fall	CS	15.6	14	0.26	8.9	5	0.71	0.20	4	0.40	2.03	5	0.43	nd	nd	nd
		CM	18.0			8.7			0.20			2.13			nd		

1- Trt (Treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-13. Burlington soil physical parameter means 2014-2015

Date	Trt[1]	Mean Weight Diameter (mm)			Total Aggregation (%)			Bulk Density 0-5cm g cm^{-3}			Bulk Density 5-10cm g cm^{-3}			Infiltration cm hr^{-1}		
		Mean	CV[2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P	Mean	CV	P
Fall 2014	CM	1.81	23	0.12	59.42	22	0.56	nd	nd	nd	nd	nd	nd	nd	nd	nd
	CM2	1.60			58.10			nd			nd			nd		
	NC	1.84			60.47			nd			nd			nd		
	T	1.90			66.18			nd			nd			nd		
Spring 2015	CM	2.32	19	0.21	65.73	10	0.86	0.92	18	0.36	1.22	13	0.56	nd	nd	nd
	CS	2.41			66.54			1.20			1.29			nd		
	NC	2.29			70.51			0.90			1.31			nd		
	T	1.75			68.38			1.06			1.36			nd		
Fall 2015	CM	2.53	30	0.28	69.94	9	0.97	1.01	9	0.18	1.30	7	0.51	1.2	61	0.54
	CS	3.06			69.74			1.11			1.30			0.8		
	NC	2.66			67.91			1.13			1.22			1.7		
	T	1.93			67.74			1.00			1.21			1.1		

1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2) T (Tillage)
nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year
3- CV= coefficient of variance percent

Table 3-14. Burlington soil physical parameter means 2016-2017

Date	Trt[1]	Mean Weight Diameter (mm)			Total Aggregation (%)			Bulk Density 0-5cm g cm^{-3}			Bulk Density 5-10cm g cm^{-3}			Infiltration cm hr^{-1}		
		Mean	CV[2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P	Mean	CV	P
Spring 2016	CM	2.53a	43	0.03	79.48	16	0.15	nd	nd	nd	nd	nd	nd	2.3	45	0.57
	CS	2.56a			71.08			nd			nd			2.5		
	NC	1.87ab			65.77			nd			nd			2.3		
	T	1.20b			60.02			nd			nd			3.0		
Fall 2016	CM	2.87	22	0.05	72.55	16	0.11	nd	nd	nd	nd	nd	nd	1.1b	65	0.01
	CS	2.77			68.65			nd			nd			0.9b		
	NC	3.10			73.70			nd			nd			3.0a		
	T	1.93			61.16			nd			nd			2.2ab		
Spring 2017	CM	nd	nd	nd	nd	nd	nd	0.73	16	0.37	1.31	7	0.83	1.6	47	0.21
	CS	nd			nd			0.82			1.31			1.2		
	NC	nd			nd			0.89			1.31			1.0		
	T	nd			nd			0.72			1.25			1.9		
Fall 2017	CM	nd	nd	nd	nd	nd	nd	0.99	13	0.63	1.37	3	0.55	2.3	65	0.60
	CS	nd			nd			0.94			1.40			2.3		
	NC	nd			nd			1.04			1.35			1.5		
	T	nd			nd			1.05			1.35			2.6		

1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2) T (Tillage)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-15. Burlington water stable aggregate means 2014-2015

Date	Trt[1]	4.75 WSA			2.00 WSA			1.00 WSA			0.50 WSA			0.25 WSA		
		g sand-free 100 g^{-1} soil														
		Mean	CV[2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P	Mean	CV	P
Fall 2014	CM	18.10	29	0.60	11.16	17	0.42	6.41	58	0.29	8.34	50	0.52	15.41	25	0.76
	CM2	14.07			12.14			6.83			9.16			15.91		
	NC	17.29			13.13			8.66			8.82			12.57		
	T	17.69			13.27			9.77			10.54			14.91		
Spring 2015	CM	26.88ab	28	0.11	10.64	14	0.74	4.73b	37	0.02	7.86b	40	0.08	15.62ab	17	0.07
	CS	28.36a			9.89			5.92b			9.22b			13.15b		
	NC	26.08ab			10.02			6.39b			11.79b			16.23ab		
	T	16.49b			9.62			9.85a			14.18a			18.24a		
Fall 2015	CM	27.87	44	0.27	15.36	19	0.15	6.03	30	0.11	8.19b	46	0.01	12.48b	35	0.03
	CS	37.77			14.43			4.25			4.93b			8.36b		
	NC	31.66			13.09			4.73			5.79b			12.64ab		
	T	19.73			10.91			7.10			12.45a			17.55a		

1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2) T (Tillage)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-16. Burlington water stable aggregate means 2016-2017

