7-2020

# Evaluating Opportunities for Integrated Crop Livestock Systems in Eastern Nebraska

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# EVALUATING OPPORTUNITIES FOR

# INTEGRATED CROP LIVESTOCK SYSTEMS IN EASTERN NEBRASKA

by

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A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Agronomy

Under the Supervision of Professors Daren Redfearn and Rob Mitchell

Lincoln, Nebraska

July, 2020

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Current agricultural systems focused on production of few commodities are facing production, economic, and environmental challenges. To address these challenges, Integrated Crop Livestock Systems (ICLS) have emerged through three primary methods 1) perennial grasslands for grazing and/or hay production, 2) crop residue grazing, and 3) cover crop grazing. To evaluate potential of ICLS mitigating current challenges, a field-scale model ICLS was developed in 2015. The ICLS includes 4-ha each of 'Newell' smooth bromegrass (*Bromus inermis* L.), 'Liberty' switchgrass (*Panicum virgatum* L.), and 'Shawnee' switchgrass. The ICLS also included 8-ha of continuous corn (*Zea mays L.*). In 2016, only hay was harvested from perennial grasslands and in 2017, 2018, and 2019 the perennial grasslands were grazed. Following grazing, the switchgrass varieties were harvested for residual biomass production post-senescence. Continuous corn included residue removal treatments with and without a cover crop. This thesis reports results from three studies. To evaluate the response of cool-season annual grass cover crops to defoliation, a greenhouse study, in conjunction with a replicated field experiment, was conducted in 2018-2019 and 2019-2020. Results showed small grains used as cover crops had decreased survivability and biomass production when defoliated during early plant establishment. Production data from the ICLS was used to construct

enterprise budgets to evaluate system profitability on marginally productive cropland. The ICLS was not consistently more profitable than continuous corn production. However, baling hay only and removing grazing from the ICLS was more profitable than continuous corn production. To evaluate ICLS as a mitigation strategy for soil GHG emissions, soil $N_2O$ and $CH_4$ were measured during each growing season in the perennial grasslands and continuous corn. Results suggested that 1) grazing perennial grasslands did not consistently impact soil GHG emissions, 2) crop residue and cover crop management may impact soil $N_2O$ emissions, and 3) continuous corn production resulted in greater soil $N_2O$ emissions than perennial grasslands due to higher application amounts of synthetic N fertilizer. The results from this research can provide options for producers implementing ICLS and insight for further development of ICLS for Eastern NE that meet production, economic, and environmental challenges.

## DEDICATION

I dedicate my work to my Lord, Savior, and Friend Jesus Christ. I pray that my work brings honor and glory to the Kingdom of God. I thank Jesus for providing me with the knowledge, energy, and wisdom to complete this work. I also dedicate this work to my wonderful, loving, caring, compassionate, supportive husband, Nate. Thank you for your endless love and support. I cherish you.

**ACKNOWLEDGEMENTS**

First and foremost, thank you to my wonderful, knowledgeable, patient, and supportive advisors Daren and Rob. Thank you for your endless feedback and encouragement. Thank you, Mom and Dad, for giving me so many opportunities growing up. Mom, thank you for running me to all the events that helped me gain the experience needed to succeed in my academic career. Dad, thank you for planting a passion deep in my heart for beef cattle and for teaching me how to work hard and never give up. Nicole, thank you for challenging me to be the best student I could be, I always looked up to you as a child. Nate, thank you for doing the dishes, cooking, and supporting me emotionally on this journey. I cannot wait to continue living this life with you, one step at a time. Thank you to my Elevate Church Family in Lincoln, your support has helped me tremendously. Thank you to all of the mentors, teachers, and professors in my life, you have helped shape me into the woman I am today. Thank you to the Wiedenhoeft's for planting a seed in my heart and watering it for regenerative agriculture and human health.

Thank you to all of the undergrad and summer help I had. This research would not have been possible without you. Also, thank you to Marty Schmer, the corn expert, and Virginia Jin the GHG expert. Their insight for this project was extremely valuable. A huge shout-out and thank you to Joshua Wehrbein and Dr. Eskridge for helping me with the statistical analyses of these studies. Thank you to Mary Drewnoski and Jay Parsons along with their graduate students for helping brainstorm ideas and edit the economic analysis.

## GRANT INFORMATION

This research is supported by the United States Department of Agriculture National Institute of Food and Agriculture, Coordinated Agriculture Projects, Award No. 2016-68004-24768. This research is also supported by the Arthur W. Sampson Fellowship Fund.

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# CHAPTER 1

# EXPLORING OPPORTUNITES FOR CROP LIVESTOCK INTEGRATION ON MARGINALLY-PRODUCTIVE DRYLAND CROPLAND IN EASTERN NEBRASKA

## Introduction to the Review

Following World War II, American agriculture became highly specialized. Farms have specialized by focusing on the production of single commodities. These specialized agricultural systems have succeeded at meeting global food demand. However, they have also resulted in negative environmental impacts, production challenges, and small profit margins. Current agricultural production practices can cause soil erosion, nutrient loss, greenhouse gas (GHG) emissions, and loss of soil organic matter (SOM). Among environmental implications, specialized agriculture has become reliant on synthetic inputs. The synthetic inputs provide tools to manage pest and fertility problems. Unfortunately, the reliance on inputs has created many production challenges such as pest resistance. In addition to these challenges, farmers are facing low commodity prices and high input costs. Researchers have proposed a solution: integrated crop livestock systems (ICLS). Re-integrating crop and livestock agriculture has the ability to mitigate environmental change, solve production problems through biodiversity, and provide economic resiliency (Russelle, Entz, and Franzluebbers 2007). Interest in ICLS has been rising as a solution to the negative impacts of specialized agriculture.

Several literature reviews have been conducted on the potential of ICLS to solve the known challenges associated with specialized agriculture (Russelle, Entz, and Franzluebbers 2007; Lemaire et al. 2014; Hilimire 2011; Sulc and Franzluebbers 2014; Sulc and Tracy 2007). Different opportunities to integrate crop and livestock agriculture exist. The literature reviews have explored three ways to integrate crop and livestock production on farm. The first way is to integrate ruminant livestock by introducing perennial vegetation back into the crop rotation. The perennial vegetation provides a valuable feed resource for ruminants. Second, crop-livestock integration can occur through ruminants grazing crop residues. Third, livestock can be re-integrated by grazing cover crops as annual forages on existing crop fields. Below is a summary of what previous literature reviews have concluded on the three types of on-farm integration.

**Integration through Perennials:**

In general, incorporating perennial grasses improves soil quality and provides feed for ruminant livestock. In addition, perennial grassland has the potential to mitigate the negative environmental consequences of intensifying cropland production (Lemaire et al. 2014). Additionally, incorporating perennial forages into crop rotations can improve soil quality by increasing soil organic carbon (SOC), soil tilth, water holding capacity, and nutrient cycling (Russelle, Entz, and Franzluebbers 2007; Hilimire 2011). Increased nutrient cycling can lead to reduced nitrogen (N) losses. In addition to the environmental benefits, crop yield can increase from adding perennial forages into the cropping rotation. The increased diversity can help decrease insect, disease, and weed pressure, leading to increased yields. Among these well-known benefits, the reviewers concluded that the effect of grazing perennial grasses on GHG emissions is not well known. In agreement with the benefits listed in the previous reviews, reviewers outlined the opportunities in the United States for integrating perennial grass sod into crop rotations (Sulc and Franzluebbers 2014). The reviewers cite two main conclusions. First, current research in the US suggests perennial sod can be added to the crop rotation to increase environmental sustainability while meeting production goals. Second, incorporating livestock into these rotations is the most efficient way to utilize forage resources and increase nutrient cycling. Another review also found numerous benefits to incorporating perennial vegetation (Sulc and Tracy 2007). Perennial pastures, especially legumes, when rotated with grain crops have positive environmental and economic benefits. However, the studies in the review harvested the forage mechanically instead of grazing. Therefore, after reviewing the literature, researchers concluded that more information is needed on the impact of grazing forages on crop productivity, soil parameters, and profitability in the US Corn Belt.

**Integration through Residue Grazing**:

A simpler way to integrate crop and livestock production is by having ruminant livestock graze crop residue. Crop residue provides feed for livestock during the perennial forage gap in autumn and winter while potentially improving profitability. Hillmire (2011) concluded that crop residue used as feed for ruminants can produce high quality animal protein, improve land use efficiency, and increase profitability. Sulc and Tracy (2007) noted that cattle grazing crop residue in the US Corn Belt is one of the simplest and most economical ways to integrate crop and livestock production. Additionally, the grazing recommendations for the Corn Belt are well known and successfully minimize the risk of negatively impacting soil quality. Sulc and Franzluebbers (2014) reported that cattle grazing corn residue is more economical than harvesting and feeding the residue. They also reported that compaction from grazing can be eliminated or decreased by proper grazing management. Overall, researchers concluded that increasing system diversification through residue grazing is possible in all regions of the US.

**Integration through Cover Crops**:

To provide a higher quality forage for grazing on existing croplands, cover crops can be planted for grazing. Little is known about integrating crop and livestock production through cover crop grazing, but it is well known that cover crops can help mitigate the negative environmental effects of annual cropping systems (Lemaire et al. 2014; Sulc and Tracy 2007). Despite the environmental benefits cover crops offer, planting and managing cover crops is costly. Livestock grazing the cover crop biomass could provide a way to offset the cost of cover crop management. Hillmire (2011) suggested cattle grazing cover crops can improve profitability. However, Sulc and Tracy (2007) concluded that little is known about proper grazing management strategies that maximize the environmental benefits cover crops provide. However, after analyzing research in the Midwest, others concluded that cover crop grazing is a viable option (Sulc and Franzluebbers 2014). Cover crop grazing has the potential to increase crop yield, improve soil quality, and reduce inputs.

**Opportunities in NE**

From the current reviewed literature, it is apparent that ICLS can help solve the environmental, productivity, and economic challenges associated with specialized agriculture. In Nebraska, agricultural systems have become highly specialized by focusing on the production of single commodities. Farms in Nebraska are facing the environmental, production, and economic challenges. Implementing ICLS in the region could help producers mitigate the challenges producers are facing from specialized production systems. For example, most economic challenges facing producers are tied to commodity production with highly correlated prices. Implementing ICLS introduces diversification which can help meet this challenge through distributing risk among enterprises. However, potential opportunities for ICLS in Nebraska have not been thoroughly explored. One possible location for ICLS in Nebraska is marginally productive cropland. Introducing ICLS on marginally productive cropland could improve profitability, environmental impact, and production challenges. In Nebraska, there are 1.34 million hectares of marginally productive cropland available (Gopalakrishnan, Negri, and Snyder 2011). Marginally productive cropland is defined as land that is poorly drained, frequently flooded, or produces less than 9 tonnes $ha^{-1}$ of corn grain. Despite the existence of marginally productive cropland and the promises of ICLS, the most viable methods of integration for Eastern NE are not well known. Additionally, the methods of integration that best solve the problems facing producers are not well known. Therefore, the purpose of this paper is to review the literature on the three potential ways crop and livestock enterprises could be integrated on marginally productive dryland in Eastern Nebraska. In addition, the potential impact of integration on 1) Productivity 2) Environment and 3) Economics is detailed.

**Integrating Crop-Livestock Systems with Perennial Pasture**

The environmental benefits of planting perennial vegetation are well known. Despite this fact, many grasslands in the Northern Great Plains (NGP) have been converted to cropland (Clay et al. 2014; Wright and Wimberly 2013). Bringing perennial vegetation back to the landscape provides an opportunity for ruminant animals to be incorporated back into the production system. Integrating livestock into cropping systems by adding perennial vegetation has been previously outlined (Sulc and Franzluebbers 2014; Entz et al. 2002; Lemaire et al. 2014; Russelle, Entz, and Franzluebbers 2007; Sulc and Tracy 2007). However, the best way to integrate livestock and crop production with perennials in the Western Corn Belt (WCB) is not well known. The following section outlines the current literature on how integrating perennial vegetation impacts the environment, crop and animal productivity, and farm profitability. The primary purpose is to explore opportunities for crop livestock integration by incorporating perennial grasses in Eastern Nebraska on marginally-productive dryland cropland.

***Environment***

Three important environmental areas impacted by the incorporation of perennial pasture are nutrient cycling, SOC, and soil GHG emissions. Below, literature was explored to identify how these environmental components are impacted by incorporating perennial pasture.

*Nutrient Cycling*

Efficient nutrient cycling is essential for creating a sustainable system. A recent review of the literature found integrating perennials into annual cropping systems can reduce nutrient leakages by using N more efficiently (Asbjornsen et al. 2014). Researchers have thoroughly studied the impact perennial legumes have on nutrient cycling in crop rotations. The most well-known legume to improve nutrient cycling is alfalfa (*Medicago sativa* L.). Integrating alfalfa into crop rotations can reduce the need for synthetic N fertilizer (Luna et al. 1994; Liebman et al. 2008). In return, reduced fertilizer inputs decrease N leaching. A review of literature in the NGP focused on integrating perennials into crop rotations found that adding perennial forages to the crop rotation decreases nitrate leaching (Entz et al. 2002). Additionally, in the central US if cropland used for ethanol production was converted to low input perennial grasses, N leaching could be reduced (Davis et al. 2012). Clearly, perennial grasses can play a role in reducing N leaching. Perennial grasses are good N scavengers, especially C-4 warm-season grasses. In New Mexico, grasslands accumulated 13% more total N than croplands (Ghimire et al. 2019). Perennial grasslands are often grazed by ruminant animals. Grazing management can reduce the need for N fertilizer (Luna et al. 1994). Reduced synthetic N fertilizer can decrease N losses. However, more recently, grazing has been shown to impact the length and volume of root biomass (Bonin et al. 2013). Decreased root length and biomass in perennial grasslands could potentially influence nutrient cycling (Bonin et al. 2013). However, they concluded that more information is needed on how grazing management influences perennial grass root growth and nutrient cycling (Bonin et al. 2013).

It is well known that when cropland is turned into perennial vegetation, N leaching can be reduced. However, more information is needed to develop grazing recommendations that maximize nutrient cycling.

*Soil Organic Carbon (SOC)*

The positive impact perennial vegetation has on soil C sequestration has been previously summarized (Asbjornsen et al. 2014; Sanderson and Adler 2008; Hendrickson, Liebig, and Sassenrath 2008; Entz et al. 2002). Specifically, switchgrass (*Panicum virgatum* L.) grown for bioenergy production increases SOC in the NGP and CGP (Liebig et al. 2008; Schmer et al. 2011; Follett et al. 2012).

Pasture and grasslands have more organic C than conventionally tilled continuous corn production (Jastrow 1996). In New Mexico, grasslands accumulated 18% more SOC than cropland (Ghimire et al. 2019). SOC and soil organic matter (SOM) are closely related. Cultivated croplands lose SOM at a greater rate than undisturbed soil accumulates SOM (Schlesinger, William 1990). When perennial grasslands are converted to row-crop production, a significant amount of C is lost (Qin et al. 2016; Gelfand et al. 2011). Researchers estimate re-paying the C debt created from the land conversion would take 40 years (Gelfand et al. 2011). Fortunately, when cropland is converted back to perennial grassland, SOC is accrued (Qin et al. 2016). Land planted to perennial grass through the Conservation Reserve Program (CRP) has shown an increase in active soil C and N, as well as an increase in soil microbial biomass (Baer, Rice, and Blair 2000). On active farms in the Prairie Pothole Region of North Dakota, soils under CRP management for at least 15 years had 9-16% higher SOC than adjacently managed annual cropland (Phillips, Eken, and West 2015). Similarly in Germany, 18 years after poorly drained cropland was converted to perennial grassland, a significant increase in SOC was observed (Auerswald and Fiener 2019). Restored prairies can also recover SOM lost through cultivation (Matamala et al. 2008). In addition, restored prairie has shown the ability to sequester C well into the future as long as it remains a prairie (Matamala et al. 2008). Perennial vegetation can help restore SOM and SOC while being used for agriculture production. Perennial vegetation can be used for livestock feed and biofuel production.

Specifically, switchgrass has been increasingly considered for use as a cellulosic biofuel. When existing grasslands were converted to switchgrass no change in SOC was observed (Qin et al. 2016). When cropland was converted to switchgrass for bioenergy production in the NGP and CGP, SOC increased (Liebig et al. 2008; Schmer et al. 2011). Importantly, in the same study, the SOC accrued over five years of switchgrass vegetation across 10 on-farm sites varied (Liebig et al. 2008; Schmer et al. 2011). In Eastern Nebraska, after 9 years of switchgrass managed for bioenergy production, SOC increased at the 0-150 cm depth (Follett et al. 2012). Additionally, the results from that study indicate that N fertilizer and harvest management can influence the amount of SOC accrued (Follett et al. 2012). In North Dakota, after 3 years of switchgrass growth, SOC increased (Frank et al. 2004). In Pennsylvania, 7 years after planting and clipping switchgrass, an increase in SOC was observed (Sanderson and Adler 2008). A European biogeochemical model found that 15 years of switchgrass after annual grain crop production has the potential to increase the SOC inventory (Nocentini and Monti 2019). Increased root biomass has been observed in switchgrass when compared to cultivated cropland. The increased root biomass is what likely leads to the observed increases in SOC (Liebig et al. 2005). In North Dakota there was more root biomass in perennial grassland soils than continuous wheat (*Triticum aestivum L.*) or a wheat fallow rotation. Similarly, researchers concluded that increased root biomass likely leads to greater SOC content (Frank, Liebig, and Tanaka 2006). Harvesting perennial grass does not adversely affect SOC. However, the impact of grazing perennial grass on SOC is not well known.

Introducing grazing animals may impact SOC. Researchers found that grazing decreased root volume when compared to non-grazed plots (Bonin et al. 2013). As root biomass increases, SOC increases. Therefore, grazing perennial grasses could potentially decrease SOC. However, in the southeast, when bahiagrass (*Paspalum notatum* Fluegge) is planted and grazed, an increase in SOC can be seen (Gamble et al. 2019). In addition, sites with a long history of perennial grass production that are grazed show no change in SOC (Sanderson and Adler 2008).

In summary, converting perennial vegetation to row crop production results in a decrease in SOC. Fortunately, when cropland is converted back to perennial grassland, SOC increases. Switchgrass has been shown to accrue SOC when harvested, although, rate and amount of accrual are dependent on location and management. Despite the known benefits of perennial vegetation on SOC, little is known about the impact of grazing perennial vegetation on SOC. A few studies suggest grazing should have no negative impact on SOC. However, more information on the best grazing management practices to maximize SOC accrual is needed for specific regions.

*Soil Greenhouse Gas (GHG) Emissions:*

In addition to a positive increase in SOC, perennial vegetation can decrease soil GHG emissions. Agricultural practices have a significant impact on the environment due to GHG emissions (Seguin et al. 2007). Temperature, moisture, cropping system, and fertilization all impact GHG emissions. Soil $CO_2$ emissions occur at different times of the year for perennial and annual crops and are largely influenced by temperature (Nocentini and Monti 2019; Lee, Doolittle, and Owens 2007). Soil $N_2O$ emissions are also impacted by groundwater content on fertilized peat soils (van Beek, Pleijter, and Kuikman 2011). When pasture is grazed and fertilized, soil $N_2O$ emissions increase (Liebig et al. 2006). However, little is known about the sole effect grazing perennial grasses has on soil GHG emissions. In New Zealand, soil $N_2O$ increased when pastures were grazed (Saggar et al. 2008). However, grazing bahiagrass at moderate stocking rates in the Southeastern

United States had no negative impacts on soil GHG emissions (Gamble et al. 2019). In Texas, adaptive multi-paddock grazing of native prairie, reduced $N_2O$ and $CH_4$ emissions when compared to continuously grazed prairie (Dowhower et al. 2020). Additionally, adaptive multi-paddock grazing has the potential to mitigate GHG emissions when compared to feedlot finishing (Stanley et al. 2018). The evidence suggests that grazing management may be able to help mitigate soil GHG emissions.

