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LIVESTOCK GRAZING IMPACTS ON CROP AND SOIL RESPONSES FOR TWO
CROPPING SYSTEMS

by

Alyssa K. Kuhn

A THESIS

Presented to the Faculty of

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LIVESTOCK GRAZING IMPACTS ON CROP AND SOIL RESPONSES FOR TWO CROPPING SYSTEMS

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University of Nebraska, 2021

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Diversified crop, forage, and livestock systems are assumed to be more sustainable and economically competitive than traditional cropping systems. Objectives of this study were to determine effects of integrating grazing livestock into corn (*Zea mays*)-soybean (*Glycine max* (L.) Merr.) (C-S) and corn-soybean-wheat (*Triticum aestivum* L.) (C-S-W) cropping systems on plant population, grain yield, soil nutrients and soil carbon dioxide (CO₂) flux following winter grazing corn residue (both systems) and an oat (*Avena sativa*) cover crop (C-S-W only) planted after wheat. For the 2019 and 2020 production seasons, neither corn nor soybean plant populations were different in the grazed or non-grazed treatments for the C-S and C-S-W rotations. During 2021 in the C-S rotation, soybean plant populations were greater ($P < 0.05$) in the grazed corn residue treatment (319,556 plants ha⁻¹) compared to the non-grazed corn residue treatment (286,520 plants ha⁻¹). Despite observed differences in soybean plant population in this year, grazing corn residue and the oat cover crop had no impact on grain yield of soybean or corn in C-S or C-S-W or wheat grain yield in C-S-W. Similarly, for both cropping systems, soil nutrients and CO₂ flux did not differ for either the grazed or non-grazed corn residue or the oat cover crop in any year of the study. To date, this partial evaluation of livestock grazing effects on grain yield suggested minimal to no reduction in plant populations in cropland grazed during winter with no apparent negative effects on either grain production or soil nutrients and CO₂ flux.

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CHAPTER 1. Review of Literature

Integrated Crop and Livestock Systems

Prior to World War II, the agriculture industry consisted mainly of farms that produced diverse crop and livestock products, cycled nutrients on-farm or through neighboring farms, and marketed their commodities locally (Dimitri et al., 2005, Rotz et al., 2005). After the war, advances in technology, machinery, and synthetic fertilizers created a shift to larger scale farms that were more specialized in their production, with crops and livestock becoming mostly separate operations (Dimitri et al., 2005; Rotz et al., 2005; Conkin, 2008).

After World War II the western Corn Belt, including North Dakota, South Dakota, Nebraska, Minnesota, and Iowa, has become comprised of traditional corn (*Zea mays*)-soybean (*Glycine max* (L.) Merr.) cropping systems with cattle integrated into these systems only when nearby grasslands were available (Wright & Wimberly, 2013). From 2006 through 2011, during the push for ethanol production which raised corn prices, 530,000 ha of perennial grasses were converted to annual row crop in the western corn belt, which reduced livestock numbers in the region. These land conversions have been occurring in areas that are at high risk of drought vulnerability and erosion (Wright & Wimberly, 2013).

The idea of integrated crop and livestock systems has been regaining popularity and interest, as concerns about productivity, water and nutrient use, soil function, and environmental sustainability become more prominent (Allen, Baker, et al., 2007;

Franzluebbers et al., 2014. Sulc & Tracy, 2007). There is also concern as the climate shifts, agricultural systems must adapt and develop resiliency to withstand these extreme weather events that are expected to become more common. A proposed management strategy that can be implemented to begin this adaptation is to create greater diversity, which can be accomplished by integrating crops and livestock back together on farms (Wright & Wimberly, 2013; Walthall, et al., 2013).

These integrated systems bring crops and livestock together on a single farm or among farms that support positive effects through increased net returns, productivity, and resource conservation (Allen, Heitschmidt, et al., 2007; Kumar, et al., 2019). Bringing livestock into cropping systems adds value by diversifying income, being another source of food production outside of the typical seasons of cash crops, adding fertility through their manure, and converting low quality plant material into high quality meat and milk products (Allen, Baker, et al., 2007). Integrated crop and livestock systems allow for nutrients and organic matter to cycle within these croplands, with livestock waste and plant residues remaining, which can help sustain and even improve fertility in these areas (Franzluebbers, et al., 2014). Creating this loop of nutrient cycling by integrating crops and livestock can reduce the need for synthetic fertilizers and increase soil organic carbon (OC) and microbial biomass, which can improve productivity (Allen, et al., 2005; Allen, Baker, et al., 2007; Acosta-Martinez, et al., 2004).

Allen, Baker, et al. (2007) conducted a seven-year study in the semi-arid Texas High Plains, comparing a traditional cotton cropping system to an alternative, integrated crop and livestock system, both irrigated from the Ogallala aquifer with subsurface drip

irrigation. The first system planted cotton (*Gossypium hirsutum*) into a terminated wheat (*Triticum aestivum* L.) cover crop each spring, and no cattle were used for grazing. The second system was an integrated cotton-livestock system being used for cotton and stocker steer production. Two paddocks were used in this integrated system, one paddock was planted into rye in September which cattle grazed from January until April when cotton was no-till planted. Cotton was harvested in November with wheat planted into the cotton residue. Cattle grazed wheat the following spring and the land was fallowed until planting of cereal rye again in September (rye-cotton-wheat-fallow). Cattle were moved to bluestem pasture when grazing was unavailable in the cotton rotation. In the first five years of the study, cotton lint yielded similarly between the two systems (averaging 1,050 kg ha⁻¹). The integrated system had a 40% reduction in nitrogen (N) fertilizer application, while increasing net return above variable costs of production by 90%, compared to the cotton monoculture. They also found that including forages in the system reduced irrigation water use by 23% compared to the cotton monoculture. After seven years they found that, when all other factors are kept mostly the same, cotton lint yields of 1,500 kg ha⁻¹ were more profitable in the monoculture system, but lint yields of 1,000 kg ha⁻¹ were more profitable for the integrated system. The average Texas High Plains cotton lint yield during this time was 630 kg ha⁻¹ (Texas Agricultural Statistics Service, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004), indicating that production in this area was not sufficient to reach these levels of profitability for the non-grazed system. Because of this this, they concluded that decreased water use in the integrated systems, along with adding diversity to the cropping systems in the Texas High Plains provided stability and productivity to

the system. (Allen, Baker, et al., 2007). By having multiple income streams through crop production and livestock production, this study shows that integrated systems can be more profitable. These diversified income streams can also provide stability in the event of fluctuating markets for either the crop or livestock commodities. The current research to be discussed later explores the effects of integrating of livestock on crop production in various cropping systems even further. More research needs to be done in the future to investigate the details of the economics of these systems.

Implementation of Integrated Crop and Livestock Systems

There are several ways that crops and livestock can be integrated into a system. These include crop and pasture rotations, crop and pasture intercropping, utilizing dual purpose crops, agroforestry, residue grazing, and cover crop grazing (Nie, et al., 2016; Sulc & Franzluebbbers, 2014). The remainder of this literature review will focus on cover crop grazing and crop residue grazing, and their effects on crop production and soil chemical and biological properties.

When considering integrating livestock into a cropping system, there can be concerns about compaction occurring (Clark, et al., 2004; Rakkar, et al., 2017). Compaction occurs when a load, (i.e., machinery or livestock) causes soil pore space size and distribution to change and overall soil density to increase, thus negatively impacting crop production and soil microbial processes (Greenwood & McKenzie, 2001). Compaction is of particular concern to crop producers because severe compaction can inhibit root and plant growth which will reduce yields and profits. In many cases, this compaction from grazing is only found in the surface soil of these fields (Franzluebbbers

& Stuedemann, 2008; Clark et al., 2004; Faé et al., 2009). Studies have found that this shallow compaction can be quickly alleviated through natural soil processes, like freeze-thaw cycles, and with biological processes as roots and organisms move through the soil (Greenwood & McKenzie, 2001; Liebig, et al., 2012). Compaction can be minimized by grazing on croplands during the fall and winter. This is during the time when the soils are typically frozen (Drewnoski, et al., 2016). Grazing during the spring may be on wet and thawed soils and, thus more susceptible to compaction (Clark et al., 2004). It has also been found that grazing on croplands managed using no-till practices, experience less compaction because of improved soil structure from reduced disturbance (Sulc & Franzluebbbers, 2014). When grazing on croplands is properly managed, with correct stocking rates, timing, and attention to weather, impacts on crop production can be mitigated (Franzluebbbers & Stuedemann, 2007).

To evaluate the impacts of spring grazing on corn residue when the soil would be thawed a study conducted in eastern Nebraska, looked at the impact of long-term grazing of corn residue in a corn-soybean rotation on subsequent grain yields. Grazing occurred during the autumn (frozen soil) and spring (wet soil) with differences from these different timings of grazing were compared to a non-grazed control over sixteen years. They found that grazing corn residues during spring resulted in slight increases in the subsequent soybean yields over the non-grazed control, 3,934 and 3,833 kg ha⁻¹, respectively, and had no effect on corn grain yield two years later. Fall grazing also resulted in slightly improved soybean grain yield compared to the non-grazed control (4,405 and 4,176 kg ha⁻¹, respectively). Slight improvements in corn grain yield were observed two years later

for the grazed treatment (13.2 Mg ha⁻¹ compared with the non-grazed treatment 13.0 Mg ha⁻¹). They noted that this site had moderate soil organic matter, and soils with higher organic matter levels can be more resistant to compaction due to soil particles being able to better bind and maintain aggregate stability (Drewnoski, et al., 2016; Soane, 1990). They concluded that soils with higher organic matter levels and taking measures to not over-graze a site can help lessen the concern of compaction through grazing regardless of timing of grazing (Drewnoski et al., 2016; Greenwood & McKenzie, 2001; Soane 1990).

Corn Residue Grazing Effect on Crop Production

When looking at traditional corn-soybean rotations, livestock can be added by grazing the corn residues after harvest and through the winter. The highest cost for livestock producers is using a stored feed source over winter, so finding grazing resources over winter can be a cost savings for livestock producers (Clark et al., 2004). Beef cattle (*Bos taurus*) will first eat the corn grain left in the field, then they will move on to the leaf and husk residues (Fernandez-Rivera & Klopfenstein, 1989). After the grain, the husk and leaf residue have the highest nutritive value of all the residue left after harvest and make up about 26% of the total residue left behind. A study by Blanco, Tatarko, et al. (2016), used a light stocking rate of 2.5 animal unit month (AUM) ha⁻¹ that left 73% residue on the surface, a heavy stocking rate of 5.0 AUM ha⁻¹ that left 55% residue on the surface, and a baling treatment that left 22% residue on the surface. Using a wind erosion simulation protocol, they determined that at least 55% residue cover should remain on the soil surface to decrease the risk of wind erosion of the soil. On the same site, Blanco, Stalker, et al. (2016) found similar results when evaluating water erosion, where the amount of sediment lost increased as residue cover percentage decreased from grazing

and baling. Stocking rates can be determined based on corn yields, and a rate should be chosen that allows a cattle producer to reduce their overall feed costs, while leaving at least 55% residue on the surface to protect from soil erosion (Blanco, Stalker, et al., 2016; Blanco, Tatarko, et al., 2016; Drewnoski, et al., 2016; Watson, et al., 2015;).

Typically, grazing corn residue occurs from November through February in eastern Nebraska. Research has found that grazing during this time did increase soil bulk density, and subsequent grain yield was not affected (Clark, et al., 2004; Rakkar, et al., 2017; Franzluebbbers & Stuedemann, 2008; Faé et al., 2009; Drewnoski, et al., 2016; Sulc & Franzluebbbers, 2014). This was due in part because cattle were grazing during a time when the soil was frozen (Lesoing, et al., 1997). To evaluate impacts of spring grazing on crop production, an experiment was developed in eastern Nebraska to investigate grazing effects of corn residue and tillage management (no-tillage or ridge tillage) on subsequent soybean yield, but they did not measure compaction. This study found that soybean yield was greater in the grazed-no-till sites by 67.25 kg ha⁻¹ compared with non-grazed no-till, and non-grazed ridge till sites (Erickson, et al., 2001). Although animals grazing can create surface level soil compaction, the effects of this on subsequent crop yields can be minimized. Properly managing grazing and restricting grazing to periods with dry or frozen soils can prevent excessive compaction (Clark, et al., 2004; Lesoing, et al., 1997).

A study in eastern Nebraska compared the effects of fall grazed corn stover to a non-grazed control, and a spring grazed corn stover to a non-grazed control, on subsequent soybean yield in a corn-soybean rotation. Here they found that over a ten-year period, both fall and spring grazing increased soybean yield over the non-grazed

treatments. They also observed that grain yield of corn planted after soybeans was improved in the fall grazed treatment compared with the non-grazed treatment, although no differences were seen in the spring grazed treatment compared to the non-grazed treatment. They concluded that in eastern Nebraska, corn residue could be grazed in the fall or spring with slight positive or no impact to subsequent crop production (Drewnoski, et al., 2016).

Clark et al. (2004) evaluated soybean yield response to grazed corn stover in Iowa in a three-year study. There were no observed differences in soybean plant population for any year of the study, regardless of whether the residue was grazed or not grazed. In the third-year cattle were allowed to graze when soil temperatures were above freezing, which led to additional compaction that caused an 8% soybean yield decrease compared with the non-grazed treatment. When averaged across years, there were no differences in soybean yield in either the grazed (2,899 kg ha⁻¹) and non-grazed (2,892 kg ha⁻¹) treatments.

Overall, research that has been done shows that livestock grazing corn residue in corn-soybean rotations seems to have minimal to no negative impact on crop production. All noted that if grazing was completed while the soil was frozen and at a rate that left enough residue cover in the field, then concerns of compaction were reduced. There needs to be more long-term research done on this topic to have a full understanding of corn residue grazing on crop production, which will be addressed in part in current research below. Further, research across different soil types, and more facets of crop

production, like crop yields other than just soybeans, plant population, and plant components need to be evaluated, which will be addressed in current research below.