Date	Trt[1]	4.75 WSA			2.00 WSA			1.00 WSA			0.50 WSA			0.25 WSA		
		g sand-free 100 g^{-1} soil														
		Mean	CV[2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P	Mean	CV	P
Spring 2016	CM	27.56a	67	0.02	12.26a	27	0.01	11.08	67	0.63	15.48	60	0.34	13.09	20	0.25
	CS	30.27a			10.39a			7.09			12.22			11.10		
	NC	19.33b			8.48b			9.73			15.10			13.13		
	T	8.38b			8.31b			9.43			18.33			15.57		
Fall 2016	CM	34.50a	29	0.06	12.78a	18	0.08	6.86	38	0.82	8.95	42	0.58	9.46b	37	0.09
	CS	34.75a			9.72b			5.41			8.74			10.03b		
	NC	39.99a			10.06ab			5.43			7.77			10.45ab		
	T	21.22b			9.27b			5.65			8.85			16.17a		
Spring 2017	CM	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	CS	nd			nd			nd			nd			nd		
	NC	nd			nd			nd			nd			nd		
	T	nd			nd			nd			nd			nd		
Fall 2017	CM	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
	CS	nd			nd			nd			nd			nd		
	NC	nd			nd			nd			nd			nd		
	T	nd			nd			nd			nd			nd		

1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2) T (Tillage)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-17. Burlington soil chemical and biological means 2014-2015

Year	Season	Trt[1]	Soil Water Content (g g^{-1}) Mean	CV [2]	P[3]	Microbial Biomass Carbon (ug C g^{-1} soil) Mean	CV	P	Dissolved Organic Carbon (ug C g^{-1} soil) Mean	CV	P	pH Mean	CV	P
2014	Fall	NC	nd	nd	nd	nd	nd	nd	nd	nd	nd	6.23	3	0.17
		CM	nd			nd			nd			6.42		
		CM2	nd			nd			nd			6.48		
		T	nd			nd			nd			6.23		
2015	Spring	NC	0.87	1	0.38	245.8	13	0.15	19.7	48	0.16	6.50	3	0.11
		CM	0.88			212.9			28.0			6.26		
		CM2	0.87			222.0			38.7			6.20		
		T	0.88			218.7			25.0			6.42		
	Fall	NC	0.22	13	0.47	95.0	59	0.37	20.9	139	0.54	6.42	2	0.59
		CS	0.22			48.2			73.3			6.39		
		CM	0.22			71.5			20.9			6.36		
		T	0.19			39.1			19.4			6.31		

1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2) T (Tillage)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-18. Burlington soil chemical and biological means 2016-2017

			Soil Water Content ($g\ g^{-1}$)			Microbial Biomass Carbon ($ug\ C\ g^{-1}$ soil)			Dissolved Organic Carbon ($ug\ C\ g^{-1}$ soil)			pH		
Year	Season	Trt[1]	Mean	CV[2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P
2016	Spring	NC	0.15	12	0.25	18.7	36	0.12	23.6	15	0.89	6.12b	2	<0.001
		CS	0.13			17.5			24.3			6.11b		
		CM	0.13			15.6			27.4			6.34a		
		T	0.15			11.9			27.1			6.28ab		
	Fall	NC	0.13	26	0.55	29.3	60	0.73	25.5	24	0.52	6.20b	1	0.01
		CS	0.14			38.7			18.8			6.15b		
		CM	0.18			18.6			21.2			6.30a		
		T	0.13			18.4			34.0			6.13b		
2017	Spring	NC	0.17	11	0.73	106.4	88	0.34	47.8	18	0.40	6.20a	2	0.06
		CS	0.18			108.2			39.6			6.13ab		
		CM	0.18			14.5			51.5			6.03b		
		T	0.17			86.4			44.2			6.00b		
	Fall	NC	0.20	7	0.55	306.0	8	0.71	19.7c	22	<0.01	5.77a	2	0.08
		CS	0.19			291.0			28.5bc			5.77a		
		CM	0.20			281.4			42.1a			5.57b		
		T	0.21			295.2			34.1b			5.67ab		

1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2) T (Tillage)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-19. Burlington soil chemical means part 1 2014-2015

			Phosphorus ppm			Potassium ppm			Calcium ppm			Magnesium ppm			Sodium ppm		
Yr	**Seas**	**Trt[1]**	**Mean**	**CV[2]**	**P[3]**	**Mean**	**CV**	**P**	**Mean**	**CV**	**P**	**Mean**	**CV**	**P**	**Mean**	**CV**	**P**
2014	Fall	NC	9.61	34	0.83	207.58	17	0.20	3056	10	0.13	539.3	19	0.79	96.39	19	0.71
		CM	11.09			218.78			3209			584.7			104.88		
		CM2	8.12			194.62			3003			596.4			105.98		
		T	10.08			225.80			3318			607.2			100.08		
2015	Spring	NC	14.60	25	0.77	209.32	16	0.51	2270	13	0.73	451.7	17	0.66	83.84	17	0.95
		CM	18.20			177.31			1990			374.2			72.65		
		CM2	18.03			198.86			2107			404.2			71.03		
		T	17.63			194.59			2114			409.4			79.32		
	Fall	NC	13.34	43	0.33	206.37	13	0.46	3214	11	0.27	574.8	12	0.25	114.86	12	0.44
		CS	11.31			198.36			3194			555.5			120.28		
		CM	19.67			199.07			3134			555.1			107.38		
		T	13.53			192.63			3040			520.0			76.01		

