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# Demonstrating Short-term Impacts of Grazing Cover Crops on Soil Health in South Dakota

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# DEMONSTRATING SHORT-TERM IMPACTS OF GRAZING COVER CROPS ON SOIL HEALTH IN SOUTH DAKOTA


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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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(Colin Tobin)

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ABSTRACT

DEMONSTRATING SHORT-TERM IMPACTS OF GRAZING COVER CROPS ON SOIL HEALTH IN SOUTH DAKOTA

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Grasslands have been rapidly converted to croplands over the last decade in the northern Great Plains. This conversion can reduce soil health and increase the region's ability to pollute the Missouri and Mississippi rivers. Therefore, the need for integrated crop livestock (ICL) practices that can protect the region's native prairies are strongly encouraged. Introducing livestock into arable cropping systems can improve nutrient cycling, soil health, and provide economic benefits. However, the detailed information about the impacts of ICL system on soil health is still lacking in the Northern Great Plains region. Therefore, the present study was conducted under a corn (*Zea mays* L.)-soybean (*Glycine max* L.)-rye (*Secale cereale* L.) rotation with no-till system at the Southeast Research Farm near Beresford, South Dakota to assess the effects of ICL systems on selected soil health parameters. Cover crops blends (Brassica/Legume-based blend, Grass-based blend, Equal blend) were planted after the rye (*Secale cereale* L.) crop, and grazing treatments (with and without) were applied after the cover crops establishment. Cover crops were grazed from November 2 through November 12, 2015. Concerns regarding the role of hoof traffic from livestock adversely affecting the near-surface soil conditions, soil health, and hydrological properties under no-till systems will be discussed. Data showed that the use of diverse cover crop mixtures provided increased biomass on the surface that can alleviate the compaction impact under these integrated crop-livestock systems. Surface (0-5 cm depth) bulk density was not significantly impacted by grazing. Some soil physical and hydrological properties were significantly affected due to the high moisture content of the soil during the grazing period. Soil organic carbon at 0-5 and 5-15 cm depths was also unaffected by grazing, except that at corn-phase, it was significantly lower under grazing treatment compared to that of ungrazed treatment. Carbon fraction data was studied to find the impact of short-term grazing on the microbial biomass, labile and stable carbon fractions from 0-5 cm and 5-10 cm depths. Grazing had no effect on beta-glucosidase enzyme activity or microbial biomass carbon. However, legume and grass blend cover crops increased the beta-glucosidase enzyme activity compared to that of control treatment. Results from this study conclude that short-term (one-year) grazing did not negatively impact the soil surface physical, hydrological, and biological properties in southeastern South Dakota

# CHAPTER 1

# INTRODUCTION

In the Northern Great Plains, agriculture is one of the main drivers of the economy. Crop and livestock production dominate in South Dakota, with the eastern portion of the state in crop production while the western portion is mainly range and pastureland and cattle production. In recent years, there has been a conversion of pasture and rangelands into croplands due to increased commodity prices. This acreage reduction has increased pressure on native rangeland and pasturelands resulting in more stress on vegetation and soil which can decline rangeland and soil health. Crops in South Dakota vary greatly across the state. The eastern half of South Dakota is dominated by a corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotation. In the center and western portion of the state, small grains are a large portion of the acres planted. This area has a typical crop rotation of corn-wheat (*Triticum aestivum* L.)-sorghum (*Sorghum bicolor* L.)/sunflowers (*Helianthus annuus* L.). Due to varying climate conditions, many winter varieties of crops are used, especially wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.). The soil moisture is limited in the state, therefore, range of conservation practices are used to conserve the moisture to improve the crop productivity.

The no-till (NT) practice is the most commonly used soil moisture conserving management technique that is used in much of South Dakota. The NT management is the planting of seeds with minimal disturbance to the soil and leaving the crop residues from the year before. This type of management helps the producers reduce soil moisture losses by leaving the residue to act as a buffer between the sun’s rays and the soil surface. Also, NT decreases soil erosion and increases soil carbon levels.

Due to lower commodity prices, integrated crop livestock systems (ICL) have been on the rise in recent years. These ICL systems have the ability to improve economics, increase soil productivity, and increase diversification. These systems can enhance soil fertility and carbon sequestration due to manure addition directly back to the soil [1]). Integrated crop-livestock systems are common throughout the world and have the ability to decrease costs of transporting feed, and animal manure, decrease labor hours, decrease in manure storage costs, and many other economic benefits. One myth that many producers have is that grazing cattle on NT cropland will damage some soil properties and in turn lead to lower crop yields. This project will help determining if grazing livestock on cover crops has a short-term impact on soil health. The increased amount of biomass on the soil surface can help alleviate the hoof pressure that causes compaction.

The grazing intensity rate varies greatly across the state of South Dakota. In the Southeastern corner of South Dakota, the average acres per animal unit is between 5-10 acres per year, while in the northwestern corner of the state is 56-65 acres per year. The Black Hills pushes the rate up to 80-100 acres per animal unit per year. Adding an ICL system to many acres of cropland across the state of South Dakota will alleviate grazing pressure on native rangeland. Also, adding cover crops to the ICL system will allow grazing animals to graze green vegetation in the late fall when rangeland supplies mature forage that is less palatable and nutritious. Therefore, the present study will investigate the short-term impacts of grazing cover crops under ICL systems on soil health parameters. To accomplish this goal, the present study is divided into two major objectives.

**Objective 1**: Assess the impacts of integrated crop-livestock systems on soil surface physical and hydrological properties.

**Objective 2**: Evaluate the short-term changes in soil C and N fractions as affected by grazing, cover crops, and grazed cover crops in an integrated crop livestock system.

# CHAPTER 2

# LITERATURE REVIEW

Introducing livestock into arable cropping systems can improve ecosystem services and provide economic benefits. In the Northern Great Plains, grasslands have been rapidly converted to croplands over the last 10 years [2, 3]. This conversion has the potential to degrade the soil health. Thus, integrated land management practices that protect the region's native prairies are needed. Integrated crop livestock (ICL) systems improve soil organic carbon (SOC), operational efficiency, economic performance, and environmental quality [4]. Livestock, when integrated into cropping systems, can improve nutrient cycling, minimizing N losses, and greatly benefiting the environment. In contrast, monoculture agricultural systems can reduce soil health by the loss of organic matter and structure because of lower organic inputs and regular disturbance to the soil because of tillage practices [5]. Cover crops and crop residue provide feed to livestock in the ICL systems while plants capture nutrients from the livestock waste. There are many benefits with these integrated systems, however, there are still some concerns regarding the role of livestock hoof traffic that can adversely affect the near-surface soil conditions, soil health, and hydrological properties. However, use of diverse cover crop mixtures can provide increased biomass on the soil surface that can alleviate the compaction impact under these ICL systems. This demonstration study was conducted on producers' farms where project findings, monitoring of soil health parameters, cover crop types grown in the grazing systems, and importance of grazing management will be demonstrated to the producers. This study will be helpful in providing useful findings about short-term (one-year) grazing impacts on soil surface physical and hydrological properties.

## 2.1. Integrated Crop-Livestock Systems

Integrated crop-livestock (ICL) systems increase ecological interactions among land use systems that improve the efficiency of agricultural ecosystems in cycling nutrients, enhancing soil quality, and preserving natural resources and the environment. Throughout the world, ICL systems are common and have been increasing in recent years because of its various economic and environmental benefits (Thornton, 2010). Integrated crop-livestock systems are examples of diversification that increases SOC (Lemaire *et al*., 2014; Snapp *et al*., 2005).

Greater grain demands due to increased population has shifted land use away from animal production systems to crop production systems and the shift in land management has begun to deteriorate productivity. Specifically, in the United States ICL systems have been on the rise in recent years because of lower commodity prices, high land rent prices, and the limited amount of grazing land for animals. Integrated crop-livestock systems throughout the world are somewhat similar to those used in the USA. Some ICL systems include the use of large and small ruminants for weed control and manure application under palms in Malaysia, grazing crop residues by ruminants in Asia (Devendra and Thomas, 2002), and grazing after cropping and during fallow in Africa (Smith *et al*., 1997). Examples of ICL systems within the United States include planting and grazing of cover crops, grazing of crop residue after harvest, and grazing of annual crops swathed for winter feed (Liebig *et al*., 2011). However, there are other types of ICL systems that are being adopted in the United States and the most commonly used ICL's are grass-based crop rotation, livestock grazing of cover crops within cash-crop rotation, grazing of crop residues, grass intercropping, dual-purpose cereal crops, and agroforestry (Sulc and Franzluebbers, 2014).

## 2.2. Integrated Crop-Livestock Systems Effects on Soil Organic Carbon (SOC) and Nutrient Cycling

Grazing systems develop complex pathways for the carbon and nitrogen in soil causing highly localized concentrations of available carbon and nitrogen. In a study near Lubbock, Texas, an ICL system was studied by Acosta-Martinez *et al*. (2004) to determine soil carbon dynamics changes to a Pullman soil (Torrertic Paleustoll). These researchers found that microbial biomass carbon and nitrogen contents were greater in the ICL system when compared to that of continuous cotton (*Gossypium hirsutum)* for the top 15-cm soil depth. Different stocking rates of grazing under livestock management systems have a strong influence on soil organic carbon dynamics. The SOC under rotational grazed systems was greater than in non-grazed, light stocking rate continuous grazing, or heavy continuous grazing systems (Teague *et al*., 2011). Excessive grazing under continuous grazing systems removes crop biomass and litter that cause soil exposure and soil degradation (Teague *et al*., 2013). In Brazil, under a clayey Oxisol soil with corn-soybean rotation in NT followed by summer grazing of black oat (*Avena strigose*) and Italian ryegrass (*Lolium multiflorum*), moderate grazing intensities (20-40 cm shoot height) led to SOC levels similar to those of non-grazed areas compared to high grazing intensity (10 cm shoot height) (Assmann *et al*., 2014). In the same study, moderate grazing intensities, with sward pasture heights between 20 and 40 cm, and a long period of a crop–livestock integration under NT, increased total particulate and mineral-associated organic carbon and nitrogen stocks similar to non-grazed areas with NT system (Assmann *et al*., 2014). A study located near New Deal, TX, on a Pullman soil (Torrertic Paleustoll) with 0-1% slope, reported that SOC increased by of 22% during a 13 years ICL rotation of Old World Bluestem *(Bothriochloa bladhii, Bothriochloa ischaemum),* and in a NT cotton-wheat-fallow-rye compared to continuous cotton (Fultz *et al*., 2013).