Cover Crop Grazing Effect on Crop Production

Traditional cash crop rotations can be further diversified by adding a cover crop into the rotation in the fall after harvest, using a winter cover crop or a short season forage crop (Sulc & Franzluebbbers, 2014). Cover crops can have multiple benefits in a cropping system, with the first being that they provide soil cover and protection after cash crop harvest (Sulc & Franzluebbbers, 2014). Another benefit is that they can also be utilized as a forage source for grazing animals (Franzluebbbers, 2007; Sulc & Tracy, 2007). As discussed above, using stored feed over winter is expensive for livestock operations so alternative grazing resources can benefit livestock producers (Clark et al., 2004). As the animal grazes the top part of the cover crop plant, they are leaving the root mass in the ground. This helps to stabilize the soil and increase the accumulation on soil carbon in the root zone. This root mass has been reported to contribute up to 70% of the total soil OC (Wilhelm, et al., 2004). In the Midwest U.S., cover crops planted in the mid-summer to early fall usually produce enough forage to sustain cattle grazing in late fall and early winter. When winter hardy species are used, this grazing period can be extended through the early spring (Sulc & Franzluebbbers, 2014).

Although we know some of the benefits of including cover crops into cropping rotations, there is limited research on how grazing cover crops affects crop production and soil function. There are a few studies that show that grazing cover crops could have minimal negative impact on crops and soils (Faé, et al., 2009; Franzluebbbers &

Stuedemann, 2007; Franzluebbbers & Stuedemann, 2008; Franzluebbbers & Stuedemann, 2015). Grazed cover crops removed 90% of above ground biomass and had no effect on subsequent sorghum, corn, and winter wheat grain yields or soil bulk density (Franzluebbbers and Stuedemann 2008). Recently, cover crop grazing did not affect soil carbon and N fractions compared with no grazing (Franzluebbbers and Stuedemann 2015). Additional research is needed to compare different soil types, tillage systems, cropping systems and climatic conditions (Blanco-Canqui, et al., 2020).

Corn silage production can also benefit from including cool-season forage cover crops in the rotation. This is because silage is harvested in late summer when there is time for cover crop growth and grazing in early winter (Faé, et al., 2009; McCormick, et al., 2006). Corn silage leaves little residue on the surface after harvest, so the cover crop would provide winter protection to the soil. Faé, et al. (2009) conducted a study in Columbus, Ohio, that evaluated an area in no-tillage continuous corn silage production for 8 years with no cover crops planted prior to the experiment. Three cover crop treatments included annual ryegrass (*Festuca perennis*), a mixture of winter rye and oat (*Avena sativa*), and a no cover crop control. Cover crops were no-till planted and followed with a N fertilizer application of 60 kg N ha⁻¹. Cover crop plots were grazed by yearling dairy heifers during winter and spring and compared to the no cover crop (non-grazed) control. They found that the two cover crop treatments were able to provide enough biomass yield with nutritive value to support grazing animal nutritional requirements. Both grazed cover crop treatments had increased soil penetration resistance in the first year of grazing, but one year later these levels were reduced and similar to the

control. In the year after grazing, soil penetration resistance in the oat and winter rye decreased from 1,453 kPa to 1,014 kPa, annual ryegrass decreased from 1,360 kPa to 1,047 kPa, and the control decreased from 1,266 kPa to 1,001 kPa. This alleviation of penetration resistance caused by cattle traffic could be from freeze-thaw cycles over winter, soil shrink-swell cycles over summer, or the growth of cover crop roots through the soil profile in the second year of this study (Greenwood & McKenzie, 2001; Lampurlanés & Cantero-Martínez, 2003; Villamil, et al., 2006). They also evaluated plant population and corn silage yield and found no cover crop treatment effect on the corn plant populations. Overall grazing the cover crops did not affect the silage yield (mean silage yield across all treatments: 2007:10,359 kg ha⁻¹, 2008: 14,870 kg ha⁻¹). Yields were lower in 2007 from below average rainfall during the growing season. Based on this data they concluded, if grazing of cover crops is properly managed then compaction can be maintained at levels that do not reduce subsequent silage yields. Thus, winter cover crops could be used as a potential supplemental feed source for cattle without impacting production (Faé, et al., 2009). Further research being done currently is discussed below on different cropping systems to increase the knowledge base on the impact of integrating livestock for cover crop grazing on crop production.

Franzluebbers and Stuedemann (2007) conducted an experiment on a sandy loam soil in Georgia, investigating tillage systems (no-tillage and conventional disk tillage), cropping systems (winter wheat - pearl millet cover crop and corn/sorghum - cereal rye cover crop), and cover crop management (no-grazing and grazing by cattle). They found that establishment of most crops was not affected by tillage or cover crop management.

Under no-till, pearl millet had lower plant populations than conventional tillage, possibly due to poorer seed to soil contact because of remaining surface residue; however, this decrease was not reflected in the biomass yield of the pearl millet. Grain crop production was highly variable across the four years of this experiment. For corn grain, there was no effect of tillage or cover crop grazing. Corn and sorghum yield decreased 23% under grazing and no-till but did not decrease yield under grazing and conventional till (Franzluebbbers and Stuedemann 2007). Overall, their results agreed with other studies that showed grain yield was positively influenced by no-till compared with to conventional till (Cassel & Wagger, 1996; Hargrove, 1985; Langdale, et al., 1984). They further noted that there was little literature available on the effect of grazing cover crops on subsequent grain yield. They concluded based on their data and a basic economic analysis that integrating crops and livestock may not be detrimental to crop production. Furthermore, yields could be increased with potential for economic gain using these systems in the southeastern United States (Franzluebbbers & Stuedemann, 2007).

Tracy and Zhang (2008) compared an integrated crop and livestock system (corn-oat-pasture rotation) to a continuous corn system in Illinois for five years. The integrated system had cattle grazing on corn residues and the pasture in the rotation, and in continuous corn there was no cattle grazing. Here they found, despite concerns of soil compaction from cattle grazing, the integrated system had no negative effect on corn production in years following grazing. In fact, the presence of cattle on the field increased corn grain yield in the integrated system (11.6 Mg ha⁻¹) over the continuous corn system (10.6 Mg ha⁻¹). They concluded that integrating crops and livestock provide mostly

positive effects on crop production without detriment through soil compaction if grazing is managed correctly.

It is well reported that there are benefits to including cover crops within cropping rotations, but little is recorded about the effect of using livestock to graze the cover crops. The current research project discussed below includes cover crops within cropping systems common to the Midwest region, that will be grazed by beef cattle, and subsequent crop production will be measured to gain understanding of this aspect of cover crops.

Grazing Effect on Soil Properties

In addition to potentially affecting crop production, livestock grazing crop residues or cover crops can also affect soil properties. Monoculture and short rotation cropping systems are prone to organic matter and soil structure loss because of soil disturbance and low organic inputs (Acosta-Martínez et al., 2004). Physical, chemical, and biological soil properties can be positively or negatively affected in integrated systems. Livestock can trample the soil surface altering the physical characteristics of the topsoil, their grazing activities can remove cover crop or residue cover which exposes the soil to the elements, and they excrete nutrients back into the system which feeds subsequent crops and microbial communities (Rakkar & Blanco-Canqui, 2018).

Soil compaction, whether caused by animals or machinery, can reduce soil pore space. This reduces oxygen diffusion through the profile and soil respiration. This can lead to decreased soil microbial biomass and potentially crop yield (Tracy & Zhang, 2008). It has been observed that impairment to the soil physical properties (i.e.,

compaction causing structure degradation) from livestock grazing croplands did not always reduce crop productivity (de Faccio Carvalho, et al., 2010). When grazing was managed correctly on their study in Brazil, they saw slight compaction when integrating cattle into cash crop rotations, but also observed that microbial activity and total OC and N increased (de Faccio Carvalho, et al., 2010).

A study conducted in Texas compared an integrated crop and livestock system using a wheat-cereal rye-cotton rotation that included grazed wheat and cereal rye to a continuous cotton system with no grazing. They found that soil OC, soil microbial biomass carbon and N, and soil enzyme activity were all greater in the integrated system than the continuous cotton (Acosta-Martínez, et al., 2004). In the integrated system, soil microbial biomass carbon averaged 237 mg kg^{-1} compared to the continuous cotton, which averaged 124 mg kg^{-1} . This suggests that adding livestock and diverse species into cropping rotations can have a positive impact on the soil function.

In the study by Tracy and Zhang (2008) referenced earlier, they found that an integrated crop and livestock system, corn-oat-pasture with cattle grazing, had a mostly positive impact on crop production compared to a continuous corn system with no grazing. They also evaluated soil function and quality by measuring soil carbon and microbial biomass. The integrated system increased total soil carbon (21 g kg^{-1}) compared to continuous corn (17.2 g kg^{-1}). These authors also found that microbial biomass was greater in the integrated system (448 mg kg^{-1}) in the final year of the study compared to continuous corn (243 mg kg^{-1}). They concluded integrating crops and

livestock and diversifying crop rotations did not negatively impact soil quality through microbial biomass and soil carbon storage (Tracy & Zhang, 2008).

When animals graze cropland, manure is distributed throughout the field, although it may be uneven. This can improve soil fertility, nutrient cycling, biological function, and reduce vulnerability to compaction (Blanco-Canqui, et al., 2015). The benefits that come from the livestock and the addition of manure have the potential ability to offset any negative effects from grazing, such as compaction.

Grazing Effects on Soil Chemical Properties

Soil's ability to store carbon can be affected by grazing crop residues. Grazing alters the amount of carbon from residue going into the soil. For example, trampling and manure deposition both can alter the decomposition rates of the residues. Ultimately, management of residue grazing can create mixed outcomes of soil carbon storage (D. Liu, et al., 2016; J. Liu, et al., 2016; Rakkar & Blanco-Canqui, 2018). There are two reasons why soil carbon may not change when residue is grazed. If at least 30% of residue cover remains following grazing or when a cropping system has high soil carbon levels that are near saturation levels, then residue grazing may not change soil carbon (Blanco-Canqui, Tatarko, et al., 2016; Rakkar, et al., 2017; Stewart, et al., 2007). In some cases of residue grazing, a decrease in soil carbon may be observed. This effect can be from the utilization of crops with low carbon inputs from their residues (Stewart, et al., 2007). It can also result from allowing grazing animals to over-graze. This was observed in a study located in Syria, where sheep were allowed to overgraze. This removed almost all the crop residues, which resulted in decreased soil carbon (Ryan, et al., 2008). It is

possible that over grazing residues can also result in increased soil carbon in integrated systems. Most likely, this would come from the manure addition of livestock grazing, which is a carbon source for the soil, with animal traffic mixing crop residues into the soil and preventing photo-oxidation of the carbon and allow soil carbon to increase (Liebig, et al., 2012; N. Liu, et al., 2012; Thomsen & Christensen, 2010; Tracy & Zhang, 2008).

Grazing crop residues can also impact other soil nutrients, like N. Rakkar and Blanco-Canqui (2018) noted in their review of grazing crop residues, that in general grazing can maintain, and even improve the soil fertility of a system if stocking rate and residue removal rate are managed correctly. Similar to soil C, animal trampling mechanically breaks down residues into smaller pieces, which allow microbes to break the residues down more quickly, releasing those nutrients into the soil system at a faster rate (Tracy & Zhang, 2008; Liebig, et al., 2012). Also, manure adds N back into the soil which can increase soil microbial activity and residue decomposition (Banegas, et al., 2015). Together, these processes can increase carbon and other nutrients. It has been found that more than 60% of grazed residue nutrients are returned to the soil system by the animal (Erickson, et al., 2003). Beef cattle specifically, retain very little N and other minerals that they ingest, which makes their excreta a fertilizer source for these integrated systems. Research has shown that these returned nutrients are more plant available than the nutrients being stored in the crop residues (Drewnoski, et al., 2016; Duncan, et al., 2016).

Grazing Effect on Soil Biological Properties

When evaluating agricultural systems for usability, sustainability, and productivity, the crops must be evaluated for growth and yield, but the soil must also be evaluated for physical, chemical, and biological properties. Because soil nutrients and the soil microbiome are intertwined, there can be changes in the microbiome when nutrient pools change. Manure, trampling, and residue removal through grazing can impact the biology of soil (Rakkar & Blanco, 2018).

Part of a healthy soil is the amount and types of soil organic matter present in the profile, which is important for its ability to support plant and animal life (Franzluebbers, et al., 2021). The biological portion of soil makes up the active fraction of soil organic matter, and this active fraction can be measured by testing the biological activity of a soil using a CO₂ flush (Franzluebbers, 2016). This CO₂ flush is accomplished by soil sampling, allowing the sample to dry, then rewetting the sample and capturing the CO₂ that is evolved as a measure of biological activity in that soil (Franzluebbers, 2016). Few studies have used this method to evaluate the differences in the active soil organic matter fraction when comparing grazed and non-grazed agricultural sites. A study in North Carolina used CO₂ flush to evaluate soil biological activity when comparing multispecies cover crop mixes, single species cover crops, and no cover crop treatments. They noted that soil biological activity was very sensitive to cover crop management, with higher test levels, indicating greater biological soil quality, found in the multispecies cover crop treatment compared with no cover crop. There were trends for multispecies treatments to have greater CO₂ flush levels than single species cover crops (Franzluebbers, et al., 2000). In addition to the CO₂ flush, they also tested carbon and N mineralization rates

and found that rates were higher in the multispecies cover crop mixes compared to no cover crop. Because biological activity, and carbon and N mineralization rates are indicators of soil quality, they concluded that utilizing cover crops as a management practice, specifically multispecies cover crop mixes, can improve soils in a way that can lead to greater resilience and productivity in these agricultural systems (Franzluebbbers, et al., 2021). While they did not evaluate the effects of grazing these cover crops on soil biological activity, knowing that cover crops can improve the below-ground attributes of a cropping system can encourage implementing this practice. However, much less is known when these cover crops are used as a livestock feed source.

Franzluebbbers, et al., (2000) considered that CO₂ flush following rewetting of dried soil was a good indicator of biological soil quality for many reasons. The test reflects current and potential microbial biomass and activity and can show immediate changes in soil due to management. It also includes the physical, chemical, and biological conditions of the soil during the rewetting and incubation process. It appears that this CO₂ flush test can be applied to many soil textures across a range of management practices without any major modifications to the test. Due to its availability in laboratories, it can be used by researchers, industry professionals, and producers (Franzluebbbers, et al., 2000).