1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2) T (Tillage)
nd: no data measured at this sampling date
2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year
3- CV= coefficient of variance percent

Table 3-20. Burlington soil chemical means part 1 2016-2017

			Phosphorus ppm			Potassium ppm			Calcium ppm			Magnesium ppm			Sodium ppm		
Yr	Seas	Trt[1]	Mean	CV [2]	P[3]	Mean	CV	P	Mean	CV	P	Mean	CV	P	Mean	CV	P
2016	Spring	NC	12.40	20	0.56	166.93	20	0.17	2704	15	0.60	479.6	17	0.47	71.86	17	0.52
		CS	10.50			168.73			2793			489.3			82.27		
		CM	12.43			178.39			2856			523.5			87.03		
		T	12.50			183.42			2865			516.5			86.95		
	Fall	NC	nd	nd	nd	140.35	13	0.92	2226	10	0.40	392.2	16	0.94	57.05	16	0.66
		CS	nd			148.95			2381			411.4			53.25		
		CM	nd			163.53			2603			466.1			65.30		
		T	nd			158.90			2485			425.8			54.10		
2017	Spring	NC	nd	nd	nd	144.67	18	0.21	2493	13	0.16	417.2	13	0.18	60.60	13	0.10
		CS	nd			139.70			2337			391.3			54.03		
		CM	nd			147.93			2478			416.0			61.70		
		T	nd			161.63			2595			443.9			64.37		
	Fall	NC	30.00	36	0.51	223.00	14	0.86	3091	9	0.37	542.3	9	0.70	108.00	9	0.26
		CS	20.33			211.67			3072			539.0			112.67		
		CM	30.67			215.33			2885			519.7			109.33		
		T	23.33			217.00			2997			522.7			85.67		

1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2) T (Tillage)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

3- CV= coefficient of variance percent

Table 3-21. Burlington soil chemical means part 2 2014-2015

Yr	Seas	Trt[1]	NO_3-N (ppm) Mean	CV[2]	P[3]	NH_4 (ppm) Mean	CV	P	Total N % Mean	CV	P	Total C % Mean	CV	P	Electrical Conductivity S m^{-1} Mean	CV	P
2014	Fall	NC	6.68	22	0.85	7.34	10	0.32	0.12	7	0.75	1.32	6	0.33	0.26	4	0.14
		CM	7.25			6.56			0.12			1.39			0.25		
		CM2	6.04			6.38			0.11			1.27			0.24		
		T	6.57			7.15			0.12			1.35			0.26		
2015	Spring	NC	5.03	29	0.27	6.18	10	0.26	0.14a	4	0.05	1.38	4	0.53	nd	nd	nd
		CM	4.81			6.75			0.13ab			1.39			nd		
		CM2	3.87			6.62			0.14ab			1.41			nd		
		T	6.28			7.17			0.13b			1.35			nd		
	Fall	NC	3.47b	65	0.01	3.54	49	0.16	0.12	6	0.64	1.32	6	0.88	nd	nd	nd
		CS	3.82b			4.47			0.13			1.37			nd		
		CM	6.97a			5.03			0.13			1.36			nd		
		T	3.66b			5.66			0.13			1.36			nd		

1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2) T (Tillage)

