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On-Farm Assessment of Soil Quality in Low and High Grazing Under Integrated Crop-Livestock System in South Dakota

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ABSTRACT

Integrated crop-livestock system (ICLS) has the potential to enhance soils quality by improving soil chemical, physical, and biological parameters especially soil organic carbon. objective of this study was to assess the impact of low and high stocking rates (number of animal per hectare) under ICLS on soil quality parameters at the farm scale and the approach of farmers in Getysburg, Roscoe and Selby sites for this system. Study sites located at three different farms that has low stocking rate of cattle grazing. Data from this study showed that low stocking rate under ICLS increased soil organic carbon (SOC) from 20.7 to 28.3 g kg⁻¹, and total nitrogen

(TN) from 2.06 to 2.60 g kg⁻¹ at the surface 0-5 cm depth. However, high stocking rates under ICLS decreased the SOC. Low stocking rate under ICLS increased the soil N but it did not impact on soil P significantly. High stocking rate decreased the BG and MBC but low stocking rate increased. High stocking rate increased the soil penetration resistance 2.43 to 2.83 MPa. Further, data showed that the low stocking rate under ICLS improved the soil quality index (SQI) while high stocking rate under ICLS decreased it. This study showed that ICLS with low stocking density can be beneficial in enhancing soil quality at the farm scale.

Keywords: Integrated crop-livestock system, soil organic carbon, soil quality

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1. Introduction

Integrated crop-livestock system (ICLS) has numerous benefits such as higher crop production, improved soil quality (Russelle et al 2007), enhanced soil structure and fertility, weed control, reduced damage of insects and diseases, and high-quality of feed for the livestock (Bullock 1992; Humphreys 1994; McKenzie et al 1999). Due to these advantages, ICLS has gained increased attention among various research professionals and the producers. However, grazing under ICLS can positively or negatively impact soils depending upon how it is being managed.

The moderate or low stocking rate which means number of animal per hectare of grazing can contribute to the improvement of soil quality and economic benefits (Savadogo et al 2007; Follett & Reed 2010). This type of grazing can enhance the SOC (Russelle et al 2007), and water infiltration (Hiernaux et al 1999). However, heavy grazing (intensive or high stocking rate) can decrease SOC and TN contents (Cui et al 2005; Han et al 2008), soil wet aggregate stability (WAS) and soil moisture content (Johnston et al 1971; Warren et al 1986), increase soil compaction resistance (SPR) due to treading by livestock and hence reduce water infiltration rate (Katsvairo et al 2006). Further, it decreases the root biomass due to high compaction (Han et al 2008), soil phosphorus (P) (Hiernaux et al 1999) and biomass productivity and increases the soil erosion due to high soil compaction (Savadogo et al 2007). Agronomy News defined

the soil quality as “the capacity of soil to function”. Soil quality context is evaluated as soil chemical, physical and biological parameters. ICLS is one of the important agriculture practice to improve the soil health.

Thus, specific objective of this study was to evaluate the impacts of different livestock stocking density under the ICLS on soil quality based on the select indicators in South Dakota and calculate the SQI value by using soil management assessment framework (SMAF) tool.

2. Material and Methods

2.1. Study sites

The study sites were chosen from three different farms located at Roscoe, Gettysburg, and Selby in South Dakota, USA. Each site has two different treatments that include ICLS and non-ICLS as the control. At the Roscoe, the mean daily temperature was 6 °C and mean annual precipitation was 444 mm (NRCS 2009), and soils were classified as fine-loamy, mixed, superactive, frigid Typic Argiustolls with 3-6% slope (USDA 2018). This site has low stocking rate (0.69 AU ha⁻¹). Grazing area in ICLS was the no-till system that was grazed during every winter (cover crops) for 7-10 years. Crops in the ICLS included corn-soybean-wheat-cover crop-alfalfa rotation. Control treatment was also in a no-till system without grazing non-cover crop under the corn-soybean rotation. Soils at the Gettysburg site were classified as fine-silty, mixed, superactive, mesic Typic Argiustolls with 2-6% slope. The mean daily temperature was 7 °C, and the mean annual precipitation was 507 mm (NRCS 2009). This site has high stocking rate (43 number of animals/hectare). Grazing area in ICLS was in a no-till system that was grazed during every winter for 16 years. Crop system in the ICLS was winter wheat-cover crop-corn-sunflower rotation. Control area was also no-till tillage system that was corn-fallow-winter wheat-cover crop rotation. Soils at the Selby site were classified as fine-silty, mixed, superactive, frigid Typic Argiustolls with 2-6% slope. The mean daily temperature was 7 °C and the average annual precipitation was 444 mm (NRCS 2009). This site has high stocking rate (42.5 number of animal/hectare). Grazing area (15 years) in ICLS was the no-till system that was corn-cover crop rotation. Control treatment was also no-till system that was grazed one time in last 8-yr. Crop system in the control treatment was corn-winter wheat-sunflower rotation.