Perennial grasslands harvested for biomass can mitigate soil GHG emissions. Current cropland has the potential to mitigate GHG emissions if converted to low-input perennial grassland for bioenergy production. In Italy, if marginally productive cropland or areas with a surplus of grain production were converted to switchgrass production, GHG savings could be maximized (Nocentini and Monti 2019). In the central US, if cropland used for ethanol production was converted to low input perennial grasses, GHG emissions could be reduced (Davis et al. 2012). Additionally, perennial grass systems have the potential to be net GHG sinks. In eastern Nebraska, switchgrass grown for bioenergy production mitigated GHG emissions (Jin et al. 2019). Conversely, continuous corn grain production maintained GHG emissions (Jin et al. 2019). Unfortunately, when perennial land is converted back to annual grain production, the soil releases GHG into the atmosphere (Asbjornsen et al. 2014).

Converting cropland to perennial grassland for bioenergy production reduces GHG emissions. However, the impact of grazing perennial grassland on soil GHG emissions is not as well known. Current research suggests that grazing management effects GHG emissions. For grazed grasslands to mitigate soil GHG exchange, grazing strategies that minimize soil GHG emissions in the CGP need to be developed.

***Production***

In addition to the previously mentioned environmental benefits, incorporating perennial vegetation into annual crop rotations can increase grain yield and produce excellent forage for cattle.

*Grain Yield*

Integrating perennial legumes into annual crop rotations can increase grain yield per hectare. When alfalfa is integrated into annual cropping systems, subsequent grain yield increases. For example, investigators who conducted a literature review of the NGP found that wheat yields are significantly higher when following 3 years of alfalfa production than when following other annual crops in wetter soils (Entz et al. 2002). In central Iowa, greater yields in corn and soybean grain occurred when rotated with alfalfa (1 or 2 years of production) instead of the typical corn-soybean rotation (Liebman et al. 2008). Mixed legume and grass perennial pastures also demonstrated an ability to increase grain yield. In the NGP, researchers found growing perennial grasses and alfalfa together for four to five years increases the following wheat yield (Franco et al. 2018). The previous two studies did not integrate livestock on the same land base. The forage was harvested and then fed to livestock. Integrating livestock into these diverse cropping systems on the same land base can be challenging. One way to meet this challenge is by integrating long-term perennial grass pasture. For example, researchers in Illinois had cattle graze perennial pastures during the growing season. When perennial pastures were dormant in the autumn, winter, and early spring, cattle grazed cover crops and crop residues. The researchers found that integrating livestock directly on to the cropland increased grain yield in the subsequent year (Tracy and Zhang 2008; Maughan et al. 2009).

Incorporating perennial legumes into crop rotations increases subsequent crop yield. Perennial grass pastures are important for integrating livestock onto cropland because they allow for ownership of the cattle throughout the production system. However, little is known about how grass pasture converted back to corn production effects corn grain yield.

*Animal Gains*

In addition to increasing grain production, cool- and warm- season perennial grass pastures provide an excellent forage resource for cattle. In the Midwest, the need for stored feeds can be reduced by grazing excess perennial forage growth (Janovick et al. 2000). Smooth bromegrass (*Bromus Inermis* L.) is one cool-season species commonly used for pasture in the Midwest. In eastern Nebraska, plant breeders developed ‘Newell’ smooth bromegrass. Grazing Newell produced 1.43 kg $hd^{-1}$ $d^{-1}$ over an average of 37 grazing days when stocked at three steers per 0.4-ha (Vogel, Mitchell, Waldron, et al. 2014). Warm-season grasses in the Midwest also have potential to produce adequate cattle gains. A 3-yr study in Iowa found an average of 529 kg of beef $ha^{-1}$ was produced on rotationally grazed switchgrass over 35 days of grazing (George et al. 1997). The same study found that rotationally grazed big bluestem (*Andropogon gerardii* L.) produced an average of 397 kg of beef $ha^{-1}$ over 48 days (George et al. 1997). Researchers who conducted a 3 year study in Nebraska, found that cattle grazing switchgrass gained between .59-.73 kg $hd^{-1}$ $d^{-1}$ on average (Anderson et al. 1988). During 1973-1975 in South Dakota, researchers demonstrated that switchgrass pastures could be grazed by yearling steers during July and August and produce adequate gains (0.93 kg $hd^{-1}$ $d^{-1}$ or 146 kg of beef $ha^{-1}$) (Krueger and Curtis 1979). Furthermore, Nebraska extension experts say when cattle graze warm season grasses throughout the summer the expected cattle gain is between 0.64-1.3 kg $hd^{-1}$ $d^{-1}$ (Mitchell and Anderson 2008). They also mention different varieties of warm-season grass pastures and the gain expected on each pasture. In Eastern Nebraska, cattle grazing ‘Trailblazer’ switchgrass gained 1.0 kg $hd^{-1}$ $d^{-1}$ producing 560 kg $ha^{-1}$; cattle grazing ‘Bonanza’ big bluestem gained 1.3 kg $hd^{-1}$ $d^{-1}$ producing 454 kg $ha^{-1}$; cattle grazing ‘Scout’ indiangrass (*Sorghastrum nutans* L.) gained 0.9 kg $hd^{-1}$ $d^{-1}$ producing 429 kg $ha^{-1}$ (Mitchell and Anderson 2008). Warm- and cool-season grass pastures can be used synergistically to produce cattle gains. For example, in Iowa, when cattle grazed smooth bromegrass in the spring and autumn and switchgrass in the summer, cattle gained on average between 53.0-111.8 kg $animal^{-1}$ (Moore et al. 2004). Additionally, perennial grassland has the potential to be used as a dual-purpose crop.

In Oklahoma, when cattle are stocked at light rates (2.5 steers $ha^{-1}$) to graze switchgrass, the cattle gain on average 0.83 kg $hd^{-1}$ $d^{-1}$ over 81 days producing 167 kg of beef $ha^{-1}$with an additional 10.6 Mg $ha^{-1}$of harvested residual forage (Mosali et al. 2013). These findings illustrate the potential for switchgrass to be used for feed for livestock and biofuel production. Due to the interest in switchgrass as a biofuel feedstock, researchers developed a new variety ‘Liberty’, specifically for biofuel production (Vogel, Mitchell, Casler, et al. 2014).

The beef production potential of cool- and warm- season grass pasture is well known for specific regions. In the WCB, switchgrass and smooth bromegrass perform well. Switchgrass also has the potential to offer management flexibility. Producers can use cattle to graze the switchgrass and/or harvest the switchgrass for biomass production. More information is needed on how switchgrass performs as a dual-purpose crop in Nebraska. Additionally, the beef production potential of 'Liberty' switchgrass and its ability to be a dual-purpose crop are not known.

### *Economics*

Including perennial vegetation on a farm needs to be profitable for producers to consider adopting perennials into their management system. System profitability is important because producer decisions are usually due to economic constraints (Seguin et al. 2007). Incorporating alfalfa into cropping rotations can increase profitability. In central Iowa, a diverse cropping system with alfalfa was found to be more profitable than the typical corn-soybean rotation in the area (Liebman et al. 2008). However, this system did not integrate cattle on the same land base. Using data from the same study, researchers found that integrating cattle by feeding the crops produced in diversified systems is profitable (Poffenbarger et al. 2017). However, the diversified system required greater capital and labor than corn-soybean rotations (Poffenbarger et al. 2017). Another way to integrate livestock into the production system is by grazing perennial grasses.

The profitability potential of perennial grass pasture is well known in specific regions. Recently, economic studies have been conducted to evaluate the profitability of grazing different perennial forages. In the NGP, yearling steers grazing perennials before feedlot entry have higher profitability potential than yearling steers directly entering the feedlot (Şentürklü et al. 2018). In Mississippi, grazing big bluestem was found to have the lowest annual pasture cost and the highest net return when compared to a diverse warm season pasture mix and a bahiagrass pasture (Rushing et al. 2019). In Nebraska, grazing big bluestem was found to be a profitable alternative to dryland corn production (Mitchell et al. 2005). In Oklahoma, when various switchgrass grazing and bioenergy feedstock scenarios were considered, moderately grazed switchgrass was the most profitable when bioenergy feedstock was valued at $0 (Biermacher et al. 2017). In Tennessee, risk averse and profit maximizing producers would select switchgrass for grazing (Boyer et al. 2019). Clearly, perennial grass pasture can be profitable in different states. Recently, there has been an increase in the interest of growing perennial grasses for cellulosic biofuel production. Switchgrass is one species that has been increasingly considered as a candidate for biofuel production. Switchgrass produces large quantities of biomass which can be used for biofuel feedstock, grazing, or both biofuel feedstock and grazing. In Oklahoma, lightly grazing switchgrass and then harvesting the residual growth for biofuel could earn \$232-523 $ha^{-1}$ depending on the price of the harvested feedstock (Biermacher et al. 2017). Switchgrass provides flexibility to the producer because it can either be grazed and/or harvested for bioenergy production (Mitchell et al. 2010).

Integrating perennial legumes into cropping rotations is profitable with and without cattle. Perennial grass grazing system profitability is determined based on the location and definition of the system. Different warm-season perennial grasses are profitable in different locations of the United States. However, little is known about the profitability of grazing switchgrass in Nebraska. Switchgrass can be used as a dual-purpose crop profitably in Oklahoma. However, the profitability of switchgrass as a dual-purpose crop in Nebraska is unknown.

**Integrating Crop and Livestock Production with Crop Residue**

Integrating perennials and livestock to form ICLS requires additional labor and capital. A less intensive way to integrate crop and livestock production is by using crop residue as a feed resource for ruminant animals. In addition, crop residues are readily available when perennial grass pasture is dormant. In developing countries, crop residue grazing by ruminant livestock is a common practice. The practice of livestock grazing crop residue is mutually beneficial. The livestock provide fertility to the soil through excreta and the residue provides feed to the livestock (Rufino et al. 2011). The global impact of grazing crop residues on soil and crop production has been thoroughly outlined (Rakkar and Blanco-Canqui 2018). In general, livestock grazing crop residue is mutually beneficial for crop and animal productivity. Additionally, livestock grazing residue with dry soil conditions prevents damage to soil quality. Furthermore, residue grazing is more economical than feeding harvested forages. Crop residue grazing can improve the ecosystem services of cropland while maintaining crop productivity and soil quality (Rakkar and Blanco-Canqui 2018). Another way to utilize crop residue is by baling the residue. Harvested corn residue has been increasingly considered for both livestock feed and cellulosic ethanol production. Baling residue has more negative effects on soil and crop productivity than grazing, mainly due to a higher residue removal rate than the rate removed by grazing.

The primary purpose of this section is to outline the existing literature on the impacts of grazing and harvesting crop residue on 1) indicators of soil quality and GHG emissions, 2) animal and crop production and 3) economic value of crop residues. Because an extensive global literature review has been conducted, the focus of the following section will outline literature directly pertaining to corn production and/or the Central Great Plains (CGP). If no studies were found on corn and/or in the specified region, other studies with different crops and regions were reviewed. Narrowing the focus of the review will help to better outline the positive and negative impacts of crop residue removal in eastern Nebraska.

### ***Environment***

#### *Soil Quality*

The impact of residue removal on soil quality is site specific. Many factors influence the change in soil quality from grazing. Factors include soil type, residue removal rate, precipitation, and crop rotation (Blanco-Canqui and Lal 2009).

General soil quality and soil structure are not highly impacted by crop residue grazing. However, residue removal may negatively influence soil quality. In Iowa, after two years of residue removal for biofuel feedstock, soil quality declined (Al-Kaisi and Guzman 2012). Soil quality was measured by changes in SOC, bulk density and water infiltration. Researchers also found that the rate of decline was highly dependent on the tillage practice and N management employed in the field (Al-Kaisi and Guzman 2012). In a long-term study on crop residue grazing in Eastern NE, researchers found that grazing residue had no impact on soil structural quality (Rakkar et al. 2017). Additionally, after conducting a study across the precipitation gradient in Nebraska, researchers concluded time and duration of grazing are better predictors of changes in soil quality than precipitation or soil type (Rakkar et al. 2018). Therefore, grazing management is the most important tool for maintaining soil quality. Below is a description of how crop residue grazing has affected multiple soil properties in the region and in corn production.

Overall, compaction, erosion, soil water, soil microbial biomass, nutrient cycling, and soil C can all be maintained or improved through proper grazing management.

*Compaction*

In general, soil compaction from livestock grazing can be mitigated via manure addition or freeze thaw cycles  (Rakkar and Blanco-Canqui 2018). Also, when grazing at proper soil moisture on no-till fields with proper stocking rates, limited to no compaction can be expected (Rakkar and Blanco-Canqui 2018). Even if an increase in compaction occurs, the compaction is below the threshold to limit crop growth (Rakkar and Blanco-Canqui 2018).

Grazing corn residue typically has little to no effect on soil compaction in the CGP region. In Eastern Nebraska on irrigated cropland planted to a corn-soybean rotation with 16 years of crop residue grazing in the fall, no impact on soil compaction was observed (Rakkar et al. 2017). However, when cattle grazed residue in the spring, a minor effect on soil compaction was observed (Rakkar et al. 2017). But, the effect was below the threshold for root restrictive growth, so crop yields were not impacted by the slight increase in compaction (Rakkar et al. 2017). Generally as you move along the precipitation gradient in NE, grazing corn residue has little to no effect on soil compaction (Rakkar et al. 2018). The compaction observed from livestock grazing is due to residue management. Precipitation, soil texture, and organic matter content of the soil do not influence compaction. In a common corn-soybean rotation in Iowa, researchers tested compaction after cattle grazed corn residue. They found changes were minimal if grazing occurs while soils are frozen (Clark et al. 2004). In Illinois, there was a chance of compaction from livestock, but corn yields were not affected (Tracy and Zhang 2008;

Maughan et al. 2009). In Illinois, under continuous corn, continually grazing or strip grazing the residue did not significantly affect soil penetration resistance despite increased bulk density from grazing (Lehman 2015). Residue baling also appears to have minimal effect on soil compaction. Residue grazing and baling can increase soil bulk density, but the effect is highly dependent on soil type and location (Blanco-Canqui et al. 2016).

The risk of soil compaction can be reduced in Eastern Nebraska by following recommended grazing management practices such as not grazing under wet soil conditions. Likewise, susceptibility to wind and water erosion can be managed by grazing management practices such as stocking rate and the amount of residue left after grazing (Rakkar and Blanco-Canqui 2018).

*Erosion*

The chance of wind and water erosion caused by grazing crop residue can be easily managed in the region. In Illinois, under continuous corn, grazing corn residue decreased wet aggregate stability, increasing the risk of erosion (Lehman 2015). However, in a corn-soybean rotation in Iowa, grazing did not impact aggregate stability, therefore, grazing did not influence erosion (Clark et al. 2004). In a long term (16-yr) residue grazing study in Nebraska, grazing had no effect on aggregate stability (Rakkar et al. 2017). Therefore, grazing corn residue does not appear to affect erosion (Rakkar et al. 2017). On the contrary, corn residue baling may increase erosion. In Nebraska, researchers found residue baling at rates greater than 50%, increased the risk of soil erosion (Rakkar et al. 2018). In a no-till corn system in west-central NE, baling residue increases the risk of wind erosion when compared to grazing the residue (Blanco-Canqui et al. 2016).

The risk of wind erosion in crop residue systems in Eastern NE can be managed by not removing more than 50% of the residue and employing grazing as the primary residue removal strategy. Similarly, soil water can be influenced by residue management.

*Soil Water*

Soil hydraulic properties are not negatively affected by grazing crop residues when proper stocking rates are used. When proper residue cover is retained, the soil water content is not negatively affected (Rakkar and Blanco-Canqui 2018). However, high rates of residue removal by baling decrease the surface soil water content (Rakkar et al. 2018). They found that soil water content was more dependent on the residue management than differences in soil texture, soil organic matter content, or precipitation (Rakkar et al. 2018).

*Microbial Biomass and Nutrient Cycling*

The impact of residue removal on soil biology has been both positive and negative (Rakkar and Blanco-Canqui 2018). Across the precipitation gradient in NE researchers found that changes in microbial biomass from residue grazing or baling is largely due to tillage and cropping system (Rakkar et al. 2018). However, one study in Eastern NE found that after 16 years of grazing residue, microbial biomass increased, specifically the actinomycetes (Rakkar et al. 2017). Increased microbial biomass in these systems may improve nutrient cycling. In general, grazing crop residues, increases soil nutrients (Rakkar and Blanco-Canqui 2018). Continual grazing of corn residue in Illinois increased soil nitrate levels (Lehman 2015). In general, more research is needed to determine the effects of crop residue removal on soil microbial populations. Carbon is an important player in soil microbial populations, serving as the microbes' main food source.

*Soil Carbon*

Soil C can be improved through livestock grazing crop residue but is management dependent. A review of the global literature found that the effect of residue removal on soil C is variable (Rakkar and Blanco-Canqui 2018). The residue removal rate and manure input determine the effect of grazing residue on soil C (Rakkar and Blanco-Canqui 2018). When soil C is saturated, grazing does not impact soil C, however, soils not saturated with C can increase or decrease soil C based on management (Rakkar and Blanco-Canqui 2018). Generally, moderate grazing can increase SOM (Rakkar and Blanco-Canqui 2018). However, a recent meta-analysis found that returning residue to the soil increased SOC (Liu et al. 2014).

Residue grazing in the region does not appear to effect SOC. Long term grazing of corn residue in Nebraska does not cause a reduction in soil C (Rakkar et al. 2017). In Illinois, livestock grazing corn residue increased microbial biomass C. Total C concentration also increased in the ICLS when compared to continuous corn production (Tracy and Zhang 2008). Similarly, when residue was baled in Eastern NE, SOC did not change. However, when stover was retained, SOC increased (Jin et al. 2019). In west-central NE a non-significant trend of decreased particulate organic matter was found when residue was baled (Blanco-Canqui et al. 2016). In Ohio, under continuous corn production when residue was baled at rates greater than 25% there was a significant decrease in SOC (Blanco-Canqui and Lal 2007).

In Eastern Nebraska, if residue removal rates do not exceed about 50%, no decrease in SOC should be observed from grazing or baling.

*Greenhouse Gas (GHG) Emissions*

The impact of grazing crop residue on GHG emissions is not well studied. Generally, GHG emissions are based on residue management, manure input, and micro-climatic changes near the soil surface (Rakkar and Blanco-Canqui 2018).

They concluded the effect of residue removal on GHG emissions is inconsistent (Rakkar and Blanco-Canqui 2018). Some studies have concluded that residue removal does not have a significant effect on GHG emissions. In a no-till, corn-soybean rotation in Iowa, $N_2O$ and $CO_2$ emissions were not negatively affected when corn stover was removed (Johnson and Barbour 2010). In Ohio, under continuous corn no-till stover removal did not have a significant effect on $CO_2$ emissions (Blanco-Canqui and Lal 2007). Other studies have found that GHG emissions increase with residue removal.

Across the US corn belt when stover was baled, $CO_2$ and $N_2O$ emissions decreased (Jin et al. 2014). The same study found that averaged across 9 locations, stover removal decreased soil GHG emissions by 5%. In Eastern NE under high N fertilization, $N_2O$ emissions decreased when residue was removed compared to when residue was retained (Jin et al. 2019). In Iowa, when corn residue was removed, the continuous corn field remained a sink for atmospheric $CO_2$ (Al-Kaisi and Guzman 2012). On the contrary, studies have found GHG emissions decrease when stover is removed. In South Dakota when corn stover was baled, $N_2O$ fluxes increased during the soybean growth phase. However there was no impact of residue harvest on GHG emissions during the corn growth phase (Lehman and Osborne 2016). Another study found that removing residue can increase global warming potential (Guzman, Al-Kaisi, and Parkin 2015). More studies assessed the effect of retaining residue on GHG emissions.