nd: no data measured at this sampling date

2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year

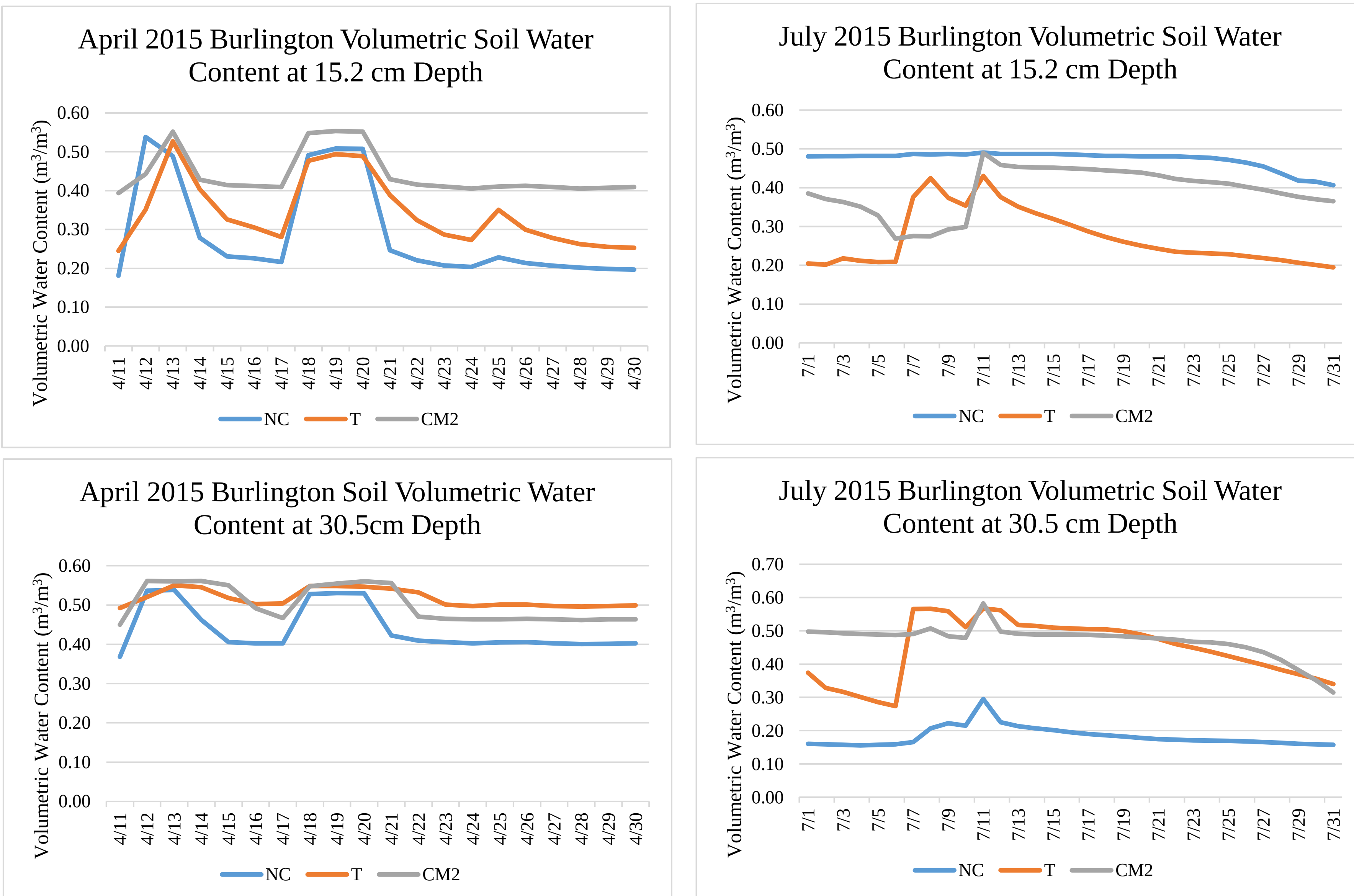
3- CV= coefficient of variance percent

Table 3-22 Burlington soil chemical means part 2 2016-2017

Yr	Seas	Trt[1]	NO_3-N (ppm) Mean	CV[2]	P[3]	NH_4 (ppm) Mean	CV	P	Total N % Mean	CV	P	Total C % Mean	CV	P	Electrical Conductivity S m^{-1} Mean	CV	P
2016	Spring	NC	10.24b	11	0.01	4.28	6	0.13	0.10	13	0.50	1.37	6	0.87	nd	nd	nd
		CS	8.96b			4.19			0.11			1.41			nd		
		CM	9.84b			4.46			0.11			1.42			nd		
		T	11.56a			4.65			0.10			1.37			nd		
	Fall	NC	2.85	19	0.11	14.05a	22	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd
		CS	3.05			13.10a			nd			nd			nd		
		CM	3.30			9.00b			nd			nd			nd		
		T	4.17			9.30b			nd			nd			nd		
2017	Spring	NC	3.90b	29	0.03	11.20	36	0.30	nd	nd	nd	nd	nd	nd	nd	nd	nd
		CS	5.90a			13.80			nd			nd			nd		
		CM	3.57b			11.50			nd			nd			nd		
		T	4.6ab			17.87			nd			nd			nd		
	Fall	NC	33.30	25	0.20	8.37	12	0.51	0.16	8	0.54	1.45	4	0.94	nd	nd	nd
		CS	23.43			8.50			0.15			1.45			nd		
		CM	35.97			9.33			0.16			1.47			nd		
		T	27.57			9.50			0.15			1.44			nd		