Integrating livestock into arable cropping systems help in improving nutrient cycling and reducing nitrogen losses. These integrated systems enhance soil fertility and carbon sequestration, as the nutrients in the forage consumed by the livestock are applied back to the soils through manure deposition (Russelle *et al*., 2007). In north central USA, winter grazing is a commonly used practice that the farmers have been using for a long time. In a study near Mandan, North Dakota, Liebig *et al*. (2011) reported that winter grazing of annual crops showed minor effects on near-surface soil properties. Further, it was noted that soil bulk density had an increased 0.1Mg $m^{-3}$ between the fall of 2007 and the spring of 2008 because of animal hoof-induced traffic during the grazing period of 2007. These researchers reported that soil nutrients such as available P, SOC, and total N increased between 2005 and 2008 in the high-traffic zone (HT), and this could be partially attributed to the increased accumulation of manure from cattle in HT zone because of the relatively close proximity of the zone to the winter shelter and water source (Liebig *et al*., 2011). Grazing in ICL systems may alter soil phosphorus (P) dynamics. The understanding of P dynamics is important because of its impact soil health. Research conducted on an Oxisol in Brazil under soybeans (*Glycine max* L.) rotated to a winter cover crop mixture of black oat (*Avena strigose*) and Italian ryegrass

(*Lolium multiflorum)* managed with NT system showed that after six years of integrated crop-livestock systems, the total P was greater in the 0-5 cm depth in grazed areas due to intensified P-cycling compared to non-grazed areas. Whereas, non-grazed treatments had higher P above the surface because of biomass accumulation (Costa *et al*., 2014).

### 2.3. Cropping Systems

Growing a variety of crops in sequence has many positive effects on soil environment. Differences in plant rooting patterns including root density and root branching at different soil depths also result in more efficient extraction of nutrients from all soil layers when a series of different crops are grown (Ma *et al*., 2013). According to the long-term research conducted by Congreves *et al*. (2015) in Canada to evaluate the impact of tillage and crop rotation on soil health of four sites in Ontario (Ridgetown, Delhi, Elora, and Ottawa) showed that crop rotation significantly affected the soil attributes including root health. Results from the study showed that soil aggregate stability is related to root health, sand, content and extractable P which highlights the interdependence of aggregate stability to root growth and penetration, erosion control, soil compaction, and aeration. Perennial crops increase plant residue and hence the carbon input into the soil. Perennial energy crops could increase SOC stocks by 15-20 Mg $ha^{-1}$ compared to annual energy crops in conventional arable systems (crop rotation with plow system) according to the research conducted over 11-yr in Germany (Gauder *et al*., 2016).

The design of low-input cropping systems including legumes in the crop rotation could be a key parameter to reduce C and N losses. An experiment conducted by Plaza-

Bonilla *et al*. (2016) that include different levels of legumes in a 3-yr rotations showed that rotations significantly affected the amount of C and N inputs, and SOC and SON, and helped in mitigating the losses of C and N. Raphael *et al*. (2016) conducted a study on changes in SOM concentrations and quality as a result of crop rotation including grasses and a legume grown in the fall/winter and spring under NT and showed that SOM was affected by spring crops. The effects of diversified cropping system on SOC and soil health parameters can also be shown in the development and growth of root system.

## 2.4. Research Gaps

There is lack of information regarding the impacts of ICL systems on soil health indicators. The growth of cover crops in the region especially in South Dakota is sometime not good because of the low moisture.  Therefore, cover crops can be recommended after the rye or oats when cover crops have longer period to grow. The information regarding type of cover crop mixtures and soils impacts due to grazing these cover crops mixtures is still lacking in the Northern Great Plains region. Therefore, a detailed investigation regarding the impacts of ICL systems on soil health indicators is strongly encouraged.

# CHAPTER 3

# MATERIALS AND METHODS

## 3.1 Study Site and Background Details

The study site is located near Beresford (43° 02' 58" N, 96° 53' 30" W), South Dakota at the Southeast Research Farm of South Dakota State University (Figure 3.1). The experiment was initiated in 2015 to study the effect of short-term grazing on soil health indicators. The soils of the experimental plots are Egan soil series (Fine-silty, mixed, superactive, mesic Udic Haplustolls) (NRCS, 2015a). These plots were established on nearly flat areas with the slope of less than 1%. The average annual rainfall is 627.4 mm and the average temperature range from -14.1°C in January to 31.8°C in July (NRCS, 2015b).

## 3.2 Grazing Treatments

The experiment has 32 plots laid out in a split-plot design. The dimensions of each plot were 30 m wide and 60 m in length. The experiment included three cover crop treatments, two grazing managements, and a control. Treatments include: (i) Grass Blend [Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*) 9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*) 4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%]; (ii) Legume blend (Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%); and (iii) Equal Blend (Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%). The cover crop treatments followed the rye (*Secale cereale*) crop during a 3-yr corn (*Zea mays* L.)-

soybean (*Glycine max* L.)-rye rotation, and all treatments were managed with a no-till system. Each cover crop treatment and grazing were replicated four times.

## 3.3 Soil Sampling

### 3.3.1 Pre-Grazing

Intact soil core samples were collected in November 2, 2015 before grazing from 0-5 and 5-10 cm soil depths of every replicated plot using a 5-cm diameter and 5-cm height core for analyzing the soil bulk density and moisture retention. In addition, soil samples were extracted from 0-5, 5-10,10-15, 15-30-cm depths using a hand soil auger unit to analyze the electrical conductivity (EC), and pH while SOC concentration, total nitrogen (TN), and soil carbon and nitrogen fractions were analyzed from only the first two depths (0 – 5 and 5 – 10 cm). Four replicated samples from each plot were extracted and mixed together to make a composite sample to represent the plot. The composite sample was sealed in plastic zip-lock bags, transported to the laboratory and stored at 4°C pending analysis. Soil samples were air dried, ground, and sieved to pass through a 2-mm sieve. In addition, soils were ground to <0.25 mm in size for analyzing the soil carbon fractions.

### 3.3.2 Post-Grazing

Soil core samples were collected on November 13, 2015, one day after cattle had been removed, and on July 1, 2016 after corn crop establishment from 0-5 and 5-10-cm soil depths of every replicated plot ($n$ = 4) using a 5-cm diameter and 5-cm height core for analyzing the soil bulk density and water retention. In addition, soil samples were also extracted from 0-5, 5-10,10-15, 15-30-cm depths using a hand soil probe unit to analyze the SOC concentration, TN, EC, pH, and soil carbon and nitrogen fractions. Similar to pre-grazing sampling methodology, four replicated samples from each plot were extracted and mixed together to make a composite sample to represent the plot. The composite sample was sealed in plastic zip-lock bags, transported to the laboratory, and stored at 4°C pending analysis. Soil samples were air dried, ground, and sieved to pass through a 2-mm sieve. In addition, soils were ground to <0.25 mm in size for analyzing soil carbon fractions.

### 3.3.3 Corn Growth Phase

Intact soil core samples were collected on July 1, 2016 before grazing from 0-5 cm soil depths of every replicated plot ($n$ = 4) using a 5-cm diameter and 5-cm height core for analyzing the soil bulk density and moisture retention. In addition, soil samples were extracted from 0-5, 5-10,10-15, 15-30-cm depths using a hand soil probe unit to analyze the SOC concentration, TN, EC, pH, and soil carbon and nitrogen fractions. Four replicated samples from each plot were extracted and mixed together to make a composite sample to represent the plot. The composite sample was sealed in plastic zip-lock bags, transported to the laboratory and stored at 4°C pending analysis. Soil samples were air dried, ground, and sieved to pass through a 2-mm sieve. In addition, soils were ground to <0.25 mm in size for analyzing the soil carbon fractions.

## 3.4. Soil Analysis

### 3.4.1 Soil Physical and Hydrological Properties

#### 3.4.1.1 Soil Bulk Density

Soil bulk density ($\rho_b$) for the 0-5 and 5-10-cm depths was determined using the core method [6]. Soil samples were dried in the oven at 105°C for 24-48 hours until a constant weight was obtained, and $\rho_b$ was calculated by dividing the oven dry soil sample with the volume of core.

#### 3.4.1.2 Water Infiltration

The water infiltration rates ($q_s$) were measured with a double-ring infiltrometer (20 cm height, with 30 and 20 cm outer and inner diameters, respectively) using a constant-head method [7]. Soil $q_s$ was measured on November 2, 2015 and July 1, 2016. One infiltration measurement was conducted in each four replicated plots (one for each plot; $n$ = 4) until the steady state achieved.

#### 3.4.1.3 Soil Water Retention

For measuring the soil water retention (SWR), cheesecloth was fixed at the bottom of intact soil core, and then these cores were saturated with water for 24 to 48 hr depending upon the depth of core sampling and soil type. The SWR was measured using tension and pressure plate extractors [8], and SWR characteristics were measured at seven (0, −0.4, −0.1, −2.5, −5.0, −10.0, −30.0 kPa) matric potentials. Furthermore, the pore-size distribution (PSD) of soil was calculated using capillary rise equation from the SWR data to estimate the pore size classes [9].

### 3.4.2 Soil Chemical Properties

Soil organic carbon concentration was determined by the dry combustion method using the CN elemental analyzer. The SOC was calculated by subtracting the soil inorganic carbon from total carbon. In addition, SOC stock (Mg $ha^{-1}$) for 2015 was also computed using the equation given by Ellert and Bettany [10]. Cold-water, hot-water, and acid extraction carbon and nitrogen fractions were determined for 0-5 and 5-10 cm using the TOC-N machine [11].

Carbon fractions (labile, recalcitrant, and inert) and nitrogen fractions (labile, recalcitrant, and inert) were analyzed using cold water, hot wate,r and acid extraction methods described by [12] and [13]. Briefly, to determine labile carbon fraction 3 g soil was placed in into 50 mL polypropylene centrifuge tubes and 30 mL distilled water was added in each tube. Soil was mixed thoroughly with water on vortex mixer for 10 seconds and then moved to an end-over-end shaker for 30 minutes at 40 rpm. After shaking, the suspension was centrifuged at 3000 rpm for 25 minutes, and supernatant was separated from soil by using 0.45 µm pore size syringe filters and termed as cold- water extracts (CWE). Soil left after separating the supernatant was used to determine recalcitrant carbon fraction. Further, 30 mL distilled water was added in each tube and mixed properly using vertex mixer for 10 seconds. These tubes were left in hot water bath at $80^{o}$ C for 12-15 hours, and then these tubes were centrifuged at 3000 rpm for 25 minutes and the supernatant was filtered using 0.45 µm pore size syringe filters and termed as hot water extracts (HWE). After the hot water extraction process, soil left in the tube was used to determine inert fraction of carbon in soil. Acid hydrolysis was carried out by taking 0.5 g of soil and adding 12.5 mL of 6*M* HCl and heating at $105^{o}$C for 12-16 hours. After the hydrolysis process, tubes were centrifuged at 3000 rpm for 25 minutes and the supernatant was filtered using 0.45 µm pore size syringe filters and termed as Acid Extracts (ACE). Total carbon and nitrogen in all three extracts (CWE, HWE, and ACE) were determined using TOC-L analyzer (Shimadzu Corporation, model- TNM-L-ROHS). These total carbon and nitrogen were considered as organic carbon and organic nitrogen in each extract by considering no inorganic carbon in soil as the pH of the soil was less 6.