Summary

When grazing crop residues or cover crops occurs on dry or frozen soils, there is generally no reduction in grain yield on the subsequent crop (Clark, et al., 2004; Drewnoski, et al., 2016; Tracy & Zhang, 2008). In fact, a few studies have also shown

that grazing crop residue could potentially increase subsequent crop yields (Drewnoski, et al., 2016; Agostini, et al., 2012). This has been attributed to improved soil fertility and microbial biomass in these systems. The addition of cattle manure provides a nutrient source to the soil, increasing microbial biomass and soil carbon in these integrated systems (Drewnoski, et al., 2016; Agostini, et al., 2012; Peacock, et al., 2001). Thus, grazing cover crops or crop residue can be a feasible management tool with minimal negative impacts to crop production only when attention is given to the soil conditions during grazing (Tracy & Zhang, 2008; Rakkar & Blanco-Canqui, 2018). With the limited data available, grazing cover crops may not negatively impact crop production, the soil, or the environment (Drewnoski, et al., 2018).

Further Needed Research

Research that integrates crops and animals can be a challenge. This is due to a combination of factors including different disciplines having varied experimental requirements. Also, long timelines must be used to evaluate impacts, experiments can be labor intensive with the collaboration of departments, and funding needed to conduct these integrated projects can be great (Allen, Baker, et al., 2007; Russell, et al., 2007). After an extensive review of integrated systems and the impacts of grazing crop residues on soil properties and crop production, Rakkar and Blanco-Canqui (2018) pointed out that there is still much research needed to fully understand how these systems function and the effects of integrating crop and livestock systems. Research needs include looking at how different management practices can impact the complexity of integrated systems. Studies are needed to evaluate tillage type and how tillage or no-tillage may be used to

mitigate compaction from livestock or result in further compaction. Evaluating cropping rotations and increased diversity of cover crops and livestock. Which cover crops function best as livestock feed must be identified and then the gaps must be filled on what will happen to subsequent crop production if those cover crops are grazed. Continued research is needed under different soil textures and organic matter, across different climate zones and seasons, with varying livestock stocking rates. There also needs to be a focus on long term research projects (greater than ten years). Additional areas include changes in soil fertility properties such as soil carbon fluxes, nutrient cycling, and microbial properties. These typically require longer response times than other soil properties like labile fractions of OC. Finally, comprehensive economic analyses are needed on all aspects of integrated systems. These should evaluate livestock feed costs, impacts on soil fertility, carbon stocks, and other costs associated with integrating crops and livestock (Allen, Baker, et al., 2007; Faé, et al., 2009; Franzluebbbers & Stuedemann, 2006; Franzluebbbers & Stuedemann, 2015; Rakkar & Blanco, 2018; Sulc & Franzluebbbers, 2014; Sulc & Tracy, 2007). Beyond the science and economic components of integrating crops and livestock, research also needs to be done on the social aspect of these systems, with focus on implementation, barriers to adoption, decision-making strategies, and policy discussions of these systems (Allen, Baker, et al., 2007; Entz, et al., 2002; Rakkar & Blanco, 2018).

Objectives

This field scale, replicated, six-year study was designed to study the long-term impacts of grazing corn residue and cover crops in the fall and winter on corn, soybean, and wheat grain production and soil properties in eastern Nebraska. The specific objectives are:

Objective 1: Determine the impact of corn residue and cover crop grazing on crop production parameters, including plant populations and grain yields, in two cropping systems.

Objective 2: Determine the impact of corn residue and cover crop grazing on soil chemical and biological properties, including nutrients and CO₂ flux, in two crop systems.

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CHAPTER 2. Corn Residue and Cover Crop Grazing Effect on Crop Production

Abstract

Integrating crops and livestock together on a single farm or among farms can have positive effects on profitability, system productivity, and resource conservation. But how this practice affects crop yields is unclear. The objective of this study was to determine the effects of integrating grazing livestock into corn (*Zea mays*)-soybean (*Glycine max* (L.) Merr.) (C-S) and corn-soybean-wheat (*Triticum aestivum* L.) (C-S-W) systems on plant population and grain yield. Corn residue was used as a winter grazing forage in the C-S system with corn residue and an oat (*Avena sativa*) cover crop planted used for forage sources in the C-S-W system. In 2019, the first production season after grazing, corn (62,753 plants ha⁻¹) and soybean (292,463 plants ha⁻¹) plant populations were not different following grazed and non-grazed corn residue and oat cover crop in either system. Grain yield for corn (5,630 kg ha⁻¹) and soybean (3,724 kg ha⁻¹) were also not affected by grazing corn residue in the C-S and C-S-W cropping systems and the oat cover crop in the C-S-W cropping system. In 2020, corn and soybean plant populations were not different following grazing the oat cover crop or corn residue. Subsequent grain yield for soybean (3,306 kg ha⁻¹), corn (8,887 kg ha⁻¹), and wheat (3,959 kg ha⁻¹) were not different in either cropping system whether grazing occurred or not. For the C-S cropping system in 2021, soybean plant population was greater ($P < 0.05$) in grazed corn residue compared to the non-grazed corn residue 319,556 vs. 286,520 plants ha⁻¹, respectively. Nonetheless, no differences were found in the subsequent soybean grain yield in the C-S system (3,170 kg ha⁻¹). Livestock grazing effects in C-S and C-S-W

cropping systems suggested minimal to no reduction in plant populations in cropland grazed during winter with no apparent negative effects on grain production.

Introduction

In the past, the agricultural industry consisted mainly of small farm that produced diverse crop and livestock products, cycled nutrients on-farm or through neighboring farms, and marketed their commodities locally (Dimitri et al., 2005; Rotz et al., 2005). Advances in technology, machinery, and synthetic fertilizers after World War II created a shift to larger scale farms that were more specialized in their production, with crops and livestock becoming separate operations (Dimitri et al., 2005; Rotz et al., 2005; Conkin, 2008). This shift to larger farms caused large conversions of grasslands in the western Corn Belt to annual row crop land, and increased concerns of natural resource utilization and conservation (Wright & Wimberly, 2013; Allen, Baker, et al., 2007; Franzluebbers et al., 2014. Sulc & Tracy, 2007). Integrated crop and livestock systems again has been proposed as an alternative management strategy to sustainably produce these food products, while generating adequate income for the producer, and not negatively impacting soils or the environment (Franzluebbers, 2007; Wright & Wimberly, 2013; Walthall et al., 2013). These integrated crop and livestock systems can be accomplished by grazing crop residues and cover crops within crop rotations.

When considering grazing and crop production, producers express concern about compaction from grazing. Severe compaction can inhibit root and plant growth which will reduce yields and profits for a crop producer. Many studies have found that in these integrated crop and livestock systems any compaction from grazing found is typically only in the surface soil, and this shallow compaction can be quickly alleviated through natural soil processes, like freeze-thaw cycles, and with biological processes as roots and

organisms move through the soil (Greenwood & McKenzie, 2001; Liebig et al., 2012; Franzluebbers & Stuedemann, 2008; Clark et al., 2004; Faé et al., 2009). Also, in the western Corn Belt corn (*Zea mays*) residue and cover crop grazing tends to take place during the fall and winter when the soil is typically frozen, which is less vulnerable to compaction than wet or thawed soils (Drewnoski et al., 2016; Clark et al., 2004).

Properly managing grazing can alleviate the concerns with integrated crop and livestock systems.

Rakkar and Blanco-Canqui (2018) discussed many studies that have looked at the impact of grazing crop residues on subsequent crop production in their recent review. These studies show that allowing livestock to graze crop residues over winter has little to no effect on subsequent grain yield production (Tracy & Zhang, 2008; Clark et al., 2004; Drewnoski et al., 2016; Ulmer, 2016; Agostini et al., 2012; Erickson et al., 2001). One long-term study in Nebraska even saw increases in soybean (*Glycine max* (L.) Merr.) yield following corn residue grazing (Drewnoski et al., 2016). Plant populations have also been evaluated in previous studies, as a parameter of crop production. These studies have shown no differences in plant populations between grazed and non-grazed crop residues, or slight increases in plant populations in the grazed corn residues compared to the non-grazed (Rakkar & Blanco-Canqui, 2018; Clark et al., 2004). The increases in plant population could be attributed to residue removal from grazing allowing for better seed to soil contact of the subsequent crop, or from a crops ability to compensate with more growth when in undesirable conditions, like soybeans (Anderson, 2019; Rakkar & Blanco-Canqui, 2018; Clark et al., 2004).

An additional level of diversity in cropping systems can be added by including a cover crop in the rotation that can be grazed. There are few studies that have evaluated the impact of cover crop grazing on subsequent crop production. Those that have been done have found that overall cover crop grazing does not impact grain yield when comparing grazed and non-grazed (de Faccio Carvalho, et al., 2010; Franzluebbers & Stuedemann, 2007; Faé et al., 2009; Lesoing et al., 1997; Tracy & Zhang, 2008, Blanco-Canqui et al., 2020).

The limited research available on corn residue and cover crop grazing seem to agree if livestock are managed to minimize compaction by grazing when soils are dry or frozen, then crop production parameters like plant population and grain yield will not be negatively impacted. There does need to be more research done on different soil types, crop rotations, and stocking rates to accurately determine the impact of crop residue and cover crop grazing in integrated crop and livestock systems on cash crop production. Thus, the objective of our study was to determine the impact of corn residue and cover crop grazing on crop production parameters, including plant populations and grain yields, in two different cropping systems in eastern Nebraska.

Materials and Methods

Research Site

The experiment was conducted at the University of Nebraska Agronomy and Horticulture Research and Teaching Farm located in Lincoln, NE (40°49'51"N 96°39'23"W). Prior to establishment of this experiment, the site was used as a hazelnut (*Corylus avellana*) orchard. To initiate this experiment, the trees were removed, and the

soil was prepared using deep tillage. Replicated plots consisting of corn-soybean (C-S) and corn-soybean-wheat (C-S-W) rotations and five cropping sequences (C-S, S-C, C-S-W, S-W-C, W-C-S) were established in fall 2017. Manure (M) was applied after oat (*Avena sativa*) was winter grazed prior to corn planting in the corn-soybean-wheat (C-S-W w/M, S-W-C w/M, W-C-S w/M) rotation.

Winter wheat ('Ruth') (*Triticum aestivum* L.) was planted into a 0.81 ha area in late October 2017. Because of the later planting date, wheat seeding rate was increased to 100 kg ha⁻¹ (90 lbs. seed/acre) to increase the likelihood of a productive stand. Within this larger area, individual plots for the 2018 corn and soybean cropping rotation were established by spraying the wheat with glyphosate (*N*-(phosphonomethyl)glycine) and no-till planting either corn or soybean in the appropriate plots of the design using field scale equipment. Plot size for each crop phase during each year was 4.5 m x 40.5 m (Figure 2.1). Following establishment of the plots, this site was managed as a rain-fed, no-till cropping system.

Soils in these plots were classified as Wymore-Askarben complex, 0 to 2% slopes with Wymore silty clay loam (Fine, smectitic, mesic Aquertic Argiudolls) and Askarben silty clay loam (Fine, smectitic, mesic Typic Argiudolls) dominating the complex.

Cropping Systems Management

Wheat Grain Production and Oats Cover Crop

Winter wheat was drilled in 19-cm rows in mid-October, following soybean harvest. Wheat was harvested using a plot combine in mid to late July. A 1.5-m swath was harvested from the center of each plot. Grain yield was determined using an on-

board combine scale. Grain yield was adjusted for moisture and reported on a dry matter (DM) basis.

In early- to mid-August following wheat grain and stover harvest, oats were planted as a double-cropped forage into the wheat stubble. Oats seed was drilled into 19-cm rows at a seeding rate of 101 kg ha⁻¹ in early to mid-August. Prior to beginning the grazing treatments, pre-grazing biomass samples were collected using a 1 m x 0.25 m metal frame. Oats were hand-clipped to ground level from respective grazed and non-grazed plots. In the spring following grazing and before planting, post-grazed biomass samples were collected from the grazed plots only, using the same procedure described for pre-grazed biomass samples. Poor growing conditions resulted in low oat forage production. In late March or early April, composted animal manure was broadcast-applied at a rate of 39,230 kg ha⁻¹ on the oat residue using a manure spreader prior to corn planting in early May.

Corn and Soybean Grain Production

Prior to planting corn and soybean in year 1, the study area was sprayed with 2, 4-D (2, 4-Dichlorophenoxyacetic acid) in early April 2018 to control broadleaf weeds. In 2018 (year 1), corn ('P1138AM', CRM 111) was planted on May 22, 2018, with soybean ('33T72R', RM 3.3) planted on May 2, 2018.

Herbicides were used for weed control on the corn and soybean plots in all years, with glyphosate applied at a rate of 1 qt/acre in early April, and flumioxazin (N-(7-fluoro-3,4-dihydro-3-oxo-4-prop-2-ynyl-2H-1,4-benzoxazin-6-yl) cyclohex-1-ene-1,2-dicarboxamide) applied at a rate of 3 oz/acre. Atrazine (1-Chloro-3-ethylamino-5-

isopropylamino-2,4,6-triazine) was also applied onto the corn plots only, at a rate of 1 qt/acre. In late April, urea (46-0-0) was applied across to all plots at a rate of 308 kg N ha⁻¹.

Corn and soybean planting dates were in early to mid-May. Both corn and soybean were planted at 76 cm row spacing. Target planting populations for corn were 30,000 plants ha⁻¹ and 130,000 plants ha⁻¹ for soybean. A post-emergent herbicide application of glyphosate was applied at a rate of 1qt/acre to corn and soybeans in all years. Following corn and beans emergence, plant populations were measured to compare differences for all grazed and non-grazed treatments. Plant populations were determined from the mean of two plants counts along a 5.334-m length of row taken randomly in the middle two rows of each corn and soybean plot and used to calculate plant populations per hectare. Plant populations for wheat were only measured in the fourth year of this study. Corn and soybean grain yield was determined using a plot combine with an on-board scale. The middle two rows from each corn and soybean plot were used to determine yield. Yield was adjusted for moisture and reported on a dry matter basis. After corn and soybean harvest in early November of 2019, 2,4-D and Dicamba (3,6-dichloro-2-methoxybenzoic acid) were sprayed on all plots, at rates of 1 pint/acre and 8 oz/acre respectively, to control weeds.

Cattle and Gazing Management

All animal-related activities implemented in this study were approved by the Institutional Animal Care and Use Committee (IACUC #1785) at the University of Nebraska-Lincoln. No animal response data was collected from this experiment. Animals

were used solely as a means of forage removal and to provide the effects of including livestock into the cropping systems. Free-choice mineral and water were always available.