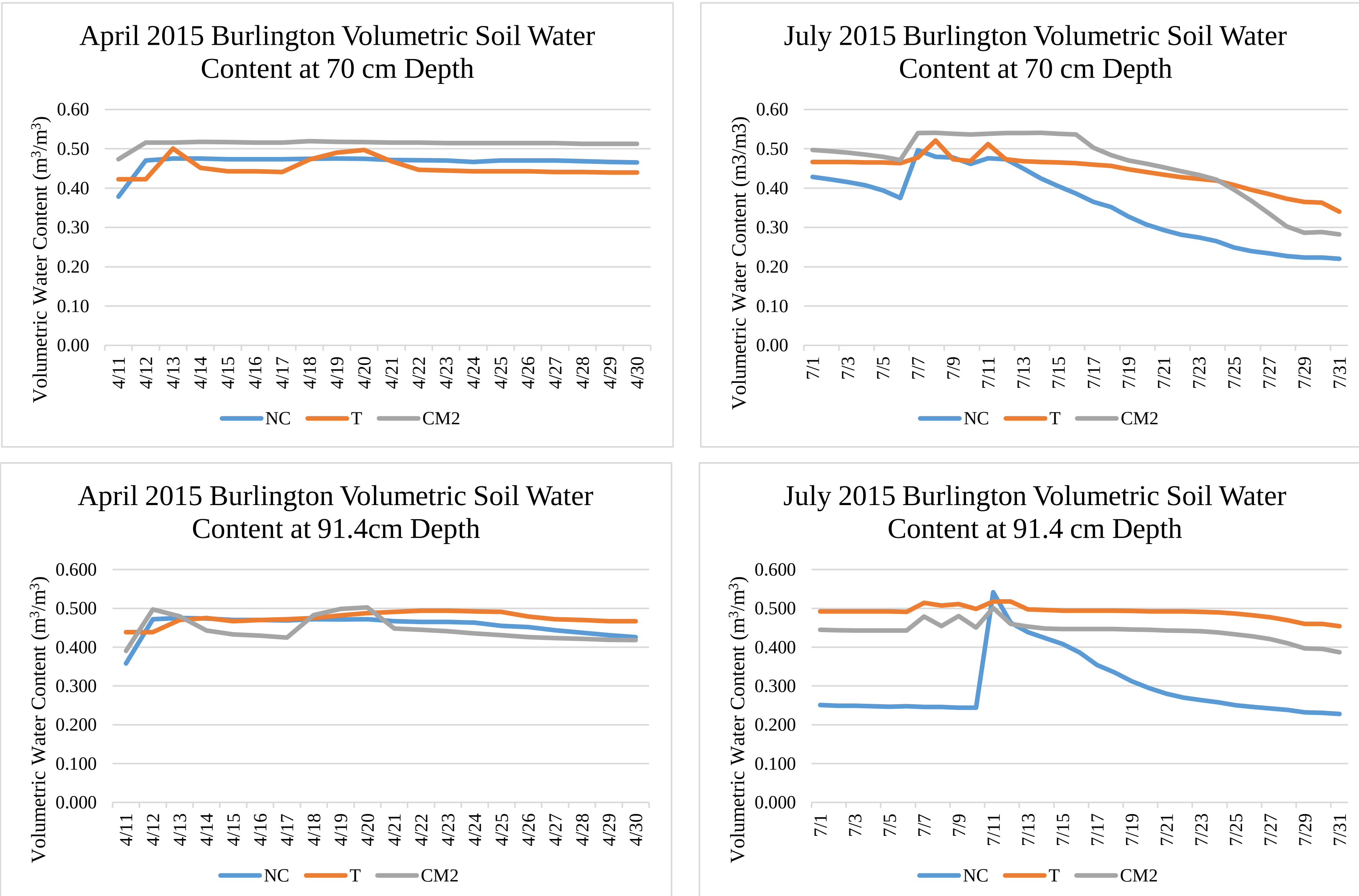
1- Trt (treatment) NC (No Cover), CS (Cover Single), CM (Cover Mixed), CM2 (Cover Mixed 2) T (Tillage)
nd: no data measured at this sampling date
2 - P = mean separations calculated on p=0.05, one-way analysis of variance within site year
3- CV= coefficient of variance percent

Figure 3-1. Burlington 12:00pm Daily Dynamic Soil Water Measurements for April and July at 15.2 cm and 30.5 cm



1-NC (No Cover), T (Tillage), CM2 (Cover Crop Mixed 2)

Figure 3-2. Burlington 12:00pm Daily Dynamic Soil Water Measurements for April and July at 70 cm and 91.4 cm Depths



1-NC (No Cover), T (Tillage), CM2 (Cover Crop Mixed 2)

Chapter 4 - Discussion

Plant Parameters

Cash crop yield was not significantly different between treatments at any location or year. This differs from the recent findings by Chalise et al. (2019) who reported a 14% yield increase in soybean yield in the cover crop treatment (rye and hairy vetch mix) over the no cover treatment in long-term no-till; however, that study also reported that the cover crop treatments had decreased bulk densities and increased infiltration rates, which would have made ideal conditions for cash crop growth. As we didn't observe any treatment effects of cover crops on soil health in our study, it does stand to reason that we did not observe any improvements in crop yield.