### 3.4.3 Soil Microbial Activity.

Soil enzyme activity and microbial biomass carbon were measured from all the grazed and ungrazed treatments in corn-establishment, and post-grazed and corn establishment periods, respectively.

#### 3.4.3.1 Beta-glucosidase enzyme

Beta-glucosidase enzyme activity was determined by placing 1 g of soil in three 50 mL Erlenmeyer flasks and 0.2 mL toluene was added in all the flasks, mixed and let to set for 15 minutes. Then 4 mL of modified universal buffer (MUB) pH 6 were added to all the flasks and 1 mL of 50 mM p-nitrophenyl-β-D-glucoside (PNG) solution was added to only two flasks and third was considered as control. All three flasks were closed with stoppers and incubated for 1 h. After incubation, 1 mL of 0.5*M* $CaCl_2$ and 4 mL of 0.1*M* THAM buffer (pH 12) were added to all three flasks, and 1 mL PNG solution was only added to the control flask. Soil suspensions were filtered and yellow color intensity of the filtered solutions were measured with spectrophotometer set at 405 nm. A calibration curve was developed with standards containing 0, 100, 200, 300, 400, and 500 nmol of p-nitrophenol solution in each flask. The amount of p-nitrophenol released from the soil was determined by using reference to calibration curves was calculated using the following equation:

Beta-glucosidase activity (µmol p-nitrophenol $Kg^{-1}$ soil $h^{-1}$) = (NCS-NCC)*V*T/DW

where, NCS is p-nitrophenol content of sample average (µg $NH_4$-N $mL^{-1}$), NCC is p-nitrophenol content of control (µg $NH_4$-N $mL^{-1}$), V is volume of PNG solution used (1 mL), T is incubation time (1 h), and DW is dry weight of soil taken (1 g).

## 3.5 Statistical Analysis.

Impacts from grazing and cover crop treatments on measured soil parameters were analyzed separately with SAS software (SAS Institute, 2007) using analysis of variance (ANOVA). The Duncan's LSD was used to assess lest significant differences between grazing and cover crops for each depth separately. Statistical differences were stated as significant at the $\alpha = 0.05$ level.

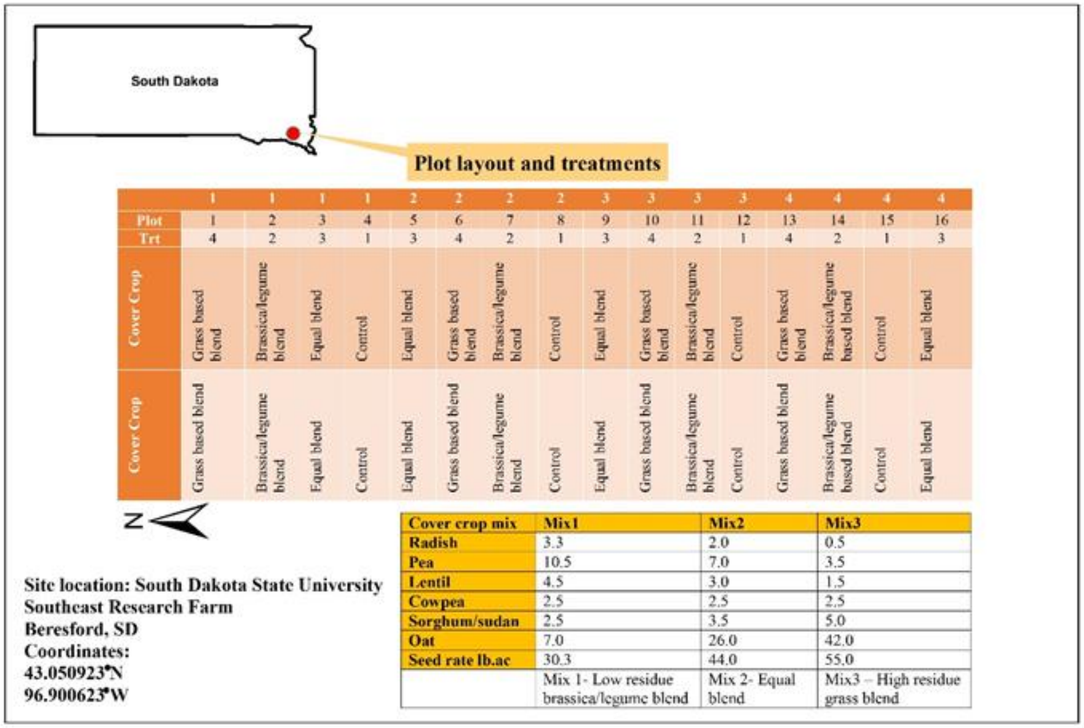


Figure 3.1. Site location, plot layout, and blend mixtures.

CHAPTER 4

RESULTS AND DISCUSSION

## 4.1. Soil pH and Electrical Conductivity

The pH data for all the treatments have been summarized in Table 1a (0 – 5 cm and 5 – 10 cm depths) and Table 1b (10 – 15 cm and 15 – 30 cm depths). Soil pH measured during the pre – grazing varied from 7.05 to 7.19 for the 0 – 5 cm depth, 6.99 to 7.15 for 5 – 10 depth, 6.96 to 7.12 for 10 – 15 cm depth, and 7.05 to 7.20 for 15 – 30 cm depth. It was seen that for all the depths for the pre – grazed samples, there were no significant differences observed across all the cover crop treatments ($P<0.93$). For the 0 – 5 cm depth, it was seen that the highest pH was observed in equal blend (7.19) cover crop treatment while lowest was in control treatment (7.05). A similar trend was observed in all the three other depths (5 – 10, 10 – 15 and 15 – 30 cm). For the post – grazed sampling time, soil pH was measured and it was again observed that no significant differences were observed for the cover crop treatments and the grazing treatment. In addition, for all the depths, no significant differences by depth were observed. The trend was similar for the corn phase soil sampling, with no significant differences in soil pH across the cover crop treatment ($P<0.91$) as well as the grazing treatment ($P<0.72$) for the 0 – 5 cm depth and by depth.

Soil electrical conductivity data has been summarized in Table 2a and 2b for the 0 – 5, 5 – 10 cm and 10 – 15, 15 – 30 cm depths, respectively. Data showed that the electrical conductivity for the pre – grazed sampling time was seen to be least in the control treatment for all the depths while all the cover crop treatments had higher values as compared to the control treatment but no significant differences were observed across the cover crop treatment ($P<0.49$ for 0 – 5 cm; $P<0.7$ for 5 – 10 cm; $P<0.92$ for 10 – 15 cm; $P<0.32$ for 15 – 30 cm). For the post – grazed sampling time, it was observed that the electrical conductivity was higher than the pre – grazed samples but again no significant differences were observed across the treatments and the grazing treatments. For instance, for the surface depth (0 – 5 cm), no significant difference was observed across the cover crop treatment ($P<0.99$) and the grazing treatment ($P<0.14$). Similar was the case for all the other depths. Similar results were observed for the corn phase samples where no significant difference was observed across the cover crop treatments and the grazing treatments for all the depths.

### 4.2. Soil Organic Carbon (SOC), Total Nitrogen (TN), Hot Water Carbon (HWC), Cold Water Carbon (CWC) and Recalcitrant Carbon (RC)

Data for the SOC and TN are summarized in Table 3 and Table 4, respectively. Data on HWC for the 0-5 and 5-10 cm depths measured at different time periods (pregrazing, post -grazing, and corn phase) are shown in Table 5. Cover crops did not significantly impact the HWC for both the depths ($P<0.76$, for 0 – 5 cm; $P<0.31$, for 5 – 10 cm) for the pre-grazed period. For the post – grazed period, it was observed that for the first depth, cover crops significantly impacted the HWC as the grass blend treatment was significantly lower than the other three cover crop treatments ($P<0.02$). Grazing did not significantly impact the HWC for both the depths ($P<0.77$, for 0 – 5 cm; $P<0.54$, for 5 – 10 cm). There was no significant interaction observed between the cover crops and the grazing treatments. For corn phase as well, it was observed that cover crops and grazing did not significantly affect the HWC for both the depths. However, it was observed that ungrazed treatment showed 7% and 5% higher HWC than the grazed for the 0 – 5 cm and 5 – 10 cm depths, respectively.

Ghani, Dexter and Perrott [12] conducted a study in New Zealand which compared different land use systems impacting the hot water carbon fraction and reported that beef/sheep or dairy grazed pastures had very high hot water carbon fractions (approximately 4 – 5 times) when compared to the cropland and gardening soils. HWC is strongly correlated to soil microbial biomass carbon and soil organic carbon [12].

Cold Water Carbon data for the 0 – 5 and 5 – 10 cm depths measured at different time periods (pregrazing, post -grazing and corn phase) are shown in Table 6. For the pre-grazed period, cover crops did not significantly affect the CWC for both the depths ($P<.41$, for 0 – 5 cm; $P<0.96$, for 5 – 10 cm). For the post-grazed period, it was observed that the cover crops ($P<0.15$) and grazing ($P<0.15$) did not significantly affect the CWC for the surface depth. For the 5 – 10 cm depth, it was observed that cover crops did not significantly affect the CWC ($P<0.7$) while grazing significantly impacted the CWC ($P<0.03$) as grazed treatment was 22% higher than the ungrazed treatment. For the corn phase, cover crops and grazing did not significantly impact the CWC at both studied depths. Also, no significant interactions were observed between the cover crops and grazing.

Recalcitrant carbon for the 0 – 5 and 5 – 10 cm depths measured at different time periods (pregrazing, post – grazing and corn phase) are shown in Table 7. For the pre-grazed period, cover crops did not significantly affect RC ($P<0.83$, for 0 – 5 cm; $P<0.12$, for 5 – 10 cm). For the post-grazed period, cover crops did not significantly affect RC ($P<.06$, for 0 – 5 cm; $P<0.07$, for 5 – 10 cm). For the post-grazed period, grazing did not significantly affect RC ($P<0.39$, for 0 – 5 cm; $P<0.07$, for 5 – 10 cm). For the corn phase, cover crops and grazing did not significantly impact the RC at both studied depths, and no significant interactions were observed between the cover crops and grazing.

