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Demonstrating Short-Term Impacts of Grazing and Cover Crops on Soil Health and Economic Benefits in an Integrated Crop-Livestock System in South Dakota

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Abstract

Integrated crop-livestock system (ICLS) is an alternative that can help in intensifying food production while benefiting the environment. However, the assessments of the impacts of ICLS on the soil and economic benefits relative to specific environments in South Dakota are still lacking. This study was to assess the effects of ICLS on soil health and economic benefits under a corn (*Zea mays* L.)-soybean (*Glycine max* L.)-rye (*Secale cereale* L.) rotation in South Dakota. Cover crops blends were planted after the rye crop, and grazing treatments (with and without) were applied after the cover crops establishment in 2015-2016. Data from this study indicate that most soil properties are not negatively impacted by grazing. However, the grazing increased soil bulk density (BD) and decreased soil organic carbon (SOC) and soil water retention (SWR) compared with the ungrazing. The effect of grazing on corn yield was not significant. The cover crops did not impact the pH, electrical conductivity (EC), total nitrogen (TN), β-glucosidase, acid hydrolysis carbon fraction, microbial biomass carbon, and SWR, but impacted the SOC, hot/cold water carbon fraction, BD, infiltration rate (q_s) in some phases and depths. The effects of different cover crop blends on corn yield were not as strong. The economic analysis showed that implementing ICLS increased the profit of the farm by \$17.23 ac^{-1} in the first year and \$43.61 ac^{-1} in the second year. These findings indicate that ICLS practices with proper management benefit soil health and producer income.

Keywords

Grazing, Corn, Rye, Cattle, Carbon, Nitrogen, Soil Physics, Soil Carbon

1. Introduction

Crop and livestock production dominate in South Dakota [1], with the eastern portion of the state in crop production while the western portion is mainly rangeland, pastureland and cattle production. In recent years, there has been a conversion of pasture and rangelands into croplands due to increased commodity prices [2]. This acreage reduction has increased pressure on native rangeland and pasturelands, resulting in more stress on vegetation 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 crop varieties are used, especially wheat (*Triticum aestivum* L.) and rye (*Secale cereale* L.) [3]. Soil moisture is limited in the state, thereby, the range of conservation practices is used to conserve moisture to improve the crop productivity [4]. The no-till (NT) practice is the most commonly used soil moisture conserving management technique that is used in much of South Dakota. It can help the producers reduce soil moisture losses by leaving the residue to act as a buffer between the sun's rays and the soil surface [5].

Integrated crop-livestock systems (ICLSs) have been on the rise in recent years [6] because the ICLSs can increase diversification, and enhance soil fertility and carbon (C) sequestration due to manure addition directly back to the soil [7]. The ICLSs are common throughout the world with numerous economic benefits such as decreasing costs of transporting feed, and animal manure, decreasing labor hours and reduced manure storage costs [8]. However, one myth that many producers have is that grazing cattle on no-till (NT) cropland will damage some soil properties and in turn lead to lower crop yields [9] [10]. The overall goal was to help to determine if grazing livestock on cover crops has a short-term impact on soil health and if the ICLS increases the producer incomes.

Integrated crop livestock systems implementation can alleviate grazing pressure on native rangeland. Also, adding cover crops to the ICLS allows grazing animals to graze green vegetation in the late fall when rangeland forage becomes less palatable and nutritious. However, farmers are most concerned about the economic benefits of the ICLS. Short-term economic profitability is an important factor for producers to consider when making decisions [11]. Despite many known beneficial attributes of cover crops, its adoption has been limited [12].

One of the reasons that producers failed to adopt the cover crops is due to the extra costs such as cover crop planting and termination and potential yield reduction from the subsequent cash crops. Government subsidy could serve as an incentive and a survey in the US corn belt found approximately 56% of producers indicating willingness to plant cover crops if cost sharing is available [13]. In addition, grazing cover crops by cattle provide another option to offset cover crop costs and increase farm revenue [14]. Therefore, the assessment of economic profitability from the ICLSs can provide information that facilitates farmers' decision making.

Existing literature that compares economic performances of different farming practices has arrived at contrasting conclusions. Some studies have reported the ICLS improves economic returns [14] [15]. In contrast, Ryschawy *et al.* (2012) assessed the economic performances of farming systems on 48 farms in southern Europe and found the ICLS did not significantly increase gross margins compared to specialized farms [16]. Therefore, it is important to evaluate the economic benefits of ICLS on a regional basis, providing more reliable profitability information to producers in this region.

Therefore, the specific objectives of the present study were to 1) assess the impacts of ICLSs on soil surface physical and hydrological properties, 2) evaluate the short-term changes in soil C and N fractions as affected by grazing, cover crops, and grazed cover crops in an ICLS, 3) evaluate the impacts of cover crop composition, grazing, and N fertilization on the corn yield, and 4) assess the economic impact of implementing ICLS.

2. Materials and Methods

2.1. Study Site and Experimental Design

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. 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). These plots were established in 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.