Two beef (*Bos taurus*) steers were used during each year of the experiment. Mean body weight ranged between 499 to 703 kg. Oat grazing (approximately 2.48 AUM ha⁻¹) occurred prior to corn residue grazing. Corn residue grazing occurred from January to March following the 2018 cropping season (9.65 AUM ha⁻¹), December to January for the 2019 cropping season (11.14 AUM ha⁻¹), and November to December following the 2020 cropping season (11.63 AUM ha⁻¹).

Following corn and soybean grain harvest and wheat planting, each 30.5-meter-long whole was equally divided using electrified fencing, to allow cattle to graze half, and be excluded from the remaining to represent the non-grazed treatment. Cattle grazed a single experimental unit before moving to the next experimental unit. Grazing began with the oat cover crops, and ended with corn residue plots. The oats cover crop was grazed until the remaining stubble was 5 centimeters tall. Cattle were allowed to graze corn residue until there were no husks observed in the plot.

Experimental Design and Analysis

This study was designed as a randomized complete block with five treatments (crop rotations) (corn-soybean, soybean-corn, corn-soybean-wheat with manure, soybean-corn-wheat with manure, and wheat-corn-soybean with manure) with grazing occurring during the corn phase and wheat/oats cover crop phase of each crop rotation. Treatment plots are 30.5 meters long by 4.6 meters wide and are then split in half to be

grazed on half and not 15.25 meters long by 4.6 meters wide. There are four replications in this study.

Results and Discussion

Weather Data

Total monthly precipitation and daily high and low temperatures for all years of this study are reported in Table 2.1. Average monthly temperatures were consistent across all years of the experiment. Total annual precipitation was greater in 2018 (905 mm) and 2019 (917 mm) compared to 2020 (600 mm) and 2021 (676 mm).

Plant population

Corn-Soybean System

In the corn-soybean system (C-S), in the first production year after grazing (2019), soybean plant populations were not different following the grazed and non-grazed corn residue in the C-S rotation (290,843 vs. 285,903 plants ha⁻¹). The S-C rotation had not yet been grazed because soybean residue was not grazed in this study.

In the second production year after grazing (2020), in the C-S rotation, corn residue had been grazed in 2018, soybeans were harvested in 2019, and no differences were found in corn plant population in the previously grazed plots or the non-grazed plots (68,388 vs 72,093 plants ha⁻¹). No differences were observed in soybean plant populations following grazed and non-grazed corn residue in the S-C rotation (254,410 vs. 258,269 plants ha⁻¹).

In 2021, the third production year after grazing, the two-crop rotations were completing two full cycles. After corn residue was grazed twice in the C-S rotation, there

was an increase in soybean plant populations in the grazed plots compared to the non-grazed plots (319,556 vs. 286,520 plants ha⁻¹). Corn plant populations were not different between the once grazed and non-grazed corn residue plots in the S-C rotation (66,999 vs. 66,073 plants ha⁻¹) (Table 2.2).

Previous work has found that corn residue grazing removed 25% of corn residue biomass compared to non-grazing in C-S systems, and a review on crop residue grazing found that most studies removed approximately 30% of residues with grazing (Anderson, 2021; Rakkar & Blanco, 2018). This removal of residue from grazing corn residue before soybean planting could have allowed for better seed to soil contact of the soybeans, causing the increased plant populations in the grazed plot compared to non-grazed.

In a three-year study in Atlantic, IA, when evaluating soybean plant populations in a C-S rotation with corn residue being grazed, no significant differences between the grazed and non-grazed treatments were found for any of the three years. Plant populations were lower overall than expected, which was attributed to variation in rainfall amount and intensity each year, but soybeans tend to compensate for inadequate plant populations by developing more branches per plant (Clark et al., 2004). These studies follow what was found in this current research.

Corn-Soybean-Wheat System

For the corn-soybean-wheat system (C-S-W), in the first production season after grazing (2019), soybean plant populations were not different following the grazed and non-grazed corn residue in the C-S-W w/M rotation (301,031 vs. 292,078 plants ha⁻¹). No grazing occurred in the S-W-C w/M rotation in 2018, because soybean residue was not

grazed in this study. Corn plant populations were not different following the grazed and the non-grazed oat cover crop in the W-C-S w/M rotation (57,119 vs. 62,985 plants ha⁻¹).

In 2020, all treatments had been grazed at least once, with the W-C-S w/M rotation having been grazed twice. Wheat plant populations were not collected for the C-S-W w/M rotation. The S-W-C w/M rotation had soybeans harvested in 2018, oat cover crop grazing in 2019, and no differences were found within the treatment for corn plant populations between the grazed and non-grazed plots (58,663 vs. 57,428 plants ha⁻¹). Similarly, no differences were found in soybean plant populations in the W-C-S w/M rotation, following oat cover crop grazing and non-grazing in 2018, and corn residue grazing and non-grazing in 2019 (294,638 vs. 261,511 plants ha⁻¹).

In 2021, the three crop rotations had completed one full cycle and were starting over. Corn plant populations were not different in the C-S-W w/M rotations, following a corn residue grazing and non-grazing in 2018, and oat cover crop grazing and non-grazing in 2019 (58,045 vs. 61,750 plants ha⁻¹). No differences were observed in soybean plant populations in grazed and non-grazed treatments after oat cover crop grazing in 2019, and corn residue grazing in 2020 in the S-W-C w/M rotation (306280 vs. 259350 plants ha⁻¹). Wheat plant populations were collected for the first time in the experiment in 2021 in the W-C-S w/M rotation and no differences were found in populations after oat cover crop and corn residue grazing and non-grazing in 2018 and 2019 respectively (1,922,332 vs 1,665,916 plants ha⁻¹) (Table 2.2).

Similar results to this study were found in a study done in a four-year study in Georgia. This study looked at a summer grain crop of sorghum (*Sorghum bicolor* L.

Moench) and winter cover crop of rye (*Secale cereale* L.) rotation. Sorghum residue was grazed immediately after harvest, then rye was planted and grazed in the spring. Sorghum plant populations were not different between the grazed and non-grazed residue and cover crop treatments (Franzluebbbers & Stuedemann, 2007). This study in Georgia also looked at a winter grain crop and summer cover crop of winter wheat and pearl millet (*Cenchrus americanus*) respectively. Here wheat was planted in the fall, harvested the next summer, then pearl millet was planted and grazed in late summer. Plant populations of wheat were taken, and there was an effect of grazing, with the grazed cover crop treatments having higher plant populations than the non-grazed cover crop (180 vs. 136 plants m⁻¹) (Franzluebbbers & Stuedemann, 2007). These results follow what was found in the C-S system of this study.

Grain yield

Corn-soybean system

In C-S system, corn residue is grazed every other year following corn harvest. So, subsequent soybean yield will be the immediate indicator of any changes due to grazing.

In 2019, the first production year after initial grazing, grazing of the corn residue in 2018 had no effect compared to the non-grazing on soybean yield in the C-S rotation (3527 vs. 3988 kg ha⁻¹). In the S-C rotation, soybean residue was not grazed in this study.

In 2020, there were similar results to 2019 in the C-S rotation, as well as in the S-C rotation. Following corn residue grazing in 2018, and soybean harvest in 2019, no effects due to grazing were found in the 2020 corn yield in the C-S rotation (8623 kg ha⁻¹

grazed vs. 9387 kg ha⁻¹ non-grazed). No differences in soybean yield were found following grazed and non-grazed corn residue the previous year (3570 vs. 3059 kg ha⁻¹).

In the third production year after grazing, 2021, the two crop rotations were completing a second cycle through the rotation. After corn residue was grazed twice in the C-S rotation, there was no difference found in soybean grain yield in the grazed plots compared to the non-grazed plots (3961 vs. 3570 kg ha⁻¹), despite an increased plant population in the grazed plots compared to non-grazed plots. Corn grain yield was not different between the once grazed and non-grazed corn residue plots in the S-C rotation (13329 vs. 13889 kg ha⁻¹) (Table 2.3).

In some previous research, it has been documented that livestock grazing increased crop production. Grain yields were found to be improved by grazing in a 16-year study in Nebraska on a C-S rotation where corn residue was grazed by stocker cattle. Fall grazing of corn residue improved soybean yields ($P < 0.01$) and corn grain yield, after a full year of no grazing because soybeans were not grazed, also tended to be improved in the grazed treatments compared to the non-grazed ($P < 0.07$) (Drewnoski, et al., 2016). The authors of this study thought that these yield increases could partially be due to the addition of cattle manure from grazing because manure can increase microbial biomass, accelerating residue break down and nutrient release and cycling to be plant available (Drewnoski et al., 2016; Peacock et al., 2001).

On the other hand, there have also been instances of decreased crop production in grazed residue systems. In the three-year study on a C-S rotation with corn residue grazing discussed above, Clark et al. (2004) found that after the second grazing event,

soybean yields were 8% lower in the grazed compared to the non-grazed. They attributed the decrease to grazing that happened while the soil was wet and not frozen. Despite this, when averaged across all three years, there was no difference between grazed and non-grazed treatments. They concluded that the risk of yield losses due to corn residue grazing is minimal, especially if grazing occurs when soils were frozen (Clark et al., 2004).

Impacts of spring grazing corn residue on soybean and corn yields were evaluated in a two-year study (Erickson et al., 2001). Spring grazing was used to allow cattle to remain in the crop fields after the ground had thawed. Results were similar to the Drewnoski et al. (2016), despite the grazing time difference, with soybean yields being greater in the grazed corn residue treatments compared to the non-grazed. The next year, corn yields were not significantly different between grazed and non-grazed treatments (Erickson et al., 2001). These studies all noted that properly managed grazing of corn residue will have minimal negative impacts on grain yield in C-S systems, which agrees with the results found in this current study.

Corn-Soybean-Wheat System

For C-S-W, in 2019, soybean plant yields were not different following the grazed and non-grazed corn residue in the C-S-W w/M rotation (3845 vs. 3536 kg ha⁻¹). Soybean residue is not grazed in this study, so grazing had not occurred in the S-W-C w/M rotation previously. Following the grazed and non-grazed oat cover crop, corn grain yield was not affected by grazing in the W-C-S w/M rotation (4362 vs. 4921 kg ha⁻¹).

In the second production season after grazing, 2020, all treatments had been grazed once, and the W-C-S w/M rotation had been grazed twice. Wheat yields were not impacted by grazing or non-grazing of corn residue two years previous in the C-S-W w/M rotation (3995 vs. 4066 kg ha⁻¹). The same results were seen in the S-W-C w/M rotation where no differences were observed in the corn yield following soybean harvest in 2018 and oat cover crop grazing and non-grazing in 2019 (8684 vs. 8802 kg ha⁻¹). In the W-C-S w/M rotation, soybean yields showed no differences between the grazed and non-grazed oat cover crop and corn residue (3285 vs. 3055 kg ha⁻¹).

In 2021, the three cover crops had completed one full cycle and were starting the rotation over. Corn yields were not different in the grazed and non-grazed C-S-W w/M rotation following two grazing events over the last three years (11573 vs. 10177 kg ha⁻¹). The S-W-C w/M had been grazed twice, with the oat cover crop in 2019 and corn residue in 2020, and no differences were found in the subsequent soybean grain yield between the grazed and non-grazed treatments (3828 vs. 3820 kg ha⁻¹). Finally, following two grazing events, no differences were found in wheat grain populations when comparing the grazed and non-grazed treatments (4093 vs. 3838 kg ha⁻¹) (Table 2.3).

Few other studies look at crop production following cover crop grazing. A Georgia study on a summer grain (sorghum) and winter cover crop (rye) rotation, referred to above, also measured sorghum grain yield. In this study they found that the mean 4-year sorghum grain yield was lower in the grazed rye cover crop treatments compared to non-grazed rye treatments when managed with no-tillage. Sorghum grain yield was not different between grazed and non-grazed rye cover crop treatments when managed with

conservation tillage. This led them to conclude that integrated crop and livestock systems may not suppress crop yields and could even lead to improvements, especially if the system is managed with conservation tillage (Franzluebbbers & Stuedemann, 2007). This current experiment was managed under no-tillage and saw no decreases in grain yield when comparing grazed and non-grazed cover crop, similar to the results in the Georgia study.

Blanco-Canqui et al. (2020) conducted a three-year study in western NE, comparing grazed and non-grazed cover crops in a continuous corn silage system. They found no differences in corn silage yield following winter grazing of cereal rye compared to non-grazed cereal rye. These results follow what was found in this study and others when comparing grazed and non-grazed cover crops in cropping systems (Franzluebbbers & Stuedemann, 2007; Faé et al., 2009; Lesoing et al., 1997; Tracy & Zhang, 2008).

Summary and Conclusions

For the C-S system, corn residue is grazed following grain harvest with soybean planted and harvested the following year. Thus, subsequent soybean grain yield is an indicator of effects of grazing corn residue with corn grain yield an indicator of any residual effects of corn residue grazing. In the C-S-W system, corn residue is grazed following grain harvest with soybean planted and harvested the following year. Following soybean harvest, wheat is planted in autumn and harvested the following summer. This is followed by an oat cover crop planted in the late summer and then grazed over winter as a stockpiled forage with corn planted in the spring following the grazed oat cover crop. Thus, corn grain yield are indicators of effects of the grazing of the

oat cover crop and any residual effects of the corn residue with soybean yield an indicator of corn residue grazing effects. In the C-S system, grazing the corn residue would occur every other year and with the C-S-W system, grazing would occur in two of three years of the rotation. Livestock incorporation can be accomplished without reducing subsequent crop production.

Overall, there were no changes within a year due to grazing on plant populations. Grazing did not affect plant populations for any crop phase in either cropping system in 2019. In 2020 there were no differences within treatments caused by grazing. In 2021, soybean plant populations were higher in the grazed compared to the non-grazed in the C-S rotation. No other crop phases in either cropping system were affected by grazing in 2021. For either system within any year, soybean yield was not affected by corn residue grazing, corn yield was not affected by oat cover crop grazing, or residual corn residue grazing, and wheat was not affected by residual corn residue grazing.