2.2. Soil sampling and analysis

Soil samples were collected in June 2017 and 2018 from all the study sites (Roscoe, Gettysburg, and Selby) at the 0-5 and 5-15 cm depths by using a soil auger and grid soil sampling. The auger soil samples were air-dried and ground to pass through a 2-mm sieve. Samples were ground using a roller mill through a 0.5-mm sieve to analyze the total soil C and N (sum of nitrate, nitrite, organic and ammonia) concentrations using dry combustion techniques with a LECO TruSpec C/N analyzer (LECO 2002). The TC was considered as SOC because pH was below 6.5. Undisturbed soil samples were used to determine soil bulk density (BD) by using core method (Grossman & Reinsch 2002). Extractable soil N (mineral nitrogen), P were analyzed using the standard operating methods (Bray and Kurtz 1945; Haby et al 1990; Warncke and Brown 1998). Soil wet aggregate stability (WAS) was analyzed using the method described by (Kemper & Rosenau 1986). Chloroform fumigation direct extraction method (CFDE) was used for analyzing microbial biomass carbon (MBC) (Beck et al 1997). Beta-glucosidase enzyme activity (BG) was analyzed using the method described by (Deng & Tabatabai 1994). Soil Penetration Resistance (SPR) was measured by using penetrometer (Bradford 1986). Further, Soil Management Assessment Framework (SMAF) method was used to determine the effect of integrated crop-livestock system on soil quality. SMAF consist of three steps; indicator selection, indicator interpretation, and integration into a soil quality index value (SQI) (Andrews 1998). In the first step, Minimum Data Set (MDS) indicators are selected using the parameters from the database (Bellocchi et al 2002; Schadt et al 2002). In the second step, the selected MDS indicators are created the graph by using nonlinear scoring curves (Karlen & Stott 1994). Last step gives final results to integrate all the indicator scores using former interpretation with index value (Karlen et al 1997). Their values were scored on a 0-1 scale based on the algorithms in the SMAF model. Score 1 is highest soil quality index value while score 0 is lowest soil quality index value.

These scores depend on soil texture, temperature, rainfall, slopes, and season (Andrews et al 2004). Soil Quality Index (SQI) value based on the SMAF method was calculated using the formula given by (Karlen et al 2014): $SQI = \text{Sum of SMAF scores} / \text{Number of indicators}$.

2.3. Statistical analysis

The effects of grazing under ICLS on soil quality parameters and SQI values for each depth in 2017 and 2018 were evaluated using scores using Analysis of Variance (ANOVA) in the SAS9.4 software (SAS 2013). Mean separation were analyzed using a protected PDIFF option (t-test) within the LSMEANS statement following PROC GLM procedure in SAS9.4. Statistical differences among the treatments were explained significant at $\alpha=0.10$ significant level. This significant level is very common in studies because variability is high in farmers sites (Halpern et al 2010) . Also, SMAF model was used to calculate the SQI value and after SAS9.4 software (SAS 2013) was used for statistical analysis.

3. Results

Data for SOC and TN under different treatments for all the three sites at the 0-5 and 5-15 cm depths in 2017 and 2018 are presented in Table 1. In 2017, grazing in ICLS significantly impacted SOC at the Gettysburg, Roscoe, and Selby sites at 0-5 and 5-15 cm depth, except for Selby site at 5-15 cm depth. High stocking decreased the SOC for 0-5 cm depth at the Gettysburg and Selby, whereas, low stocking density increased it at the Roscoe site. A similar trend was observed in 2018 where low stocking density increased the SOC but high stocking density decrease it, however, differences were not always significant.