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 (fallow). Treatments include: 1) 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%]; 2) Legume blend (Pea 34.6%, Oats 23.3%, Lentil 14.8%, Radish 10.9%, Cowpea 8.2%, Sorghum Sudan 8.2%); and 3) 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.

Corn (P8673AM) was direct seeded on 16 June 2016. Nitrogen (N) fertilizer treatments of 0 and 90 lb N ac^{-1} (applied pre-emergence as UAN) were imposed in 30' wide strips across each grazing block. At harvest, the N plots were harvested using a 4-row plot combine (Kincaid model 2065) with a harvest sample of 15' (4 rows) by 25' in length. One of the four replications was dropped from the analysis because of excessively wet conditions in that block.

2.2. Data Measurement

Pre-grazing intact soil core samples were collected on November 2, 2015, before grazing 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 (BD) 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 soil organic carbon (SOC) concentration, total nitrogen (TN), and soil C and N fractions (microbial, labile, recalcitrant) were analyzed from only the first two depths (0 - 5 and 5 - 10 cm) to determine the short-term impact. Four replicated samples from each plot were extracted and mixed together to make a composite sample to represent the plot. Soil samples were air-dried, ground, and sieved to pass through a 2-mm sieve. Post-grazing soil samples were collected on November 13, 2015, one day after cattle had been removed. Soil samples in corn phase were collected on July 1, 2016.

Bulk density for the 0 - 5 and 5 - 10 cm depths was determined using the core method [17]. 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 [18]. Soil water retention (SWR) was measured using tension and pressure plate extractors [19], 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 [20]. 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 ($Mg \cdot ha^{-1}$) for 2015 was also computed using the equation given by Ellert and Bettany (1995) [21]. 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 [22]. C fractions (labile, recalcitrant, and inert) and N fractions (labile, recalcitrant, and inert) were analyzed using cold water, hot water, and acid extraction methods described by Ghani *et al.* (2003) and Silveira *et al.* (2008) [23] [24]. Total carbon and nitrogen in all three extracts [cold-water extracts (CWE), hot water extracts (HWE), and Acid Extracts (ACE)] were determined using TOC-L analyzer (Shimadzu Corporation, model-TNM-L-ROHS). *β*-glucosidase enzyme activity was determined by the method of Eivazi and Tabatabai (1988) [25]. The substrate analogue *para*-nitrophenyl-*β*-d-glucopyranoside (*p*NPG) was used in the method. The amount of *para*-nitrophenol (*p*NP) released from the soil was determined by using a reference to calibration curves was calculated using the following equation:

$$\beta\text{-glucosidase activity}\left(\mu\text{mol } para\text{-nitrophenol Kg}^{-1}\text{ soil h}^{-1}\right)$$
$$=(\text{NCS}-\text{NCC})*\text{V}*\text{T}/\text{DW}$$

where NCS is the *para*-nitrophenol content of sample average (μg NH_4-N mL^{-1}), NCC is the *para*-nitrophenol content of control (μg NH_4-N mL^{-1}), V is the volume of PNG solution used (1 mL), T is incubation time (1 h), and DW is the dry weight of soil taken (1 g) [25].

2.3. Economic Analysis

A partial budgeting analysis in this study was conducted to assess the economic impact of implementing ICLS. The word "partial" indicates that only costs and returns varying as a consequence of implementing new practice need to be considered in the analysis [26] [27]. Partial budgeting allows assessing the economic impact without knowing all the costs and returns information [28].

2.4. Statistical Analysis

Impacts from grazing and cover crop treatments on measured soil parameters were analyzed separately using all pairwise differences method by a mixed model estimated by the GLIMMIX procedure in SAS9.4 (SAS, 2013). Yield data were analyzed using standard ANOVA for a split-split plot design with the GLM procedure in SAS9.4 (SAS, 2013). Statistical differences were stated as significant at $\alpha = 0.05$ level.

3. Results and Discussion

3.1. Soil pH and Electrical Conductivity (EC)

The pH data for all the treatments have been summarized in **Table S1**. Soil pH measured during the pre-grazed period 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. For all the depths in the pre-grazed period, there were no significant differences observed across all the cover crop treatments ($P < 0.93$). For the 0 - 5 cm depth, the highest pH was observed in the equal blend (7.19) cover crop treatment while the lowest was in the 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, no significant differences in soil pH were observed for the cover crop treatments and the grazing treatment. The trend was similar for the corn phase, 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. These agreed with the observations of Martins *et al.* (2014) and da Silva *et al.* (2014) [29] [30]. Soil pH is a predictor of various chemical activities within the soil (acidity, neutral, or alkalinity). Many crops including corn grow best when soil pH is close to neutral (pH 6 to 7.5) [31]. Because the mean pH values under all treatments at all depths were from 6.87 to 7.19, which belong to the best range of crop growth, the introduction of cover crops and grazing into the cash crop rotations did not impact soil acidity.