Based on the results we observed in this study coupled with results from other similar studies, it is possible to diversify cropping systems and integrate livestock without positive or negative effects on crop production. Although not specifically addressed in this study, a benefit to diversifying cropping systems is the provision of livestock feed resources. For producers with livestock, this could reduce purchased feed costs. Similarly, if a crop producer does not own livestock, these feed resources can still be used by livestock producers through mutual leasing arrangements.

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Table 2.1. Total precipitation (mm), mean high, and mean low temperatures (°C) from 2018 to 2021 for Lincoln, Nebraska.

-----Precipitation (mm)-----												
Year	January	February	March	April	May	June	July	August	September	October	November	December
2018	10.4	18.8	68.8	17.0	56.6	224.3	34.3	110.5	181.1	68.8	30.2	84.3
2019	19.1	40.4	67.3	28.7	185.2	111.3	103.6	70.9	86.4	119.1	20.1	65.3
2020	32.8	3.3	42.4	22.4	129.3	80.0	145.5	32.3	41.1	10.2	30.5	30.5
2021	38.9	20.1	132.8	44.2	64.8	113.3	43.9	86.6	16.3	102.6	12.4	.
-----Average High Temperature (°C) -----												
	January	February	March	April	May	June	July	August	September	October	November	December
2018	1.9	1.8	11.2	14.8	28.1	31.4	31.2	30.2	25.9	16.8	7.2	4.9
2019	1.5	-2.6	7.4	19.6	21.6	29.2	31.5	28.9	29.5	15.8	9.7	6.6
2020	1.9	6.8	13.1	18.6	21.1	31.9	31.2	30.7	25.6	16.8	14.7	5.9
2021	3.4	-3.6	15.2	19.0	22.8	31.9	31.3	32.4	28.8	20.7	14.0	.
-----Average Low Temperature (°C) -----												
	January	February	March	April	May	June	July	August	September	October	November	December
2018	-10.7	-10.8	-1.2	-1.1	13.6	18.8	18.4	17.9	14.5	3.8	-5.4	-6.8
2019	-9.0	-12.3	-4.3	4.7	9.8	16.5	19.9	18.5	16.9	2.8	-3.7	-6.1
2020	-7.8	-7.5	0.6	1.2	10.1	19.1	19.9	17.2	10.6	2.6	-1.6	-8.1
2021	-6.9	-15.1	1.0	4.2	11.0	17.5	18.5	19.0	13.3	6.7	0.2	.

Table 2.2. Means of plant populations in corn residue and oat cover crop grazing experiment, under no-till and dryland management in corn-soybean (C-S) and corn-soybean-wheat (C-S-W) systems in eastern Nebraska. After 2018, only rotations grazed at least once were included for a grazed vs. non-grazed comparison. Means with different uppercase letters in the same year and cropping system differ significantly at $p < 0.05$. Dashes indicate crops that were not present that year for the rotation, or where data was not collected.

			Crop Phase					
			Corn		Soybean		Wheat	
Year	Cropping System	Previous Grazing Events	Grazed	Non-Grazed	Grazed	Non-Grazed	Grazed	Non-Grazed
			-----plants ha ⁻¹ -----					
2018 [†]	C-S ^{††}	0	0.9446 ^A (67771)	-	-	-	-	-
	S-C	0	-	-	1.0656 ^A (357841)	-	-	-
	C-S-W (w/M)	0	0.9963 ^A (64992)	-	-	-	-	-
	S-W-C (w/M)	0	-	-	0.9936 ^A (330671)	-	-	-
	W-C-S (w/M)	0	-	-	-	-	-	-
SE=0.0470^{††}								
2019	C-S	1	-	-	0.9945 ^{AB} (290843)	0.9776 ^{AB} (285903)	-	-
	C-S-W (w/M)	1	-	-	1.0293 ^{AB} (301031)	0.9987 ^A (292078)	-	-
	W-C-S (w/M)	1	0.9102 ^B (57119)	1.0037 ^{AB} (62985)	-	-	-	-
SE=0.0292								

2020	C-S	1	1.0806 ^{AB} (68388)	1.1095 ^A (72093)	-	-	-	-
	S-C	1	-	-	1.0105 ^{ABCD} (254410)	0.9543 ^{CDE} (258269)	-	-
	C-S-W (w/M)	1	-	-	-	-	-	-
	S-W-C (w/M)	1	0.9242 ^{DE} (58663)	0.8857 ^E (57428)	-	-	-	-
	W-C-S (w/M)	2	-	-	1.0531 ^{ABC} (294638)	0.9821 ^{BCDE} (261511)	-	-
SE=0.0368								
2021	C-S	2	-	-	1.0494 319556 ^{AB}	0.7322 286520 ^C	-	-
	S-C	1	1.0305 ^{AB} (66999)	1.0745 ^{AB} (66073)	-	-	-	-
	C-S-W (w/M)	2	0.9915 ^{AB} (58045)	0.9035 ^{BC} (61750)	-	-	-	-
	S-W-C (w/M)	2	-	-	1.1334 ^A (306280)	0.9919 ^{AB} (259350)	-	-
	W-C-S (w/M)	2	-	-	-	-	0.9921 ^{AB} (1922332)	1.0079 ^{AB} (1665916)
SE=0.0617								

†2018 is the first year of the study, before any grazing treatments had been applied, so there was no differentiation between grazed and non-grazed

††Values within a cropping system were normalized and used to determine differences in grazing treatments. Values in parentheses are actual plant populations.

†††Standard errors were calculated using normalized values.

Table 2.3. Means of grain yields in corn residue and oat cover crop grazing experiment, under no-till and dryland management in corn-soybean (C-S) and corn-soybean-wheat (C-S-W) systems in eastern Nebraska. After 2018, only rotations grazed at least once were included for a grazed vs. non-grazed comparison. Means with different uppercase letters in the same year and cropping system differ significantly at $p < 0.05$. Dashes indicate crops that were not present that year for the rotation, or where data was not collected.

Year	Cropping System	Previous Grazing Events	Crop Harvested					
			Corn		Soybean		Wheat	
			Grazed	Non-Grazed	Grazed	Non-Grazed	Grazed	Non-Grazed
			-----kg/ha-----					
2018 [†]	C-S ^{††}	0	0.9490 ^A (11831)	-	-	-	-	-
	S-C	0	-	-	0.9471 ^A (3880)	-	-	-
	C-S-W (w/M)	0	1.0296 ^A (13314)	-	-	-	-	-
	S-W-C (w/M)	0	-	-	1.0529 ^A (4313)	-	-	-
	W-C-S (w/M)	0	-	-	-	-	0.9050 ^A (4524)	-
SE=0.0862^{†††}								
2019	C-S	1	-	-	0.9471 ^A (3527)	1.0709 ^A (3988)	-	-
	C-S-W (w/M)	1	-	-	1.0324 ^A (3845)	0.9495 ^A (3536)	-	-
	W-C-S (w/M)	1	0.9223 ^A (4362)	0.8741 ^A (4921)	-	-	-	-
SE=0.1448								

2020	C-S	1	1.0131 ^A (8623)	1.0136 ^A (9387)	-	-	-	-
	S-C	1	-	-	1.0747 ^A (3570)	0.9699 ^A (3059)	-	-
	C-S-W (w/M)	1	-	-	-	-	1.0092 ^A (3995)	0.9908 ^A (4066)
	S-W-C (w/M)	1	1.0427 ^A (8684)	0.9510 ^A (8802)	-	-	-	-
	W-C-S (w/M)	2	-	-	0.9431 ^A (3285)	1.0123 ^A (3055)	-	-
SE=0.0564								
2021	C-S	2	-	-	1.0470 ^{AB} (3961)	0.9315 ^{BC} (3570)	-	-
	S-C	1	1.0888 ^{AB} (13329)	1.1345 ^A (13889)	-	-	-	-
	C-S-W (w/M)	2	0.9454 ^{BC} (11573)	0.8313 ^C 10177	-	-	-	-
	S-W-C (w/M)	2	-	-	1.0118 ^{AB} (3828)	1.0097 ^{AB} (3820)	-	-
	W-C-S (w/M)	2	-	-	-	-	1.0412 ^{AB} (4093)	0.9768 ^{ABC} (3838)
SE=0.0589								

†2018 is the first year of the study, before any grazing treatments had been applied, so there was no differentiation between grazed and non-grazed

††Values within a cropping system were normalized and used to determine differences in grazing treatments. Values in parentheses are actual plant populations.

†††Standard errors were calculated using normalized values.

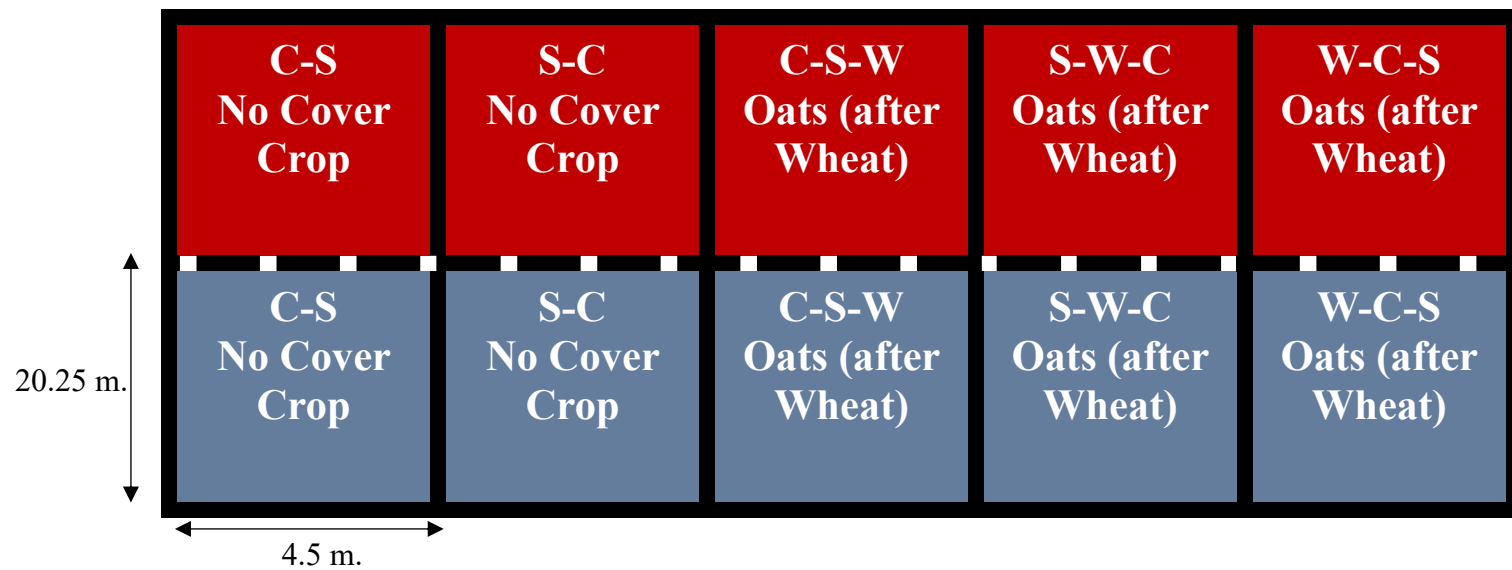


Figure 2.1 Schematic diagram of plot design representing one replication of four reps in this study. Each rotation is listed at the top and whether a cover crop is included in the rotation (C=Corn, S=Soybean, W=Wheat). For the grazed and non-grazed comparison, a fence, denoted by the dashed line, was constructed the middle of the plots after harvest to contain cattle on one-half of each plot (red=grazed, blue=non-grazed).

CHAPTER 3. Corn Residue and Cover Crop Grazing Effect on Soil Properties

Abstract

Integrated crop and livestock systems are proposed as an alternative management strategy to traditional cropping systems. Integrated systems can generate additional producer income without negatively impacting soil physical properties or reducing crop yields. However, there is limited research on how these integrated systems will affect the biological and chemical properties of soils. This study was conducted on a silty clay loam soil and managed as a field-scale, dryland, no-till site. Soil nutrient statuses and carbon dioxide (CO₂) respiration responses to grazing and non-grazing in corn (*Zea mays*)-soybean (*Glycine max* (L.) Merr.) (C-S) and corn-soybean-wheat (*Triticum aestivum* L.) (C-S-W) systems were evaluated. Corn residue was utilized as a winter forage source in both cropping systems, and a double-cropped oat (*Avena sativa*) cover crop following wheat was also used in the C-S-W system. Soil nitrogen (N), phosphorus (P), potassium (K), organic carbon (OC), and soil CO₂ flux were measured following grazing. Across all three years of this study, grazing corn residue and the oat cover crop had no impact on the measured soil chemical and biological properties for corn, soybean, and wheat in either cropping system. These results indicate that livestock can be integrated into cropping systems to graze corn residue and cover crops without affecting soil nutrient supply and selected soil parameters.

Introduction

Historically, agricultural systems were managed by including crops and livestock together on farm or on neighboring farms (Dimitri et al., 2005; Rotz et al., 2005). Over time there has been shift to larger, more specialized farms that separate the production of crops and livestock (Dimitri et al., 2005; Rotz et al., 2005; Conkin, 2008). This has created concerns about the shifting climate, farm productivity, water and nutrient use and loss, soil function, and environmental sustainability (Allen, Baker, et al., 2007; Franzluebbbers et al., 2014. Sulc & Tracy, 2007). Beginning to integrate crops and livestock back into the same systems has been proposed as a management strategy to combat these concerns (Wright & Wimberly, 2013; Walthall, et al., 2013). Integrating crops and livestock together on a single farm or among farms supports positive effects through increased net returns, productivity, and resource conservation (Allen, Heitschmidt, et al., 2007; Kumar, et al., 2019). These systems allow for nutrients and organic matter to cycle within these croplands, with livestock waste and plant residues remaining, which can help sustain and even improve fertility in these areas (Franzluebbbers et al., 2014). This loop of nutrient cycling by integrating crops and livestock can reduce the need for synthetic fertilizers and increase soil organic carbon (OC) and microbial biomass, which can improve productivity (Allen, et al., 2005; Allen, Baker, et al., 2007; Acosta-Martinez, et al., 2004).

Crops and livestock can be integrated by grazing crop residues and cover crops. When animals graze cropland, manure is distributed throughout the field, although it may be uneven. This can improve soil fertility, nutrient cycling, biological function, and

reduce vulnerability to compaction, indicating that the benefits coming from livestock and the addition of manure has the potential to offset any negative soil effects from grazing (Blanco-Canqui et al., 2015).