Table 1- Mean soil organic carbon (SOC) and total nitrogen (TN) under grazing and control (non-grazing) treatments at the 0-5 and 5-15 cm depths in 2017 and 2018 at the Gettysburg, Roscoe, and Selby in South Dakota, USA

Locations	Stocking Rate	Treatments	SOC ($g\ kg^{-1}$)				TN ($g\ kg^{-1}$)			
			2017		2018		2017		2018	
			0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
Gettysburg	High	Grazing	26.6 ^{b†}	19.9 ^b	25.6 ^a	18.2 ^a	2.40 ^b	1.89 ^b	2.42 ^a	1.84 ^a
		Control	29.3 ^a	23.3 ^a	22.3 ^a	14.7 ^a	2.63 ^a	2.10 ^a	2.16 ^a	1.60 ^a
Roscoe	Low	Grazing	28.3 ^a	23.5 ^a	27.2 ^a	22.9 ^a	2.60 ^a	1.88 ^a	2.38 ^a	1.84 ^a
		Control	20.7 ^b	16.8 ^b	19.2 ^b	15.2 ^b	2.06 ^b	1.55 ^a	2.10 ^b	1.37 ^b
Selby	High	Grazing	26.7 ^b	16.6 ^a	23.4 ^b	14.6 ^b	2.43 ^b	1.61 ^b	2.33 ^b	1.43 ^b
		Control	31.2 ^a	20.7 ^a	27.3 ^a	21.7 ^a	2.87 ^a	2.01 ^a	2.69 ^a	1.99 ^a

[†]Means within the same column followed by different small letters for each study sites are significantly different at $P<0.10$ for the grazing treatment

Data for total nitrogen (TN) under the grazing treatment at the 0-5 and 5-15 cm depths at all three sites in 2017 and 2018 are presented in Table 1. Data showed that low stocking density at the Roscoe site significantly increased the TN at 0-5 and 5-15 cm depths for 2017 (26 and 21%) and 2018 (13 and 34%), except that it was not different in 2017 at 5-15 cm depth. However, high stocking density decreased the TN at 0-5 cm and 5-15 cm depths in 2017 and 2018 for Gettysburg and Selby sites, however, differences were not significant at the Gettysburg site for 2018.

Data for soil N and P under different treatments for all the three sites at the 0-5 and 5-15 cm depths in 2017 and 2018 are presented in Table 2. In 2017, grazing under ICLS significantly impacted soil N at all the sites for 0-5 and 5-15 cm depths, except for Roscoe site at the 5-15 cm depth. High and low stocking increased the soil N at the Roscoe and Selby site, whereas, high stocking density decreased it at the Gettysburg site for two depths. There was a similar trend in 2018 although differences were not always significant.

Low and high stocking density at the Roscoe and Selby sites increased the soil P at both the soils depths for either year except that differences were not significant at the 0-5 and 5-15 cm depths for 2018. However, high stocking density decreased the soil P at 0-5 cm depth for Gettysburg site.

Table 2- Mean extractable soil nitrogen (N) and soil phosphorus (P) under grazing and control (non-grazing) treatments at the 0-5 and 5-15 cm depths in 2017 and 2018 at the Gettysburg, Roscoe, and Selby in South Dakota, USA

Locations	Stocking Rate	Treatments	Soil N (mg kg ⁻¹)				P (mg kg ⁻¹)			
			2017		2018		2017		2018	
			0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm	0-5 cm	5-15 cm
Gettysburg	High	Grazing	17.2 ^{b†}	11.5 ^b	12.4 ^b	11.9 ^a	14.5 ^b	8.13 ^a	14.3 ^a	3.33 ^a
		Control	28.5 ^a	20.5 ^a	28.8 ^a	7.63 ^a	31.7 ^a	13.1 ^a	21.3 ^a	4.23 ^a
Roscoe	Low	Grazing	40.6 ^a	26.5 ^a	26.2 ^a	11.1 ^a	11.9 ^a	8.56 ^a	5.03 ^a	2.35 ^a
		Control	24.8 ^b	13.3 ^a	15.4 ^b	5.33 ^b	11.2 ^a	5.56 ^b	5.33 ^a	1.67 ^a
Selby	High	Grazing	29.3 ^a	11.4 ^a	39.5 ^a	10.7 ^a	34.4 ^a	8.88 ^a	26.7 ^a	2.33 ^a
		Control	17.4 ^b	5.61 ^b	42.4 ^a	8.63 ^b	10.5 ^b	5.44 ^b	7.00 ^b	1.67 ^a