Cover crop biomass was not significantly different between treatments at any location, or year where both treatments had adequately established. The Valley Falls location chose to use radish for the CS treatment in the beginning of the experiment, however, as radish was not able to adequately establish with late fall plantings, the switch was made to wheat. This underscores the importance of selecting cover crop species that will fit well with each unique cropping system and environment.

The lack of number of species effect on biomass differs from a key result that Finney et al. (2016) found in Pennsylvania, where the researchers found a positive relationship with cover crop biomass and number of species used. The Hutchinson location compared a CS of rye to a CM of rye, vetch, and pea; however there was no difference in biomass by treatment. This contrasts Wortman, et al., (2012), who's Nebraska-based study found that mixes generally yielded less than a single component of the mix grown in monoculture.

Based on the cover crop biomass, the cover crop treatments were able to adequately establish in all site years with the exception of Valley Falls in 2015. As there was no difference between cover crop treatments in biomass, it can be implied that the physical biomass residue should have equally impacted the cash crop planting and stand establishment.

The cover crop seed cost ranged from \$14.82 ha-1 for CS Valley Falls to \$85.22 ha-1 for Burlington CM2 (Table 3-3). Depending on the species choice and number of components, a large difference in seed cost was seen across the sites. Using the rates from the Burlington location, the CS treatment would cost \$53.35 ha^{-1} in seed, and the CM2 treatment would cost \$85.22 ha^{-1} in seed (Shoup et al. 2016). This range in prices underscores the importance of thoroughly evaluating the goal of cover cropping for each individual farm. A producer who is interested in cover cropping for benefits such as erosion control may find that a single species cover crop will still produce adequate biomass and be more economic appropriate for their purpose (Locke et al., (2015). Other producers may have more pressing environmental concerns driving their species selection. For example, a producer who wants to ensure the establishment of a cover crop may opt for a mix as mixes have been show to provide resiliency to environmental stress due to natural tolerances (Wortman, et al., 2012). As cover crop treatments made no measurement impact on cash crop yield or cover crop biomass, it may be advised that producers in Eastern Kansas use other decision factors such as seed cost and cover cropping purpose for species selections.

Soil Physical Parameters

Bulk density was not significantly different among the treatments at any location, year, or sampling time. While many long-term studies have found that cover cropping reduces bulk density in the surface layers (Haruna and Nkongolo, 2016; Blanco-Canqui et al, 2011; Chalise et al., 2019), one two-yeary study (Haruna et al., 2018) found similar results to ours. The 2018 study by Haruna examined the treatment effects of cover crop vs no cover and moldboard tillage vs no-tillage. Previous to the start of the two-year study, the land was in 50 years of moldboard tillage. This is similar to the design our experiment, where the land was all managed as no-till for <10 years previous to the start of the study. This suggests that detecting changes in bulk density from the additional treatment of cover cropping may take many years to be observed.

Long-term no-till has been shown to improve bulk density, which may have been the dominating factor in this study. According to the USDA NRCS (2014) the ideal bulk density for a silty clay (Burlington) is <1.10 g cm^{-3}, <1.40 g cm^{-3} for a clay loam (Valley Falls), and <1.40 g cm^{-3} for a loam (Hutchinson). The bulk densities that affect root growth are 1.10 g cm^{-3} for a silty clay, 1.60 g cm^{-3} for a clay loam, and 1.63 g cm^{-3} for a loam. The Burlington and Valley Falls mean bulk densities were all less than the values that would affect root growth, and Hutchinson had a one-time sampling in the spring of 2016 that was over this value. All the sites had been in long-term no-till before this study began which may have been the dominating factor controlling bulk densities.

Infiltration was only significant in the spring 2016 sampling at Burlington, and the trend did not repeat. The coefficient of variance percent ranged from 45-65% (Tables 3-12, 3-13) indicating the large spread in infiltration readings within all sampling times. Observation notes from the time of sampling indicate that wind may have affected the rate of water releasing from the infiltrometer, which may have contributed to the spread of the data. Soil moisture conditions at time of sampling can greatly impact the results, however gravimetric soil moisture content was not significantly different between treatments at that sampling time. It is possible that spatial variation in soil moisture existed between the site of the infiltrometer and where the soil cores were taken from. Spatial temporal variability in hydraulic properties can be due to inherent soil properties, as well as management practices such as tillage, residue management, or compaction from field operations (Mubarak et. al, 2010). From visual observation notes at the time of sampling, it could be possible that the soil was drier in the NC and T plots likely due to the lack of soil cover, therefore they may have infiltrated at a faster rate than the moister cover crop plots. It is important to note that this is a standalone instance of significance that was not repeated in future samplings.

In contrast to our result, Haruna et al., (2018) found an increase in infiltration rates in their cover cropping treatments after only two years. For fifty years previous to this, however, the land had been in annual moldboard plow tillage. This rapid improvement in infiltration rates from cover cropping may have been seen here due to degraded physical properties of soil from tillage at the start of the experiment (Magdoff and Van Es, 2009). Whereas, our experiment began with soil that had already been in no-tillage for over ten years which could be why we didn't see similar results to Haruna et al (2018).