Rakkar and Blanco-Canqui (2018) noted in their review of grazing crop residues that in general grazing can maintain and even improve the soil fertility of a system if stocking rate and residue removal rate are managed correctly. Animal trampling and the addition of manure allows microorganisms to break residues down more quickly, which improves nutrient cycling and creates more plant available nutrients than those being stored in crop residues (Tracy & Zhang, 2008; Liebig, et al., 2012; Banegas, et al., 2015; Drewnoski, et al., 2016; Duncan, et al., 2016). In a long-term study in Nebraska, it was found that there were no differences in soil nitrogen (N), phosphorus (P), or potassium (K) when comparing grazed and non-grazed corn (*Zea mays*) residue (Rakkar et al., 2017). When cover crops are included as an additional layer of diversity, they can also be grazed by livestock. A study in western Nebraska found that this cover crop grazing has no effect on any soil fertility properties, including N, P, K, and organic matter when comparing grazed to non-grazed cover crop (Blanco-Canqui et al., 2020).

Soil biology is also directly impacted by added diversity from livestock and cover crops. Few studies have evaluated soil biology parameters between grazed and non-grazed corn residues and cover crops. One study found that microbial biomass was greater in the integrated crop and livestock system which included grazing, compared to a continuous corn rotation that was not grazed (Tracy & Zhang, 2008). Another study did

not compare grazed to non-grazed residue or cover crops but compared the biology of multi-species cover crop mixes to single cover crop mixes. Here they found that carbon dioxide (CO₂) flushes, indicating soil microbial activity, were higher in the multi-species mixes compared to the single species (Franzluebbers et al., 2000).

Through the work that has been done, it seems that greater diversity through more crops in a rotation, cover crops, and the addition of livestock has no negative, and a possibly positive impact to soil fertility and biology parameters. But much more research needs to be done on specific impacts of grazing crop residues and cover crops on soil chemical and biological properties. Thus, the objective of our study was to determine the impact of corn residue and cover crop grazing on soil chemical and biological properties, including plant available nutrients and CO₂ flux, in two cropping systems.

Materials and Methods

Site Description

The experiment was conducted at the University of Nebraska Agronomy and Horticulture Research and Teaching Farm located in Lincoln, NE (40°49'51"N 96°39'23"W). Prior to establishment of this experiment, the site was used as a hazelnut (*Corylus avellana*) orchard. To initiate this experiment, the trees were removed, and the soil was prepared using deep tillage. Replicated plots consisting of corn-soybean (C-S) and corn-soybean-wheat (C-S-W) rotations and five cropping sequences (C-S, S-C, C-S-W, S-W-C, W-C-S) were established in fall 2017. Manure (M) was applied after oat was

winter grazed prior to corn planting in the corn-soybean-wheat (C-S-W w/M, S-W-C w/M, W-C-S w/M) rotation.

Winter wheat ('Ruth') (*Triticum aestivum* L.) was planted into a 0.81 ha area in late October 2017. Because of the later planting date, wheat seeding rate was increased to 100 kg ha⁻¹ (90 lbs. seed/acre) to increase the likelihood of a productive stand. Within this larger area, individual plots for the 2018 corn and soybean cropping rotation were established by spraying the wheat with glyphosate (*N*-(phosphonomethyl)glycine) and no-till planting either corn or soybean in the appropriate plots of the design using field scale equipment. Plot size for each crop phase during each year was 4.5 m x 40.5 m (Figure 3.1). Following establishment of the plots, this site was managed as a rain-fed, no-till cropping system.

Soils in these plots were classified as Wymore-Askarben complex, 0 to 2% slopes with Wymore silty clay loam (Fine, smectitic, mesic Aquertic Argiudolls) and Askarben silty clay loam (Fine, smectitic, mesic Typic Argiudolls) dominating the complex.

Cropping Systems Management

Wheat Grain Production and Oats Cover Crop

Winter wheat was drilled in 19-cm rows in mid-October, following soybean harvest. Wheat was harvested using a plot combine in mid to late July. A 1.5-m swath was harvested from the center of each plot. Grain yield was determined using an on-board combine scale. Grain yield was adjusted for moisture and reported on a dry matter (DM) basis.

In early- to mid-August following wheat grain and stover harvest, oats (*Avena sativa*) were planted as a double-cropped forage into the wheat stubble. Oats seed was drilled into 19-cm rows at a seeding rate of 101 kg ha⁻¹ in early to mid-August. Prior to beginning the grazing treatments, pre-grazing biomass samples were collected using a 1 m x 0.25 m metal frame. Oats were hand-clipped to ground level from respective grazed and non-grazed plots. In the spring following grazing and before planting, post-grazed biomass samples were collected from the grazed plots only, using the same procedure described for pre-grazed biomass samples. Poor growing conditions resulted in low oat forage production. In late March or early April, composted animal manure was broadcast-applied at a rate of 39,230 kg ha⁻¹ on the oat residue using a manure spreader prior to corn planting in early May.

Corn and Soybean Grain Production

Prior to planting corn and soybean in year 1, the study area was sprayed with 2, 4-D (2, 4-Dichlorophenoxyacetic acid) in early April 2018 to control broadleaf weeds. In 2018 (year 1), corn ('P1138AM', CRM 111) was planted on May 22, 2018, with soybean ('33T72R', RM 3.3) planted on May 2, 2018.

Herbicides were used for weed control on the corn and soybean plots in all years, with glyphosate applied at a rate of 1 qt/acre in early April, and flumioxazin (N-(7-fluoro-3,4-dihydro-3-oxo-4-prop-2-ynyl-2H-1,4-benzoxazin-6-yl) cyclohex-1-ene-1,2-dicarboxamide) applied at a rate of 3 oz/acre. Atrazine (1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine) was also applied onto the corn plots only, at a rate of 1

qt/acre. In late April, urea (46-0-0) was applied across to all plots at a rate of 308 kg N ha⁻¹.

Corn and soybean planting dates were in early to mid-May. Both corn and soybean were planted at 76 cm row spacing. Target planting populations for corn were 30,000 plants ha⁻¹ and 130,000 plants ha⁻¹ for soybean. A post-emergent herbicide application of glyphosate was applied at a rate of 1qt/acre to corn and soybeans in all years. After corn and soybean harvest in early November of 2019, 2,4-D and Dicamba (3,6-dichloro-2-methoxybenzoic acid) were sprayed on all plots, at rates of 1 pint/acre and 8 oz/acre respectively, to control weeds.

Cattle and Gazing Management

All animal-related activities implemented in this study were approved by the Institutional Animal Care and Use Committee (IACUC #1785) at the University of Nebraska-Lincoln. No animal response data was collected from this experiment. Animals were used solely as a means of forage removal and to provide the effects of including livestock into the cropping systems. Free-choice mineral and water were always available.

Two beef (*Bos taurus*) steers were used during each year of the experiment. Mean body weight ranged between 499 to 703 kg. Oat grazing (approximately 2.48 AUM ha⁻¹) occurred prior to corn residue grazing. Corn residue grazing occurred from January to March following the 2018 cropping season (9.65 AUM ha⁻¹), December to January for

the 2019 cropping season (11.14 AUM ha⁻¹), and November to December following the 2020 cropping season (11.63 AUM ha⁻¹).

Following corn and soybean grain harvest and wheat planting, each 30.5-meter-long whole was equally divided using electrified fencing, to allow cattle to graze half, and be excluded from the remaining to represent the non-grazed treatment. Cattle grazed a single experimental unit before moving to the next experimental unit. Grazing began with the oat cover crops, and ended with corn residue plots. The oats cover crop was grazed until the remaining stubble was 5 centimeters tall. Cattle were allowed to graze corn residue until there were no husks observed in the plot.

Soil Properties

Soil samples were collected from corn and soybean plots from late March to early April. Soil samples during the wheat phase of the rotation were taken immediately following wheat grain harvest in July. The differences in soil sampling dates were to allow wheat to complete its growth cycle so that the young plants were not damaged in the early spring. At each sampling, seven soil samples were collected using a hand probe to 30 cm. Each sample separated into 0 to 15cm (topsoil), and 15 to 30 cm(subsoil). Each fraction was placed in a clean bucket and mixed to a composite topsoil and subsoil sample for each plot.

Soil samples were then sent to Ward Laboratories to be analyzed. A general nutrient analysis was conducted on the 0 to 15- and 15 to 30-cm soil depth, to measure pH, buffer pH, CEC, base saturation, soluble salts, organic matter, nitrate-N, P, K,

calcium, magnesium, sodium, sulfur, zinc, iron, manganese, and copper. Additionally, OC was measured at both sampling depths (Ward Guide, Kearney, NE).

A nitrate soil test was used to determine the amount of N in the soil during spring soil sampling. This test measures the amount of nitrate left in the soil and available for the next crop. Values reported are in kilograms of N per hectare, for samples that were collected to a 15-centimeter depth. A P test was done using a Mehlich P-III extraction because of its usability across a wide range of soil types. This test estimates a relative amount of plant available P. Values are reported in parts per million (ppm) P for samples collected to a 15-centimeter depth. An ammonium acetate extraction was used to determine the amount of plant available K in the soil. Values are reported in parts per million K (ppm K) for samples collected to a 15-centimeter depth. Water soluble OC was measured to show how much carbon is available for use by plants and microbes in the soil. Values are reported as a percent OC (%OC) from a soil sample taken to a depth of 15-centimeters. Soil respiration estimated using a 24-h CO_2 flux from the 0 to 15-cm depth was used as an indirect measure of the potential soil microbial activity. This CO_2 flush is accomplished by taking the soil sample, allowing the sample to dry, then rewetting the sample and capturing the CO_2 that comes from the sample as a measure of biological activity in that soil (Franzluebbers, 2016; Ward Guide, Kearney, NE).

Experimental Design and Analysis

This study was designed as a randomized complete block with five treatments (crop rotations) (corn-soybean, soybean-corn, corn-soybean-wheat with manure,

soybean-corn-wheat with manure, and wheat-corn-soybean with manure) with grazing occurring during the corn phase and wheat/oats cover crop phase of each crop rotation. Treatment plots are 30.5 meters long by 4.6 meters wide and are then split in half to be grazed on half and not 15.25 meters long by 4.6 meters wide. There are four replications in this study.

Results

Weather Data

Total monthly precipitation and daily high and low temperatures for all years of this study are reported in Table 3.1. Average monthly temperatures were consistent across all years of the experiment. Total annual precipitation was greater in 2018 (905 mm) and 2019 (917 mm) compared to 2020 (600 mm) and 2021 (676 mm).

Corn-Soybean System

Soil Nutrients

At the beginning of the soybean phase in 2019, there were no differences in soil N after grazing corn residue compared with non-grazed residue (94 vs. 120 kg N ha⁻¹). Similarly, there were no soil N differences at the beginning of the second corn phase in 2020 after grazing corn residue in 2018 (122 vs. 101 kg N ha⁻¹). In the soybean phase in 2020, we also observed no differences in the grazed versus non-grazed soil N immediately following 2019 corn residue grazing (97 vs. 110 kg N ha⁻¹). In 2021, there were no differences in soil N in the soybean phase between grazed and non-grazed (78 vs. 76 kg N ha⁻¹). The corn phase in 2021 had been grazed once before in 2019, and soil

N was not different between grazed and non-grazed treatments (69 vs. 76 kg N ha⁻¹) (Table 3.2).

In the first soybean phase after grazing in 2019, there were no differences in soil P in grazed and non-grazed (104 vs 97 ppm P). In the second corn phase in 2020, after corn residue grazing in 2018, there were also no differences in soil P between grazed and non-grazed (106 vs. 90 ppm P). Similarly, the second soybean phase in 2020, had no difference in soil P in grazed versus non-grazed treatments immediately following corn residue grazing in 2019 (82 vs. 82 ppm P). In 2021, there were no differences in soil P in the soybean phase which had been grazed twice previously (88 vs. 76 ppm P), or the corn phase which had corn residue previously grazed once (71 vs. 73 ppm P) (Table 3.3).

The first soybean phase after corn residue grazing in 2019 had no difference in soil K between grazed and non-grazed (686 vs. 738 ppm K) treatments. The second corn phase in 2020, in which corn residue was grazed during 2018, also had no differences in soil K in grazed compared to non-grazed (697 vs. 680 ppm K). The 2020 soybean phase did not have differences in soil K in grazed and non-grazed either (657 vs. 677 ppm K). Similarly, the soybean phase in 2021, following two corn residue grazing events had no differences in soil K in grazed and non-grazed (586 vs. 631 ppm K), and the corn phase had no differences in soil K in grazed versus non-grazed after one previous corn residue grazing event in 2019 (620 vs 649 ppm K) (Table 3.4).

Organic Carbon

In 2019, in the first soybean phase, there were no differences in soil OC when comparing grazed and non-grazed corn residue (1.88 vs. 1.95 % OC). The next year, 2020, the second corn phase had been grazed once on corn residue in 2018, and no differences in OC were found between the grazed and non-grazed treatments (2.17 vs. 2.07 % OC). Similarly in the 2020 soybean phase, after one grazing event of corn residue in 2019, there were no differences in soil OC (2.04 vs. 2.10 % OC) for either the grazed or non-grazed treatments (Table 3.5).

Carbon Dioxide Flux

In 2019, which was the first production year after grazing, there were no differences in CO₂ flux in the soybean phase for grazed and non-grazed corn residue (66 vs. 80 ppm CO₂-C). The following year we observed similar results. Again, there were no differences in CO₂ flux seen in the corn phase, following grazed corn residue in 2018 between the grazed and non-grazed treatments (119 vs. 138 ppm CO₂-C). Corn residue grazing for the 2020 soybean phase occurred during 2019 and showed no differences in CO₂ flux when comparing grazed and non-grazed treatments (85 vs. 78 ppm CO₂-C). In 2021, corn residue grazing had occurred twice and no differences for CO₂ flux were observed for either grazed (99 ppm CO₂-C) or non-grazed treatments (123 ppm CO₂-C). Likewise, following one grazing event in 2019, the corn phase had no differences in CO₂ flux when comparing grazed and non-grazed treatments (102 vs. 105 ppm CO₂-C) (Table 3.6).