In general, when residue is retained, $N_2O$ emissions decrease, and C GHG emissions increase. In North Dakota, in a corn-SB rotation, when residue was retained, researchers observed a decrease in $N_2O$ emissions 2 out of 3 years (Wegner et al. 2018). In Ohio, when stover was retained, $CO_2$ fluxes tended to be higher (Blanco-Canqui and Lal 2007). A recent meta-analysis also found that when residue is returned to the soil, $CH_4$ and $CO_2$ emissions may increase (Liu et al. 2014). Unfortunately, the effect of grazing residue on GHG emissions is not well known. Only one study in the Midwest has assessed the effect of grazing residue on GHG emissions. In Illinois when residue was grazed, $CO_2$ effluxes were inconsistent when related to soil compaction and cattle presence (Tracy and Zhang 2008). Clearly the impact of residue removal on GHG emissions is contradictory.

Jin et al. (2014) states that site specific management is essential to mitigate GHG emissions. In conclusion, site specific management is essential because GHG emissions vary spatially, temporally, and based on environmental conditions (Jin et al. 2014). Additionally, it is important to note that little is known about the impacts of grazing residue on soil GHG emissions.

## ***Production***

### *Grain Yield*

In general, livestock grazing crop residue does not negatively impact grain yield (Rakkar and Blanco-Canqui 2018). However, if grazing occurs when the soil is too wet, grain yield can be negatively influenced. Below are findings on the impact residue removal has on grain yield related to corn production and the CGP region.

In the Midwest grain yields are not negatively influenced by crop residue grazing. In Illinois, when a diverse crop rotation including winter cover crops was used and where corn stover was grazed one year and winter cover crops were grazed the next, corn grain yields increased (Tracy and Zhang 2008; Maughan et al. 2009). In Eastern NE, under irrigation and a corn soybean rotation, grain yields were not negatively affected by cattle grazing crop residue (Rakkar et al. 2017). In Iowa, grazing corn residue had little to no impact on the following soybean yield as long as grazing occurred when the soil was frozen or the field was disked before planting (Clark et al. 2004). In Illinois, under tillage and continuous corn production,  grazing residue did not influence the following grain yield (Lehman 2015). In Eastern Nebraska, under a corn-soybean rotation, corn residue grazing increased soybean yield and did not affect corn yield (Drewnoski et al. 2016). Across multiple sites and crop rotations in Nebraska, grazing corn residue did not influence corn grain yield  (Ulmer 2016). In West-Central NE, residue grazing or baling did not significantly affect corn grain yield (Stalker et al. 2015). Grazing or harvesting crop residue appears to have little to no effect on grain yield.

In South Dakota, under rain-fed conditions, in a no-tillage corn or soybean rotation, grain yield was not impacted by corn residue removal at a rate of 55% (Lehman and Osborne 2016). In Iowa, in a no-till corn soybean rotation, grain yield was not affected by corn stover harvest (Johnson and Barbour 2010).  In Ohio, under continuous corn production when stover was baled at rates greater than 50%, corn grain yield was reduced (Blanco-Canqui and Lal 2007). In Nebraska, no difference in corn yield was observed between land with and without stover removal (Jin et al. 2014).

In general grazing and harvesting crop residue does not negatively impact corn grain yield. Corn residue can be grazed in Eastern NE when soils are dry at proper stocking rates without negatively impacting yield. Corn stover may be harvested and baled at a 50% removal rate with no likely negative impact on crop yield.

*Cattle Production*

Grazing crop residue provides a valuable feed resource for ruminant livestock (Rakkar and Blanco-Canqui 2018). In west central NE, beef cows in late gestation that grazed corn residue gained weight at light (2.5 AUM $ha^{-1}$) and heavy (5 AUM $ha^{-1}$) stocking rates (Stalker et al. 2015). Cows grazed corn residue from late November to early February with initial average body weights of 440 and 443 kg $hd^{-1}$ for the groups stocked at 2.5 AUM $ha^{-1}$ and 5 AUM $ha^{-1}$, respectively (Stalker et al. 2015). The cattle at lower stocking rates gained more than those at heavy stocking rates (Stalker et al. 2015).

Grazing crop residue maintains mature cow weight and can provide an excellent source of roughage for growing cattle in Nebraska. Additionally, grazing crop residue provides an economic advantage to both crop and livestock enterprises.

***Economic Impact of Crop Residue Grazing***

In addition to serving as a winter feed source, grazing crop residue provides an economic advantage to both crop and livestock enterprises. Adopting residue grazing can reduce winter feed cost and improve the profitability of livestock operations (Karn et al. 2005). Because there are no negative impacts on soil properties and an economic advantage to residue grazing, producers in the region have readily adopted the practice. Residue provides a valuable feed resource for cattle and a way to diversify the income stream crop producers receive. In NE, SD, KS, and ND corn stover grazing is worth $95 million for the crop sector and $191 million for the livestock sector (Redfearn et al. 2019)

In Nebraska, researchers studied how cattle grazing crop residue impacted system profitability. When cows and their calves grazed crop residues, profitability potential increased (Anderson et al. 2005). Cows grazed residue in the winter, and calves grazed residue after weaning. Following residue grazing, the calves were moved to pasture during spring and summer, then sent to the feedlot for finishing. The calves that grazed residue before feedlot entry had lower weaning and slaughter breakeven than calves that entered the feedlot after weaning (Anderson et al. 2005). There was also a lower cost per weaned calf in the treatment where cows grazed residue and were fed hay, compared to cows only fed hay (Anderson et al. 2005). Therefore, in Nebraska, crop residue grazing is a viable tool for improving crop and livestock enterprise profitability.

Crop residue is an extremely valuable resource to the crop and livestock producer in Nebraska to aid in farm profitability. When crop residue is used for grazing, livestock should be stocked at proper rates to maintain no more than 25% residue removal in Nebraska (Rasby, Drewnoski, and Stalker 2014). The practice has been widely adapted and should be considered to integrate crop and livestock production.

**Integrating Crop and Livestock Production using Cover Crop/Annual Forage Grazing**

The practice of planting cover crops is rising in popularity due to the various ecosystem services they offer. Cover crops reduce erosion, nutrient losses, GHG emissions and run off (Kaspar and Singer 2015). Cover crops also increase soil C and support soil biology (Kaspar and Singer 2015). In Nebraska, producers plant cover crops primarily to reduce soil erosion and suppress weeds (Oliveira, Butts, and Werle 2019). However, cover crop adoption has been limited because cover crops do not provide immediate financial return to the farmer (Kaspar and Singer 2015). Grazing cover crops can provide a form of livestock integration that increases land use efficiency, potentially leading to improved profitability (Carvalho et al. 2018). In Brazil, cattle moderately grazing cover crops produces sustainable production of both animal protein and grain (Carvalho et al. 2018). The synergy between the two systems has the potential to lead to higher profits and increase system resilience (Carvalho et al. 2018).

### ***Environment***

#### *Compaction*

Compaction caused by grazing animals on cropland may be a barrier to adopting cover crop grazing as an ICLS strategy. However, the compaction caused by animals grazing cover crops, if observed, is minor and does not affect subsequent plant growth. In Georgia, grazing cover crops did not impact soil penetration resistance in no-till production (Franzluebbers and Stuedemann 2008b). In Alberta, researchers found that grazing intensity can be used to manage soil compaction when annual forages are grazed. However, all grazing intensities resulted in compaction levels below the level that restricts root growth (Twerdoff et al. 1999). In Ohio, after a cover crop was grazed, compaction increased but did not impact yield and was gone within a year (Faé et al. 2009). In southern Iowa, preliminary data showed that cattle grazing cereal rye (*Secale cereal L.*) had minimal negative impact on soil compaction (Lundy et al. 2018).

Compaction caused by grazing animals does not appear to be a problem in ICLS.

*Water*

Water holding capacity of soil is important for agroecosystem function both to prevent runoff and hold water for crop growth. In Georgia, the stability of soil aggregates was not affected by grazing cover crops, but, water infiltration decreased when cover crops were grazed compared to non-grazed cover crops (Franzluebbers and Stuedemann 2008b). In North Dakota, infiltration rate was not affected by swath grazing in winter when no till management was used (Liebig et al. 2011). In the Texas High Plains, an ICLS with annual forage grazing compared to continuous cotton production reduced the need for irrigation water by 24% (Allen et al. 2007; Johnson et al. 2013; Allen et al. 2005). Therefore, ICLS could provide an opportunity for producers in areas where wells are running dry or where water withdrawal is either limited or regulated (Allen et al. 2007; Johnson et al. 2013; Allen et al. 2005).

ICLS with ruminant grazing animals appears to potentially improve water use efficiency.

*Plant Organic Matter Production (roots/litter)*

Addition of plant litter, root biomass, and root exudates increase soil C and provide multiple environmental benefits. Benefits include reduced soil erosion through cover cropping practices. When a cover crop is grazed, the accumulation of belowground (root) biomass is the most important factor that contributes SOC (Faé et al. 2009).

Little research has been done to determine the impact of cover crop grazing on root growth. In Ohio, researchers found evidence that cover crop grazing negatively impacts root growth. However, the grazed cover crop area still had greater root biomass than the area without a cover crop (Faé et al. 2009). Additionally, grazing intensity did not significantly affect triticale (x*Tritosecale*) root mass (Mapfumo et al. 2002). Litter or above-ground plant biomass also can be an important contributor to soil health. The litter of triticale decreased as grazing intensity increased in both fall and spring (Mapfumo et al. 2002). Decreased litter contribution led to decreased C and N pools (Mapfumo et al. 2002). Additional research has been done on dual-purpose crops used for both grain and grazing.

In Australia, canola (*Brassica Napus L.*) has been used as a dual-purpose crop for grazing and oilseed production. Researchers found that grazing reduced plant dry matter, but if proper irrigation was provided the following yield was unaffected (McCormick, et al. 2012). In another study, researchers observed that when well-established wheat was grazed as a dual-purpose crop, root depth, rate of penetration, and above-ground biomass was unaffected (Kirkegaard et al. 2015). The biomass production was unaffected because the plant re-growth was able to keep up with the defoliation from grazing animals (Kirkegaard et al. 2015). However, when the wheat was repeatedly defoliated at the four-leaf stage, researchers observed decreased rooting depth (Kirkegaard et al. 2015). Additionally, repeated defoliation during early plant establishment decreased above-ground biomass (Kirkegaard et al. 2015).

Little is known about the impact of grazing or defoliation on above and below ground biomass production. Additionally, how the grazing affects the ecosystem services provided by cover crops is not well known.

*Soil Nutrients*

Cover crops increase SOC and reduce N leaching. In Illinois, after 12-yrs of cover crops, SOC increased (Olson, Ebelhar, and Lang 2014). In the Northern Corn Belt, a rye cover crop in a corn-soybean rotation, following corn, decreased nitrate leaching (Strock, Porter, and Russelle 2004). Unfortunately, there is limited information on how grazing cover crops impacts their ability to increase SOC and reduce N leaching.

In Georgia, researchers concluded that grazing cover crops was a viable option because grazing did not consistently negatively impact soil C and N (Franzluebbers and Stuedemann 2008b). Similarly, in Brazil, 9 years of light and moderate grazing intensities resulted in similar C and N stocks to non-grazed plots (Assmann et al. 2014). However, heavy grazing intensity did lead to soil deterioration (Assmann et al. 2014). In the southeastern U.S., grazing cover crops did not impact N mineralization (Franzluebbers and Stuedemann 2015). Additionally, grazing cover crops appears to boost microbial content in the soil. Researchers observed that grazing cover crops increased particulate organic C and microbial biomass (Faé et al. 2009). Under no-till management, they also observed an increase in soil microbial C when grazing of cover crops was compared to no grazing (Franzluebbers and Stuedemann 2015).

Limited information is available on how grazing of cover crops affects the C and N cycle. However, it appears that grazing cover crops does not negatively impact the soil C and N content.

*Soil GHG*

Cover crops also have the potential to decrease GHG emissions through reduced fertilizer use. In Minnesota, when cover crops and reduced tillage were implemented into a corn-soybean rotation, $CH_4$ fluxes were negligible (Bavin et al. 2009). However, in the same study, $N_2O$ emissions were higher when no cover crop was used (Bavin et al. 2009). Researchers concluded the increase was due to different fertilizer use (Bavin et al. 2009). Anhydrous ammonia was applied in the conventional system whereas urea was applied to the system with reduced tillage and cover crops (Bavin et al. 2009). In agreement with this finding, monocropping was found to increase $N_2O$ emissions because of the need for higher synthetic fertilizer (Abagandura et al. 2019). These findings indicate that fertilizer source and rate impact soil GHG emissions. In the Great Plains, cover crops have been proven to decrease $N_2O$ emissions. In South Dakota, 2 of 3 years, they observed that cover crops decreased nitrous oxide emissions (Wegner et al. 2018). Cover crops can decrease soil $N_2O$ emissions.

However, the impact of livestock grazing cover crops on soil GHG emissions is contradictory. When an ICLS with winter cover crop grazing was compared to a continuous cropping system, $N_2O$ emissions increased (Piva et al. 2014). Researchers hypothesize the increase was likely due to additional fertilizer and observed compaction in the ICLS (Piva et al. 2014). However, another study found that an ICLS in Brazil with cover crop grazing mitigated $N_2O$ emissions when compared to continuous cropland (Dieckow et al. 2015). Additionally, researchers found that grazing annual forages in South Dakota did not impact $N_2O$ or $CH_4$ emissions but grazing did reduce $CO_2$ (Abagandura et al. 2019).

These findings support that cover crop grazing may decrease GHG emissions but emphasize the need for more research. Additional research needs to be conducted to identify the impact of grazing cover crops on soil GHG emissions.

***Production***

*Grain Crop Yield*

For producers to adopt cover crop grazing, grain yield needs to remain unaffected or improved. Generally, grazing cover crops has no impact on subsequent grain yield. In Brazil, researchers found that cattle grazing an oat (*Avena sativa L.*) cover crop did not impact the following soybean grain yield (Da Silva et al. 2014). In Texas, researchers found that cotton yield was similar between a conventional cotton system and ICLS with cover crop grazing (Allen et al. 2007; Johnson et al. 2013). In Ohio, if cover crops were grazed with appropriate management under no-till, the following corn silage yield was not impacted (Faé et al. 2009). However, it is possible that cover crop grazing can improve grain yield through manure addition to the soil. In Brazil, the input of cattle manure improved soybean yield (Da Silva et al. 2014). Higher grazing intensities have the potential to negatively influence the following grain yield. In Brazil, when an annual ryegrass (*Lolium multiflorum*) and oat cover crop mixture was heavily grazed by cattle, the following corn grain yield was negatively impacted (Franchin et al. 2014). However, the same study found that the negative impact of grazing on corn yield could be mitigated with light to moderate grazing in combination with a shank method of planting (Franchin et al. 2014). In the Midwest, ICLS with cover crop grazing have improved grain yield. In Illinois, when cover crops were grazed by cattle the following grain yield improved when compared to a continuous corn production system (Maughan et al. 2009; Tracy and Zhang 2008).

The limited literature suggests that cover crops grazed by cattle with proper management does not negatively impact the following grain yield. In some cases, cover crop grazing may improve grain yield.

*Ruminant Animal Performance*

Cover crops can provide high quality forage for ruminants when perennial pastures are dormant. In different regions, cover crops provide adequate forage for animal performance. In Brazil, cattle that grazed a mixture of oats and ryegrass had adequate performance (Kunrath et al. 2014). In the Texas High Plains, when steers were stocked at 1.75 hd $ha^{-1}$, rye provided 33.5 grazing days, and wheat provided 25.3 grazing days (Allen et al. 2007). In Ohio, winter annual grass cover crops provided 105 AU grazing d $ha^{-1}$ when planted after corn silage harvest (Faé et al. 2009). The heifers that grazed the winter annual grasses gained an average of 0.81 kg $d^{-1}$ (Faé et al. 2009). In southern Iowa, preliminary data showed that cattle grazing cereal rye supplemented with distiller's grain and soyhull can achieve an ADG of 0.7-1.4 kg $hd^{-1}$ (Lundy et al. 2018). In Nebraska, steers that grazed an oat/brassica mix planted after wheat harvest, over 50 days in winter gained 0.7-0.9 kg $hd^{-1}$ (Ulmer et al. 2016). Despite adequate animal performance, only 2% of surveyed producers in Nebraska report that increased grazing opportunity is a benefit to planting cover crops (Oliveira et al. 2019).

Cover crops produce high quality forage which in turn produce adequate ruminant animal gains. However, the challenge of cover crop growth and establishment exists for northern climates.

*Cover Crop Growth*

The success of cover crop grazing is highly dependent on the success of cover crop establishment. The planting date of the cover crop largely determines if enough forage will be available for either autumn or spring grazing. Typically, 40-60 days are needed to produce adequate forage growth for grazing (Drewnoski and Redfearn 2015). The date the cover crop can be planted is determined by the cash crop system used. In Nebraska, if a producer wants to provide forage in the fall, the cover crop should be planted after wheat, hybrid seed corn, or corn silage to produce adequate grazable forage (Drewnoski and Redfearn 2015). Planting after these cash crops should ensure a planting date during the first week of September which should be early enough to produce adequate grazable forage in autumn (Drewnoski and Redfearn 2015). If the cropping system requires later planting dates, winter hardy species can be planted mid-September-early October to provide a spring grazing opportunity (Drewnoski and Redfearn 2015). Cereal grains used as cover crops have been found to provide adequate forage growth. They also hold quality well over time, allowing for management flexibility (Coblentz and Walgenbach 2010). In Ohio, cereal rye produced 38% more forage than annual ryegrass which provided an additional 37 grazing days (Faé et al. 2009). Researchers have also found that grazing if done properly, can improve the cover crop growth rate as long as producers allow enough leaf growth to occur before grazing initiation (Gardner and Faulkner 2010).

An adequate amount of growing degree days is needed to produce grazeable forage in the autumn. Cropping system is a large determining factor in the amount of grazeable cover crop biomass. Little research exists on spring forage availability of winter hardy species.

***Economics***

Cover crops provide numerous environmental and production benefits; however, they are costly to manage. In Nebraska, the cost of seeding a small grain is \$74- 99 $ha^{-1}$ (Drewnoski and Redfearn 2015). Additionally, surveyed Midwest producers illustrated that cover crops generally have a negative effect on whole farm profitability (Plastina et al. 2018). The negative effect is due to additional management costs including cover crop establishment and termination (Plastina et al. 2018). Using ruminant livestock to graze cover crops is one way to mitigate the negative effect cover crops have on farm profitability.

Researchers throughout the United States have evaluated the feasibility of using cover crops as forage. In the Texas High Plains an ICLS with cattle grazing annual forages had less variation in profitability when compared to continuous cotton production (Johnson et al. 2013). In addition, the system provided ecological diversity which benefited soil health and wildlife populations (Johnson et al. 2013). These types of ICLS can improve profitability while reducing the need for external inputs (Allen et al. 2005). Fortunately, after reviewing the limited data available, investigators have concluded that cover crops can be grazed to provide economic return without negatively impacting the soil (Drewnoski et al. 2018). Grazing cover crops can positively impact the crop producer by generating a secondary revenue source. Similarly, grazing cover crops can also be advantageous for the livestock producer. In the NGP, researchers concluded that cattle grazing annual forage allowed for delayed feedlot entry, which produced greater profitability potential (Şentürklü et al. 2018). In Ohio, researchers found that daily feed costs could be decreased by heifers grazing an oat rye cover crop mix instead of being fed in confinement (Faé et al. 2009). In the southeast, researchers found that cattle grazing cover crops did not negatively impact the soil (Franzluebbers and Stuedemann 2015). Therefore, the economic benefit of additional cattle gain can be used to promote the use of cover crops in the region (Franzluebbers and Stuedemann 2015).