EC data has been summarized in **Table S2** for the 0 - 5, 5 - 10, 0 - 15, and 15 - 30 cm depths. Data showed that the EC for the pre-grazed was 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 in the cover crop treatment ($P < 0.49$ for 0 - 5 cm; $P < 0.7$ for 5 - 10 cm; $P < 0.92$ for 10 - 5 cm; $P < 0.32$ for 15 - 30 cm). For the post-grazed period, The EC was higher than the pre-grazed but no significant differences were observed across the cover crop treatments and the grazing treatments. Similar was the case for all the other depths. For the corn phase, no significant difference in EC was also observed across the cover crop and grazing treatments for all the depths. The grazing effects on EC in this study agreed with the previous studies [32] [33]. However, Lenssen *et al.* (2013) reported that EC under the grazing in fallow (0.35 $dS \cdot m^{-1}$) in wheat-summer fallow rotations was significantly lower than that for the tilled fallow (0.43 $dS \cdot m^{-1}$) [34]. Soil EC is a measure of the ability of the solution to conduct electricity, which indicates the presence or absence of salts. The threshold EC is 1.7 $dS \cdot m^{-1}$ for corn, 5.6 $dS \cdot m^{-1}$ for soybean, 11.4 $dS \cdot m^{-1}$ for rye, and 6.0 $dS \cdot m^{-1}$ for wheat [35]. All means of EC values at different treatments for all four depths were less than 1.7 $dS \cdot m^{-1}$ except for the equal blend at the 15 - 30 depth (1.81 $dS \cdot m^{-1}$), but the following crop corn field had 1.03 $dS \cdot m^{-1}$ (**Table S2**). Therefore, the grazing and cover crops did not affect the crops' growth in terms of the EC observations.

3.2. 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 1** and **Table 2**, respectively. They were significantly affected by the cover crops and grazing in the corn phrase (the data in the post-grazed period were missing). In the corn phrase, mean SOC contents in the ungrazed (28.22 and 22.45 $g \cdot kg^{-1}$) were significantly higher than that for the grazed (25.64 and 21.17 $g \cdot kg^{-1}$) at the 0 - 5 and 5 - 10 cm depths, respectively. Mean SOC contents in the grass blend (23.49 $g \cdot kg^{-1}$) was significantly higher than that for the legume blend (21.74 $g \cdot kg^{-1}$), equal blend (21.59 $g \cdot kg^{-1}$), and control (20.42 $g \cdot kg^{-1}$) at the 5 - 10 cm depth (**Table 1**). Mean TN contents in the ungrazed (2.66 $g \cdot kg^{-1}$) were significantly lower than that for the grazed (2.83 $g \cdot kg^{-1}$) at the 0 - 5 depth in the corn phase (**Table 2**). The grazing increasing SOC (it differs from the results of this study) and TN concentrations in the ICLS have demonstrated by many previous studies [36] [37] [38]

Table 1. 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	SOC (g·kg^{-1})			
	Depths (cm)			
	0 - 5		5 - 10	
	Pre-grazed	Corn-phase	Pre-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	0.3	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.

Table 2. 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	TN (g·kg^{-1})			
	Depths (cm)			
	0 - 5		5 - 10	
	Pre-grazed	Corn-phase	Pre-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	0.9	0.38
G	-	0.04	0.78	0.1
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.

[39]. In this study, the grazing effects on TN due to cattle manure [7] can last till the corn phase. However, the effects on SOC could not be maintained till the corn phase because of soil distribution due to tillage for planting and other factors. This distribution may reduce the SOC concentration. Total SOC can be divided into two parts: 1) old SOC, which is mainly humic substances and is relatively stable, and 2) new input organic C, which comes from cover crops (shoots, roots, root senescence, and exudates) and is easily decomposed and thus a major microbial C source [40], resulting in increase of microbial production derived from the binding agents [41] [42]. In this study at the 5 - 10 cm depth, the input of organic C material came only from root exudates and root dieback materials during the cover crops' growing.

Data on HWC and CWC for the 0 - 5 and 5 - 10 cm depths measured at different time periods are shown in **Table 3**. For the post-grazed period, cover crops significantly impacted the HWC as the grass blend treatment was transiently lower than the other three cover crop treatments (including control) at the first depth ($P < 0.02$). This differs from the previous results of a study that showed that the cover crops increased soil labile organic C pools [43]. There was no significant interaction observed between the cover crops and the grazing treatments. For the 5 - 10 cm depth, the grazing significantly impacted the CWC ($P < 0.03$) as grazed treatment was 22% higher than the ungrazed treatment. Also, no significant interactions were observed between the cover crops and grazing (**Table 3**). The cover crops and grazing did not significantly affect Recalcitrant carbon in the three periods and the two depths (**Table S3**). HWC contents in soils are strongly correlated with CO_2 evolution which would indicate that a proportion of the HWC must be easily available for microbial utilization. The HWC is a component of the labile soil organic matter (SOM) and closely related to soil microbial biomass and micro-aggregation. Therefore, it can be used as one of the soil quality indicators in soil-plant ecosystems [23]. In this study, the grass blend had transiently lower HWC, which indicated that the soil quality under the grass blend was lower than that for other three treatments at that time. Cold water extraction methods were introduced in the late 1980s to estimate easily mineralizable SOM in the different fields [44]. Labile soil C pools have been suggested as sensitive indicators of SOM changes [44].