A common concern from producers is that a cover crop will negatively affect cash crop yields by reducing soil profile water. This project attempted to collect thorough soil moisture data to address this concern. Demonstrative graphs show that at the Burlington location in April of 2015, there did not appear to be a difference in volumetric water content between CM2, NC, or T. Overall, it appears that in April and July the CM2 provided the most consistent soil moisture through the profile (Figure 3-1, Figure 3-2). Given that the soil moisture appeared to be similar across treatments in April, it would be expected that soil moisture would affect cash crop stand establishment equally across treatments. This contrasts the result by Ewing et al. (1991)

who found the cover crops reduced soil moisture before corn planting and negatively impacted yield in Central California. In Ewing's study, however, the cover crop was terminated before cash crop planting which the author's cited as a source of soil moisture loss. It is likely that as our cash crop was planted into a green cover crop, soil moisture losses were reduced at the time of planting. Given that the CM2 treatment held consistent moisture readings in July, it appeared that the cover crop did not hinder the cash crop in the heat of the Kansas summer or at the time of planting.

The dynamic soil water measurements were included as a demonstration of the comparison that can be made with daily soil moisture data, but also for the challenges that come with collecting this type of data. The data set intended to include three years of daily soil moisture data at six depths for three treatments at each site. Managing the soil moisture probes, however, proved to be a time consuming and difficult task. Due to mechanical issues with the cables and rampant rodent interference, the data set lacks completion. In this experiment, with locations spread several hours apart, collecting quality daily soil moisture data was not viable.

The Burlington location was the only site to have differences in soil aggregates. The aggregates in the tillage plots were getting smaller over time from the mechanical breakdown of annual tillage. In 2015 and 2016 the NC treatment also began to show higher proportions of the 0.25mm WSA and less 4.75mm and 2.00mm WSA than the cover crop plots. This implies that the cover crops were positively contributing to aggregate stability likely through the additions of organic matter to the soil. (NRCS, 1996)

In a 15-year study Blanco-Canqui et al. (2011) found improvements in wet aggregate stability from cover cropping in a no-till wheat-grain sorghum rotation. This cropping rotation allowed for year round soil cover, and for the cover crop treatment to be planted in June. With the establishment of the cover crop in June, the cover crop would have been able to establish and produce more biomass for several months until winter. As our study involved fall cover crops and was only three years into the treatments, it is within reason that we would not have come to the same conclusion as Blanco-Canqui et al (2011).

Changes in dynamic soil properties may take many years to be observed. This is emphasized by Nouwakpo et al., (2018) who found after fourteen years no-till improved aggregate stability in the 0-15cm layer. Given this, it stands to reason that our soils may have improved their aggregate stability since converting to no-till management over a decade ago, and that this parameter may not have measurably improved in the last three years.

Soil Chemical Parameters

Significantly higher DOC concentrations were observed in the mixed cover crop treatment at the Burlington location for the fall 2017 sampling time. The higher DOC could be attributed to the higher root exudates from the legume component of the cover crop, the faster breakdown of the legume cover crop, or from differences in the microbial community structure (Kalbitz et al., 2000). Given that a more diverse plant community has been shown to support a more diverse microbial community, it is possible that the microbial community in the CM plots could be composed differently than in the other treatments. This would in turn mean different carbon cycling mechanisms that may contribute to temporal differences in DOC concentration (Kalbitz et al., 2000). Future sampling should be done to determine the community structure differences between treatments.

The cover crop biomass was not significantly different between treatments in the spring of spring 2017, so the increased DOC is not from a difference in amount of biomass, but likely the bioavailability of that biomass. The legume containing CM cover crops would have a lower

C:N than rye, and therefore breakdown more rapidly making more labile nitrogen available in the soil, increasing the food source for the soil microbes. (NRCS, 2009)

This same relationship may have been the driver behind increased total nitrogen in the spring of 2015 at the Hutchinson location. The CM plots had significantly higher total nitrogen than the NC plots, but neither were significantly different from CS. The CM treatment contained rapeseed which is known for its ability to accumulate high amounts of nitrogen which can be available to the cash crop in early spring (Clark, 2007). This release of nitrogen is susceptible to leaching losses if it exceeds the cash crop's nitrogen demand (Clark, 2007). Therefore, decomposition of the CM which contained vetch and rapeseed likely created a more nitrogen rich soil environment than in the NC plots which had no crop biomass. While this difference is significant, the absolute difference is less than a tenth of a percent, and it did not repeat in the 2016 samplings.

Soil pH had limited, and sporadic instances of significance. While these instances were of statistical significance, the differences were not of agronomic significance. The ideal pH range for a corn and soybean rotation is 5.5 to 7.0, and all observed values were within this range (Leikam et al, 2007; Mallarino, 2007).