### 4.3. Soil Microbial Activity (β-glucosidase enzyme and soil microbial biomass)

Soil enzyme, β-glucosidase was analyzed for the samples collected during the corn – phase and the data is summarized in Table 8. The values ranged between 21.39 mg $kg^{-1}$ to 22.89 mg $kg^{-1}$. The highest value was observed in equal blend treatment while the lowest in the legume blend treatment. However, no significant differences were observed across the cover crop treatments. In addition, grazing did not impact the enzyme activity significantly ($P<0.63$), but ungrazed treatment showed numerically higher values than the grazed treatments. No interactions were observed between the cover crops and grazing treatments.

Previous studies have found that no-till management has the ability to bring SOC levels up compared to conventional tillage, while increasing β-glucosidase due to high SOC levels. Stott, Andrews, Liebig, Wienhold and Karlen [14] found that no-till corn with a vetch (*Vicia sativa*) cover crop increased the β-glucosidase activity over no-till corn with no cover crop and continuous corn.

Microbial biomass carbon was analyzed for the samples collected during the post-grazed and corn – phase and the data is summarized in Table 9. The post-grazed samples ranged from 3.57 mg kg$^{-1}$ to 5.40 mg kg$^{-1}$. The highest value was observed in the grass blend while the lowest in the legume blend. However, no significant differences were observed across the cover crop treatments, grazing treatments, or the interactions between the cover crops and grazing treatments. Similarly, the corn – phase yielded similar results in microbial biomass carbon. The values ranged from 6.22 mg kg$^{-1}$ to 8.11 mg kg$^{-1}$, which was an increase in all microbial biomass carbon from the post – grazed sampling. However, no significant differences were observed across the cover crop treatments, grazing treatments, or the interactions between the cover crops and grazing treatments.

Moderate grazing techniques can enhance microbial diversity resulting in a positive effect on microbial activity, resulting in a higher amount of metabolically active microbes [15]. Ghani, Dexter and Perrott [12] reported that soil microbial biomass carbon was significantly higher in the grazed soils when compared to the cropland and other land use types. Similar findings were reported by [16].

4.4. Soil Bulk Density

Soil bulk density was measured for two depths (0 – 5 cm, 5 – 10 cm) and the data is summarized in Table 10. For the pre – grazed sampling event, bulk density did not differ significantly across the cover crop treatments for both the depths ($P<0.6$, for 0 – 5 cm; $P<0.74$, for 5 – 10 cm). Cover crops did not impact the soil bulk density for any depth at any of the sampling time. However, grazing significantly impacted the soil bulk density for 0-5 cm depth during the corn phase, which was planted after grazing. The soil bulk density at this sampling time was lower for ungrazed (1.13 Mg m$^{-3}$) compared to grazed (1.25 Mg m$^{-3}$). A similar trend was observed for the 5-10 cm depth right after the grazing (post grazing period). Grazing (1.36 Mg m$^{-3}$) increased bulk density by 6.2% compared to that of ungrazed (1.28 Mg m$^{-3}$) treatment. Interactions impact of cover crop by grazing on soil bulk density were not significant.

One factor that could affect the soil's susceptibility to compaction would be the moisture percentage.  In the post – grazing and corn – phase sampling times, there were higher moisture percentages.  As moisture percentage increases the soil's strength is decreased and is more prone to compaction [17]. Similar results were observed in Pana, Illinois by Tracy and Zhang [16]. A study conducted in Georgia by Franzluebbers and Stuedemann [18], reported that soil bulk density did not vary significantly in short – term grazing while long – term management may show some significant changes. Similar study conducted by Maughan, Flores, Anghinoni, Bollero, Fernández and Tracy [19] in Pana, Illinois, reported that cattle grazing led to increased soil compaction. Thus, it is evident from the studies mentioned above that presence of cattle impacted the soil bulk density and infiltration rates due to soil compaction due to the cattle.

## 4.5. Soil Water Retention (SWR)

Soil water retention measured across the different pressures and the treatments for the pre – grazing phase is shown in Table 11a, post – grazing phase in Table 11b, and corn phase in Table 11c. Data (0 – 5 cm depth) shown for the pre – grazing phase shows that grass blend had the least water retention at all pressures while the highest was observed in control. There were no significant differences observed across the cover crop treatments. For the second depth (5 – 10 cm depth), again no differences were observed across the treatments at all pressures.

During the post – grazed period (Table 12b), data showed control treatment had highest SWR across all the treatments but no significant differences were observed across all treatments. This means that cover crops did not have any impact on the SWR at all pressures or at any depths. However, it was observed that grazing had significant impact on the SWR for the 0 – 5 cm depth. Ungrazed treatment had a significantly higher SWR than the grazed ones. For the second depth, grazing as well as cover crops did not significantly impact the SWR. There was no interaction observed between the cover crop and grazing treatments.

For the corn – phase, it was observed that cover crops did not significantly impact the SWR at all pressures. However, grazing significantly impacted the SWR with ungrazed having significantly higher SWR than the grazed treatments. No interaction was found between the cover crops and the grazing treatments.

## 4.6. Soil Water Infiltration Rate

Water infiltration rate measurements have been shown in Table 12. Infiltration rate measurements were done during the pre – grazing and the corn phase. Data for the infiltration rate showed that for the pre – grazed period, cover crop treatments did not impact the water infiltration rate ($P<0.63$). Again, for the corn phase period, it was observed that cover crops did not impact the water infiltration rate significantly ($P<0.52$) as well as grazing did not have significant impacts on water infiltration rate ($P<0.12$)

though the infiltration rate in ungrazed treatment was 107% higher than the grazed treatment. There were no interactions observed between the cover crop treatment and the grazing treatment ($P<0.27$). The overall trend was that no significant differences were observed across all treatments.

The lower water infiltration rate in the corn phase could be due to the grazing of animals. The hoof action can decrease soil macropores resulting in less aeration and a higher chance of water-logging [17].

Table 1a. Soil pH as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0-5 and 5-10 cm depths.

| Treatments | Depths (cm) | | | | | |
|---|---|---|---|---|---|---|
| | ------------0-5----------- | | | ------------5-10----------- | | |
| | pH | | | | | |
| | Pre-grazed | Post-grazed | Corn-phase | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | | | | |
| Grass blend | 7.09[a†] | 7.05[a] | 7.11[a] | 6.99[a] | 6.98[a] | 7.03[a] |
| Legume blend | 7.13[a] | 6.87[a] | 7.23[a] | 7.06[a] | 6.94[a] | 7.17[a] |
| Equal blend | 7.19[a] | 6.91[a] | 7.29[a] | 7.04[a] | 7.00[a] | 7.18[a] |
| Control | 7.05[a] | 6.87[a] | 7.25[a] | 7.15[a] | 7.17[a] | 7.08[a] |
| **Grazing (G)** | | | | | | |
| Ungrazed | - | 7.02[a] | 7.25[a] | - | 6.99[a] | 7.16[a] |
| Grazed | - | 6.92[a] | 7.18[a] | - | 7.06[a] | 7.08[a] |
| Analysis of variance (P>F) | | | | | | |
| CC | 0.93 | 0.8 | 0.91 | 0.9 | 0.72 | 0.89 |
| G | - | 0.55 | 0.72 | - | 0.65 | 0.64 |
| CC x G | - | 0.82 | 0.95 | - | 0.96 | 0.99 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.

[††]Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

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Table 1b. Soil pH as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 10-15 and 15-30 cm depths.

| **Treatments** | **Depths (cm)** | | | | | |
|---|---|---|---|---|---|---|
| | ------------10-15----------- | | | ------------15-30----------- | | |
| | pH | | | | | |
| | Pre-grazed | Post-grazed | Corn-phase | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | | | | |
| Grass blend | 6.96[a†] | 6.87[a] | 6.98[a] | 7.06[a] | 7.04[a] | 7.06[a] |
| Legume blend | 7.04[a] | 6.91[a] | 7.05[a] | 7.18[a] | 7.03[a] | 7.05[a] |
| Equal blend | 7.01[a] | 7.03[a] | 7.07[a] | 7.05[a] | 6.99[a] | 7.07[a] |
| Control | 7.12[a] | 7.08[a] | 7.00[a] | 7.20[a] | 7.15[a] | 7.05[a] |
| **Grazing (G)** | | | | | | |
| Ungrazed | - | 7.03[a] | 7.06[a] | - | 7.07[a] | 7.07[a] |
| Grazed | - | 6.91[a] | 6.99[a] | - | 7.03[a] | 7.05[a] |
| Analysis of variance (P>F) | | | | | | |
| CC | 0.8 | 0.54 | 0.98 | 0.64 | 0.4 | 0.99 |
| G | - | 0.29 | 0.65 | - | 0.57 | 0.89 |
| CC x G | - | 0.96 | 0.99 | - | 0.16 | 0.99 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.

[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

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Table 2a. Soil electrical conductivity (EC, µS $cm^{-1}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0-5 and 5-10 cm depth.

| **Treatments** | **Depths (cm)** | | | | | |
|---|---|---|---|---|---|---|
| | ------------0-5----------- | | | ------------5-10----------- | | |
| | Electrical Conductivity (µS $cm^{-1}$) | | | | | |
| | Pre-grazed | Post-grazed | Corn-phase | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | | | | |
| *Grass blend* | 711[a†] | 1074[a] | 1080[a] | 863[a] | 1118[a] | 761[a] |
| *Legume blend* | 813[a] | 1124[a] | 1399[a] | 827[a] | 920[a] | 876[a] |
| *Equal blend* | 901[a] | 1127[a] | 1571[a] | 767[a] | 1057[a] | 1030[a] |
| *Control* | 688[a] | 1104[a] | 1340[a] | 630[a] | 1025[a] | 910[a] |
| **Grazing (G)** | | | | | | |
| *Ungrazed* | - | 1197[a] | 1179[a] | - | 1127[a] | 844[a] |
| *Grazed* | - | 1017[a] | 1516[a] | - | 933[a] | 945[a] |
| Analysis of variance (P>F) | | | | | | |
| CC | 0.49 | 0.99 | 0.61 | 0.7 | 0.92 | 0.66 |
| G | - | 0.14 | 0.21 | - | 0.35 | 0.51 |
| CC x G | - | 0.4 | 0.99 | - | 0.93 | 0.8 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.