Grazing cover crops can be economically advantageous for both the crop and livestock producer. Although, the most economical system for the region is not well known.

**Conclusion**

In conclusion, ICLS should be considered in Eastern NE to meet the production, profitability, and environmental challenges facing the producer. Three main types of integration have shown promise for agricultural systems in Eastern Nebraska. Although integration of perennial vegetation shows promise, more research to develop the best system is needed. Generally, converting cropland to perennial grasses reduces nutrient loss, reduces soil GHG emissions, and increases SOC. Additionally, mechanically harvesting the grasslands sustains these trends. However, the best grazing management practices to reduce nutrient loss, reduce soil GHG emissions, and increase SOC need to be developed for the region. In the region, smooth bromegrass and switchgrass, along with other native, perennial warm-season grasses, and mixtures can produce adequate cattle gains. However, more information is needed on how switchgrass performs as a dual-purpose crop in Nebraska for grazing and bioenergy production. Lastly, more research is needed on the economic viability of implementing switchgrass in Nebraska for grazing or dual-purpose use. A simpler form of ICLS includes crop residue grazing. Crop residue grazing has been readily adopted and should continue to be expanded in the region due to economic, production, and environmental benefits. However, more research is needed on the impact of grazing corn residue on soil GHG emissions. A form of ICLS that can increase forage quality and availability when perennial grasses are dormant is cover crop grazing. However, little is known about the impact of grazing on cover crop above- and below-ground biomass, which appears to influence the environmental services offered by cover crops. Additionally, little is known about the impact cattle grazing cover crops has on soil GHG emissions. It is apparent that cattle grazing cover crops is beneficial to both the crop and livestock enterprises. However, the success of this practice is largely controlled by forage availability, which is affected by planting date. Additionally, little is known about the spring forage availability of winter hardy species in the region. However, an optimal system for Eastern NE has not been well defined. Overall, each of the three ICLS strategies present opportunities for producers to meet environmental, production, and economic challenges.

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# CHAPTER 2

# RESPONSE OF COOL-SEASON ANNUAL GRASSES TO DEFOLIATION DURING EARLY PLANT ESTABLISHMENT


## Abstract

Cool-season annual grass cover crops are gaining popularity among row-crop producers because of the soil conservation benefits they offer. However, managing cover crops can have substantial input costs, which can be partially offset through grazing. The objective of this study was to understand how cool-season small grain cover crops responded to clipping height and frequency in a greenhouse study and cattle presence during autumn triticale emergence in a complementary field experiment. In the greenhouse study, we measured above- and below-ground biomass production from cereal rye (*Secale cereale L.*), winter wheat (*Triticum aestivum L.*), winter triticale (*Triticosecale*), and oat (*Avena sativa L*). Plants were clipped to either a 5- or 10-cm stubble height (clipping height) and at 7- or 14-day intervals (clipping frequency). A non-clipped control was included. A field study was also conducted where steers grazed corn stover previously sown to triticale in the autumn. The impact of cattle presence on triticale production was measured in both the autumn and spring for each growing season. Results from the greenhouse study showed two and a half and six times the number of experimental units clipped to 10-cm remained when compared to those clipped to 5-cm in 2018 and 2019, respectively. In 2018 and 2019, the non-clipped control produced more root biomass than the clipped treatments. In 2018, the plants clipped at 14-d intervals produced double the amount of biomass during the simulated grazing season when compared to plants clipped at 7-d intervals. In 2019, rye and triticale produced more biomass during the simulated grazing season when clipped at 14-d intervals than 7-d

intervals. Furthermore, in spring of 2019, the non-grazed stover paddocks had 23% greater frequency of occurrence than grazed stover paddocks. Defoliation and cattle presence during early establishment resulted in reduced biomass production and winter survival of cool-season annual grasses. Our results suggest that grazing during early establishment is not the best practice if producing cover crop above- and below-ground biomass is the main objective.

**Introduction**

Cover crops provide a potential mechanism for soil regeneration. Cover crops can be various plants, but cool-season annual grasses tend to be the most popular type, comprising more hectares than brassicas (126,780-ha), legumes (107,383-ha), or warm season annuals (29,575-ha) (CTIC 2017). Cool-season annual grasses comprised 246,399-ha in the United States in 2017 (CTIC 2017). Cover crops can reduce soil erosion, build soil organic matter, and increase nutrient retention (Hargrove, 1991; Magdoff and Harold, 2009; Noland *et al.*, 2018). Cover crops maintain litter on the soil surface which can provide soil structure improvements, increased water infiltration, reduced impacts from heavy precipitation events, including less runoff, erosion, and evaporation (Naeth et al. 1990; Willms, Smoliak, and Bailey 1986). Cover crops also help retain nutrients. One example is triticale (x*Triticosecale*) scavenging both carbon and nitrogen in the autumn and spring (Mapfumo et al. 2002). The retained nutrients in the cover crop are then recycled. The above- and below-ground cover crop residue is broken down by soil microorganisms with nutrients returned to the soil for the cash crop to utilize (Magdoff and Harold 2009; Mc Calla 1978). Even though the benefits of cover crops have been shown, producers are still concerned because cover crops can be costly to manage, including additional operational costs such as buying seed, planting, and termination (Snapp et al. 2005). Additionally, a recent survey in the Midwest revealed that cover crops typically have a negative effect on whole farm profitability (Plastina et al. 2018).

Extra operational costs discourage some producers from planting cover crops because the cover crop does not typically generate direct revenue. However, cover crops can provide an opportunity for additional revenue by extending the grazing season on an integrated crop-livestock production system. Cereal rye (*Secale cereale L.*), a common cover crop, has sufficient growth to graze 2.7 cows $ha^{-1}$ for 30 days in the spring (Faé et al. 2009). By incorporating livestock back on to the land, proper ecosystem function can be restored by increasing nutrient cycling, microbial activity, and organic matter content (Tracy and Zhang 2008). Livestock can be placed on agricultural land to graze cover crops and as a result increase the resilience of the system. However, some concern exists on how the root biomass of the cover crop is affected by grazing. Reduced root biomass could negatively impact the environmental benefits offered by the cover crop.

When perennial grasses are defoliated, root biomass decreases (Gao, Giese, and Lin 2008; Mapfumo et al. 2002). Therefore, if cover crops are grazed, a decrease in root and shoot biomass production is expected. Defoliated canola (*Brassica napus L.*) has decreased root and shoot biomass (McCormick *et al.*, 2012). However, triticale, a cool-season annual, shows root biomass under light, moderate, and heavy grazing intensities that is not significantly different from each other (Mapfumo et al. 2002). Additionally, grazing has no substantial effect on rooting depth or root mass in well-established wheat (*Triticum aestivum L.*), another cool-season annual (Kirkegaard et al. 2015).

The observed differences from previous studies suggest cover crops should be grazed differently than perennials to optimize soil health. Adequate growth of cover crops is essential to increase soil organic matter, microbial activity, and nutrient retention (Hargrove, 1991; Magdoff and Harold, 2009; Noland *et al.*, 2018). Cover crop roots provide important ecosystem services. Based on previous studies, properly managed grazing appears to have little impact on root growth of cool-season annual grasses when managed as a grazed forage crop. However, rooting depth of wheat decreases when defoliation occurs during early plant establishment (Kirkegaard et al. 2015). Avoiding defoliation during early establishment in Eastern NE may be a challenge for some producers. The challenge exists because cover crops are typically planted after corn (*Zea mays* L.) or soybean (*Glycine max* L.) harvest in autumn, and corn residue is a valuable forage resource in autumn and winter in Nebraska (Redfearn et al. 2019; Schmer et al. 2017). Therefore, a producer may want their cattle to graze the corn stover during autumn, before the cover crop is well-established. We do not know how grazing will affect above- and below-ground biomass production and plant survival of cool-season annual grass cover crops during early plant development. Additionally, limited information is available on which cool-season annual grass species provides the greatest soil health benefits and forage productivity.

We explored if defoliation or exposure to cattle presence during early establishment of cool-season annual grass cover crops negatively affected above- and below-ground biomass production. The first objective was to measure the response of cool-season annual grasses to clipping heights and frequencies to simulated defoliation by measuring above- and below-ground biomass in the greenhouse. In order to identify management strategies for cover crop grazing, this experiment explored three clipping heights (non-clipped and clipped to either a 10- or 5-cm stubble height) at two frequencies (7- and 14-d) using four cool-season annual grass species (winter wheat, winter triticale, cereal rye, and oat (*Avena sativa* L.)). Biomass production throughout the growing season, final above-ground biomass, and root biomass were recorded for each experimental unit. In general, defoliation during early plant establishment had negative repercussions.

Since the greenhouse study was conducted in potted sand and plants were not grazed, a field study was conducted for comparison. The second objective was to measure the response of winter triticale to cattle presence during early plant establishment in a field experiment. To measure this response, plant stands were evaluated using frequency of occurrence, and plant above-ground biomass. The results from the field study support the generalization that defoliation during early plant establishment had negative repercussions.

The third objective was to use the information from the greenhouse and field studies to develop grazing recommendations for cool-season annual grass cover crops in Eastern Nebraska. Data from these studies will guide grazing management practices as well as provide insight for future studies on best management practices for cover crop grazing. These management practices will optimize soil health and forage production. Proper grazing recommendations are essential to increase the resiliency of agroecosystems by integrating livestock into cropping systems.

## Materials & Methods

### *Greenhouse Study*

#### *Experiment Location & Designs*

The experiment was conducted in the USDA Forage Research Laboratory greenhouse located in Lincoln, NE. The experiment was repeated two times, the first in autumn of 2018 and the second in autumn of 2019. The length of the study was eight weeks in order to represent a typical grazing season of cover crops (Drewnoski and Redfearn 2015). Ambient light and temperature were used to simulate fall-planted cover crops. Four cool-season, annual, small grain grass species were used including: oats (*Avena sativa* L.), cereal rye (*Secale cereale* L.), triticale (*xTriticosecale*), and wheat (*Triticum aestivum* L.). In addition to a non-clipped control, two levels of clipping were used to maintain a stubble height of 5-cm and 10-cm. Plants were clipped at 7- and 14-d intervals to represent different grazing frequencies. Each treatment combination had three replications. Pot locations on greenhouse benches were randomized within each replication. The 7- and 14-d intervals were on separate benches to reduce competition from the 14-d interval plants.

*Planting & Plant Care*

Round pots (25 cm tall by 22.5 cm diameter) were lined with landscaping fabric to prevent sand from leaving the pot. Sand was used as the growth media because of its ease of being efficiently and effectively washed from the roots. Pots were then filled with sand and 22 seeds were placed on top of the sand. Seeds were covered with 2.5 cm of sand to ensure consistent seeding depth. Seeds were planted on August 30, 2018 and August 29, 2019. Varieties of the species used were: Elbon cereal rye, SY TF 813 PVP winter hardy triticale, WB 4303 West Bred winter wheat, and Kona oats. Pots were watered as needed and 3 tablespoons of Miracle-Gro (The Scotts Company LLC, 2019), a granular fertilizer with analysis 15-30-15, per 9.5 liters of water was supplied at watering when needed to provide nutrients to the plant throughout the duration of the experiment. Stand counts were taken at the beginning and at 14-d intervals for each pot in 2018 and at

7-d intervals in 2019. Two weeks after emergence, plant material was hand-clipped with scissors to a 5- or 10-cm stubble height. Hand removal of fall-armyworms (*Spodoptera frugiperda* Smith) was needed in 2018 because they entered the greenhouse from outside. Some aphid feeding activity was observed and recorded in 2019.

*Simulated Grazing Measurements*

Defoliation began September 18, 2018 with the final clipping on November 13, 2018. In 2019, defoliation began September 17 and the last clipping was November 12. Defoliation height was measured at the beginning of the study from sand level and marked with a sharpie on a wooden dowel inserted into the center of the pot. Clipped plant material was placed in a labeled paper bag, weighed, dried for a minimum of 72 hours at 50ºC, and then weighed again. The clipping events were summed for each pot to calculate total biomass produced during the simulated grazing season. Experimental units (EU's) were eliminated from the study if an estimated 75% of the plants in the pot were senesced. Dates of death were recorded for each EU and the residual biomass was clipped to sand level, dried, and weighed according to the above protocol. At the completion of the study the remaining EU's were clipped to sand level and residual above-ground biomass was weighed and recorded according to the study protocol.

*Root Measurements (Below-ground biomass)*

At completion of the study, root biomass was measured to determine relative differences among treatments. Large root masses were separated from the sand by rinsing with water. Additional roots were removed by flotation in water. Remaining roots were separated using a 2-mm sieve. Roots were processed like the above-ground biomass. To account for remaining sand particles attached to the dry roots, an ashing procedure was used on the dried roots. Roots with remaining sand particles were placed in previously weighed glass vials. Vials were placed in a muffle furnace at 450ºC for six hours to burn all organic material. Vials were then moved to a 100º C oven for at least 16 hours. Vials were removed and caps placed back on and allowed to cool for three hours or until weights of the vials were stable. Cooled vials were weighed to four decimal places. Root mass was calculated by subtracting weight of the ash, vial, and cap from the combined weight of the vial, cap, and initial mass (USDA-ARS FRL).

*Statistical Analysis*

Differences in residual above-ground biomass, biomass production during the simulated grazing season, root mass, and total combined biomass were analyzed as an RCBD using the PROC GLIMMIX procedure in SAS. Significance for the main effects and interaction terms were evaluated using a p-value<0.05. Significant year interaction was observed so 2018 and 2019 were analyzed separately for further analysis. Normality and homogeneous variance were evaluated using the conditional studentized residuals and the UNIVARIATE procedure in SAS. Data was transformed as needed to account for non-normality and/or heterogeneous variance. Transformed data was then evaluated using the PROC GLIMMIX procedure in SAS. Significance for main effects and interaction terms were evaluated using a p-value <0.05. LS-means were reported for either the significant main effects or significant interactions.

***Field Study***

*Cover Crop & Grazing Management*

The field study was located at the Eastern Nebraska Research and Extension Center near Mead, NE. The field study was part of a larger, 20-ha field-scale model demonstration site. The continuous corn portion of the study (8-ha) had 50% of the land planted to a triticale cover crop (Figure 2-1). In 2018, triticale was planted on September 17 at 56 kg $ha^{-1}$. In 2019, the triticale was planted on October 9 at 112 kg $ha^{-1}$. In 2018, the corn stover and triticale was grazed by 6 steers per 1.35 ha paddock from September 27 to October 12 for 15 days. In 2019, the corn stover and triticale was grazed by 6 steers per 1.35 ha paddock from October 23 to October 29 for 6 days. Cattle were removed when forage availability became limiting. When cattle began jumping the fence, the cattle were removed from the paddocks. Half of the paddock (0.68-ha) was planted to triticale each year. In the same block, 0.68-ha were planted to triticale and not grazed. A total of 3 replications (blocks) were included. To evaluate the impact of cattle presence during early plant emergence on triticale stand and biomass production, frequency of occurrence and harvested biomass were collected for grazed and non-grazed areas.

*Frequency of Occurrence & Biomass Measurements*

Frequency of occurrence and biomass measurements were collected using a 76-cm by 76-cm frame to evaluate triticale production. In autumn 2018, two subsamples per grazed experimental unit were taken and averaged for frequency of occurrence and biomass production. Three or four subsamples were taken and averaged per non-grazed experimental unit for frequency of occurrence and two subsamples were taken and averaged per non-grazed experimental unit for biomass production. Frequency of occurrence was measured on October 11. Biomass was sampled on October 23. In autumn 2019, three subsamples per experimental unit were taken and averaged for frequency of occurrence and two subsamples per experimental unit were taken and averaged for biomass production. Six subsamples were taken and averaged per non-grazed experimental unit for frequency of occurrence and three subsamples were taken and averaged per experimental unit for biomass production. Data for autumn 2019 was collected November 6. In spring 2019 and 2020, three subsamples per grazed experimental unit were taken and averaged for frequency of occurrence and biomass production. Six subsamples were taken and averaged per non-grazed experimental unit for frequency of occurrence and biomass production. Frequency of occurrence samples were taken on March 26, and April 1 in 2019 and 2020, respectively. Biomass was sampled on April 23 and April 22 in 2019 and 2020, respectively. Forage biomass samples were dried for 72-hr or until a steady weight was held.

*Statistical Analysis*

The statistical analyses for the field data were conducted as a randomized complete block design with repeated measures. SAS statistical software was used with the PROC GLIMMIX procedure. Each growing season (Autumn 2018-Spring 2019; Autumn 2019-Spring 2020) was analyzed separately because of different planting rates and grazing durations. For the autumn 2018-spring 2019 season biomass production and frequency of occurrence, there was a significant grazing treatment by time (autumn/spring) interaction (p-value<0.05). Therefore, the LS means reported are those of each grazing treatment and time combination. For autumn 2019/spring 2020 biomass production, only time was significant (p-value<0.05), so the LS means reported is for each time only. No significant differences were found among time and/or treatment for frequency of occurrence measurements in autumn 2019/spring 2020.

## Results

### *Greenhouse Experiment*

The results suggested a species by height interaction for residual above-ground and below-ground biomass production. Generally, the non-clipped control produced the greatest amount of biomass followed by the 10-cm clipping height with the least biomass production from the 5-cm clipping height. Clipping frequency appeared to impact the production of biomass throughout the simulated grazing season. Generally, plants clipped at 14-d intervals produced more forage than plants clipped at 7-d intervals. Plants clipped to a 10-cm stubble height at 14-d intervals resulted in greater survivability than plants clipped to a 5-cm stubble height at 14- or 7-d intervals. In general, defoliation during early plant establishment had negative repercussions.

*Survival*

Longevity of Treatment Combinations

To determine the effect of clipping frequency and clipping height during early establishment on plant survival EU's were removed when an estimated 75% of the plants in the EU were dead. Our unexpected plant death resulted in all oat EU's being removed during the study both years except two replications clipped to 10-cm at the 14-d interval in 2018 (Table 2-1). Likewise, in 2018, winter triticale only had 2 EU's remaining at the end of the study (Table 2-1). In 2018, cereal rye and winter wheat were closer to each other in survival, 41.67%, and 75.00% of clipped EU's remained, respectively (Table 2-1). In 2019, percent survival for species were similar. Winter triticale had 25% of clipped EU's remaining and winter wheat and cereal rye had 41.67% and 50% of clipped EU's remaining, respectively. These results indicated wheat and cereal rye provided the best survivability. In 2018 and 2019 all species clipped to 5-cm at 7-d intervals were removed except one winter wheat and one cereal rye EU in 2018. However, in 2018, 3 winter wheat and 1 cereal rye EU clipped to 10-cm at 7-d intervals remained at the conclusion of the study. Therefore, one third of the EU's subject to clipping, remained for the 10-cm 7-d interval in 2018 (Table 2-1). In 2019 the survival decreased, only one fourth of the EU's subject to clipping remained for the 10-cm 7-d interval. Importantly, in 2018 over two and a half times the amount of EU's clipped to 10-cm remained when compared to the EU's clipped to 5-cm. Similarly, in 2019, 6 times the amount of EU's clipped to 10-cm remained compared to the EU's clipped to 5-cm. Importantly, in 2018 we also found 6 of 24 EU's clipped at 7-d intervals and 12 of 24 EU's clipped at 14-d intervals remained at the conclusion of the study (Table 2-1). In 2019, only 3 of 24 EU's clipped at 7-d intervals and 11 of 24 EU's clipped at 14-d intervals remained at the conclusion of the study. These results indicate that a longer clipping interval resulted in greater plant survivability. Additionally, clipping to a higher stubble height (10-cm) has the potential to produce greater survivability.