3.3. Soil Microbial Activity: β-Glucosidase Enzyme and Soil Microbial Carbon (MBC)

Soil enzyme, β-glucosidase, was analyzed for the samples collected during the corn phase and the data are summarized in **Table 4**. The values ranged between 21 $mg \cdot kg^{-1}$ to 22 $mg \cdot kg^{-1}$. The highest value was observed in equal blend treatment while the lowest in the legume blend treatment. However, no significant differences in the enzyme activities were observed among the cover crop treatments and. No interactions were observed between the cover crops and grazing treatments. Previous studies have found that no-till management can bring SOC

Table 3. Soil carbon (C) fractions (mg·kg^{-1}) measured using hot and cold water methods as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0 - 5 and 5 - 15 cm depths.

Treatments	Hot Water C Fraction (mg·kg^{-1})					
	Depths (cm)					
	0 - 5			5 - 10		
	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	0.76	0.02	0.69	0.31	0.36	0.5
G	-	0.77	0.29	-	0.54	0.6
CC × G	-	0.41	0.9	-	0.42	0.83
	Cold Water C Fraction (mg·kg^{-1})					
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	-	0.4	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.

Table 4. Enzyme Beta-glucosidase (mg·kg^{-1}) measured as influenced by different cover crops mixtures under grazed and ungrazed treatments for the corn phase.

Treatments	Beta-Glucosidase (mg·kg^{-1})
	Depth (cm)
	0 - 5
	Corn-Phase
Cover Crops (CC)	
Grass Blend	21.74^{a†}
Legume Blend	21.39^{a}
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.

levels up compared to conventional tillage while increasing *β*-glucosidase due to high SOC levels. For example, Stott *et al.* (2010) 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 [45]. The *β*-glucosidases are required by organisms (some fungi, bacteria) that can consume it. These enzymes are powerful tools for degradation of plant cell walls by pathogens and other organisms consuming plant biomass. Enzyme activities are widely used as reliable soil quality indicators [46] because they are closely related to important soil properties such as organic matter content, soil physical properties, and microbial activities or biomass [47]. Therefore, the soil enzymes have ecological significance and are more sensitive to environmental stress and respond rapidly to changes in land management [48]. Grazing did not impact the enzyme activity significantly in this study (**Table 4**).

MBC for the post-grazed and corn phase are summarized in **Table S4**. MBC in the post-grazed 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 in 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 in the cover crop treatments, grazing treatments, or the interactions between the cover crops and grazing treatments. This differs from the previous results that showed that soil MBC was significantly higher in the grazed soils when compared to the cropland and other land use types [23]. Similar findings were reported by Tracy and Zhang (2008) [49]. In fact, only the moderate grazing techniques can enhance microbial diversity, resulting in a positive effect on microbial activity and a higher amount of metabolically active microbes [50].

3.4. Soil Bulk Density (BD) and Water Infiltration Rate (q_s)

BD at the 0 - 5 and 5 - 10 cm depths is summarized in **Table 5**. For the pre-grazed period, BD 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 BD for any depth at any of the sampling time. However, grazing significantly impacted the BD for 0 - 5 cm depth during the corn phase, which was planted after grazing. The BD 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-grazed period). Grazing (1.36 Mg·m^{-3}) increased BD by 6.2% compared to that of ungrazed (1.28 Mg·m^{-3}) treatment. Interactions impact of the cover crop by grazing on BD was not significant. Measurements of q_s have been shown in **Table S5**. Data showed that for the pre-grazed period, cover crop treatments did not impact the q_s ($P < 0.63$). For the corn phase period, cover crops also did not impact the q_s significantly ($P < 0.52$), as well as grazing, did not have significant impacts on water infiltration rate ($P < 0.12$). There were no significant effects of interactions between the cover crop treatment and the grazing treatment ($P < 0.27$). The overall trend was no significant differences across all treatments.

Previous studies have reported that the grazing can increase BD [32] [34] [51] [52], which results in soil compaction, negatively affecting soil water and crop growth. Therefore, the balance of the soil compaction from the grazing and the effects of the compaction on soil water and crop growth is a key aspect of the land management [53]. One factor that could affect the soil's susceptibility to compaction would be the moisture percentage. In the post-grazed 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 [51]. Similar results were observed in Pana, Illinois by Tracy and Zhang (2008) [49]. However, another study conducted in Georgia by Franzluebbers and Stuedemann (2008) who reported that BD did not vary significantly in short-term grazing while long-term management may show some significant changes [54]. A similar study conducted by Maughan *et al.* (2009) in Pana, Illinois, reported that cattle grazing led to increased soil compaction, but the soil

Table 5. 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	Bulk Density (Mg·m^{-3}) Depths (cm) 0 - 5			5 - 10	
	Pre-grazed	Post-grazed	Corn-phase	Pre-grazed	Post-grazed
Cover Crops (CC)					
Grass Blend	1.18^{a†}	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	0.9
G	-	<0.0001	<0.0001	-	0.02
CC × 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.

compaction did not negatively influence corn yield, in part because any significant soil compaction was eliminated by annual tillage [55]. In this study, it is evident that presence of cattle increased the soil bulk density due to soil compaction grazed by the cattle. Similarly, the trend for lower water infiltration rate in the corn phase could be due to the grazing of animals through which the hoof action can decrease soil macropores, resulting in less aeration and a higher chance of water-logging [51]. However, the compaction by the grazing can be alleviated through tillage, rotation, cover crops, or the use of no-till management in the ICLSs with cycles of annual freeze/thaw and wet/dry [38].