Corn-Soybean-Wheat System

Soil Nutrients

In 2019, no differences in soil N caused by grazing were found in the soybean phase following corn residue grazing (105 vs. 119 kg N ha⁻¹) or the corn phase following oat cover crop grazing (113 vs. 143 kg N ha⁻¹). In 2020, the wheat phase had been previously grazed in 2018 on corn residue, and no differences were found in soil N in grazed and non-grazed (55 vs. 55 kg N ha⁻¹). The corn phase had one oat cover crop grazing event in 2019, with no differences in soil N being observed when comparing grazed and non-grazed (105 vs. 103 kg N ha⁻¹). And similarly, following two previous grazing events, one on an oat cover crop and one on corn residue, soil N was not different between grazed and non-grazed in the 2020 soybean phase (94 vs. 99 kg N ha⁻¹). In 2021, all phases in the C-S-W system had been previously grazed twice. No differences in soil N were found in the corn (72 vs. 78 kg N ha⁻¹), soybean (109 vs. 86 kg N ha⁻¹), or wheat (82 vs. 97 kg N ha⁻¹) phases when comparing grazed and non-grazed treatments (Table 3.2).

In 2019, no differences in soil P were found in the soybean phase following corn residue grazing in 2018 between grazed and non-grazed (91 vs. 85 ppm P). After one grazing event of oat cover crop in 2018, the corn phase also had no differences in soil P when comparing grazed and non-grazed (89 vs. 95 ppm P). In 2020, soil P was not different when comparing grazed and non-grazed in the wheat phase following one grazing event of corn residue in 2018 (65 vs. 80 ppm P). The corn phase was immediately following oat cover crop grazing in 2019, and there were no differences in soil P in

grazed and non-grazed treatments. Similarly, the soybean phase in 2020 had no differences in soil P between grazed and non-grazed after two consecutive grazing events (88 vs. 89 ppm P). In 2021, all phases of the C-S-W rotation had been grazed twice previously. In the corn phase no differences were found in soil P between grazed and non-grazed treatments (65 vs. 65 ppm P). Following two consecutive grazing events in 2019 on an oat cover crop and 2020 corn residue, the 2021 soybean phase had no differences in grazed and non-grazed soil P (70 vs. 66 ppm P). Likewise, no differences in soil P were observed when comparing grazed and non-grazed of the wheat phase in 2021 (64 vs. 72 ppm P) (Table 3.3).

For 2019, no differences in soil K were found in the soybean phase after one grazing event on corn residue when comparing grazed and non-grazed (643 vs. 680 ppm K). Following a grazing event on oat cover crop, no differences in soil K were observed between grazed and non-grazed in the corn phase (731 vs. 794 ppm K). In 2020, the wheat phase had no differences between grazed and non-grazed soil K (632 vs. 658 ppm K). The corn phase also showed no differences in soil K in grazed and non-grazed treatments following one previous grazing event of oat cover crop in 2019 (776 vs. 795 ppm K). Similarly, the soybean phase, which had been grazed consecutively twice, had no differences in soil K between grazed and non-grazed (688 vs. 721 ppm K). In 2021, all phases had been grazed twice. The corn phase had no differences in soil K between grazed and non-grazed treatments (599 vs. 639 ppm K). Two consecutive grazing events occurring before the soybean phase, and no differences in soil K were observed between

grazed and non-grazed (648 vs. 657 ppm K). Similarly, in the 2021 wheat phase, soil K was not different between grazed and non-grazed (586 vs. 651 ppm K) (Table 3.4).

Organic Carbon

In 2019, the soybean phase showed no effect on OC due to grazing corn residue when comparing grazed and non-grazed treatments (1.84 vs. 1.84 %OC). In the corn phase following oat cover crop grazing, no differences in OC were found between grazed and non-grazed (1.95 vs. 2.08 %OC). In 2020, the wheat phase had been previously grazed once on corn residue and no differences in OC were found when comparing grazed and non-grazed (1.94 vs. 1.96 %OC). After one grazing event of the oat cover crop, the corn phase had no differences in OC between the grazed and non-grazed (2.09 vs. 2.01 %OC) treatments. Likewise, the soybean phase, which had been grazed previously twice, had no differences in OC between grazed and non-grazed treatments (2.02 vs. 2.04 %OC) (Table 3.5).

Carbon Dioxide Flux

In 2019, there were no differences in CO₂ flux in the soybean phase following corn residue grazing when comparing grazed and non-grazed (69 vs. 73 ppm CO₂-C). The corn phase followed oat cover crop grazing and CO₂ flux was not different between grazed and non-grazed (54 vs. 97 ppm CO₂-C). For 2020, the wheat phase had no differences in CO₂ flux between grazed and non-grazed corn residue (127 vs. 112 ppm CO₂-C). In the corn phase, following oat cover crop grazing, no differences in CO₂ flux were observed when comparing grazed and non-grazed (103 vs. 149 ppm CO₂-C). After

two grazing events, the soybean phase had no differences between grazed and non-grazed CO₂-C flux (115 vs. 143 ppm CO₂-C). The 2021 CO₂ flux results were similar to the other two years. All phases were grazed once on corn residue and once on oat cover crop by 2021. In the corn phase CO₂ flux was not different when comparing grazed and non-grazed (115 vs. 99 ppm CO₂-C). CO₂ flux was not affected by grazing in the soybean phase when comparing grazed and non-grazed treatments (140 vs. 24 ppm CO₂-C). Finally, in the wheat phase CO₂ flux was not different between grazed and non-grazed (115 vs. 118 ppm CO₂-C) (Table 3.6).

Discussion

Soil Nutrients

Rakkar and Blanco-Canqui (2018) noted in their review of grazing crop residues, that in general, grazing can maintain and even improve the soil fertility of a system if stocking rate and residue removal rate are managed correctly. Here, animal trampling mechanically breaks down residues into smaller pieces, allowing microbes to break the residues down more quickly, releasing those nutrients into the soil system at a faster rate (Tracy & Zhang, 2008; Liebig, et al., 2012). Also, manure adds N back into the soil which can increase soil microbial activity and residue decomposition (Banegas, et al., 2015). Together, these processes can increase carbon and other nutrients. It has been found that more than 60% of grazed residue nutrients are returned to the soil system by the animal (Erickson, et al., 2003). Beef cattle specifically, retain very little N and other minerals that they ingest, making their excreta a nutrient source for these integrated systems. Research has shown that these returned nutrients are more plant available than

the nutrients being stored in the crop residues (Drewnoski, et al., 2016; Duncan, et al., 2016).

A long-term, 16-year, corn residue grazing study in NE was conducted on an irrigated corn-soybean rotation. At the end of 16 years, the authors evaluated the impact of corn residue grazing on soil fertility properties (Rakkar et al., 2017). They found similar results to this study, with no differences in soil N, P, or K when comparing grazed and non-grazed corn residue treatments from a 0-10 cm soil depth. They also measured soil calcium and sulfur and found that corn residue grazing decreased calcium compared to non-grazing, while grazing increased soil sulfur compared to non-grazed. They concluded that after 16 years of grazing corn residue in a no-till corn-soybean rotation there were slight positive to no effect on soil fertility (Rakkar et al., 2017).

Similar results to this study and previous work were found in a three-year cover crop grazing study in western NE referenced about in the yield section, where cereal rye was planted as a cover crop in a continuous corn silage system. Cover crop grazing had no effect on any soil fertility property, including N, P, K, and organic matter when compared to the non-grazed cover crop (Blanco-Canqui et al., 2020).

Tracy and Zhang (2008) evaluated N in an IL study from 2002 through 2005 and the effects of grazing on soil compaction, yield, nutrient pools, and microbial biomass. They compared a continuous corn system that was not grazed, to an integrated system that consisted of a corn-oat-pasture rotation, where cattle grazed corn residues and cool season annuals. However, they found that total N increased from 1.1 to 1.6 g kg⁻¹ in the

corn-oat-pasture rotation over four years but did not change over time in the continuous corn rotation.

Organic Carbon

The capability of the soil to store carbon may be affected by grazing crop residues. Grazing alters the amount of carbon from residue going into the soil. For example, trampling and manure deposition both can alter the decomposition rates of the residues. Ultimately, management of residue grazing can create mixed outcomes of soil carbon storage (D. Liu, et al., 2016; J. Liu, et al., 2016; Rakkar & Blanco-Canqui, 2018). The current study showed no changes in OC between grazed and non-grazed treatments. There are two reasons why soil carbon may not change when residue is grazed. First, if at least 30% of residue cover remains following grazing and secondly, when a cropping system has high soil carbon levels that are near saturation levels, then residue grazing may not change soil carbon (Blanco-Canqui, Tatarko, et al., 2016; Rakkar, et al., 2017; Stewart, et al., 2007). In some cases of residue grazing, a decrease in soil carbon may be observed. This effect can be from the utilization of crops with low carbon inputs from their residues (Stewart, et al., 2007). It can also result from over-grazing of grazing animals. This was observed in a study in Syria, where sheep were allowed to overgraze wheat residue. This removed almost all the crop residues and resulted in decreased soil carbon (Ryan, et al., 2008). It is also possible that over grazing residues can result in increased soil carbon in integrated systems. Most likely, this would occur from the manure addition of livestock grazing, which is a carbon source for the soil, with animal traffic mixing crop residues into the soil and preventing photo-oxidation of the carbon

and allow soil carbon to increase (Liebig, et al., 2012; N. Liu, et al., 2012; Thomsen & Christensen, 2010; Tracy & Zhang, 2008).

Carbon Dioxide Flux

Manure, trampling, and residue removal through grazing can impact soil biology (Rakkar & Blanco, 2018). Few studies have used CO₂ flux evaluate differences in the active soil organic matter fraction to compare the effects of grazed and non-grazed treatments. Although this study did not observe any differences in CO₂ flux, other studies have shown an increased flux in more biologically diverse agricultural systems. A study in North Carolina used CO₂ flush to evaluate soil biological activity that compared multispecies cover crop mixes, single species cover crops, and no cover crop treatments. They noted that soil biological activity was sensitive to cover crop management, with greater levels found in the multispecies cover crop treatment compared with no cover crop. They attributed this to greater biological soil quality (Franzluebbers, et al., 2000).

Tracy and Zhang (2008) compared grazed and non-grazed corn residue and cool season annuals in a continuous corn and a corn-oat-pasture rotation and measured soil compaction, yield, nutrient pools, and microbial biomass. Tracy and Zhang (2008) found that microbial biomass was greater in the integrated system during the final year of the study compared with continuous corn (448 mg kg⁻¹ vs. 243 mg kg⁻¹ microbial biomass C). They concluded that the integration of crops and livestock and diversifying crop rotations did not negatively impact soil quality through microbial biomass and soil carbon storage.

Conclusion

Based on the results of this study, soil nutrients, OC, and CO₂ flux were not affected by grazing corn residue in the C-S and C-S-W cropping or an oat cover crop in the C-S-W cropping system. This study was conducted on a silty clay loam with moderately high organic matter (mean = 4.0%). One reason for observing no differences in the soil properties of this experiment could be because of the high organic matter at this site. High organic matter can retain nutrients and buffer from extreme fluctuation in nutrient content within the upper soil profile. The lack of changes in OC could also be attributed to the increased organic matter, but another reason for this could be that OC changes slowly. It is possible that not enough time has elapsed in this experiment for any treatment differences to be observed. On soils with lower organic matter, we might expect crop diversification or livestock integration changes to be observed more quickly.

Similarly, the lack of observed responses in the CO₂ fluxes would be for similar reasons, but also that microbial communities are very sensitive to seasonal changes in temperature and precipitation. Since sampling in this experiment took place at the same time each year, and only one time point was collected, fluctuations in CO₂ were not found. Future research should focus on collecting samples at multiple time points throughout the growing seasons to observe any potential changes in these properties.

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Table 3.1. Total precipitation (mm), mean high, and mean low temperatures (°C) from 2018 to 2021 for Lincoln, Nebraska.

-----Precipitation (mm)-----												
Year	January	February	March	April	May	June	July	August	September	October	November	December
2018	10.4	18.8	68.8	17.0	56.6	224.3	34.3	110.5	181.1	68.8	30.2	84.3
2019	19.1	40.4	67.3	28.7	185.2	111.3	103.6	70.9	86.4	119.1	20.1	65.3
2020	32.8	3.3	42.4	22.4	129.3	80.0	145.5	32.3	41.1	10.2	30.5	30.5
2021	38.9	20.1	132.8	44.2	64.8	113.3	43.9	86.6	16.3	102.6	12.4	.
-----Average High Temperature (°C) -----												
	January	February	March	April	May	June	July	August	September	October	November	December
2018	1.9	1.8	11.2	14.8	28.1	31.4	31.2	30.2	25.9	16.8	7.2	4.9
2019	1.5	-2.6	7.4	19.6	21.6	29.2	31.5	28.9	29.5	15.8	9.7	6.6
2020	1.9	6.8	13.1	18.6	21.1	31.9	31.2	30.7	25.6	16.8	14.7	5.9
2021	3.4	-3.6	15.2	19.0	22.8	31.9	31.3	32.4	28.8	20.7	14.0	.
-----Average Low Temperature (°C) -----												
	January	February	March	April	May	June	July	August	September	October	November	December
2018	-10.7	-10.8	-1.2	-1.1	13.6	18.8	18.4	17.9	14.5	3.8	-5.4	-6.8
2019	-9.0	-12.3	-4.3	4.7	9.8	16.5	19.9	18.5	16.9	2.8	-3.7	-6.1
2020	-7.8	-7.5	0.6	1.2	10.1	19.1	19.9	17.2	10.6	2.6	-1.6	-8.1
2021	-6.9	-15.1	1.0	4.2	11.0	17.5	18.5	19.0	13.3	6.7	0.2	.

Table 3.2. Means of soil nitrogen (N) concentrations, in kg N ha⁻¹, for corn residue and oat cover crop grazing experiment, under no-till and dryland management in corn-soybean (C-S) and corn-soybean-wheat (C-S-W) systems in eastern Nebraska. Soil samples were taken in the spring after corn and soybean emergence for corn and soybean phases, and in summer after wheat harvest for wheat phase. After 2018, only rotations grazed at least once were included for a grazed vs. non-grazed comparison. Means with different uppercase letters in the same year and cropping system differ significantly at p<0.05. Dashes indicate crops that were not present that year for the rotation, or where data was not collected.