†Means within the same column followed by different small letters for each study sites are significantly different at P<0.10 for the grazing treatment.

Data for BG, MBC, BD, SPR, and WAS under different treatments for all three sites at the 0-5 cm depth in 2017 and 2018 are presented in Table 3. Data showed that high stocking density grazing decreased the BG (2017) or no impact (2018), however, low stocking density has no impact (2017) or increased (2018) the BG. A similar trend was observed for the MBC, however, differences were not always significant. Data showed that grazing did not impact soil BD and SPR, except that low stocking density decreased the soil BD in 2017 and high stocking density at Selby increased the SPR in 2017. Furthermore, grazing increased the WAS in 2017 but unaffected in 2018 as compared to the control treatments for all the sites. Data for SQI under different treatments for all the three sites at the 0-5 and 5-15 cm depths in 2017 and 2018 are presented in Figure 1. In 2017, grazing in ICLS significantly impacted the SQI at Gettysburg, Roscoe, and Selby sites at 0-5 and 5-15 cm depths, except for Selby site at the 5-15 cm depth. High stocking rate decreased the SQI at the both depths for Gettysburg and Selby sites, whereas, low stocking density increased the SQI at the Roscoe site. There was a similar trend in 2018 and high stocking rate decreased the SQI at the 0-5 cm depth, except for Selby site. At the 5-15 cm depth, grazing in ICLS did not significantly impact the SQI.



Figure 1- Mean soil quality index (SQI) under grazing and control (non-grazing) treatments at the 0-5 and 5-15 cm depths in 2017 and 2018 at the Gettysburg, Roscoe, and Selby in South Dakota, USA

Table 3- Mean beta-glucosidase (BG), microbial biomass carbon (MBC), bulk density (BD), soil penetration resistance (SPR) and wet aggregate stability (WAS) under grazing and control (non-grazing) treatments at the 0-5 cm depth in 2017 and 2018 at the Gettysburg, Roscoe, and Selby in South Dakota, USA

Locations	Stocking Rate	Treatments	BG ($\mu\text{g ml}^{-1}$)		MBC ($\mu\text{g g}^{-1}$)		BD (g cm^{-3})		SPR (MPa)		WAS (%)	
			2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Gettysburg	High	Grazing	24.6 ^{bf}	73.0 ^a	73.01 ^b	119.1 ^b	1.34 ^a	1.33 ^a	2.36 ^a	2.37 ^a	81.5 ^a	84.5 ^a
		Control	36.3 ^a	89.7 ^a	118.0 ^a	220.5 ^a	1.38 ^a	1.43 ^a	2.48 ^a	2.47 ^a	78.2 ^b	78.1 ^a
Roscoe	Low	Grazing	20.1 ^a	97.4 ^a	249.8 ^a	227.0 ^a	1.48 ^b	1.37 ^a	1.93 ^a	2.53 ^a	90.3 ^a	91.2 ^a
		Control	22.7 ^a	77.0 ^b	69.72 ^b	150.8 ^b	1.52 ^a	1.37 ^a	2.29 ^a	2.16 ^a	84.9 ^b	82.6 ^a
Selby	High	Grazing	22.6 ^b	35.0 ^b	65.04 ^b	236.1 ^a	1.48 ^a	1.41 ^a	2.83 ^a	2.14 ^a	88.3 ^a	84.2 ^a
		Control	40.2 ^a	99.6 ^a	168.7 ^a	234.2 ^a	1.34 ^a	1.40 ^a	2.43 ^b	2.17 ^a	81.8 ^b	78.9 ^a