3.5. Soil Water Retention (SWR)

SWR measured across the different pressures and the treatments are shown in **Table S6**, **Figure 1** and **Figure 2**, **Figure S1** and **Figure S2**. Data at the 0 - 5 cm depth for the pre-grazing period shows that the grass blend had the least water retention at all pressures while the highest was observed in control. For the 5 - 10 cm depth, no differences were also observed across the treatments at all pressures (**Table S6(a)**). Soil water retention during the post-grazed period, data showed no significant differences 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 a significant impact on the SWR for the 0 - 5 cm depth. Ungrazed treatment had a significantly higher SWR than the grazed ones at the 0 - 5 cm depth. For the second depth, grazing and cover crops did not significantly impact the SWR. There was no interaction observed between the cover crop and grazing treatments (**Table S6(b)**). 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 at the 0 - 5cm depth. No interaction was found between the cover crops and the grazing treatments (**Table S6(c)**). SWR under the cover crops and grazing treatments in the three periods had down toward curves with increasing pressure (-kPa) (**Figure 1** and **Figure 2**, and **Figures S1-S3**). The grazing effects on SWR in this study have been reported by previous studies [56] [57]. This is primarily because 1) pore size distribution in the top soil can be altered by a decrease of pore volume due to grazing, thereby reducing soil water retention [58] [59]. 2) The finer soil texture in the ungrazing fields than the grazing plots may retain more water. 3) The grazing can largely destroy the vegetation coverage, resulting in wind and water erosion [60] and causing a higher evaporation but a less transpiration [61]. 4) The higher SOC in the ungrazing fields (**Table 1**) has a high capacity to retain water, generally improving the water retention [62].

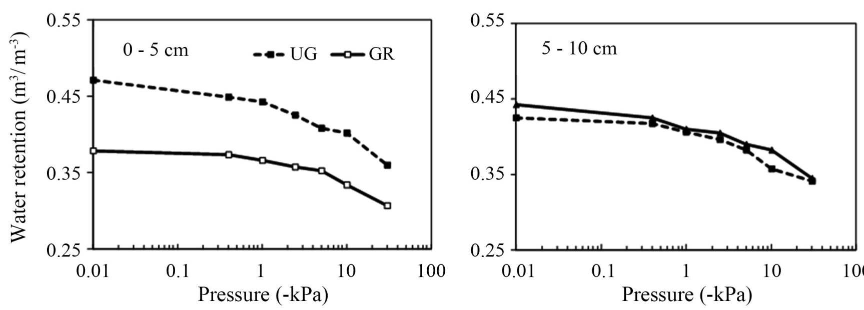

Figure 1. Soil water retention ($m^3 \cdot m^{-3}$) as influenced by different grazing treatments for the 0 - 5 and 5 - 10 cm depths during the post-grazed period.

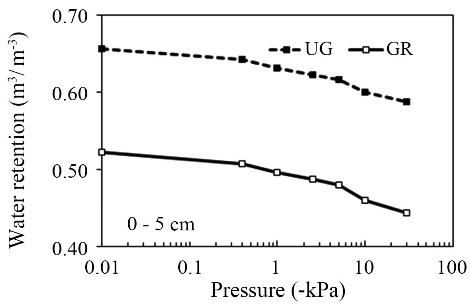

Figure 2. Soil water retention ($m^3 \cdot m^{-3}$) as influenced by different grazing treatments for the 0 - 5 depth during the corn-phase period.

3.6. Corn Yields

Corn data under different treatments are presented in **Table 6** and **Table S7**. The effect of N application was statistically significant ($P < 0.05$) (**Table 6**). The corn yield under N fertilizer (112 bu·ac^{-1}) was significantly higher than that for no N fertilizer (96 bu·ac^{-1}) (**Table S7**). The effect of different cover crops on corn yield was not as strong but still seemed to be a factor ($P < 0.10$). The effect of grazing was non-significant ($P = 0.70$) (**Table 6**), but the corn yield under the grazing (106 bu·ac^{-1}) was slightly higher than that for ungrazing (102 bu·ac^{-1}) (**Table S7**). None of the treatments showed a significant impact on plant stand. All interactions between the three main effects on yield and stand were non-significant in this trial. There was a weak interaction between grazing and N application effects ($P < 0.20$) (**Table 6**). These results indicate that the well-managed grazing did not negatively impact yield of the following corn crop even under wet conditions [34] [63] [64]. The cover crop blends with a strong cool-season broadleaf component tend to increase the yield of the following corn crop—in this case by 8 to 17 bu·ac^{-1}—whereas grass-based cover crop mixes do not help yield of the following corn crop. This is consistent with previous work done at the Southeast Farm, South Dakota, where corn consistently yields better following a broadleaf cover crop blend, but not after a grass-based blend (data not shown). There was a weak trend for the following corn crop to need less N following grazing (*i.e.* it was less responsive to N fertilizer); however, this effect was not statistically significant and therefore this topic needs to be studied further before any conclusions regarding N fertilization can be made.