Year	Cropping System	Previous Grazing Events	Crop Harvested					
			Corn		Soybean		Wheat	
			Grazed	Non-Grazed	Grazed	Non-Grazed	Grazed	Non-Grazed
			-----kg N ha ⁻¹ -----					
2018[†]	C-S	0	118 ^A	-	-	-	-	-
	S-C	0	-	-	107 ^A	-	-	-
	C-S-W (w/M)	0	124 ^A	-	-	-	-	-
	S-W-C (w/M)	0	-	-	141 ^A	-	-	-
	W-C-S (w/M)	0	-	-	-	-	101 ^A	-
SE=22.8								
2019	C-S	1	-	-	94 ^B	120 ^{AB}	-	-
	C-S-W (w/M)	1	-	-	105 ^B	119 ^{AB}	-	-
	W-C-S (w/M)	1	113 ^{AB}	143 ^A	-	-	-	-
SE=10.9								
2020	C-S	1	122 ^A	101 ^A	-	-	-	-
	S-C	1	-	-	97 ^A	110 ^A	-	-

	C-S-W (w/M)	1	-	-	-	-	55 ^B	55 ^B
	S-W-C (w/M)	1	105 ^A	103 ^A	-	-	-	-
	W-C-S (w/M)	2	-	-	94 ^A	99 ^A	-	-
SE=9.69								
2021	C-S	2	-	-	78 ^B	76 ^B	-	-
	S-C	1	69 ^B	76 ^B	-	-	-	-
	C-S-W (w/M)	2	72 ^B	78 ^B	-	-	-	-
	S-W-C (w/M)	2	-	-	109 ^A	86 ^{AB}	-	-
	W-C-S (w/M)	2	-	-	-	-	82 ^{AB}	97 ^{AB}
SE=9.95								
†2018 is the first year of the study, before any grazing treatments had been applied, so there was no differentiation between grazed and non-grazed								

Table 3.3. Means of soil phosphorus (P) concentrations, using Mehlich P-III in ppm P, for corn residue and oat cover crop grazing experiment, under no-till and dryland management in corn-soybean (C-S) and corn-soybean-wheat (C-S-W) systems in eastern Nebraska. Soil samples were taken in the spring after corn and soybean emergence for corn and soybean phases, and in summer after wheat harvest for wheat phase. After 2018, only rotations grazed at least once were included for a grazed vs. non-grazed comparison. Means with different uppercase letters in the same year and cropping system differ significantly at $p < 0.05$. Dashes indicate crops that were not present that year for the rotation, or where data was not collected.

Year	Cropping System	Previous Grazing Events	Crop Harvested					
			Corn		Soybean		Wheat	
			Grazed	Non-Grazed	Grazed	Non-Grazed	Grazed	Non-Grazed
			-----ppm P-----					
2018[†]	C-S	0	99 ^A		-		-	
	S-C	0	-		68 ^B		-	
	C-S-W (w/M)	0	92 ^{AB}		-		-	
	S-W-C (w/M)	0	-		88 ^{AB}		-	
	W-C-S (w/M)	0	-		-		89 ^{AB}	
SE=8.20								
2019	C-S	1	-	-	104 ^A	97 ^A	-	-
	C-S-W (w/M)	1	-	-	91 ^A	85 ^A	-	-
	W-C-S (w/M)	1	89 ^A	95 ^A	-	-	-	-
SE=10.5								
2020	C-S	1	106 ^A	90 ^{AB}	-	-	-	-
	S-C	1	-	-	82 ^{AB}	82 ^{AB}	-	-

	C-S-W (w/M)	1	-	-	-	-	65 ^B	80 ^{AB}
	S-W-C (w/M)	1	84 ^{AB}	90 ^{AB}	-	-	-	-
	W-C-S (w/M)	2	-	-	88 ^{AB}	89 ^{AB}	-	-
SE=9.09								
2021	C-S	2	-	-	88 ^A	76 ^A	-	-
	S-C	1	71 ^A	73 ^A	-	-	-	-
	C-S-W (w/M)	2	65 ^A	65 ^A	-	-	-	-
	S-W-C (w/M)	2	-	-	70 ^A	66 ^A	-	-
	W-C-S (w/M)	2	-	-	-	-	64 ^A	72 ^A
SE=9.91								
†2018 is the first year of the study, before any grazing treatments had been applied, so there was no differentiation between grazed and non-grazed								

Table 3.4. Means of soil potassium (K) concentrations, in ppm K, for corn residue and oat cover crop grazing experiment, under no-till and dryland management in corn-soybean (C-S) and corn-soybean-wheat (C-S-W) systems in eastern Nebraska. Soil samples were taken in the spring after corn and soybean emergence for corn and soybean phases, and in summer after wheat harvest for wheat phase. After 2018, only rotations grazed at least once were included for a grazed vs. non-grazed comparison. Means with different uppercase letters in the same year and cropping system differ significantly at $p < 0.05$. Dashes indicate crops that were not present that year for the rotation, or where data was not collected.

			Crop Harvested					
			Corn		Soybean		Wheat	
Year	Cropping System	Previous Grazing Events	Grazed	Non-Grazed	Grazed	Non-Grazed	Grazed	Non-Grazed
			-----ppm K-----					
2018[†]	C-S	0	727 ^A		-		-	
	S-C	0	-		674 ^A		-	
	C-S-W (w/M)	0	735 ^A		-		-	
	S-W-C (w/M)	0	-		738 ^A		-	
	W-C-S (w/M)	0	-		-		700 ^A	
SE=38.0								
2019	C-S	1	-	-	686 ^B	738 ^{AB}	-	-
	C-S-W (w/M)	1	-	-	643 ^B	680 ^{AB}	-	-
	W-C-S (w/M)	1	731 ^{AB}	794 ^A	-	-	-	-
SE=34.0								
2020	C-S	1	697 ^{CD}	680 ^{CD}	-	-	-	-
	S-C	1	-	-	657 ^{CD}	677 ^{CD}	-	-

	C-S-W (w/M)	1	-	-	-	-	632 ^D	658 ^{CD}
	S-W-C (w/M)	1	776 ^{AB}	795 ^A	-	-	-	-
	W-C-S (w/M)	2	-	-	688 ^{CD}	721 ^{BC}	-	-
SE=24.8								
2021	C-S	2	-	-	586 ^A	631 ^A	-	-
	S-C	1	620 ^A	649 ^A	-	-	-	-
	C-S-W (w/M)	2	599 ^A	639 ^A	-	-	-	-
	S-W-C (w/M)	2	-	-	648 ^A	657 ^A	-	-
	W-C-S (w/M)	2	-	-	-	-	586 ^A	651 ^A
SE=33.1								
†2018 is the first year of the study, before any grazing treatments had been applied, so there was no differentiation between grazed and non-grazed								

Table 3.5. Means of soil organic carbon (OC) concentrations, in %OC, for corn residue and oat cover crop grazing experiment, under no-till and dryland management in corn-soybean (C-S) and corn-soybean-wheat (C-S-W) systems in eastern Nebraska. Soil samples were taken in the spring after corn and soybean emergence for corn and soybean phases, and in summer after wheat harvest for wheat phase. After 2018, only rotations grazed at least once were included for a grazed vs. non-grazed comparison. Means with different uppercase letters in the same year and cropping system differ significantly at $p < 0.05$. Dashes indicate crops that were not present that year for the rotation, or where data was not collected.

Year	Cropping System	Previous Grazing Events	Crop Harvested					
			Corn		Soybean		Wheat	
			Grazed	Non-Grazed	Grazed	Non-Grazed	Grazed	Non-Grazed
			-----%OC-----					
2018[†]	C-S	0	2.22 ^A		-		-	
	S-C	0	-		2.01 ^A		-	
	C-S-W (w/M)	0	2.08 ^A		-		-	
	S-W-C (w/M)	0	-		2.18 ^A		-	
	W-C-S (w/M)	0	-		-		2.19 ^A	
SE=0.11								
2019	C-S	1	-	-	1.88 ^A	1.95 ^A	-	-
	C-S-W (w/M)	1	-	-	1.84 ^A	1.84 ^A	-	-
	W-C-S (w/M)	1	1.95 ^A	2.08 ^A	-	-	-	-
SE=0.09								
2020	C-S	1	2.17 ^A	2.07 ^A	-	-	-	-
	S-C	1	-	-	2.04 ^A	2.10 ^A	-	-

	C-S-W (w/M)	1	-	-	-	-	1.94 ^A	1.96 ^A
	S-W-C (w/M)	1	2.09 ^A	2.01 ^A	-	-	-	-
	W-C-S (w/M)	2	-	-	2.02 ^A	2.04 ^A	-	-
SE=0.11								
†2018 is the first year of the study, before any grazing treatments had been applied, so there was no differentiation between grazed and non-grazed								

Table 3.6. Mean of soil carbon dioxide (CO₂) flux amounts, in ppm CO₂-C, for corn residue and oat cover crop grazing experiment, under no-till and dryland management in corn-soybean (C-S) and corn-soybean-wheat (C-S-W) systems in eastern Nebraska. Soil samples were taken in the spring after corn and soybean emergence for corn and soybean phases, and in summer after wheat harvest for wheat phase. After 2018, only rotations grazed at least once were included for a grazed vs. non-grazed comparison. Means with different uppercase letters in the same year and cropping system differ significantly at p<0.05. Dashes indicate crops that were not present that year for the rotation, or where data was not collected.

Year	Cropping System	Previous Grazing Events	Crop Harvested					
			Corn		Soybean		Wheat	
			Grazed	Non-Grazed	Grazed	Non-Grazed	Grazed	Non-Grazed
			-----ppm CO ₂ -C-----					
2018[†]	C-S	0	116 ^A		-		-	
	S-C	0	-		123 ^A		-	
	C-S-W (w/M)	0	129 ^A		-		-	
	S-W-C (w/M)	0	-		145 ^A		-	
	W-C-S (w/M)	0	-		-		145 ^A	
SE=22.0								
2019	C-S	1	-	-	66 ^A	80 ^A	-	-
	C-S-W (w/M)	1	-	-	69 ^A	73 ^A	-	-
	W-C-S (w/M)	1	54 ^A	97 ^A	-	-	-	-
SE=19.9								
2020	C-S	1	119 ^{AB}	138 ^{AB}	-	-	-	-

	S-C	1	-	-	85 ^{AB}	78 ^B	-	-
	C-S-W (w/M)	1	-	-	-	-	127 ^{AB}	112 ^{AB}
	S-W-C (w/M)	1	103 ^{AB}	149 ^A	-	-	-	-
	W-C-S (w/M)	2	-	-	115 ^{AB}	143 ^A	-	-
SE=22.4								
2021	C-S	2	-	-	99 ^A	123 ^A	-	-
	S-C	1	102 ^A	105 ^A	-	-	-	-
	C-S-W (w/M)	2	115 ^A	99 ^A	-	-	-	-
	S-W-C (w/M)	2	-	-	140 ^A	124 ^A	-	-
	W-C-S (w/M)	2	-	-	-	-	115 ^A	118 ^A
SE=14.6								
†2018 is the first year of the study, before any grazing treatments had been applied, so there was no differentiation between grazed and non-grazed								

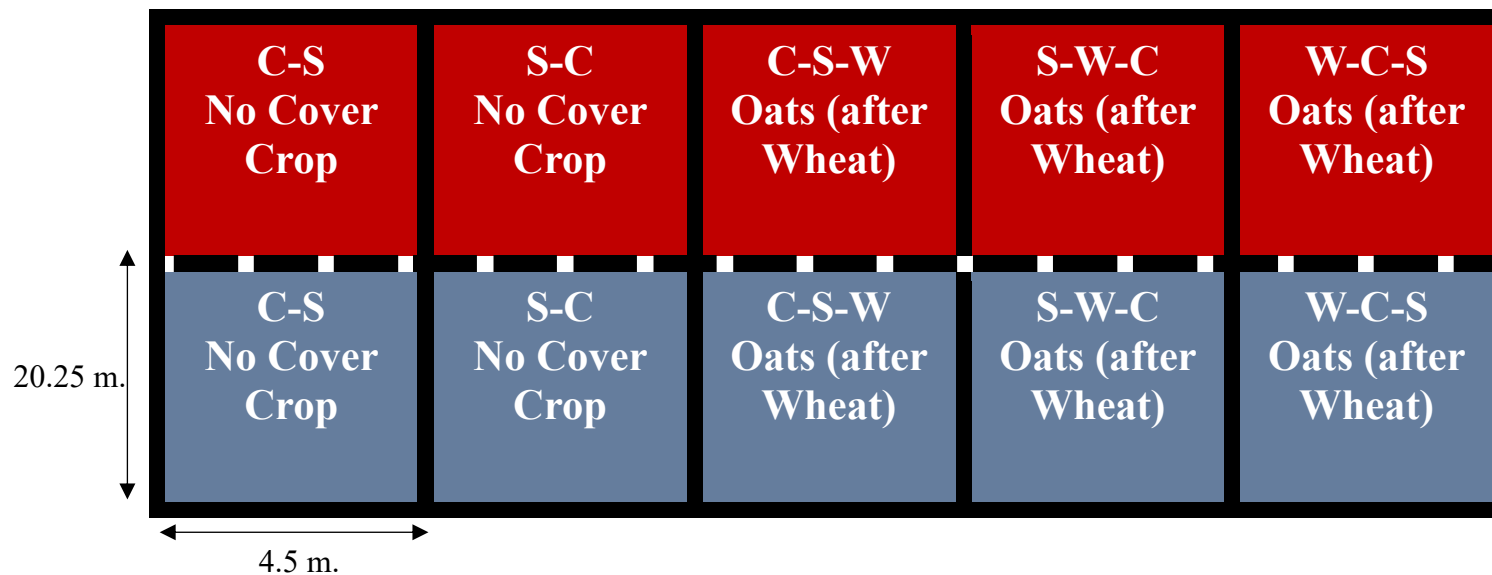


Figure 3.1 Schematic diagram of plot design representing one replication of four reps in this study. Each rotation is listed at the top and whether a cover crop is included in the rotation (C=Corn, S=Soybean, W=Wheat). For the grazed and non-grazed comparison, a fence, denoted by the dashed line, was constructed the middle of the plots after harvest to contain cattle on one-half of each plot (red=grazed, blue=non-grazed).