Chapter 5 - Conclusions

There are many different factors that can lead a producer to implement cover cropping. Soil health improvements, erosion control, and landlord requirements are some of the main factors that come into consideration. This study did not find any yield penalty or benefit from cover cropping at any site or location, and there were no trends suggesting a multi-species cover crop provided more benefits than a single species. A producer who is interested in cover cropping for benefits such as erosion control may find that a single species cover crop will still produce adequate biomass and be more economic appropriate for their purpose.

This three-year study did not find any trends of improved soil health from cover cropping in the established no-till setting. With sixteen soil health parameters examined across three different soil types, it appears that producers who are in established long-term no-till in eastern Kansas may not see short-term health benefits from cover cropping. Improvements in dynamic soil health may take many years to be observed, and so it is possible that differences in soil health may be detectable if this study was to continue long-term.

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Appendix A - Monthly Precipitation Data

Figure A-5-1. Valley Falls monthly precipitation data from NOAA Regional Climate Centers

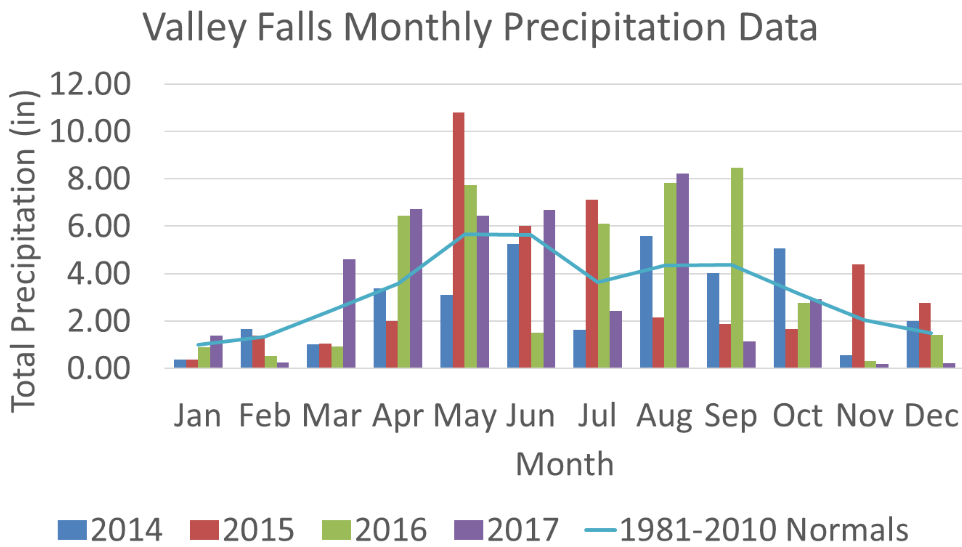

Figure A-5-2. Hutchinson monthly precipitation data from NOAA Regional Climate Centers

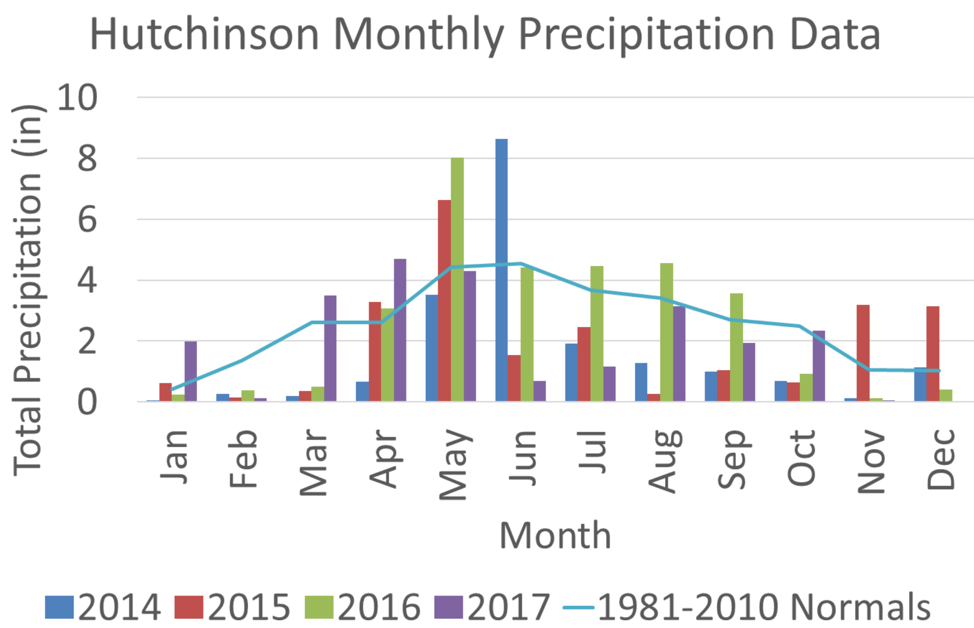

Figure A-5-3. Burlington monthly precipitation data from NOAA Regional Climate Centers