3.7. Economic Analysis

A partial budget analysis table can be divided into two columns, positive effect, and negative effect (**Table 7**). Positive effect includes added income and reduced costs. Assume that the same number of cattle will be raised on the farm under both the ICLS approach and the existing approach. ICLS implementation reduces the need for forage and therefore, reduces forage cost. For cover crop grazing, the stocking rate applied in our experiment is 0.75 animal unit (AU) ac^{-1} for 90 days. Assume the forage consumption rate is 26 pounds of dry forage per AU day, then the total forage amount saved during the grazing season is $1750 lb ac^{-1}. Based on the estimated forage cost of $120 ton^{-1}[1], the reduced forage cost is thus $105 ac^{-1}. Added income is possible if the consequent cash crop yield increases after grazing cover crops. In this study, since the interaction effect of ICLS on cash crop yield is not significant, it means there is no added income from additional cash crop revenue in the short term.

Negative effect includes reduced income and added costs. Three cover crop cost items belong to the added costs, which are cover crop seed, planting and termination costs, and others. Cover crop seed cost is calculated as $24.84 ac^{-1}, which is the average cost of three different blends, with a seed mixture fee of

[1]Based on Department of Ag market news, Alfalfa Large Squares in Western South Dakotais priced at $120.00 ton^{-1} for Premium/Good quality as of Nov 3-10, 2016.

Table 6. ANOVA table for main effects and interactions for corn plant stand and grain yield for grown in a cover crop by grazing by N application study at the Southeast Research Farm in 2016.

Source	Stand P-value	Yield P-value
Cover Crop (CC)	0.86	0.10
Nitrogen (N)	0.21	0.01
Grazing (G)	0.72	0.70
CC*N	0.91	0.55
CC*G	0.81	0.58
N*G	0.95	0.11
CC*N*G	0.95	0.50

Table 7. Partial budget: utilizing cover crops to integrate grazing on the cropland (1st year). Unit: $\$\cdot ac^{-1}$.

Positive Effect		Negative Effect	
Added income		Reduced income	
Cash crop yield increase	0.00	Cash crop yield decrease	0.00
Reduced cost		Added cost	
Reduced forage cost	105.00	Cover crop seed cost	24.84
		Cover crop planting cost	17.50
		Cover crop termination cost	11.70
		Fence wire and post	14.00
		Fence energizer	6.00
		Water tank cost	6.38
		Water hauling cost	7.35
Total positive effect	105.00	Total negative effect	87.77
Net effect	17.23		

\$0.07 lb^{-1}. Cover crop planting was accomplished using grain drill with an average custom rate of \$17.50 ac^{-1}. The herbicide used to terminate cover crop at the end of grazing season costs \$4.70 ac^{-1} for the purchase of 32 oz Round-up Weather-max with an application cost of \$7.00 ac^{-1}. Fencing costs are composed of costs from poly-braided wire, step-in pig tail posts and a solar powered fence energizer. Depending on the shape of the field, fence wire and post generally cost \$12 to \$16 ac^{-1}, averaging \$14 ac^{-1}. Fence energizer costs \$300 each and is capable of charging 50 acres, thus its cost averages at \$6 ac^{-1}. The cost of a 600-gallon round poly stock tank is \$255 each. Assume water consumption rate for beef cattle is 2 gallons per 100 pounds of body weight per day. A 600-gallon tank could, therefore, supply 30,000 pounds of cattle per day. Assuming the average stocker weight is 750 pound, the 600-gallon tank can thus serve 40 head of cattle on 40 acres of cover crop land. The cost of the water tank is, therefore, \$6.38 ac^{-1}. Water hauling cost is \$7.35 ac^{-1}, comprised of pickup cost and water cost, given that water serving 40 cattle on 40 acres was hauled every day during the 90-day grazing period.

The difference between total positive effect and the total negative effect is referred to as net effect, which shows the difference in profitability between the new ICLS practice and the existing practice. Table 7 showed that the net effect is \$17.23 ac^{-1}, which indicates that implementing ICLS will increase the profit of the farm by \$17.23 in the first year. As the fence wire, post, energizer and water tank costs could last for at least 10 years, the costs of these elements will drop to 0 in the 2nd year, which will further boost the net effect to \$43.61 ac^{-1}. In the long term, we expect economic profit will increase even more, as a cover crop will increase water holding capacity, which will reduce the yield risk during the drought season. Furthermore, an increase in SOM in the long term will reduce the need for N fertilizer application, which can add further to the reduced costs.