[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

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Table 2b. Soil electrical conductivity (EC, µS $cm^{-1}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 10-15 and 15-30 cm depth.

| **Treatments** | **Depths (cm)** | | | | | |
|---|---|---|---|---|---|---|
| | ------------10-15----------- | | | ------------15-30----------- | | |
| | Electrical Conductivity (µS $cm^{-1}$) | | | | | |
| | Pre-grazed | Post-grazed | Corn-phase | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | | | | |
| *Grass blend* | 905[a†] | 1262[a] | 816[a] | 1285[a] | 1535[a] | 761[a] |
| *Legume blend* | 822[a] | 1100[a] | 964[a] | 943[a] | 1030[a] | 876[a] |
| *Equal blend* | 868[a] | 1224[a] | 1096[a] | 979[a] | 1805[a] | 1030[a] |
| *Control* | 728[a] | 1205[a] | 1026[a] | 818[a] | 1308[a] | 910[a] |
| **Grazing (G)** | | | | | | |
| *Ungrazed* | - | 1310[a] | 911[a] | - | 1335[a] | 945[a] |
| *Grazed* | - | 1086[a] | 1040[a] | - | 1504[a] | 844[a] |
| Analysis of variance (P>F) | | | | | | |
| CC | 0.92 | 0.97 | 0.68 | 0.32 | 0.27 | 0.66 |
| G | - | 0.37 | 0.45 | - | 0.55 | 0.51 |
| CC x G | - | 0.59 | 0.56 | - | 0.28 | 0.8 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.
[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.
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Table 3. Soil organic carbon (SOC, g kg$^{-1}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0-5 and 5-10 cm depth.

| Treatments | Depths (cm) | | | | | |
|---|---|---|---|---|---|---|
| | ------------0-5----------- | | | ------------5-10----------- | | |
| | SOC (g kg$^{-1}$) | | | | | |
| | Pre-grazed | Post-grazed | Corn-phase | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | | | | |
| *Grass blend* | 28.96$^{a}$ | - | 28.36$^{a}$ | 22.76$^{a}$ | - | 23.49$^{a}$ |
| *Legume blend* | 30.19$^{a}$ | - | 26.79$^{a}$ | 25.98$^{a}$ | - | 21.74$^{b}$ |
| *Equal blend* | 29.41$^{a}$ | - | 25.93$^{a}$ | 22.57$^{a}$ | - | 21.59$^{b}$ |
| *Control* | 27.90$^{a}$ | - | 26.65$^{a}$ | 22.90$^{a}$ | - | 20.42$^{b}$ |
| **Grazing (G)** | | | | | | |
| *Ungrazed* | - | - | 28.22$^{a}$ | - | - | 22.45$^{a}$ |
| *Grazed* | - | - | 25.64$^{b}$ | - | - | 21.17$^{b}$ |
| | Analysis of variance (P>F) | | | | | |
| CC | 0.77 | - | 0.59 | .30 | - | 0.005 |
| G | - | - | 0.09 | - | - | 0.02 |
| CC x G | - | - | 0.48 | - | - | 0.007 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.

[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

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Table 4. Soil total nitrogen (TN, g $kg^{-1}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0-5 and 5-10 cm depth.

| **Treatments** | **Depths (cm)** | | | | | |
|---|---|---|---|---|---|---|
| | ------------0-5----------- | | | ------------5-10----------- | | |
| | TN (g $kg^{-1}$) | | | | | |
| | Pre-grazed | Post-grazed | Corn-phase | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | | | | |
| *Grass blend* | 2.76$^{a}$ | - | 2.75$^{a}$ | - | 2.34$^{a}$ | 2.37$^{a}$ |
| *Legume blend* | 2.90$^{a}$ | - | 2.81$^{a}$ | - | 2.27$^{a}$ | 2.29$^{a}$ |
| *Equal blend* | 2.84$^{a}$ | - | 2.75$^{a}$ | - | 2.34$^{a}$ | 2.15$^{a}$ |
| *Control* | 2.81$^{a}$ | - | 2.69$^{a}$ | - | 2.34$^{a}$ | 2.28$^{a}$ |
| **Grazing (G)** | | | | | | |
| *Ungrazed* | - | - | 2.66$^{b}$ | - | 2.34$^{a}$ | 2.19$^{a}$ |
| *Grazed* | - | - | 2.83$^{a}$ | - | 2.32$^{a}$ | 2.35$^{a}$ |
| | Analysis of variance (P>F) | | | | | |
| CC | 0.93 | - | 0.72 | - | 0.90 | 0.38 |
| G | - | - | 0.04 | - | 0.78 | 0.10 |
| CC x G | - | - | 0.11 | - | 0.83 | 0.72 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.

[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

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Table 5. Soil carbon (C) fractions (mg $kg^{-1}$) measured using hot water method as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0-5 and 5-15 cm depth.

| **Treatments** | **Depths (cm)** | | | | | |
|---|---|---|---|---|---|---|
| | ------------0-5----------- | | | ------------5-15----------- | | |
| | ----------------------C (mg $kg^{-1}$)---------------------- | | | | | |
| | Pre-grazed | Post-grazed | Corn-phase | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | | | | |
| *Grass Blend*[††] | 20.17[a] | 13.22[b] | 19.65[a] | 14.23[a] | 14.02[a] | 15.19[a] |
| *Legume Blend* | 19.06[a] | 17.81[a] | 19.68[a] | 13.51[a] | 13.07[a] | 15.04[a] |
| *Equal Blend* | 18.32[a] | 18.68[a] | 18.51[a] | 14.56[a] | 13.03[a] | 13.81[a] |
| *Control* | 18.03[a] | 18.12[a] | 18.12[a] | 12.66[a] | 11.69[a] | 12.67[a] |
| **Grazing (G)** | | | | | | |
| *Ungrazed* | - | 17.39[a] | 19.60[a] | - | 13.23[a] | 14.52[a] |
| *Grazed* | - | 16.78[a] | 18.37[a] | - | 12.64[a] | 13.83[a] |
| | | | Analysis of Variance (*P>F*) | | | |
| CC | .76 | 0.02 | 0.69 | .31 | 0.36 | 0.50 |
| G | - | 0.77 | 0.29 | - | 0.54 | 0.60 |
| CC × G | - | 0.41 | 0.90 | - | 0.42 | 0.83 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.

[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

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Table 6. Soil carbon (C) fraction (mg $kg^{-1}$) measured using cold water as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0-5 and 5-15 cm depth.

| **Treatments** | **Depths (cm)** ------------0-5----------- | | | ------------5-15----------- | | |
|---|---|---|---|---|---|---|
| | -----------------------C (mg $kg^{-1}$)---------------------- | | | | | |
| | Pre-grazed | Post-grazed | Corn-phase | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | | | | |
| *Grass Blend*†† | $8.31^{a}$ | $6.80^{ab}$ | $5.31^{a}$ | $5.76^{a}$ | $5.34^{a}$ | $4.17^{a}$ |
| *Legume Blend* | $7.92^{a}$ | $8.24^{a}$ | $5.55^{a}$ | $5.77^{a}$ | $5.69^{a}$ | $4.20^{a}$ |
| *Equal Blend* | $7.37^{a}$ | $7.07^{ab}$ | $4.66^{a}$ | $5.98^{a}$ | $5.44^{a}$ | $3.82^{a}$ |
| *Control* | $8.51^{a}$ | $6.80^{b}$ | $5.40^{a}$ | $5.97^{a}$ | $4.98^{a}$ | $3.70^{a}$ |
| **Grazing (G)** | | | | | | |
| *Ungrazed* | - | $6.89^{a}$ | $5.03^{a}$ | - | $5.96^{b}$ | $4.05^{a}$ |
| *Grazed* | - | $7.57^{a}$ | $5.43^{a}$ | - | $4.77^{a}$ | $3.90^{a}$ |
| | Analysis of Variance (*P>F*) | | | | | |
| CC | 0.41 | 0.19 | 0.31 | 0.96 | 0.73 | 0.58 |
| G | - | 0.19 | 0.26 | - | 0.02 | 0.64 |
| CC × G | - | 0.40 | 0.09 | - | 0.85 | 0.61 |

†Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.

†† Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

Southeast Research Farm, Beresford, SD; 43.049N, 96.902W, Egan Soil Series, Fine-silty, mixed, superactive, mesic Udic Haplustoll

Table 7. Soil carbon (C) fraction (mg $kg^{-1}$) measured using acid hydrolysis as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0-5 and 5-15 cm depth.

| Treatments | Depths (cm) | | | | | |
|---|---|---|---|---|---|---|
| | ------------0-5----------- | | | ------------5-15----------- | | |
| | ----------------------C (mg $kg^{-1}$)---------------------- | | | | | |
| | Pre-grazed | Post-grazed | Corn-phase | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | | | | |
| *Grass blend* | 337.6[a†] | 331.6[a] | 275.0[a] | 306.2[a] | 274.5[a] | 292.0[a] |
| *Legume blend* | 320.1[a] | 317.9[a] | 263.8[a] | 293.8[a] | 301.1[a] | 295.9[a] |
| *Equal blend* | 333.1[a] | 337.7[a] | 280.3[a] | 324.6[a] | 292.7[a] | 311.8[a] |
| *Control* | 322.7[a] | 323.9[b] | 290.2[a] | 323.5[a] | 264.8[a] | 292.8[a] |
| **Grazing (G)** | | | | | | |
| *Ungrazed* | - | 337.6[a] | 257.2[a] | - | 293.8[a] | 306.3[a] |
| *Grazed* | - | 348.7[a] | 296.6[a] | - | 274.0[a] | 291.7[a] |
| Analysis of variance (P>F) | | | | | | |
| CC | 0.83 | 0.06 | 0.64 | 0.12 | 0.07 | 0.89 |
| G | - | 0.39 | 0.14 | - | 0.07 | 0.42 |
| CC x G | - | 0.85 | 0.46 | - | 0.32 | 0.97 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.
[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.
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Table 8. Enzyme Beta-glucosidase (mg $kg^{-1}$) measured as influenced by different cover crops mixtures under grazed and ungrazed treatments for the corn phase.

| **Treatments** | Corn Phase |
|---|---|
| | **Beta-Glucosidase (mg $kg^{-1}$)** |
| **Cover Crops (CC)** | |
| *Grass Blend*†† | 21.74[ab†] |
| *Legume Blend* | 21.39[b] |
| *Equal Blend* | 22.89[a] |
| *Control* | 21.98[a] |
| **Grazing (G)** | |
| *Ungrazed* | 22.12[a] |
| *Grazed* | 21.88[a] |
| Analysis of Variance (*P>F)* | |
| CC | 0.21 |
| G | 0.63 |
| CC × G | 0.52 |

†Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at $P<0.05$.

†† Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

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Table 9. Microbial Biomass Carbon (mg $kg^{-1}$) measured as influenced by different cover crops mixtures under grazed and ungrazed treatments for the post – grazed and corn phase.

| Treatments | ------------0-5 cm----------- | | |
|---|---|---|---|
| | ------------(mg $kg^{-1}$)------------ | | |
| | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | |
| *Grass blend* | - | 5.40[a] | 8.11[a] |
| *Legume blend* | - | 3.57[a] | 6.40[a] |
| *Equal blend* | - | 4.25[a] | 7.04[a] |
| *Control* | - | 5.13[a] | 6.22[a] |
| **Grazing (G)** | | | |
| *Ungrazed* | - | 4.38[a] | 6.73[a] |
| *Grazed* | - | 4.75[a] | 7.48[a] |
| Analysis of variance (P>F) | | | |
| CC | | 0.35 | 0.42 |
| G | | 0.73 | 0.42 |
| CC x G | | 0.65 | 0.58 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.
[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.
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Table 10. Soil bulk density (Mg $m^{-3}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0-5 and 5-15 cm depths.

| **Treatments** | **Depths (cm)** | | | | | |
|---|---|---|---|---|---|---|
| | ------------0-5----------- | | | ------------5-15----------- | | |
| | Bulk Density (Mg $m^{-3}$) | | | | | |
| | Pre-grazed | Post-grazed | Corn-phase | Pre-grazed | Post-grazed | Corn-phase |
| **Cover Crops (CC)** | | | | | | |
| *Grass blend* | $1.18^{a\dagger}$ | $1.19^{a}$ | $1.22^{a}$ | $1.28^{b}$ | $1.32^{a}$ | - |
| *Legume blend* | $1.14^{a}$ | $1.15^{a}$ | $1.21^{a}$ | $1.28^{b}$ | $1.32^{a}$ | - |
| *Equal blend* | $1.14^{a}$ | $1.18^{a}$ | $1.19^{a}$ | $1.26^{b}$ | $1.35^{a}$ | - |
| *Control* | $1.19^{a}$ | $1.17^{a}$ | $1.19^{a}$ | $1.34^{a}$ | $1.31^{a}$ | - |
| **Grazing (G)** | | | | | | |
| *Ungrazed* | - | $1.13^{b}$ | $1.14^{b}$ | - | $1.29^{b}$ | - |
| *Grazed* | - | $1.22^{a}$ | $1.27^{a}$ | - | $1.36^{a}$ | - |
| Analysis of variance (P>F) | | | | | | |
| CC | 0.16 | 0.49 | 0.79 | 0.03 | 0.90 | |
| G | - | <.0001 | <.0001 | - | 0.02 | - |
| CC x G | - | 0.65 | 0.19 | - | 0.89 | - |

†Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.

†† Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

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Table 11a. Soil water retention ($m^3\ m^{-3}$) as influenced by different cover crops mixtures for the 0-5 and 5-10 cm depths during the pre – grazed period.

| **Treatments** | **0 - 5 cm** | | | | | | |
|---|---|---|---|---|---|---|---|
| | ---------------------------$m^3\ m^{-3}$---------------------------- | | | | | | |
| | Pressure (-kPa) | | | | | | |
| | 0.01 | 0.4 | 1.0 | 2.5 | 5.0 | 10.0 | 30.0 |
| **Cover Crops (CC)** | | | | | | | |
| *Grass blend*†† | 0.47[a†] | 0.46[a†] | 0.45[a†] | 0.44[a†] | 0.43[a†] | 0.43[a†] | 0.40[a†] |
| *Legume blend* | 0.50[a] | 0.49[a] | 0.49[a] | 0.48[a] | 0.47[a] | 0.46[a] | 0.43[a] |
| *Equal blend* | 0.51[a] | 0.49[a] | 0.48[a] | 0.47[a] | 0.46[a] | 0.45[a] | 0.42[a] |
| *Control* | 0.51[a] | 0.50[a] | 0.49[a] | 0.48[a] | 0.47[a] | 0.47[a] | 0.44[a] |
| | Analysis of variance (P>F) | | | | | | |
| CC | 0.66 | 0.62 | 0.61 | 0.63 | 0.66 | 0.66 | 0.66 |
| | **5 – 10 cm** | | | | | | |
| **Cover Crops (CC)** | | | | | | | |
| *Grass Blend*†† | 0.45[a] | 0.45[a] | 0.44[a] | 0.43[a] | 0.42[a] | 0.42[a] | 0.39[a] |
| *Legume Blend* | 0.45[a] | 0.47[a] | 0.46[a] | 0.44[a] | 0.44[a] | 0.43[a] | 0.39[a] |
| *Equal Blend* | 0.47[a] | 0.47a | 0.46[a] | 0.45[a] | 0.44[a] | 0.43[a] | 0.41[a] |
| *Control* | 0.46[a] | 0.45[a] | 0.45[a] | 0.44[a] | 0.43[a] | 0.43[a] | 0.39[a] |
| | Analysis of variance (P>F) | | | | | | |
| CC | 0.87 | 0.89 | 0.87 | 0.93 | 0.96 | 0.96 | 0.96 |

†Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.

†† Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

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Table 11b. Soil water retention ($m^3\ m^{-3}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0-5 cm depth during the post – grazed period.

| Treatments | 0 - 5 cm | | | | | | |
|---|---|---|---|---|---|---|---|
| | ---------------------------$m^3\ m^{-3}$---------------------------- | | | | | | |
| | Pressure (-kPa) | | | | | | |
| | 0.01 | 0.4 | 1.0 | 2.5 | 5.0 | 10.0 | 30.0 |
| **Cover Crops (CC)** | | | | | | | |
| *Grass Blend*[††] | 0.43[a] | 0.41[a] | 0.41[a] | 0.39[a] | 0.38[a] | 0.37[a] | 0.33[a] |
| *Legume Blend* | 0.41[a] | 0.39[a] | 0.38[a] | 0.37[a] | 0.36[a] | 0.35[a] | 0.32[a] |
| *Equal Blend* | 0.43[a] | 0.42[a] | 0.41[a] | 0.39[a] | 0.38[a] | 0.37[a] | 0.34[a] |
| *Control* | 0.44[a] | 0.43[a] | 0.42[a] | 0.41[a] | 0.40[a] | 0.38[a] | 0.35[a] |
| **Grazing (G)** | | | | | | | |
| *Ungrazed* | 0.47[a] | 0.45[a] | 0.44[a] | 0.43[a] | 0.41[a] | 0.40[a] | 0.36[a] |
| *Grazed* | 0.38[b] | 0.37[b] | 0.37[b] | 0.36[b] | 0.35[b] | 0.33[b] | 0.31[b] |
| | Analysis of variance (P>F) | | | | | | |
| CC | 0.70 | 0.55 | 0.53 | 0.52 | 0.34 | 0.35 | 0.50 |
| G | <.0001 | <.0001 | <.0001 | 0.0003 | 0.0022 | 0.0004 | 0.001 |
| CC × G | 0.19 | 0.16 | 0.13 | 0.11 | 0.09 | 0.07 | 0.08 |
| | **5 - 10 cm** | | | | | | |
| **Cover Crops (CC)** | | | | | | | |
| *Grass Blend*[††] | 0.44[a] | 0.42[a] | 0.42[a] | 0.40[a] | 0.39[a] | 0.37[a] | 0.33[a] |
| *Legume Blend* | 0.43[a] | 0.42[a] | 0.40[a] | 0.39[a] | 0.38[a] | 0.36[a] | 0.36[a] |
| *Equal Blend* | 0.44[a] | 0.43[a] | 0.42[a] | 0.41[a] | 0.39[a] | 0.38[a] | 0.36[a] |
| *Control* | 0.43[a] | 0.41[a] | 0.40[a] | 0.39[a] | 0.37[a] | 0.35[a] | 0.32[a] |
| **Grazing (G)** | | | | | | | |
| *Ungrazed* | 0.44[a] | 0.42[a] | 0.41[a] | 0.40[a] | 0.39[a] | 0.38[a] | 0.34a |
| *Grazed* | 0.42[a] | 0.42[a] | 0.41[a] | 0.39[a] | 0.38[a] | 0.36[a] | 0.34[a] |
| | Analysis of variance (P>F) | | | | | | |
| CC | 0.76 | 0.76 | 0.67 | 0.68 | 0.63 | 0.51 | 0.34 |
| G | 0.16 | 0.16 | 0.35 | 0.52 | 0.55 | 0.09 | 0.89 |
| CC × G | 0.71 | 0.71 | 0.66 | 0.59 | 0.62 | 0.47 | 0.55 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.
[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.
Southeast Research Farm, Beresford, SD; 43.049N, 96.902W, Egan Soil Series, Fine-silty, mixed, superactive, mesic Udic Haplustoll

Table 11c. Soil water retention ($m^3\ m^{-3}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0-5 cm depth during the corn - phase period.

| Treatments | 0 - 5 cm | | | | | | |
|---|---|---|---|---|---|---|---|
| | Corn - phase | | | | | | |
| | Pressure (-kPa) | | | | | | |
| | 0.01 | 0.4 | 1.0 | 2.5 | 5.0 | 10.0 | 30.0 |
| **Cover Crops (CC)** | | | | | | | |
| *Grass Blend*[††] | 0.58[a] | 0.57[a] | 0.56[a] | 0.55[a] | 0.54[a] | 0.53[a] | 0.51[a] |
| *Legume Blend* | 0.58[a] | 0.57[a] | 0.56[a] | 0.56[a] | 0.55[a] | 0.53[a] | 0.52[a] |
| *Equal Blend* | 0.58[a] | 0.57[a] | 0.56[a] | 0.55[a] | 0.55[a] | 0.53[a] | 0.51[a] |
| *Control* | 0.59[a] | 0.58[a] | 0.57[a] | 0.56[a] | 0.54[a] | 0.53[a] | 0.52[a] |
| **Grazing (G)** | | | | | | | |
| *Ungrazed* | 0.66[a] | 0.64[a] | 0.63[a] | 0.62[a] | 0.61[a] | 0.60[a] | 0.59[a] |
| *Grazed* | 0.52[b] | 0.51[b] | 0.49[b] | 0.48[b] | 0.47[b] | 0.46[b] | 0.44[b] |
| | Analysis of variance (P>F) | | | | | | |
| CC | 0.70 | 0.55 | 0.53 | 0.52 | 0.34 | 0.35 | 0.50 |
| G | <.0001 | <.0001 | <.0001 | 0.0003 | 0.0022 | 0.0004 | 0.001 |
| CC × G | 0.19 | 0.16 | 0.13 | 0.11 | 0.09 | 0.07 | 0.08 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.
[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.
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Table 12. Soil Infiltration Rate (mm $hr^{-1}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments.

| **Treatments** | Pre-Grazed | Corn Phase |
|---|---|---|
| | **Infiltration Rate (mm $hr^{-1}$)** | |
| **Cover Crops (CC)** | | |
| *Grass Blend*[††] | 195[a†] | 42[a] |
| *Legume Blend* | 147[a] | 15[b] |
| *Equal Blend* | 167[a] | 25[ab] |
| *Control* | 137[a] | 30[ab] |
| **Grazing (G)** | | |
| *Ungrazed* | - | 37[a] |
| *Grazed* | - | 19[a] |
| Analysis of Variance (*P>F*) | | |
| CC | 0.45 | 0.21 |
| G | - | 0.06 |
| CC × G | - | 0.33 |

[†]Mean values followed by different lower letters between each treatment (cover crop and grazing) within each depth represent significant differences at P<0.05.