*Above-ground biomass*

To determine effects of different clipping heights at different frequencies on residual above-ground biomass of cereal rye, winter triticale, winter wheat, and oat plants were clipped to 5- and 10-cm heights at 7- and 14-d intervals. A species x height interaction was detected in 2019 ($P < 0.05$) for the residual above-ground biomass. In 2018, species and height main effects were significant ($P<0.05$). Therefore, data presented are the LS-means for 2018 and 2019 at the species by height interaction level.

Within a species, the non-clipped control for all species produced greater residual above-ground biomass in both years of the study. When compared to the 10- and 5-cm height, in 2018, the non-clipped control had at least 3.9 and 9 times more residual above-ground biomass, respectively (Figure 2-2). Likewise, when compared to the 10- and 5-cm height, in 2019, the non-clipped control had at least 3.8 and 10.7 times more residual above-ground biomass, respectively (Figure 2-3). Significant differences ($P < 0.05$) between the 10- and 5-cm clipping height within species were also detected. Every 10-cm clipping height produced more residual above-ground biomass than the 5-cm clipping height. Notably, in 2018 at the 10-cm clipping height, triticale produced nearly 3.1, oats nearly 2.9, wheat 2.2, and cereal rye 2.1 times more residual above-ground biomass than the 5-cm clipping height (Figure 2-2). Likewise, in 2019 at the 10-cm clipping height cereal rye produced nearly 5.4, triticale 4.7, wheat 4, and oats nearly 2.8 times more residual above-ground biomass than the 5-cm clipping height (Figure 2-3). These results indicate clipping height significantly impacts the litter remaining on the soil surface.

Clipping heights across species were also compared. Winter wheat and cereal rye produced the most biomass for the non-clipped control (Figure 2-2). Triticale produced a similar amount of residual above-ground biomass as both cereal rye and oat, and oat produced the least amount of biomass for the non-clipped control (Figure 2-2). Similarly, in 2019, winter wheat, cereal rye, and triticale produced more biomass than oat (Figure 2-3). In 2018, biomass production followed the 10- and 5-cm clipping heights. In 2018, at the 10-cm level wheat produced more residual above-ground biomass than triticale and oat ($P < 0.05$, Figure 2-2). Cereal rye produced a similar amount of biomass as wheat and triticale but produced significantly more biomass than oat ($P < 0.05$, Figure 2-2). Furthermore, at the 5-cm height wheat produced significantly ($P < 0.05$) more residual above-ground biomass than triticale and oat. Similarly, at the 5-cm height cereal rye produced significantly (P < 0.05) more residual above-ground biomass than oat (Figure 2-2). However, in 2019 no significant species differences were observed at the 5- or 10-cm height (Figure 2-3)**.** These results indicate that winter wheat, cereal rye, and triticale could be more tolerant to defoliation than oat.

*Below-ground biomass*

To determine effects of different clipping heights at different frequencies on root biomass of cereal rye, winter triticale, winter wheat, and oat plants were clipped to 5- and 10-cm heights at 7- and 14-d intervals. A significant species x height interaction was detected both years (P < 0.05) for the root biomass. Therefore, the data presented are the LS-means for each year at the species by height interaction level.

The non-clipped control produced significantly (P < 0.05) more root biomass both years than clipped treatments for cereal rye, winter wheat, oat, and winter triticale (Figure 2-4**;** Figure 2-5). Winter wheat, triticale, and cereal rye produced (P<0.05) more biomass when clipped to a 10-cm stubble height when compared to a 5-cm stubble height in both 2018 and 2019 (Figure 2-4; Figure 2-5). Both years, oat did not produce a significant difference in root biomass among clipping height (Figure 2-4; Figure 2-5). In 2018, cereal rye and triticale produced about twice the root biomass when clipped to 10-cm instead of 5-cm (Figure 2-4). Wheat produced about three times the amount of root biomass when clipped to a 10-cm height instead of a 5-cm height (Figure 2-4). In 2019, wheat and cereal rye produced about double the amount of root biomass when clipped to a 10-cm height instead of a 5-cm height (Figure 2-5). Triticale produced about a third more root biomass when clipped to a 10-cm height instead of a 5-cm height (Figure 2-5). These results indicate that defoliation during early plant establishment reduces root growth. Additionally, moderate defoliation of winter wheat, triticale and cereal rye may produce more root biomass than heavily defoliating those species.

In 2018, wheat produced more root biomass for the non-clipped control than cereal rye and oat (Figure 2-4). Additionally, triticale produced more root biomass than oat (Figure 2-4)**.** Similarly, in 2019, winter wheat, cereal rye and triticale produced significantly greater root biomass for the non-clipped control than oat (Figure 2-5). In 2018 at the 10-cm clipping height, wheat produced almost two times the root biomass than the other species (Figure 2-4). In 2019, the 10-cm clipping height winter wheat and cereal rye produced almost double ($P<0.05$) the amount of root biomass as oat (Figure 2-5). Additionally, triticale produced more root biomasss than oat, but no significant difference was detected (Figure 2-5). However, in 2018 and 2019 at the 5-cm height no significant difference between species existed for root biomass (Figure 2-4; Figure 2-5). These results indicate that winter wheat clipped to a 10-cm stubble height may maximize root production when compared to other species clipped to a 10-cm stubble height, especially oat.

*Production Season*

To determine effects of different clipping heights at different frequencies on biomass production during the simulated grazing season of cereal rye, winter triticale, winter wheat, and oat plants were clipped to 5- and 10-cm heights at 7- and 14-d intervals. In 2018, the main effects of species and interval were significant ($P<0.05$). Therefore, the data presented for 2018 are LS-means for both the species and interval main effects. In 2019, the species by interval interaction was significant ($P<0.05$).

Therefore, the data presented for 2019 are the LS-means at the species by interval interaction level.

In 2018, the plants clipped at 14-d intervals produced almost double the amount of biomass during the simulated growing season as the plants clipped at 7-d intervals (Figure 2-6). In 2018, wheat produced greater biomass during the simulated grazing season than all other species (Figure 2-7). In 2019, cereal rye and triticale produced significantly ($P<0.05$) more biomass during the simulated grazing season when clipped at 14-d intervals than at 7-d intervals (Figure 2-8). However, oat and wheat produced similar amounts of biomass at both clipping intervals (Figure 2-8). At the 7-d interval, wheat produced ($P<0.05$) double the amount of biomass during the growing season than the other species (Figure 2-8). At the 14-d clipping interval winter wheat, winter triticale, and cereal rye produced at least triple ($P<0.05$) the amount of biomass as oat (Figure 2-8). These results indicate that grazing winter wheat, cereal rye, or triticale less frequently can maximize the forage production throughout the simulated grazing season.

*Total Biomass*

To determine effects of different clipping heights at different frequencies on total biomass production of cereal rye, winter triticale, winter wheat, and oat plants were clipped to 5- and 10-cm heights at 7- and 14-d intervals. In 2018, the species main effect and height by interval interaction were found to be significant ($P<0.05$). Therefore, the data presented for 2018 are LS-means for both the species main effect and height by interval interaction. In 2019, the species by height interaction was found to be significant ($P<0.05$). Therefore, the data presented for 2019 are the LS-means at the species by height interaction level.

In 2018, winter wheat produced significantly ($P<0.05$) more total biomass than winter triticale, cereal rye, and oat (Figure 2-9). Additionally, cereal rye and triticale produced significantly ($P<0.05$) more total biomass than oat (Figure 2-9). The non-clipped control for the 7- and 14-d clipping interval produced ($P<0.05$) greater biomass than clipping to a 5- or 10-cm stubble height (Figure 2-10). Additionally, the 10-cm clipping height produced significantly ($P<0.05$) greater total biomass than the 5-cm clipping height for both intervals (Figure 2-10). Interestingly, the plants clipped to 10-cm at 14-d intervals produced over 1.5 times more ($P<0.05$) total biomass than the plants clipped to 10-cm at 7-d intervals (Figure 2-10). In 2019, winter wheat, winter triticale and cereal rye produced significantly ($P<0.05$) more total biomass than oat at the non-clipped level (Figure 2-11). At the 5-cm clipping height no significant ($P<0.05$) differences were found among species (Figure 2-11). However, at the 10-cm clipping height, wheat produced more than oat ($P<0.05$), and cereal rye produced more total biomass than triticale and oat ($P<0.05$) (Figure 2-11). Within species, winter wheat and cereal rye produced at least double ($P<0.05$) the amount of total biomass at the 10-cm clipping height than the 5-cm clipping height (Figure 2-11). These results indicate that defoliation negatively impacts biomass production however, if defoliation must occur, defoliating to a higher stubble height, less frequently can maximize total biomass production during early plant establishment. Additionally, winter wheat and cereal rye appear to produce the most total biomass.

***Field Experiment***

The results from the field experiment support the evidence in the greenhouse study. Cattle presence during early plant establishment negatively impacted winter cover crop survival and above-ground biomass production.

*Biomass*

Decreased triticale stands reduces biomass availability for both forage production and ecosystem services. We evaluated the effect of cattle presence during early triticale establishment on biomass production. Therefore, forage biomass was sampled in the autumn after grazing, and in the spring before cover crop termination. Both years forage biomass increased from autumn to spring as expected (Figure 2-13; Figure 2-14). The first year in autumn, the non-grazed plots had almost 3 times more biomass than the grazed plots (Figure 2-13). In the spring, the non-grazed plots had double the amount of biomass as the grazed plots (Figure 2-13). The second year, cattle presence did not significantly impact biomass production (Figure 2-14) likely because the stover grazing duration was reduced. These results indicate that cattle presence during early plant establishment for a longer duration may have a negative impact on biomass production.

*Frequency of Occurrence*

We evaluated the impact of cattle presence during early triticale establishment in a field setting. Therefore, we collected percent frequency of occurrence in grazed and non-grazed areas after grazing in the autumn and spring. Stands in the Spring of 2019 were reduced by greater than 20% compared to stands in autumn (Figure 2-12). Additionally, in the spring the non-grazed areas had 23% greater stands than grazed areas (Figure 2-12). However, in the second year, corn stover with triticale was grazed for a shorter duration (less intensely), which resulted in no significant differences from autumn to spring or among grazing treatments. Our results indicate that cattle presence for a longer duration during early plant establishment in the autumn may result in reduced winter survival and decreased spring stands.

**Discussion**

The purpose of our greenhouse and field studies were to gain insight on how grazing cool-season annual grasses during early development affects above- and below-ground biomass production. Information from both studies will guide cover crop grazing recommendations for cool-season annual grass species in Eastern Nebraska. These studies suggest that defoliation during early plant establishment (e.g. two weeks after plant emergence) is not recommended due to decreased above- and below-ground biomass production and decreased plant stands. Our study showed defoliation during early establishment had several negative repercussions on plant survival, shoot production, root production, and total biomass production.

Our results suggest that plant senescence in the greenhouse study was caused by cold weather, shortened day length, and additional stress from clipping to a 5- and 10-cm stubble height. Only 37.5% and 29.2% of the EU's subject to clipping survived to the end of the 8-week study in 2018 and 2019, respectively (Table 2-1). In addition, we found moderate defoliation (10-cm stubble height) at a lower frequency (14-d clipping interval) resulted in greater longevity than heavy defoliation both years (Table 2-1). Furthermore, the field study supported our findings in the greenhouse. Cattle presence in autumn of 2018 negatively impacted winter survivability by reducing plant stands in Spring of 2019 (Figure 2-12). However, no significant differences were found in the field study for

Autumn 2019/Spring 2020 likely due to late cover crop planting and reduced duration of cattle presence. The evidence indicates grazing heavily during early emergence may have negative consequences, leading to plant death during winter and reduced spring stands. The observed plant death may be explained by the decrease in rooting depth and shoot production known to occur in winter wheat (Kirkegaard et al. 2015). Decreased root production can lead to decreased water and nutrient intake which can lead to plant death (Gregory 1994). Decreased shoot production can lead to less leaf area, decreasing photosynthetic capacity and plant growth (Joggi, Hofer, and Nosberger 1983). Cover crop survival is important because it allows living plants to be present in the soil. Those living plants can decrease nutrient leaching and reduce erosion.

Above- and below-ground biomass is an indicator of the living plants' productivity. In the greenhouse, we observed a decrease in both root and shoot production of clipped plants when compared to non-clipped control plants (Figure 2-4; Figure 2-5; Figure 2-2; Figure 2-3). Additionally, clipping frequency influenced the shoot biomass production. Generally, clipping at 14-d intervals produced a greater amount of biomass than clipping at 7-d intervals (Figure 2-6; Figure 2-8). The greenhouse findings on above-ground biomass were further supported by the findings in the field study. Cattle presence in the autumn of 2018 decreased the above-ground biomass production of winter triticale in both autumn 2018 and spring 2019 (Figure 2-13). The field and greenhouse studies produced similar findings to existing literature. Grazing canola resulted in decreased biomass production (McCormick *et al.*, 2012). Although a brassica, the study further supports our observed decrease in shoot and root biomass production under clipping to a 5- and 10-cm stubble height. Winter wheat and triticale also had decreased shoot production when exposed to a wide variety of grazing intensities (Mapfumo et al. 2002; Kirkegaard et al. 2015). Importantly, shoot biomass decreases at higher grazing frequencies and intensities in winter wheat (Kirkegaard et al. 2015). These studies support our findings of decreased biomass production during simulated grazing and residual above-ground biomass production when exposed to clipping, especially when clipped to a 5-cm stubble height. The studies also support our finding that more frequent clipping decreased plant biomass. In our study, moderate defoliation to a 10-cm stubble height resulted in greater residual above- and below-ground biomass compared with heavy defoliation to a 5-cm stubble height (Figure 2-2**;** Figure 2-3**;** Figure 2-4**;** Figure 2-5). Additionally, more frequent clipping at 7-d intervals generally resulted in decreased biomass production during the growing season (Figure 2-6; Figure 2-8)**.** Therefore, our findings suggest grazing to a higher stubble height has the potential to provide more total biomass, while not grazing produces the most biomass. Additionally, grazing at lower frequencies can maximize forage production during the grazing season. In addition to reduced above-ground biomass production, we also found that among species, clipping reduced root biomass compared with no clipping (Figure 2-4; Figure 2-5). These results can be explained by an observed decrease in rooting depth of winter wheat that is subject to defoliation (Kirkegaard et al. 2015).

Moderate, less frequent grazing may enhance winter survival, shoot biomass production, and root biomass production compared with heavy grazing. Specifically, moderately (10-cm height) clipping winter wheat, winter triticale, or cereal rye optimized root and shoot biomass production (Figure 2-4; Figure 2-5). Decreased root production when plants were exposed to defoliation can be explained by plant assimilate allocation.

Root assimilates are reallocated to shoot growth to aid in recovery after defoliation (Briske and Richards 1993). This allows shoot production to increase while root production decreases after defoliation. Therefore, defoliation to a higher stubble height less frequently allows for increased root production leading to a plant that can access soil resources and produce more forage.

The decreased root production observed under defoliation can also be explained by the seed germination and early plant development. Seminal roots emerge first from the seed and are the most important for accessing deep soil resources (Watt et al. 2006). Later, nodal roots emerge and develop (Watt et al. 2006). Nodal root growth is restricted to the upper layer of the soil when plants have later emergence (Watt et al. 2006). When grasses are young and actively growing, up to 50% of plant assimilate may be distributed to root growth (Gregory and Atwell 1991; Gregory 2006). When a defoliation event occurs during early plant development, assimilate may be diverted from root growth to aid in shoot regrowth (Briske and Richards 1995). The diversion of plant assimilates from root development to shoot repair might explain why clipping plants to 10- and 5-cm stubble heights reduced root growth.

The effects of grazing intensity on root characteristics have been observed in several perennial grasses, winter wheat grown for grain production, triticale, and canola. Root biomass in smooth bromegrass is greater under medium intensity than heavy grazing intensity (Mapfumo et al. 2002). On the contrary, root biomass in meadow bromegrass decreased under medium and heavy grazing (Mapfumo et al. 2002). Perennial grass root biomass commonly decreased under defoliation (Gao, Giese, and Lin

2008; Matches 1992). These findings support our observations of decreased root biomass production in cool season annuals.

However, when winter wheat and winter triticale are grazed, different impacts on root biomass occur depending on management. Rooting depth of winter wheat decreased when heavy defoliation occurred during early establishment (Kirkegaard et al. 2015). Root length density in grazed areas also decreases (Kirkegaard et al. 2015). These characteristics can lead to decreased root biomass. On the other hand, well established stands of winter wheat subject to defoliation did not exhibit decreased root biomass production (Kirkegaard et al. 2015). Our finding of decreased root biomass when plants are subject to moderate or heavy defoliation during early emergence is supported by these previous findings. Additionally, no differences among grazing intensities on root biomass production in winter triticale were found (Mapfumo et al. 2002). Our research found differences between clipping triticale to a 10- and 5-cm stubble height in 2018 and 2019 (Figure 2-4; Figure 2-5). When triticale was clipped to a 10-cm instead of a 5-cm stubble height, almost double the root biomass was produced. In agreement with our findings, an increase in average root biomass at the moderate defoliation intensity when compared to the heavy grazing intensity of winter triticale can be expected (Mapfumo et al. 2002). These findings support the idea that grazing to a higher stubble height have the potential to produce greater root biomass than grazing to a lower stubble height. Based on our study and previous evidence, grazing during early establishment results in decreased root biomass production, which can lead to decreased survival and shoot production.

Current evidence shows that grazing during early establishment especially at high intensities can have detrimental effects on biomass production and stand survival.

However, grazing well-established plant stands produces adequate biomass and plant survival (Kirkegaard et al. 2015; Mapfumo et al. 2002). Current grazing recommendations for cool-season annuals suggest waiting until 40-60 days after emergence in order to have sufficient biomass production and survivability (Drewnoski and Redfearn 2015). Future research is needed to determine if grazing between 14-40 days following emergence is sufficient without compromising root and shoot growth. The greenhouse study had two limitations. Plants were clipped and not grazed with the study conducted in a greenhouse using sand for the growth medium. Both limitations did not allow us to determine defoliation responses in the field with different soil types and animal grazing activity. The first limitation was addressed by monitoring stand and biomass production of winter triticale in a field setting. The second limitation was not addressed. However, the controlled environment allowed us to evaluate the specific plant responses, including biomass production throughout a simulated grazing season. Additionally, we were able to readily evaluate the root biomass of different clipping heights and frequencies in the top 20-cm of sand. Further research in a field setting to monitor cover crop root response to defoliation is needed.

**Conclusions**

In conclusion, grazing cool-season annual grasses during early establishment is not recommended. Defoliation during early establishment resulted in reduced biomass production and winter survival of cool-season annual grasses. Our results suggest that grazing during early establishment is not the best practice if producing cover crop above- and below-ground biomass is the main objective. Therefore, if a producer wants to graze cornstalks and have a successful cover crop, they will need to wait for the cover crop to be well established before allowing cattle on the field. However, if grazing of the cover crop must occur during early growth, grazing winter wheat, winter triticale, or cereal rye to a higher stubble height, less frequently is the most desirable. Grazing to a higher stubble height, less frequently during early plant establishment has the potential to produce more biomass and result in a better stand than grazing to a lower stubble height more frequently.