4. Conclusion

In this study, we explored more options during various parts of the growing season and the impacts of grazing and cover crops on soil properties, corn yield, and economic benefits. These findings can help us understand how grazing cattle during the fall season affects certain soil properties which in-turn affect the soil health and producer income. Results from this study showed that when we applied proper grazing management techniques (40% - 60% biomass removal), soil properties were not negatively impacted by grazing except for SOC, BD, and soil water retention. An increase in bulk density was observed at the 0 - 5 cm depth with grazing. SOC and soil water retention under the grazing were significantly lower than those for the ungrazed plots. The effect of grazing on corn yield was not significant. The cover crops did not impact the pH, EC, TN, Enzyme β-glucosidase, acid hydrolysis C fraction, microbial biomass carbon, and soil water retention, but impacted the SOC, hot/cold water C fraction, BD, infiltration rate in some phases and depths. The effects of different cover crop blends on corn yield were not as strong. The economic analysis showed the difference in profitability between the new ICLS practice and the existing practice, indicating that implementing ICLS can increase the profit of the farm by \$17.23 in the first year and \$43.61 ac^{-1} in the second year. These findings indicate that ICLS practices with proper management can benefit soil health and producer incomes. Since some soil properties were negatively impacted during this short-term study, further studies in the long-term effect of grazing cover crops should be conducted.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Abbreviations

ICLS, integrated crop-livestock system; NRCS, natural resources conservation service; NT, no-till; N, nitrogen; TN, total nitrogen; UAN, urea and ammonium nitrate; C, carbon; SOC, soil organic carbon; q_s, water infiltration rate; CWE, cold water extract; HWE, hot water extract; ACE, acid extract; RC, recalcitrant carbon; SWR, soil water retention; EC, electrical conductivity; BD, soil bulk density; ANOVA, analysis of variance.

Appendix

Table S1. Soil pH as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0 - 5, 5 - 10, 10 - 15, and 15 - 30 cm depths.

Treatments	pH					
	Depths (cm)					
	0 - 5			5 - 10		
	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 × G	-	0.82	0.95	-	0.96	0.99
		10 - 15			15 - 30	
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 × 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.

Table S2. Soil electrical conductivity (EC) as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0 - 5, 5 - 10, 10 - 15, and 15 - 30 cm depths.

Treatments	**Electrical Conductivity (dS·m^{-1})**					
	Depths (cm)					
	0 - 5			5 - 10		
	Pre-grazed	Post-grazed	Corn-phase	Pre-grazed	Post-grazed	Corn-phase
Cover Crops (CC)						
Grass blend	0.71^{a†}	1.07^{a}	1.08^{a}	0.86^{a}	1.12^{a}	0.76^{a}
Legume blend	0.81^{a}	1.12^{a}	1.40^{a}	0.83^{a}	0.92^{a}	0.88^{a}
Equal blend	0.90^{a}	1.13^{a}	1.57^{a}	0.77^{a}	1.06^{a}	1.03^{a}
Control	0.69^{a}	1.10^{a}	1.34^{a}	0.63^{a}	1.03^{a}	0.91^{a}
Grazing (G)						
Ungrazed	-	1.20^{a}	1.18^{a}	-	1.13^{a}	0.84^{a}
Grazed	-	1.02^{a}	1.52^{a}	-	0.93^{a}	0.95^{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 × G	-	0.4	0.99	-	0.93	0.8
	10 - 15			15 - 30		
Cover Crops (CC)						
Grass blend	0.905^{a†}	1.26^{a}	0.82^{a}	1.29^{a}	1.54^{a}	0.76^{a}
Legume blend	0.822^{a}	1.10^{a}	0.96^{a}	0.94^{a}	1.03^{a}	0.88^{a}
Equal blend	0.868^{a}	1.22^{a}	1.10^{a}	0.98^{a}	1.81^{a}	1.03^{a}
Control	0.728^{a}	1.21^{a}	1.03^{a}	0.82^{a}	1.32^{a}	0.91^{a}
Grazing (G)						
Ungrazed	-	1.31^{a}	0.91^{a}	-	1.34^{a}	0.95^{a}
Grazed	-	1.09^{a}	1.04^{a}	-	1.50^{a}	0.84^{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 × 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 $P < 0.05$.

Table S3. 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	Acid Hydrolysis C Fraction (mg·kg^{-1})					
	Depths (cm)					
	0 - 5			5 - 10		
	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 × 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 $P < 0.05$.

Table S4. 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	Microbial Biomass Carbon (mg·kg^{-1})	
	Depths (cm)	
	0 - 5	
	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 × 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 $P < 0.05$.

Table S5. Soil infiltration rate ($mm \cdot hr^{-1}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments.

Treatments	Infiltration Rate ($mm \cdot hr^{-1}$)	
	Pre-Grazed	Corn Phase
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 $P < 0.05$.