[†]Means within the same column followed by different small letters for each study sites are significantly different at $P < 0.10$ for the grazing treatment

4. Discussion

For SOC, heavy grazing can reduce plant residue and increase soil compaction and reduce SOC (Hiernaux et al 1999). Increased compaction can reduce the SOC content by decreasing resistance to deformation and rebound effects (Soane 1990). Our findings are in accord with some previous results that showed that SOC content was decreased with the increase in grazing intensity (Cui et al 2005; Han et al 2008). Stark et al 2002 reported that SOC did not improve by reindeer grazing due to overgrazing or unsuitable timing. Similar to our finding, a previous study demonstrated that moderate grazing improved the SOC in Tibetan Plateau (Hafner et al 2012).

For TN, similar findings were reported by Hoffmann et al 2008 from a study that showed the TN reduced by 0.4 kg ha⁻¹ because grazing reduced the crop residue left on the soil. Grazing, when used appropriately, can enhance TN in mixed-grass rangeland (Schuman et al 1999). Further, it depends on type of the plant, legumes or cover crop used for grazing because these crops can enhance the nitrogen in the soil.

For soil N, a study showed that grazing positively affected soil N availability compared to the non-grazing treatment in Yellowstone National Park (Hamilton III & Frank 2001). Seagle et al 1992 showed that the soil N content under high and low stocking rate was higher than the non-grazing treatment under grasslands. For soil P, similar findings were reported by Marrs et al 1989; Neff et al 2005.

For soil BG and MBC, studies showed that increasing low grazing intensity increased the BG in subarctic tundra in Fennoscandia (Stark et al 2015). Further, grazing enhanced the MBC due to increased available nitrogen (Lopez et al 1977). However, intensive grazing reduced the MBC (Holt 1997). Similarly, Bardgett and Leemans 1995 also reported that intensive grazing reduced the MBC by 44% due to the fact that heavy grazing can reduce plant residue and increase soil compaction and decrease MBC (Hiernaux et al 1999).

For soil SPR and BD, grazing treatments increased the SPR due to compaction from animals on the soil (Mulholland & Fullen 1991; Chanasyk & Naeth 1995; Broersma et al 2000). Grazing treatments with high stocking rate increased the soil BD (Willatt & Pullar 1984; Chanasyk & Naeth 1995; Zhou et al 2010; Pulido et al 2018). Another study conducted in Inner Mongolia showed that intensive grazing increased the BD (Steffens et al 2008).

For SQI, it has been reported that heavy grazing (high stocking rate) can decrease the soil quality (Han et al 2008) because high stocking rate can decrease the soil physical quality (da Silva et al 2003). Similar to our findings, a study showed that the low or moderate grazing had the highest SQI values as compared to the non-grazing treatment; and non-grazing treatment had the higher SQI value compared to heavy grazing in the USA (Wienhold et al 2004). This was partially due to the differences in stocking rate for grazing.

5. Conclusions

This study was conducted to explore the responses of high and low stocking rates under ICLS on soil quality parameters at three different locations (Gettysburg, Roscoe, and Selby) in South Dakota. Data showed that low stocking rate increased the SOC and TN while high stocking rate decreased the SOC and TN compared to the non-grazing treatments. High stocking rate decreased the BG and MBC content than the non-grazing treatment. In addition, high stocking density grazing increased and low stocking density decreased the BD and SPR, however, differences were not always significant. Grazing treatments significantly influenced soil N and P, and low and high stocking rate increased the soil N and P content compared to non-grazing treatment, except Gettysburg site. Results showed that grazing treatments significantly influenced the soil quality. High stocking rate decreased the SQI value while low stocking rate increased it compared to the non-grazing treatment at the 0-5 and 5-15 cm depths. Data from this study conclude that low stocking grazing is beneficial in enhancing the soil quality. Our study and previous study showed that low stocking rate under ICLS can be helpful for improving soil quality.

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Abbreviation and Symbol	
<i>ICLS</i>	Integrated crop-livestock system
<i>SOC</i>	Soil organic carbon
<i>SMAF</i>	Soil Management Assessment Framework
<i>SQI</i>	Soil Quality Index
<i>TN</i>	Total Nitrogen

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