**Table 2- 1.** Week the experimental unit (EU) was removed from the study in 2018 and 2019.

Numbers in columns four and five represent number out of 3 replications of treatment combinations (EU’s) remaining at the end of the study for each treatment combination. Numbers in the sixth and seventh columns represent number of EU’s remaining out of twelve EU’s at the conclusion of the study at the indicated clipping height and interval.

| Height | Interval | | Remaining EU's by End of Study | | Total Left in Each Height and Interval | |
|---|---|---|---|---|---|---|
| | | **Species** | *2018* | *2019* | *2018* | *2019* |
| *5-cm* | *7-d* | | | | 2 | 0 |
| | | *Oat* | 0 | 0 | | |
| | | *Winter Wheat* | 1 | 0 | | |
| | | *Winter Triticale* | 0 | 0 | | |
| | | *Rye* | 1 | 0 | | |
| *10-cm* | *7-d* | | | | 4 | 3 |
| | | *Oat* | 0 | 0 | | |
| | | *Winter Wheat* | 3 | 2 | | |
| | | *Winter Triticale* | 0 | 0 | | |
| | | *Rye* | 1 | 1 | | |
| *5-cm* | *14-d* | | | | 3 | 2 |
| | | *Oat* | 0 | 0 | | |
| | | *Winter Wheat* | 2 | 0 | | |
| | | *Winter Triticale* | 0 | 0 | | |
| | | *Rye* | 1 | 2 | | |
| *10-cm* | *14-d* | | | | 9 | 9 |
| | | *Oat* | 2 | 0 | | |
| | | *Winter Wheat* | 3 | 3 | | |
| | | *Winter Triticale* | 2 | 3 | | |
| | | *Rye* | 2 | 3 | | |

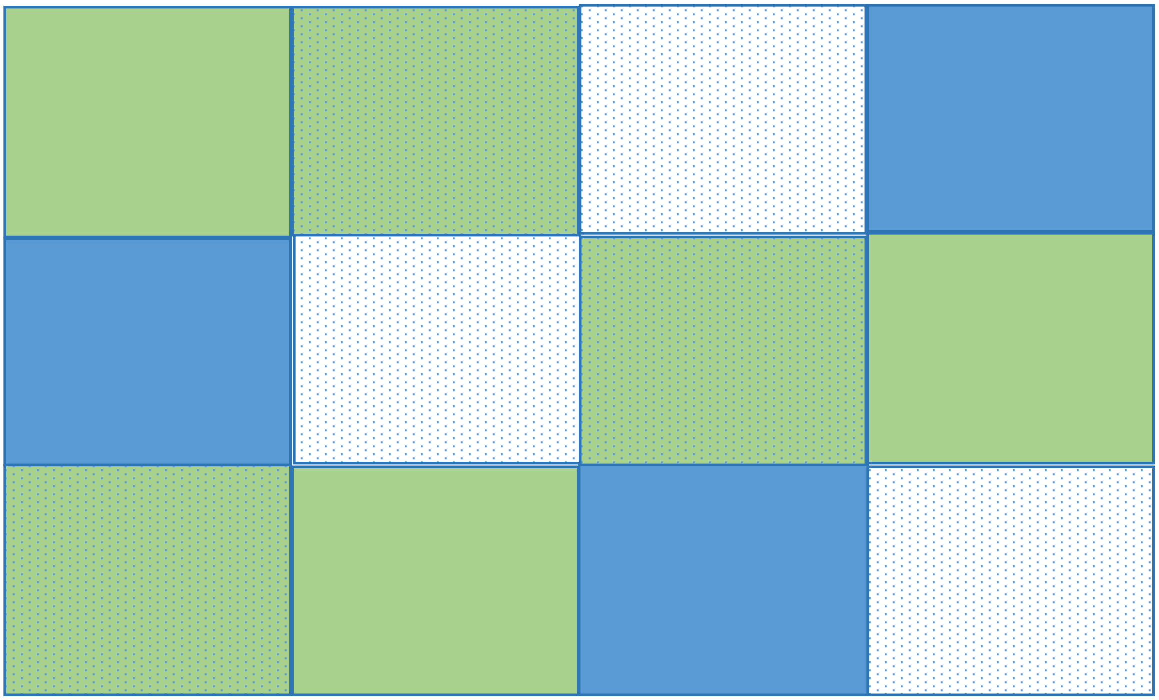

**Figure 2- 1.** Field map of cover crop and grazing treatments.

Field layout for the continuous corn portion of the field-scale model demonstration site. The size of the corn field was 8-ha. Each EU is 0.68-ha. The green represents the grazing paddock. The dots represent where the cover crop was planted. The solid blue represents no grazing or cover crop. There were 3 replications of every treatment combination. The 1.35-hectare paddocks were grazed by 6-steers in the autumn after corn grain harvest.

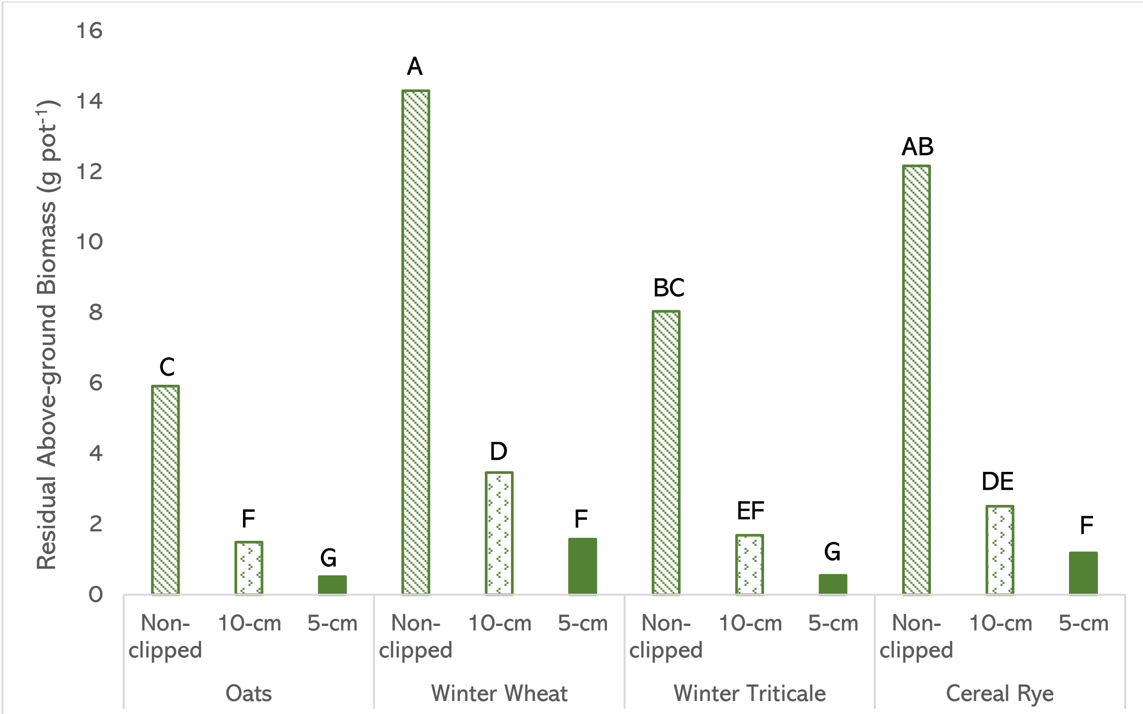


**Figure 2- 2.** Residual above-ground biomass of oats, winter wheat, winter triticale, and cereal rye at each clipping height in 2018.

Plants were clipped to a 5- or 10-cm stubble height at 7- or 14- day intervals. A non-clipped control was included. Treatments with the same letter are not different *($P<0.05$)*.

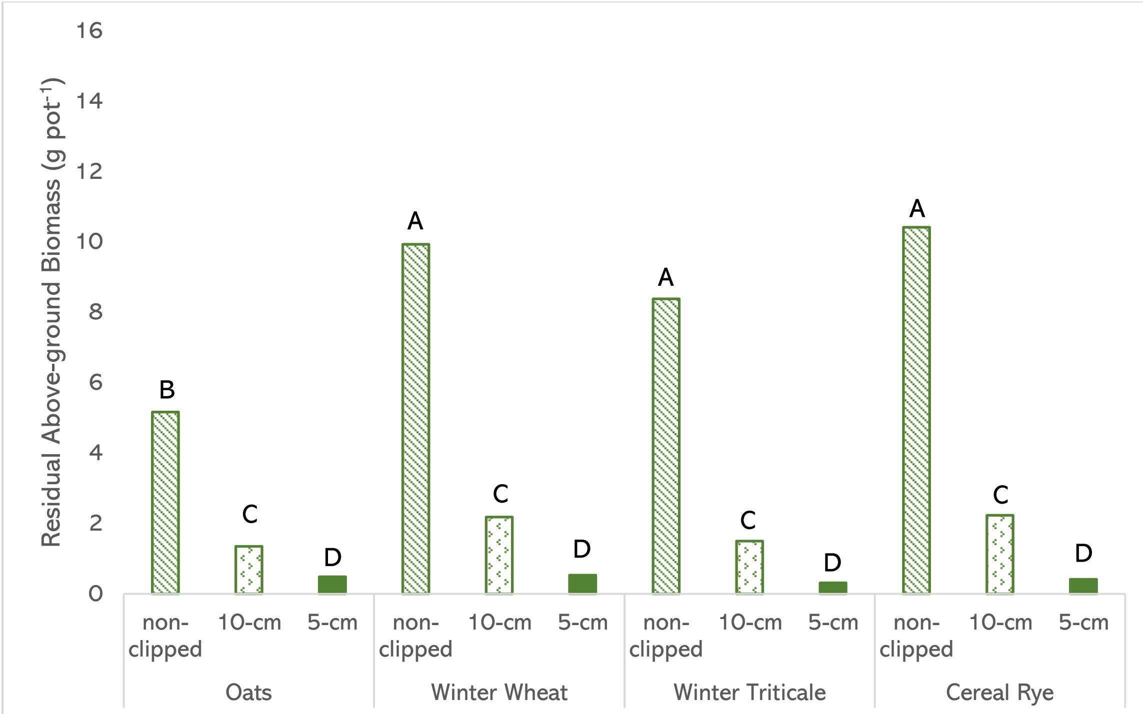


**Figure 2- 3.** Residual above-ground biomass of oats, winter wheat, winter triticale, and cereal rye at each clipping height in 2019.

Plants were clipped to a 5- or 10-cm stubble height at 7- or 14- day intervals. A non-clipped control was included. Treatments with the same letter are not different *(P<0.05)*.

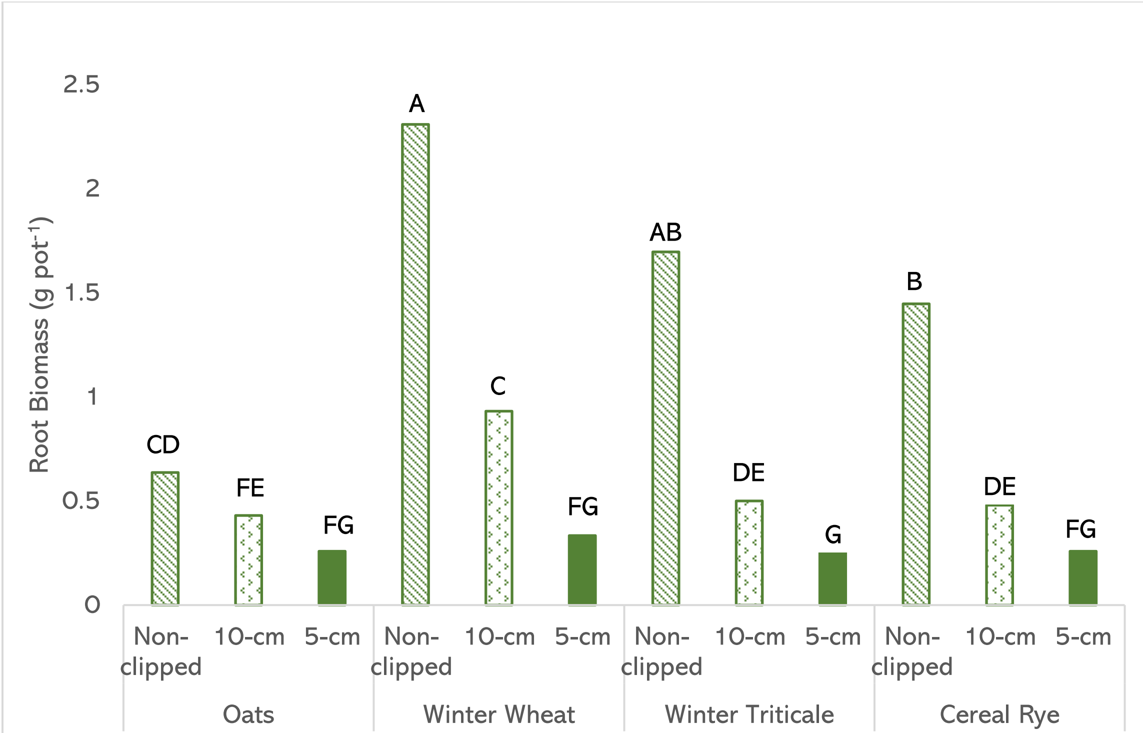


**Figure 2- 4.** Root biomass of oats, winter wheat, winter triticale, and cereal rye at each clipping height in 2018.

Plants were clipped to a 5- or 10-cm stubble height at 7- or 14- day intervals. A non-clipped control was included. Treatments with the same letter are not different *(P<0.05)*.

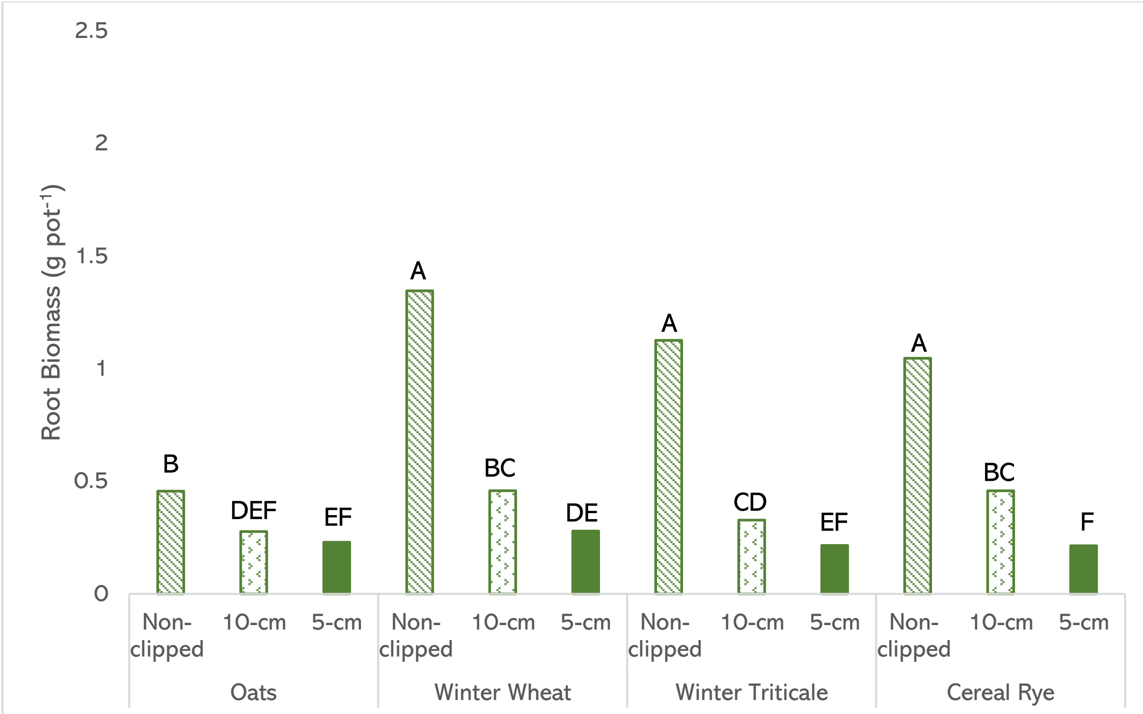


**Figure 2- 5.** Root biomass of oats, winter wheat, winter triticale, and cereal rye at each clipping height in 2019.

Plants were clipped to a 5- or 10-cm stubble height at 7- or 14- day intervals. A non-clipped control was included. Treatments with the same letter are not different *($P<0.05$)*.

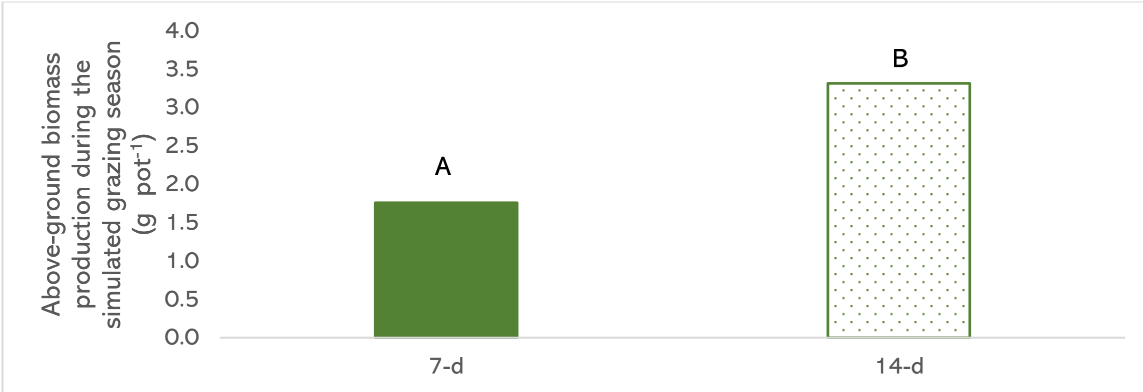


**Figure 2- 6.** Above-ground biomass production during the simulated grazing season averaged across species and clipping height in 2018.

Plants were clipped to a 5- or 10-cm stubble height at 7- or 14- day intervals. The clipped plant matter during the simulated growing season was summed to analyze the difference in forage production among treatments. Treatments with the same letter are not different *($P<0.05$)*.

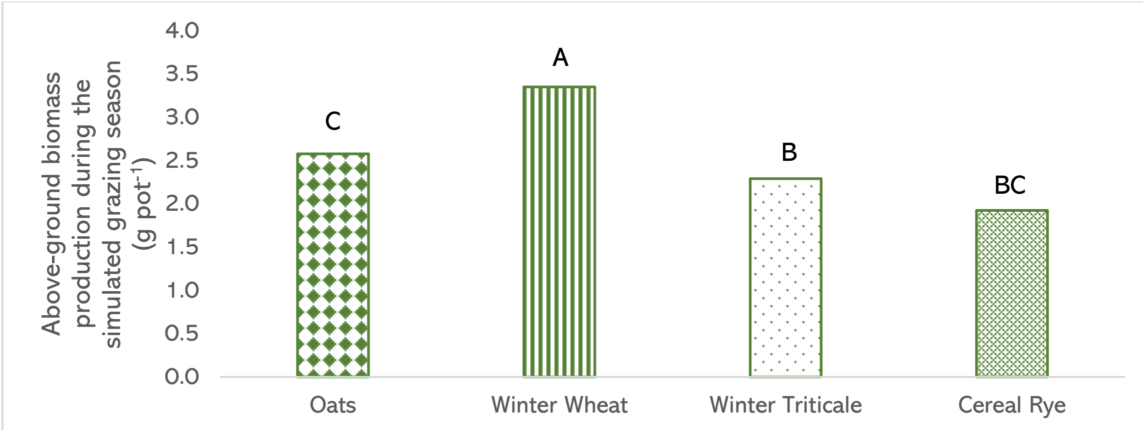


**Figure 2- 7.** Above-ground biomass production during the simulated grazing season of oats, winter wheat, winter triticale, and cereal rye averaged across clipping height and frequency in 2018.

Plants were clipped to a 5- or 10-cm stubble height at 7- or 14- day intervals. The clipped plant matter during the simulated growing season was summed to analyze the difference in forage production among treatments. Treatments with the same letter are not different *($P<0.05$)*.