Table S6. (a) Soil water retention ($m^3 \cdot m^{-3}$) as influenced by different cover crops mixtures for the 0 - 5 and 5 - 10 cm depths during the pre-grazed period; (b) Soil water retention ($m^3 \cdot m^{-3}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0 - 5 cm depth during the post-grazed period; (c) Soil water retention ($m^3 \cdot m^{-3}$) as influenced by different cover crops mixtures under grazed and ungrazed treatments for the 0 - 5 cm depth during the corn-phase period.

(a)

Treatments	Soil Water Retention ($m^3 \cdot m^{-3}$) in Pre-Grazed						
	0 - 5 cm						
	Pressure (−kPa)						
	0.01	0.4	1	2.5	5	10	30
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

(b)

Treatments	Soil Water Retention ($m^3 \cdot m^{-3}$) in Post-Grazed						
	0 - 5 cm						
	Pressure (−kPa)						
	0.01	0.4	1	2.5	5	10	30
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	0.7	0.55	0.53	0.52	0.34	0.35	0.5
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

(c)

Treatments	Soil Water Retention ($m^3 \cdot m^{-3}$) in Corn Phase						
	0 - 5 cm						
	Pressure (−kPa)						
	0.01	0.4	1	2.5	5	10	30
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)							

Continued

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	0.7	0.55	0.53	0.52	0.34	0.35	0.5
G	<0.0001	<0.0001	<0.0001	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.

Table S7. Main effects of cover crop blend, N application, and grazing on plant stand and yield for late-planted corn at the Southeast Research Farm in Beresford, SD in the 2016 growing season. Interaction effects were non-significant for these variables, so only main effects are shown here.

Treatment	Stand	Yield
	plants·ac^{-1}	bu·ac^{-1}
Cover Crop Blend		
Equal Blend	25,047	113
Broadleaf Blend	23,595	104
Grass Blend	24,321	101
Control	24,948	96
Mean	24,478	104
LSD (0.10)	NS†	13
Nitrogen Fertilizer		
Yes	24,873	112
No	24,079	96
P-Value	NS	*
Grazed		
Yes	24,053	106
No	24,866	102
P-Value	NS	NS

*denotes statistical significance at the 0.05 level. †NS, not significantly different.

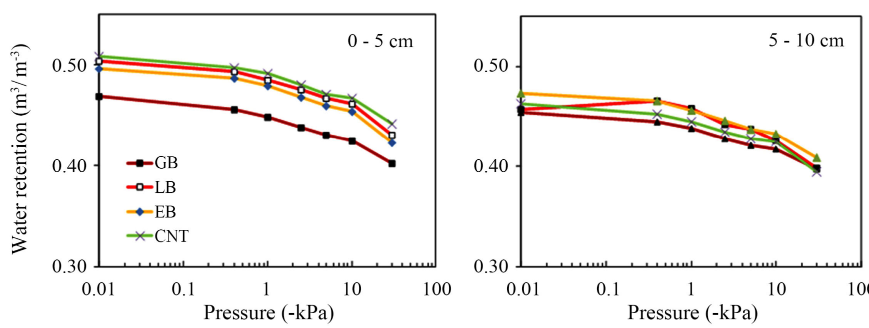

Figure S1. Soil water retention (m^3·m^{-3}) as influenced by different cover crops mixtures for the 0 - 5 and 5 - 10 cm depths during the pre-grazed period.

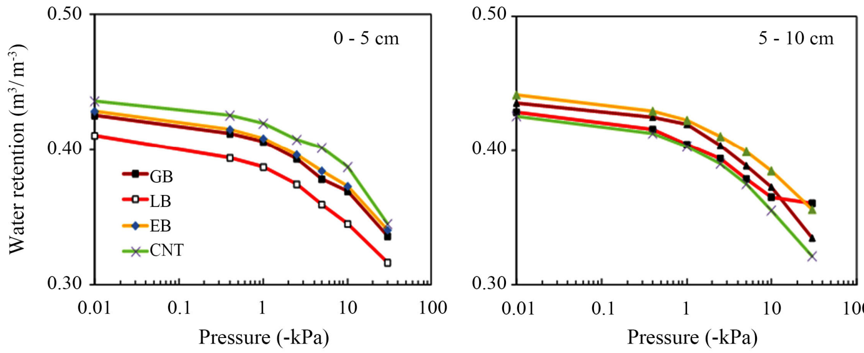

Figure S2. Soil water retention ($m^3 \cdot m^{-3}$) as influenced by different cover crops mixtures for the 0 - 5 and 5 - 10 cm depths during the post-grazed period.

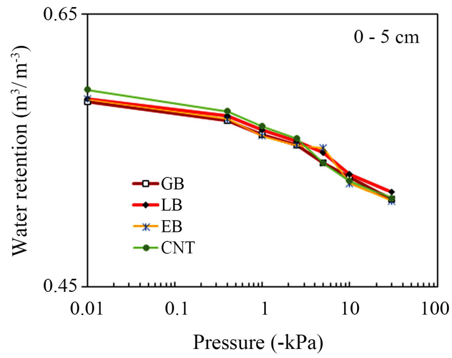

Figure S3. Soil water retention ($m^3 \cdot m^{-3}$) as influenced by different cover crop mixtures for the 0 - 5 depth during the corn-phase period.