[††] Grass blend includes Oats (*Avena sativa*) 76.4%, Sorghum (*Sorghum × drummondii*)9.1%, Pea (*Pisum sativum*) 6.3%, Cowpea (*Vigna unguiculata*)4.5%, Lentil (*Lens culinaris*) 2.7%, Radish (*Raphanus sativus*)1%; Legume Blend includes Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%, and Equal Blend includes Oats 59.1%, Pea 16%, Sorghum 8%, Lentil 6.8%, Cowpea 5.1%, Radish 5%.

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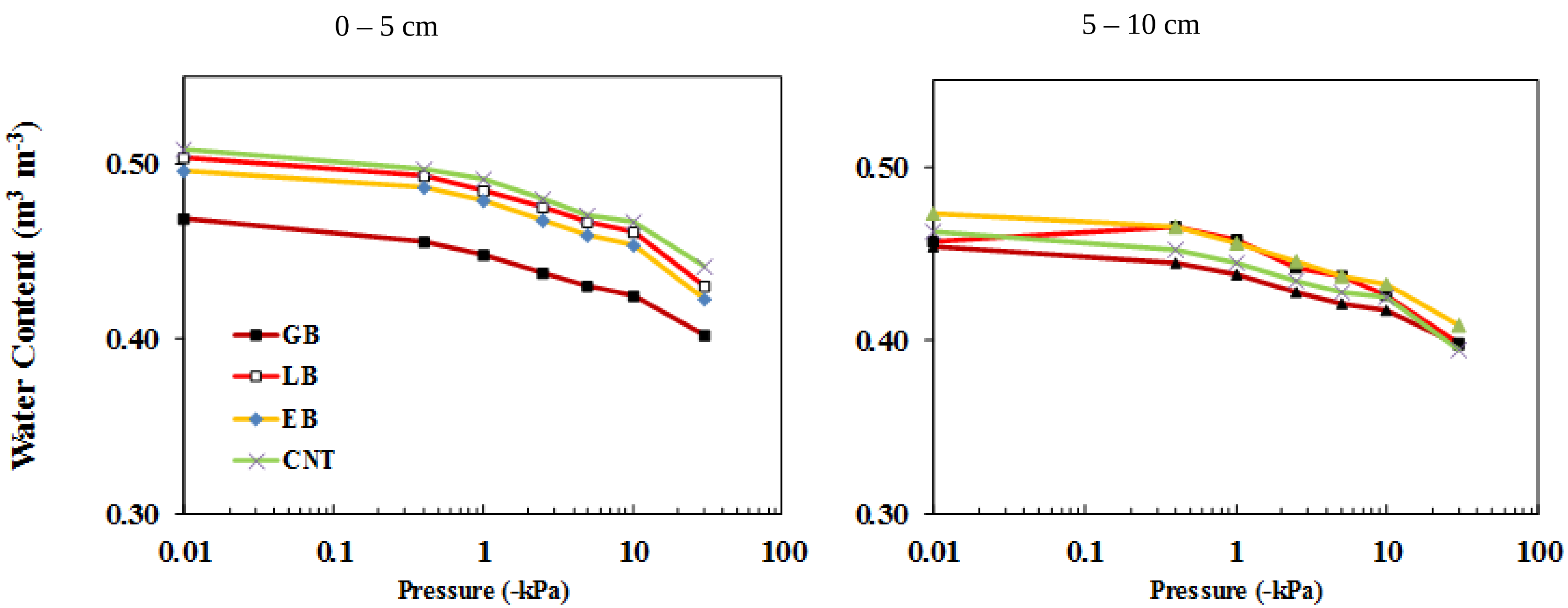


Figure 4.1 Soil water retention ($m^3$ $m^{-3}$) as influenced by different cover crops mixtures for the 0-5 and 5-10 cm depths during the pre – grazed period.

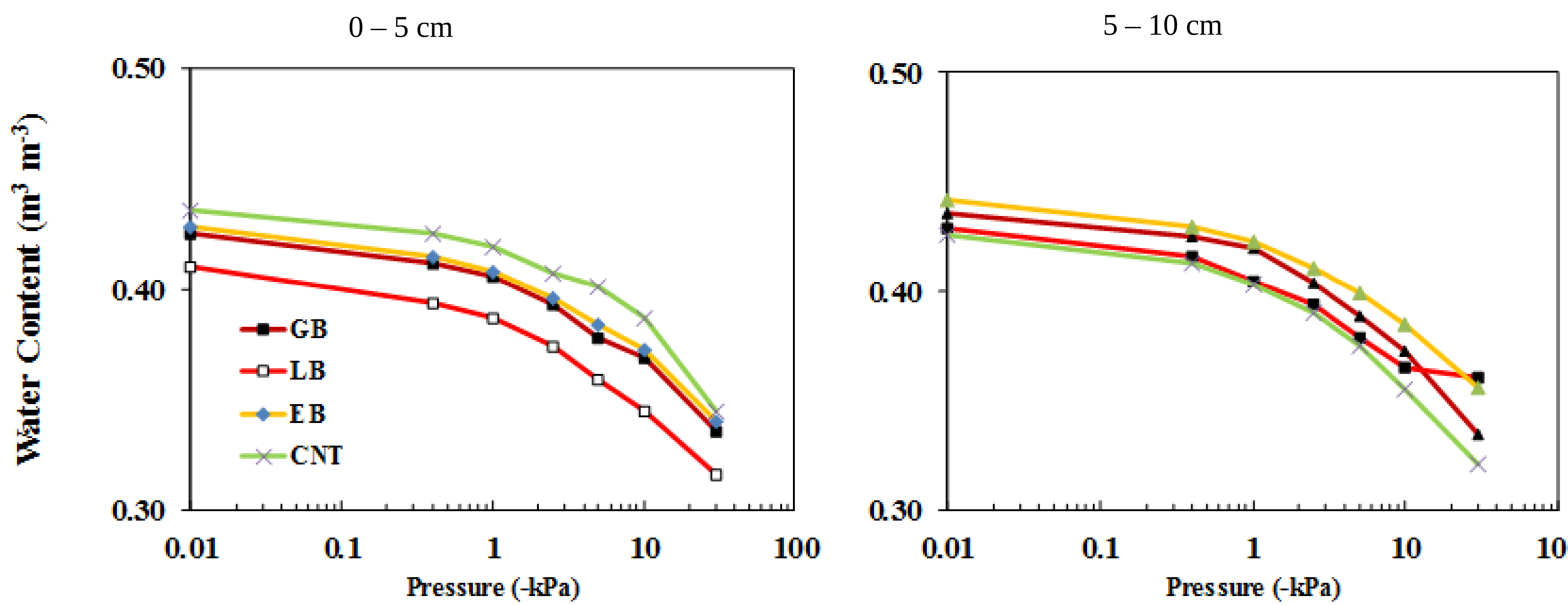


Figure 4.2 Soil water retention ($m^3$ $m^{-3}$) as influenced by different cover crops mixtures for the 0-5 and 5-10 cm depths during the post – grazed period.

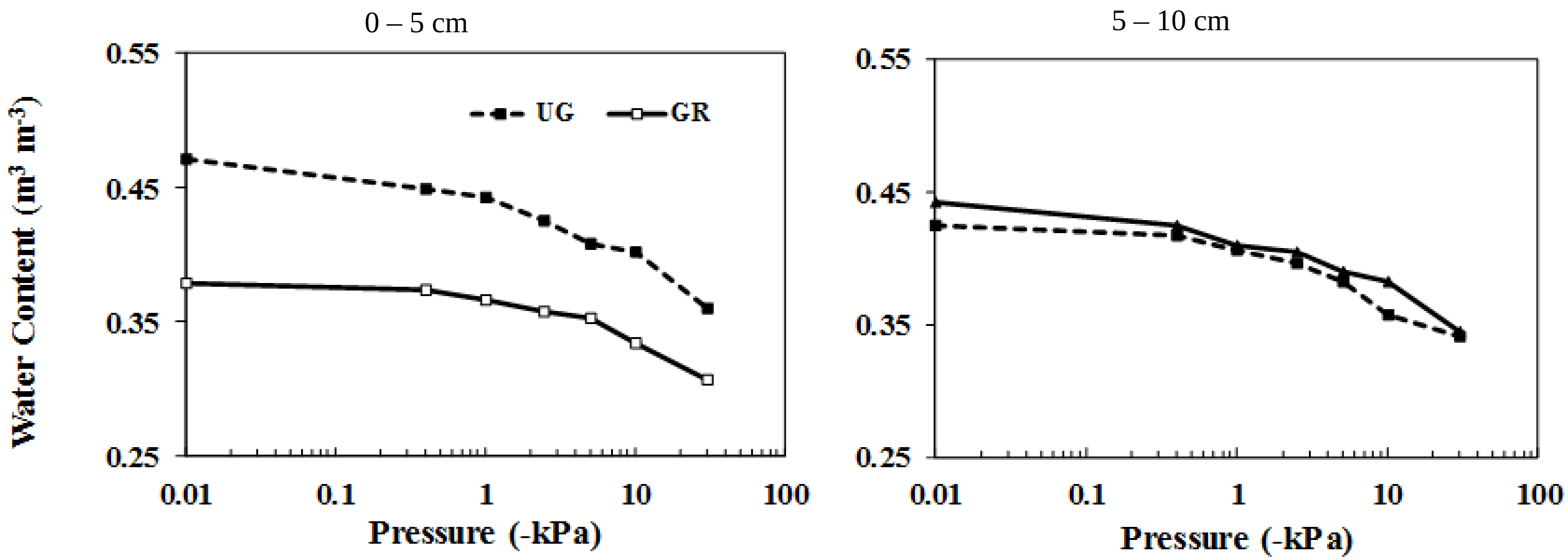


Figure 4.3 Soil water retention ($m^3$ $m^{-3}$) as influenced by different grazing treatments for the 0-5 and 5-10 cm depths during the post – grazed period.