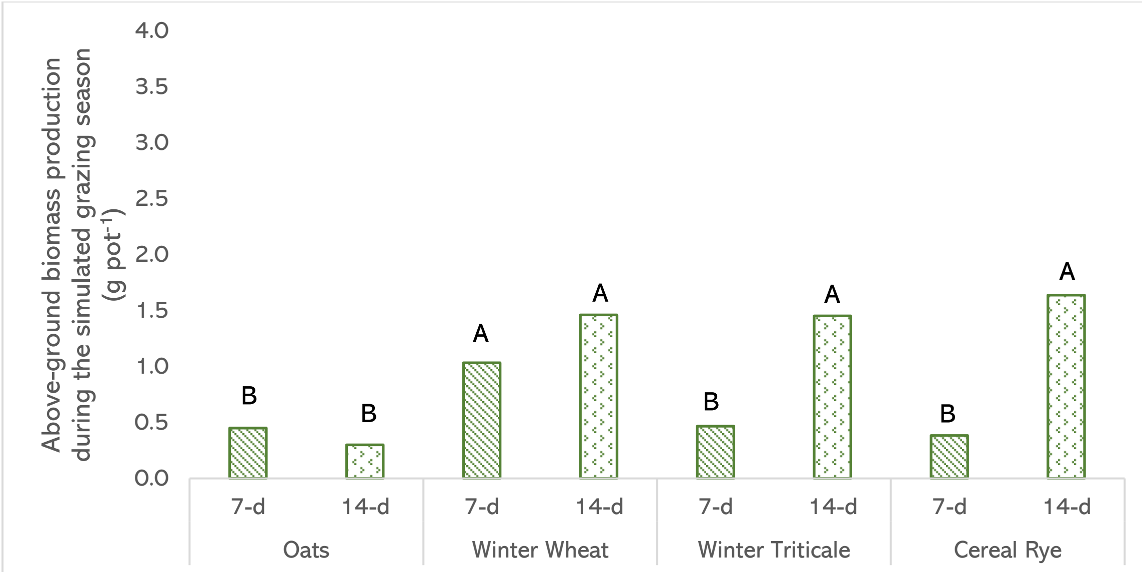


**Figure 2- 8.** Above-ground biomass production during the simulated grazing season of oats, winter wheat, winter triticale, and cereal rye averaged across clipping height in 2019.

Plants were clipped to a 5- or 10-cm stubble height at 7- or 14- day intervals. The clipped plant matter during the simulated growing season was summed to analyze the difference in forage production among treatments. Treatments with the same letter are not different *($P<0.05$)*.

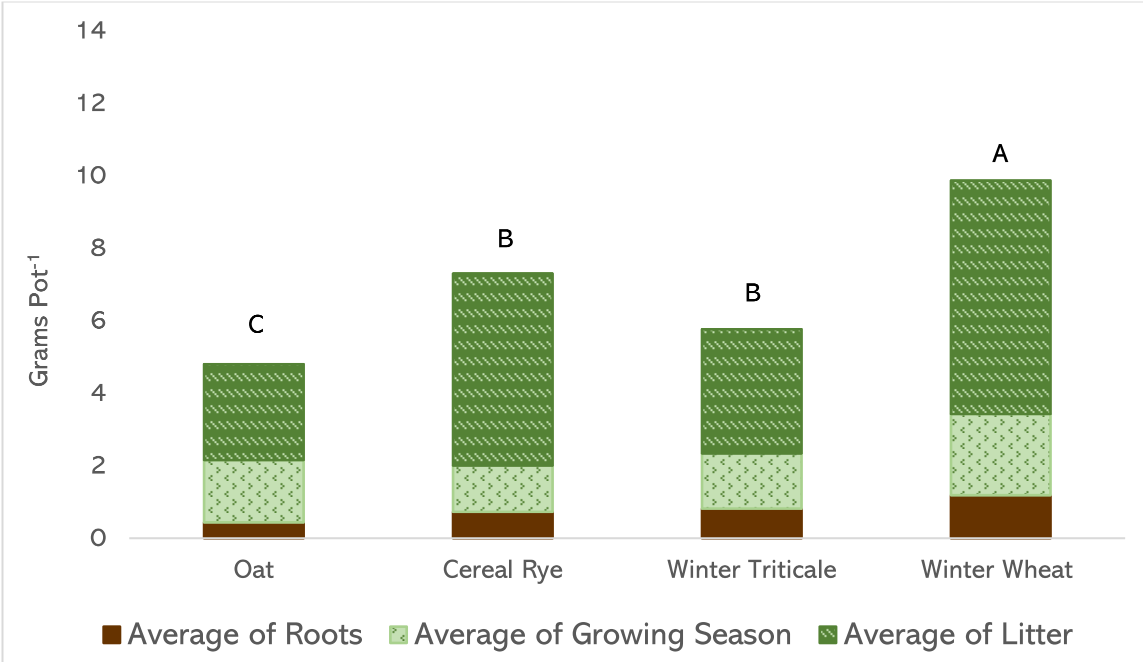


**Figure 2- 9.** Total biomass production of species in 2018.

Bottom brown bar, average dry root mass. Middle light green bar, average forage production during simulated grazing season. Top dark green bar, average residual above-ground biomass at completion of grazing season. A, B, and C denote statistical difference ($P<0.05$) among species.

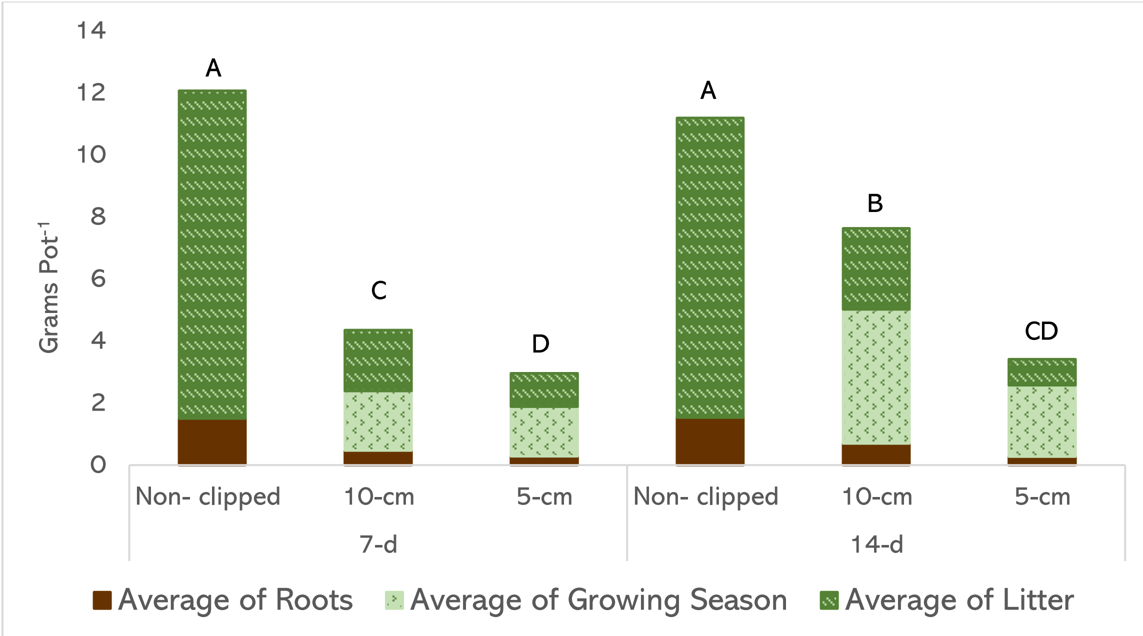


**Figure 2- 10.** Total biomass production at the height by interval interaction level in 2018.

Bottom brown bar, average dry root mass. Middle light green bar, average forage production during simulated grazing season. Top dark green bar, average residual above-ground biomass at completion of grazing season. A, B, C, and D denote statistical difference ($P<0.05$) at the height x interval level.

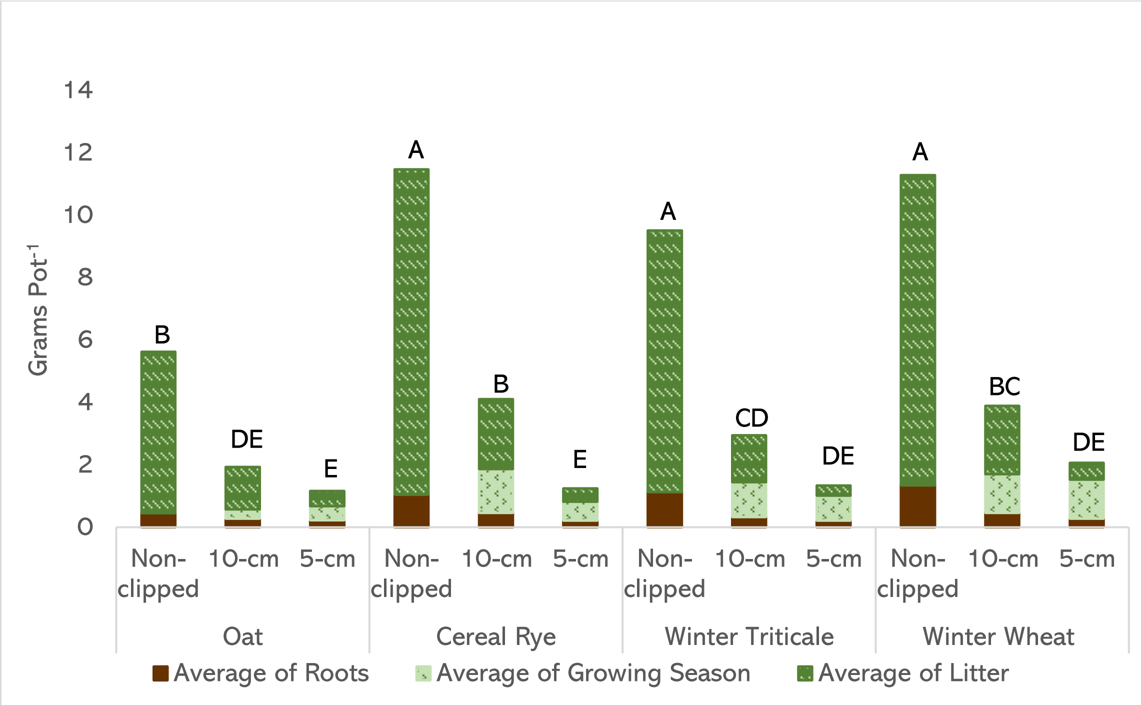


**Figure 2- 11.** Total biomass production at the species by height interaction level in 2019.

Bottom brown bar, average dry root mass. Middle light green bar, average forage production during simulated grazing season. Top dark green bar, average residual above-ground biomass at completion of grazing season. A, B, C, D, and E denote statistical difference (P<0.05) at the species x height level.

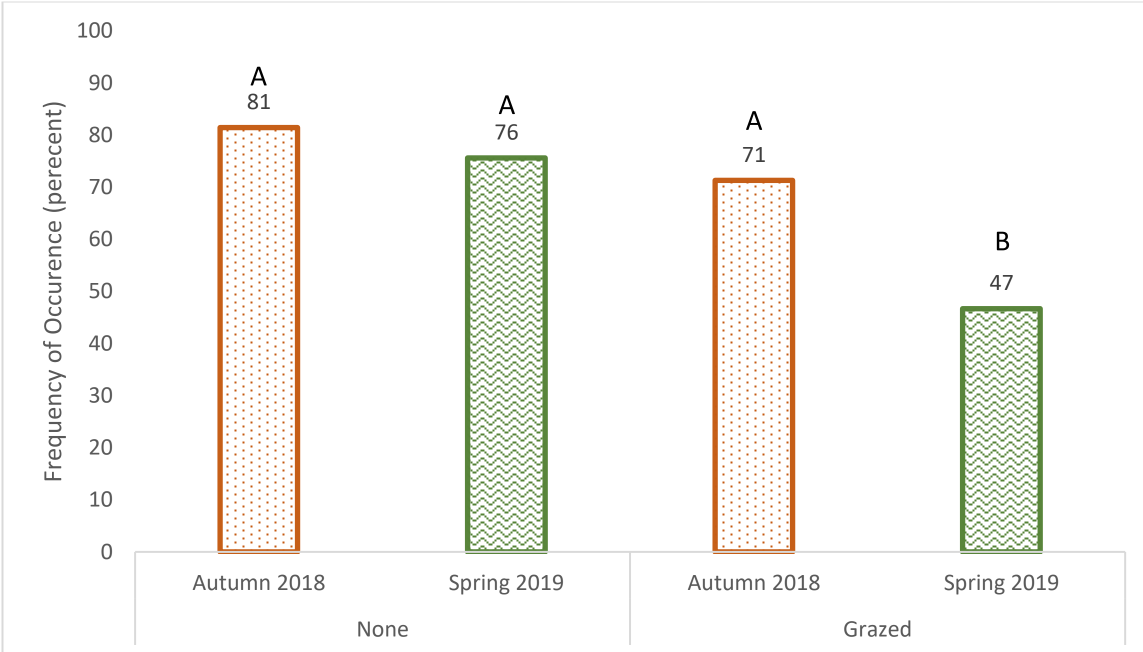


**Figure 2- 12.** Frequency of occurrence for non-grazed and grazed triticale during autumn 2018 and spring 2019.

Corn stover with triticale cover crop was grazed from September 27 to October 12. Biomass was sampled in the autumn on October 11 and in the spring on March 26. Dark orange bar with dots, average frequency of occurrence of triticale for autumn of 2018. Dark green bar with squiggly lines, average frequency of occurrence of triticale for spring of 2019. Different letters, A and B, denote statistical difference ($P<0.05$).

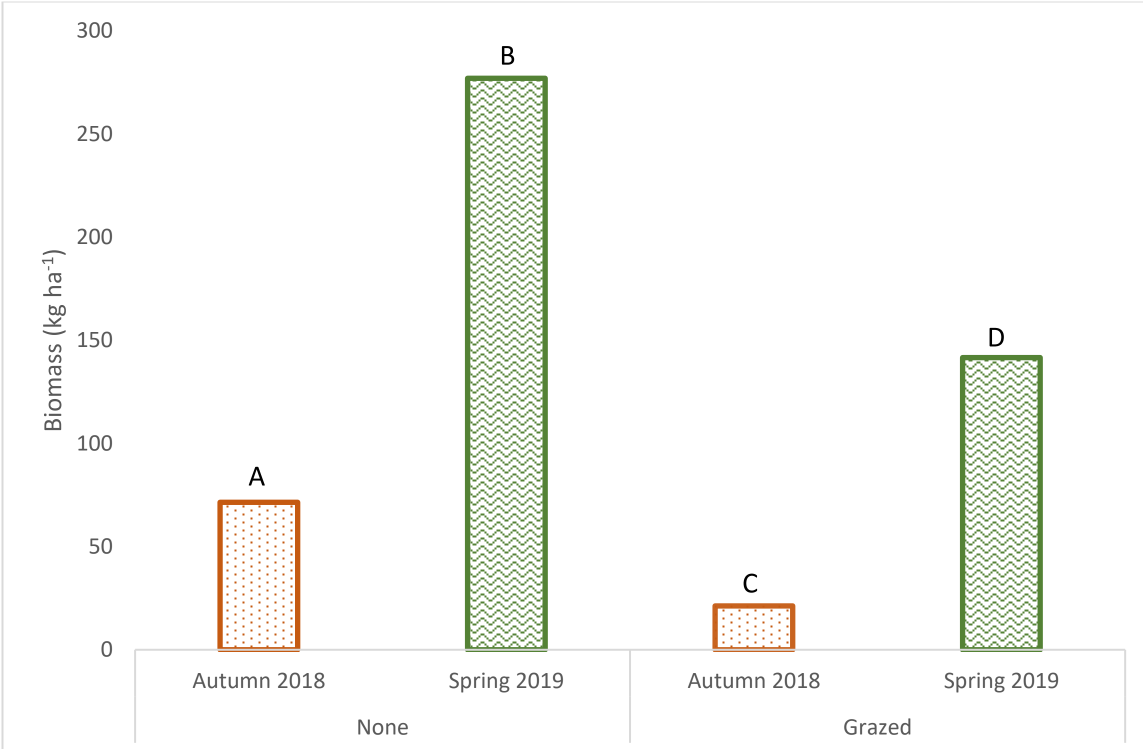


**Figure 2- 13.** Biomass production for non-grazed and grazed triticale during autumn 2018 and spring 2019.

Corn stover with triticale cover crop was grazed from September 27 to October 12. Biomass was sampled in the autumn on October 23 and in the spring on April 23. Dark orange bar with dots, average biomass production of triticale for autumn of 2018. Dark green bar with squiggly lines, biomass production of triticale for spring of 2019. Different letters, A, B, C, D, denote statistical difference ($P<0.05$).

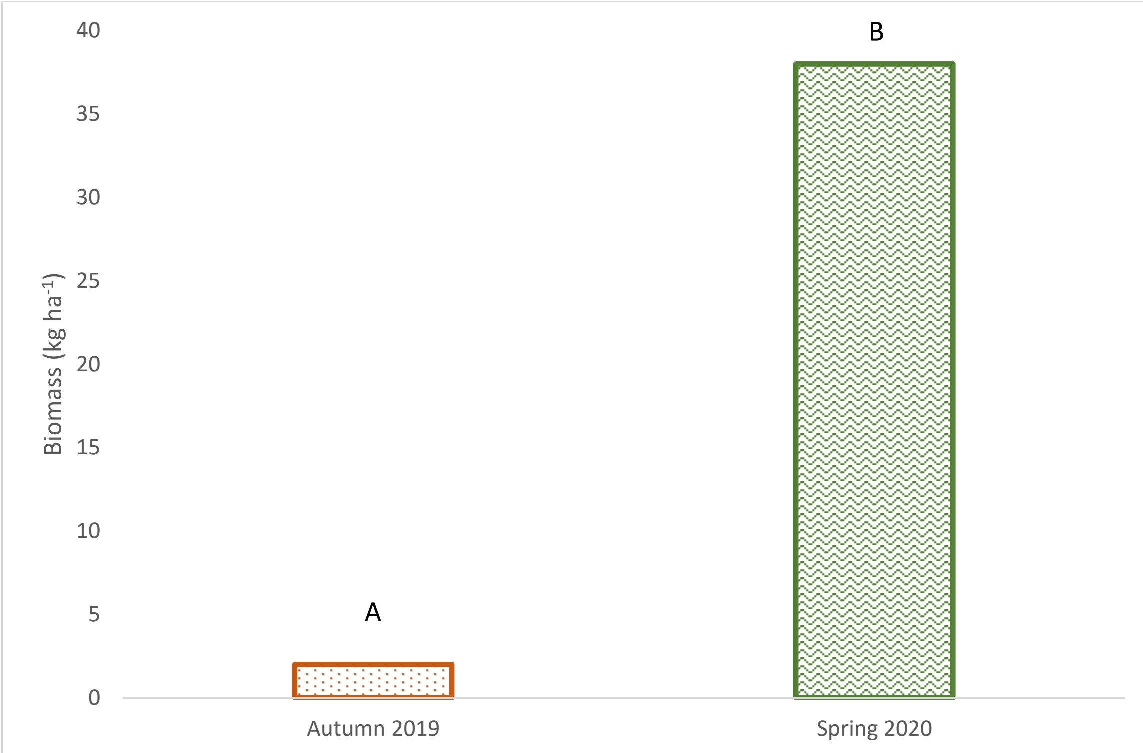


**Figure 2- 14.** Biomass production of triticale during autumn 2019 and spring 2020.

Corn stover with triticale cover crop was grazed from October 23 to October 29. Biomass was sampled in the autumn on November 6 and in the spring on April 22. Dark orange bar with dots, average biomass production of triticale for autumn of 2019. Dark green bar with squiggly lines, biomass production of triticale for spring of 2020. Different letters, A and B, denote statistical difference (P<0.05).