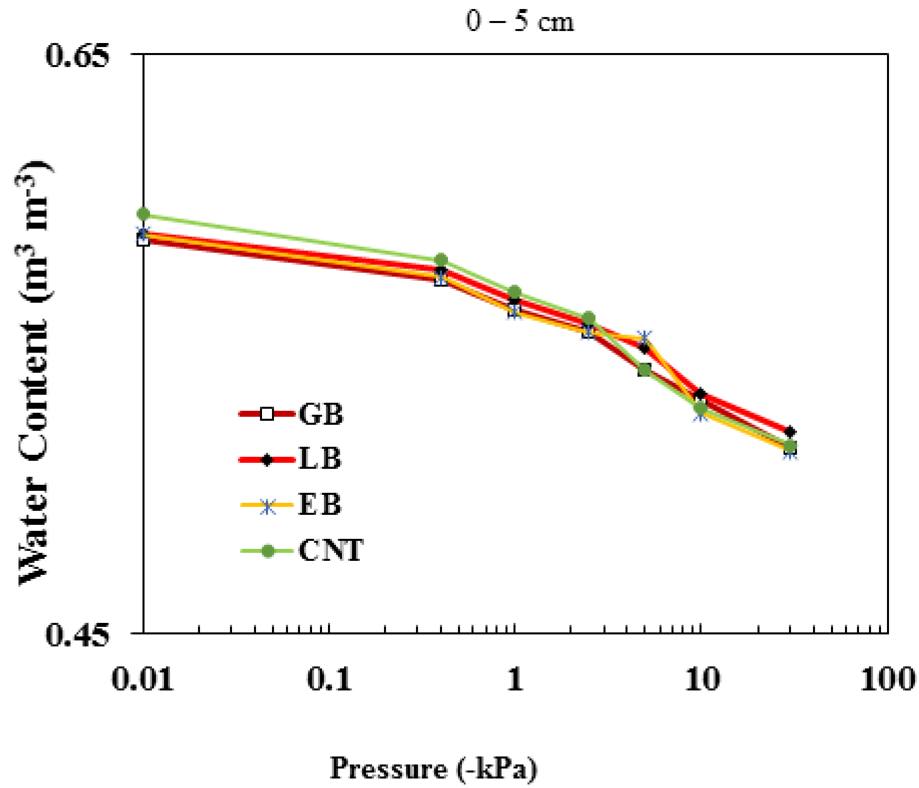


Figure 4.4 Soil water retention ($m^3$ $m^{-3}$) as influenced by different cover crop mixtures for the 0-5 depth during the corn - phase period.

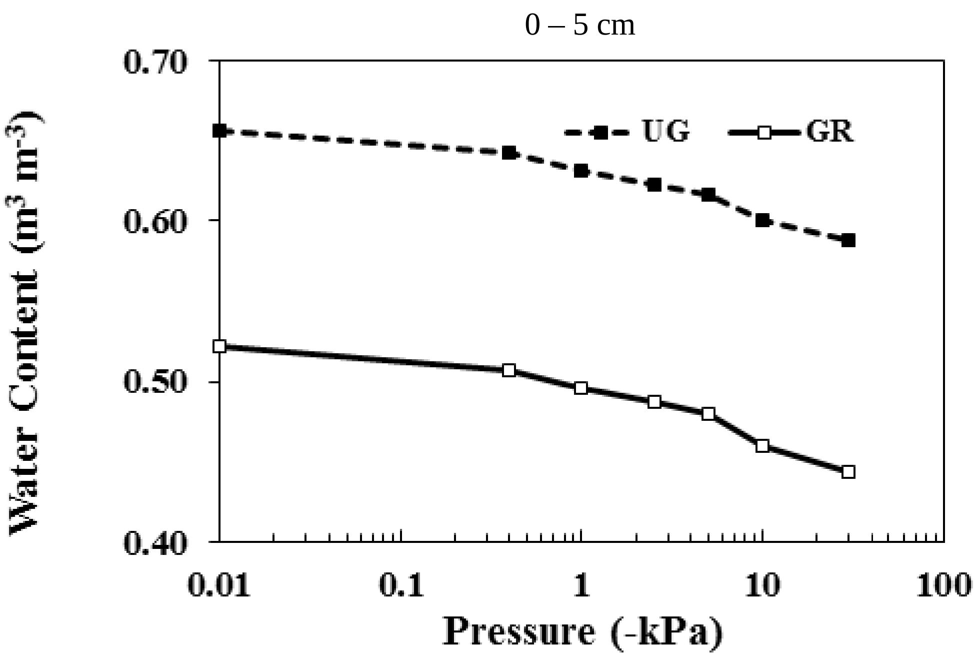


Figure 4.5 Soil water retention ($m^3$ $m^{-3}$) as influenced by different grazing treatments for the 0-5 depth during the corn-phase period.

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# CHAPTER 5

# CONCLUSIONS

Grazing during the growing season can prove to be difficult. Excess moisture can increase the opportunity of compaction of the soil due to hoof traffic. Therefore, it is important to conduct such experiment so we can explore more options during different parts of the growing season and see impacts of grazing on soil properties. This present study has helped us to understand how grazing cattle during the fall season can affect certain soil properties which in-turn affect the soil health.

Results from this study concluded that if we manage proper grazing techniques (40 – 60% biomass removal), soil properties are not negatively impacted by grazing due to the vegetation barrier between hoof and soil. One problem with fall grazing of crops include the chance of having moist soils which could increase the chance of compaction. Moisture acts as a lubricant between the soil particles resulting in a lower percentage of macropores and an increase of micropores. Moreover, an increase in bulk density was observed at the 5 – 10 cm depths after grazing compared to non-grazing. Infiltration rate observations also show a major change during the corn – phase.

Carbon sequestration can have favorable effects on fertility and crop production. Though no major changes were found in the recalcitrant carbon, hot water, and cold water carbon fractions in the corn – phase which was followed by grazing cover crops, there was an increase in the amount of microbial biomass carbon of nearly 34%.

Previous studies have shown that integrated crop-livestock systems are beneficial in a long term rotation. Though some properties were negatively impacted during this short-term study, further studies in the long-term effect of grazing cover crops can help us understand how the properties may be positively impacted. Data from this study suggest studies to also look at different landscape positions, different grazing periods, and different cover crop mixes to help us better understand the effect of integrated crop-livestock systems on soil health and on the environment.

APPENDIX


Figure A.1. Soil Auger sampling from 30 cm soil depth

Figure A.2 Double ring infiltration rate method for measuring water infiltration

Figure A.3 Cattle grazing cover crop treatments, November 13, 2015

Figure A.4 Hoof Marks after removal of cattle, November 13, 2015

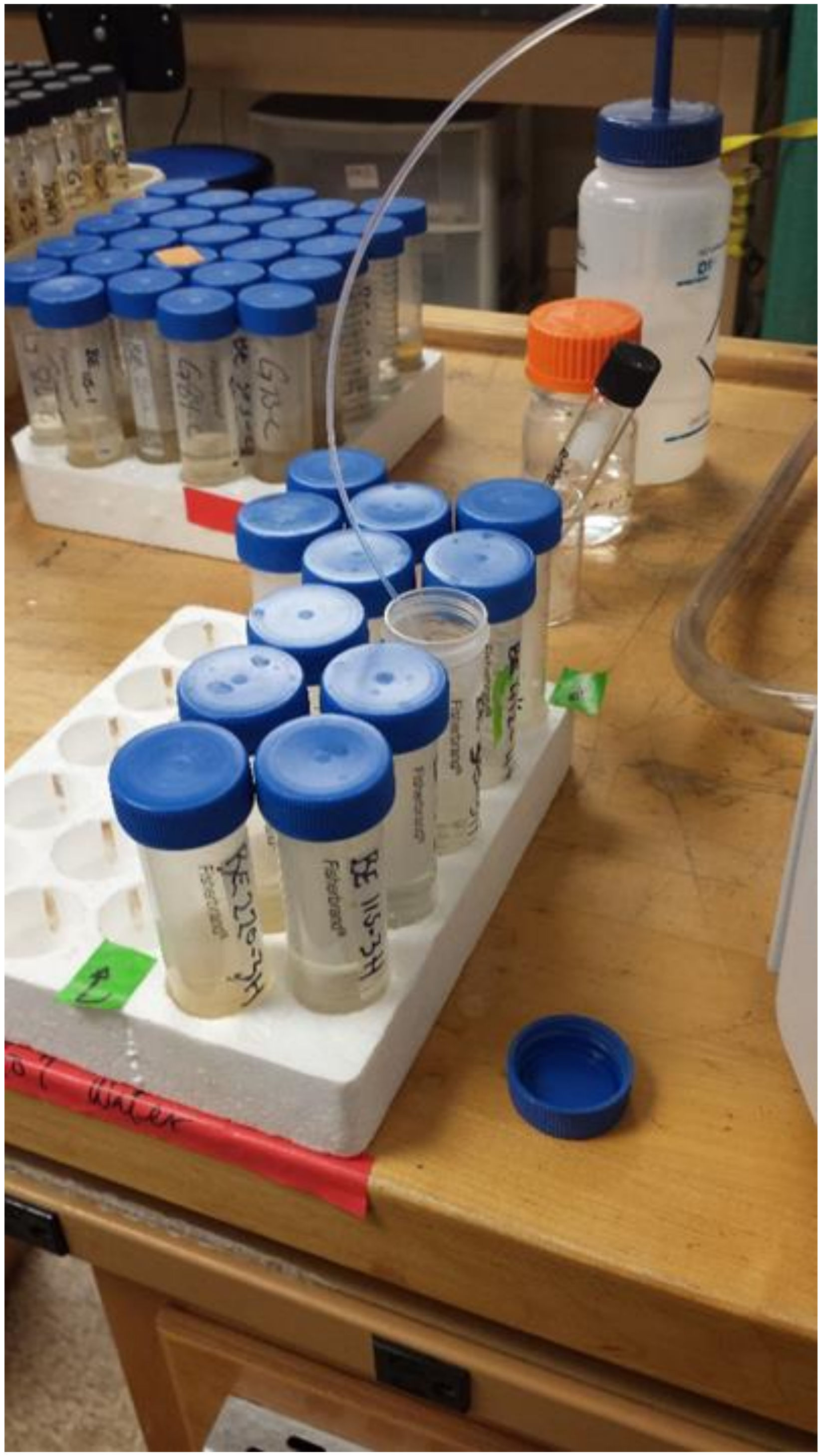

Figure A.5. Carbon Fraction Analysis

Figure A.6. Corn seeded into winter rye regrowth

Figure A.7 Corn seeded into winter rye regrowth

Figure A.8. Soil auger samples taken July 1, 2016 (corn – phase)

VITA

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