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# CHAPTER 3

# AN ECONOMIC ANALYSIS OF A MODEL INTEGRATED CROP LIVESTOCK SYSTEM IN EASTERN NEBRASKA

## Abstract

Farm diversification in the United States has decreased since the conclusion of WWII. The current specialized agricultural system focused on the production of a few commodities is facing production, economic, and environmental challenges. Amidst these challenges, Integrated Crop Livestock Systems (ICLS) have emerged as a possible solution. One method of integration includes incorporating perennial grasslands. To explore the viability of ICLS in Eastern Nebraska through perennial grasslands, a field-scale model ICLS was established on marginally productive, poorly drained cropland. The ICLS includes 4-ha each of 'Newell' smooth bromegrass (*Bromus inermis* L.), 'Liberty' switchgrass (*Panicum virgatum* L.), and 'Shawnee' switchgrass. The ICLS also includes 8-ha of continuous corn (*Zea mays L.*) production. In 2018 and 2019, 18 yearling steers grazed 4-ha of Newell in spring and autumn. During summer, the herd was equally divided prior to grazing 4-ha of Liberty or 4-ha of Shawnee for 3 months. Both switchgrass varieties were harvested for biomass post-senescence. The 8-ha of continuous corn was grown using best management practices. To determine if the ICLS was more profitable than continuous corn production on marginal land, production data from the study was used to construct enterprise budgets to evaluate system profitability. The ICLS was not consistently more profitable than continuous corn production. However, baling hay only and not grazing the ICLS was consistently more profitable than continuous corn production. Our results indicate ICLS with perennial grass vegetation and continuous corn have the potential to be more profitable than continuous corn on

poorly drained cropland in Eastern NE. Incorporating perennial grass for either grazing or hay production in Eastern NE can increase farm profitability on marginal land while improving the farm's environmental impact.

**Introduction**

Farm diversity has decreased since the conclusion of WWII (Dimitri, Effland, and Conklin 2005; Sulc and Tracy 2007). Modern agriculture has successfully met global food demand, but the success of modern highly specialized systems came at a cost. These intensive, highly specialized systems typically focus on the production of a few commodities and can cause soil erosion, nutrient loss, decreased soil organic carbon (SOC), pest resistance, water pollution, and greenhouse gas (GHG) emissions (Sulc and Tracy 2007). Amidst the highly specialized agricultural systems, Integrated Crop Livestock Systems (ICLS) have emerged to mitigate these negative effects. Integrating livestock back onto the land can increase economic and environmental resiliency through diversification (Parthasarathy and Ndjeunga 2005; Devendra and Thomas 2002; Tracy and Zhang 2008). An ICLS can exist in many forms. Farm level integration can include livestock grazing annual cover crops, annual crop residues, or perennial grasses (Sulc and Tracy 2007; Russelle, Entz, and Franzluebbers 2007). By incorporating livestock back on to the land, proper ecosystem function can be restored by increasing nutrient cycling, microbial activity, and soil organic matter content (Tracy & Zhang 2008). One way to mitigate the negative environmental implications caused by modern row-crop production practices is to plant perennial grasses (Asbjornsen et al. 2014).

Ecosystem services provided by perennial vegetation are well known on a landscape scale (Asbjornsen et al. 2014). Perennial vegetation increases soil organic carbon (Nocentini and Monti 2019; Entz et al. 2002; Liebig et al. 2008; Sanderson 2008), decreases nitrogen leaching (Davis et al. 2012; Entz et al. 2002), improves soil quality (Maughan et al. 2009; Tracy and Zhang 2008), and has the potential to decrease GHG emissions (Jin et al. 2019; Davis et al. 2012). The Conservation Reserve Program (CRP) encourages producers to plant marginally productive cropland to perennial vegetation through payments for land planted to perennial vegetation. When grain prices increased in the mid-2000's, land planted to perennial vegetation was returned to row-crop production (Wright and Wimberly 2013; Clay et al. 2014). Increased input costs and depressed grain prices have made planting row-crops on marginally productive land less lucrative. One way to stabilize farm net return is by diversifying enterprises. Converting marginally productive land back to perennial grassland provides an opportunity to integrate grazing animals back into the production system, potentially increasing the economic and environmental resiliency of the farm. However, establishing perennial vegetation can be costly (Biermacher et al. 2017; Jacobs et al. 2016; Mitchell et al. 2005).

Fortunately, incorporating perennial vegetation into the landscape can be profitable. In central Iowa, diverse crop rotations with perennial legumes are more profitable than traditional corn (*Zea mays* L.) -soybean (*Glycine max* L.) rotations (Liebman et al. 2008). Perennial grass pastures throughout the United States have also demonstrated the potential to be profitable. Big bluestem (*Andropogon gerardii* L.) is a common warm-season grass that has been studied for profitability. In Mississippi, grazing big bluestem is profitable because of the low annual pasture cost and high net return when compared to other commonly used forages (Rushing et al. 2019). In Nebraska, planting big bluestem and grazing it with yearling steers can be more profitable than planting dryland corn (Mitchell et al. 2005). The potential profitability of switchgrass (*Panicum virgatum* L.) has also been studied. Risk averse producers in Tennessee who are profit maximizing would select switchgrass for grazing (Boyer et al.

2019). In Oklahoma, lightly and moderately grazing switchgrass with cattle is profitable but heavily grazing switchgrass is not (Biermacher et al. 2017). The same study looked at switchgrass as a dual-purpose crop, for both grazing and biomass production. Researchers found that lightly grazing (2.2 steers $ha^{-1}$) switchgrass and harvesting residual growth for biomass was the most profitable switchgrass system (Biermacher et al. 2017). If managed properly, switchgrass can provide livestock feed via grazing and residual biomass production in the same growing season, profitably. Non-irrigated, marginally productive cropland in Eastern Nebraska provides the potential to plant perennial grasses for grazing to increase farm net return. The profitability of perennial grass grazing ICLS compared to continuous corn on marginally productive dryland in the Western Corn Belt is not known.

Therefore, we sought to determine if a field-scale ICLS model demonstration site in Eastern NE could be profitable. The field-scale ICLS site includes 4-ha each of 'Newell' smooth bromegrass, 'Liberty' switchgrass, and 'Shawnee' switchgrass. In addition, the site includes 8-ha of continuous corn production. The first objective of the study was to determine if grazing perennial grasslands, harvesting residual biomass, and raising continuous corn on marginally productive land increased profitability when compared to continuous corn production. To determine potential profitability of the ICLS in Eastern NE, animal weight gain and corn yields from the field-scale site were used with market data to build enterprise budgets. Enterprise budgets were used to calculate system profitability for 2018 and 2019.

The second objective of the study was to evaluate the sensitivity of the ICLS to variation in market prices. A sensitivity analysis was conducted to evaluate the stability of the profit potential of the grazing enterprise using data from the site in combination with cattle market data for Nebraska from 2009-2019.

The third objective was to evaluate potential alternative perennial grass ICLS for the region. To evaluate alternative perennial grass systems for the region, the potential profitability of two scenarios was assessed: 1) Renting pasture on the gain and 2) Only harvesting hay. The two alternative systems were compared with the profitability of the ICLS and continuous corn.

## Materials & Methods

### *Field-scale Model Demonstration Site*

The site was located at the Eastern Nebraska Research and Extension Center located near Ithaca, Nebraska. The site was established on 20-ha of non-irrigated, marginally productive cropland in 2015. For this study, marginally productive cropland is defined as poorly drained soil. Approximately 40% of the land at the site is classified as somewhat poorly drained (Table 3-1)**.** The soils on the site are approximately 13.5% Fillmore silt loam, 19.7% Yutan silty clay loam, 40.3% Tomek silt loam, and 26.5% Filbert silt loam (Table 3-1)**.** Non-irrigated, marginally productive cropland provides an opportunity to increase farm profitability and environmental sustainability by diversifying land use through integration of perennial vegetation (Mitchell et al. 2016). In order to diversify land use at the site, 12-ha were planted to perennial grass and 8-ha were kept in continuous corn production. Of the 12-ha planted to perennial grass, 4-ha each were planted to 'Newell' smooth bromegrass (*Bromus inermis* L.), 'Liberty' switchgrass (*Panicum virgatum* L.), and 'Shawnee' switchgrass. Newell was planted because of the cultivar's increased digestibility when compared to other smooth bromegrass varieties. The increased digestibility leads to higher cattle average daily gains than its' predecessor 'Lincoln' smooth bromegrass (Vogel, Mitchell, Waldron, et al. 2014). Liberty was planted because it is a lowland ecotype developed for use as a cellulosic bioenergy crop (Vogel, Mitchell, Casler, et al. 2014). Shawnee was planted because it is an upland ecotype that was developed to have improved forage quality, leading to greater potential animal gains (Vogel et al. 1996). Including the two varieties of switchgrass allows for comparison of animal gain and biomass production potential of the varieties. Additionally, including a grazing variety and biomass producing variety of switchgrass offers management flexibility. In 2018 and 2019 the site received 86.9 cm and 84.5 cm of rainfall, respectively, within 2% of the 30-yr average (Figure 3-1).

***Perennial Grass Management***

The Newell and Liberty pastures were established in 2015. Shawnee was established in 2006. All perennial grass pastures were harvested for hay in 2016 to allow for adequate plant establishment before grazing. In 2017, Newell was grazed in the spring by 18-hd of crossbred yearling steers (341.6 kg $hd^{-1}$). The herd was moved to flash graze the Liberty for 7-d to determine the impact of brief grazing on biomass yield. No animal weight gain data was collected from the flash grazing event. Following the flash grazing event, the 18-hd of steers (367 kg $hd^{-1}$) grazed the Shawnee until September 1. Finally, the steers were moved back to Newell to graze the re-growth for one month. No data is presented for 2016 or 2017 since management was different. In 2018 and 2019, 18-hd of crossbred yearling steers (393.7 kg $hd^{-1}$; 288.9 kg $hd^{-1}$, respectively) grazed the Newell pasture from May-June. After grazing Newell, the herd was divided and 9-hd (416.0 kg $hd^{-1}$; 339.3 kg $hd^{-1}$, respectively) grazed the Liberty for 79 days and the other 9-hd (413.0

kg $hd^{-1}$; 339.7 kg $hd^{-1}$, respectively) grazed the Shawnee for 79 days. At the conclusion of grazing the Shawnee and Liberty pastures, the herd was recombined and the 18-hd (456.8 kg $hd^{-1}$; 362.4 kg $hd^{-1}$, respectively) returned to graze the regrowth of the Newell pasture. Figure 3-3 lists the specific dates of each grazing event. The same grazing sequence was followed in 2018 and 2019 in order to have two years of identical management for the economic analysis (Figure 3-4). Cattle weight gain data was collected after each grazing event to determine cattle average daily gain on each forage resource. The limit feeding protocol outlined by Watson et al. was used to determine animal weight gain (Watson et al. 2013). Cattle weight gain data was used to construct the grazing enterprise budget.

***Row- Crop Management***

In 2018 and 2019 the corn (*Zea mays* L.) was planted at 65,236 seeds $ha^{-1}$. The field was fertilized with 140 kg of nitrogen (N) per hectare applied as urea (46-0-0). Pre- and post- emergent herbicide was applied in 2018 and 2019. In 2018, pre-emergent herbicide was applied on April 17 (Table 3-2). Then, 2.63 L $ha^{-1}$ of Roundup Powermax was applied on May 24 followed by 2.34 L $ha^{-1}$ of Roundup Powermax and 0.18 L $ha^{-1}$ of Callisto on June 13 (Table 3-2). In 2019, pre-emergent herbicide was applied on April 17 followed by one post-emergent application of herbicide on June 17 (Table 3-2). Corn yields were measured using a John Deere 3620 Greenstar yield monitor and were extracted with GIS software. The corn yields were used to construct the continuous corn budget.

***Evaluating ICLS System Profitability***

Three 20-ha ICLS were compared to 20-ha of continuous corn in 2018 and 2019. The ICLS were compared to continuous corn production because corn is the primary cash crop in Eastern NE. The three ICLS were based off the actual management and data collected from the field-scale site. The difference between the three ICLS was the number of hectares assigned to each switchgrass variety. Each system, ICLS and continuous corn, were based on 20-ha of land, the size of the field-scale model demonstration site.

Each ICLS consisted of 12-ha of grazing, 8-ha of residual hay production, and 8-ha of continuous corn. The 8-ha of hay production was the residual biomass harvested in November after livestock grazed the Liberty and Shawnee pastures. The diversified ICLS reflects the profitability of the actual field-scale model demonstration site in Eastern Nebraska. The diversified ICLS consists of 4-ha of Newell for grazing, 4-ha each of Liberty and Shawnee for grazing and residual hay production, and 8-ha of continuous corn. In order to evaluate the potential profitability of each of the switchgrass varieties, two systems were evaluated using data from the field-scale model demonstration site. The Newell-Liberty-Newell ICLS (Liberty ICLS) consisted of 8-ha of Liberty pasture and 4-ha of Newell pasture for the grazing enterprise. The Newell-Shawnee-Newell ICLS (Shawnee ICLS) consisted of 8-ha of Shawnee pasture and 4-ha of Newell pasture for the grazing enterprise. In the study, 8-ha of each switchgrass variety was not grazed or hayed, only 4-ha of each variety was grazed and hayed. Therefore, the data collected from the site was doubled to calculate the production data for the 8-ha of Liberty and Shawnee. In order to assess the profitability of the ICLS and continuous corn, enterprise budgets were developed for each system using production data from the field-scale model demonstration site.

*Enterprise Budgets*

General Assumptions

The land value for all enterprise budgets was \$7660.26 $ha^{-1}$. This was the average value of rainfed cropland in the state of Nebraska for 2019. To calculate opportunity cost, a rate of 3% was used. To calculate real estate tax, a tax rate of 1.35% was applied to the land value. These assumptions were supplied by the 2019 UNL crop budgets. The returns reported for all enterprises do not include land opportunity cost because no enterprise was profitable when the full rate of land opportunity cost was applied.

Pasture Establishment Budget

In order to calculate the cost of establishing pasture, multiple sources were used. To determine the seeding rate, cost of seed, planting, pre-herbicide, post-herbicide, spraying and interest the ISU Ag Decision Maker Converting Cropland to Switchgrass was used (Jacobs, Mitchell, and Hart 2016). The value of real estate taxes was used for the cost of land and was determined from the 2019 UNL Crop budgets using the Nebraska dryland state average of \$7660.26 $ha^{-1}$ at a rate of 1.35%. The cost of water development for cattle was taken from Mitchell *et al.* (2005). The fencing cost was calculated using the 2018 UNL Custom Rate Survey state average per kilometer of fence, \$5,676.86 $km^{-1}$. The cost is based on fencing 32-ha of pasture (Mitchell et al. 2005). The assumed life of the pasture was 30 years and an interest rate of 5.5% was used to calculate the yearly establishment cost. The yearly amortized establishment cost per hectare was calculated by the following equation: total cost of establishment*(0.055/((1+0.055)^-30)). (Supplementary Information D)

Steer Grazing Budget

The steer grazing enterprise budget included the cost of purchasing the cattle, interest for purchasing the cattle, labor, veterinary services, mineral, transportation, and marketing for the cattle. In addition, the amortized cost of pasture establishment, pasture fertilization, interest on operating capital, and real estate tax on the land were included. The average purchase weight was calculated as the average weight of the 9 steers at the beginning of grazing in May. The price per kg was calculated using the market price in Nebraska for the weight class of steers on the date nearest the beginning of grazing. The number of cattle and hectares grazed listed in the budget reflect the actual management of the field-scale model demonstration site. The labor, vet, and marketing costs were calculated using the average producer reported cost from 2008-2018 in Nebraska, South Dakota, & North Dakota reported through the University of Minnesota FINBIN. The cost of mineral was calculated using the feeding rate at the site of 2 oz $hd^{-1}$ $d^{-1}$. The transportation was calculated using the distance from the Eastern Nebraska Research and Extension Center to the Wahoo Livestock Sale Barn (16.9-km) at a rate of \$2.49 $km^{-1}$ reported through the UNL 2018 Custom Rate Survey for hauling cattle with a gooseneck trailer. The establishment cost allocated is explained in the pasture establishment cost budget. The cost of fertilizer, spreading fertilizer, and interest rate were calculated using the information in the ISU Ag Decision Maker tool Converting Cropland to Switchgrass (Jacobs, Mitchell, and Hart 2016). The average selling weight was calculated as the average weight of the 9 steers at the conclusion of grazing in September. The price per kg was calculated using the market price in Nebraska for the weight class of steers on the date nearest the conclusion of grazing. (Supplementary Information F and G)

Continuous Corn Budget

The continuous corn budget was constructed based on the management of the field-scale model demonstration site using the UNL Crop Budgets. Budget number 21-Corn from 2019 was used as the base template. From there, the field operations were changed to reflect the actual management of the system. The average yield from the 8-ha system, including wet and non-harvested areas of the field, was entered into the budget to help calculate yield-dependent costs. The seeding and fertilizer rates were adjusted to 65,236 seeds $ha^{-1}$ and 140 kg $ha^{-1}$ of nitrogen applied as urea (46-0-0). The herbicide products and rates were adjusted to reflect the management for each year (Table 3-2). The average price of corn in Nebraska for the harvested month was used. Revenue from renting cornstalks for grazing was also added because corn residue grazing is a common practice in Nebraska (Schmer et al. 2017; Redfearn et al. 2019). (Supplementary Information A)

Continuous Corn ICLS Budget

The only thing changed for the ICLS continuous corn enterprise budget was the ownership cost of machinery. The costs associated with machinery ownership in the ICLS budget were increased because the corn machinery was spread over 60% fewer hectares. This is because the ICLS only has 8-ha of continuous corn production instead of 20-ha. Therefore, the cost of machinery ownership per hectare increased by 2.5 times. (Supplementary Information B)

Hay Budget

The purpose of the hay enterprise budget was to determine if harvesting residual hay would increase net return to the pasture. The hay enterprise budget does not include any land opportunity cost, land tax, or pasture establishment cost. The entire land tax and establishment cost for the pasture is charged to the steer grazing enterprise. This is because the grazing enterprise was the primary enterprise we were interested in evaluating. The harvesting of residual biomass was considered a bonus. The hay budget was developed using the UNL Crop Budgets. Crop Budget 48-Grass hay for 2019 was used (Supplementary Information H). The field operations were adjusted to reflect actual management of the field-scale model demonstration system. The yield in the budget was also adjusted to reflect the amount of residual hay harvested each year from the pasture in November. The price of hay was calculated using USDA NASS market data. The hay price was the average price for large, fair quality round bales in Nebraska during November and December. Revenue was calculated by yield times price (Supplementary Information J). Not every farmer considering adopting an ICLS model has hay equipment. Additionally, farmers considering adopting an ICLS may want to modify their ownership of corn production equipment to increase profitability.

### Own Machinery or Custom Farm?

In order to evaluate if owning hay and row-crop machinery was more profitable than custom farming hay and corn, custom farm budgets were built for hay and corn enterprises. For the custom corn budget, spraying herbicide, spreading fertilizer, planting, and harvesting services were calculated using the average custom rate for Eastern Nebraska listed on the UNL 2018 custom rate survey. The cost of seed, herbicide, and fertilizer for corn production was used from the 2019 UNL crop budgets, specifically, budget number 21-no till continuous dryland corn. The UNL crop budget was also used to determine the interest rate, real estate opportunity cost, and real estate taxes. The fertilizer rate, planting rate, yield, corn price, and cornstalk rental price remained the same as the continuous corn budget where machinery ownership was assumed.

(Supplementary Information C) For the custom hay budget, the cost of mowing, raking, baling, and moving the bales were calculated using the Nebraska state average custom rate from the UNL 2018 custom rate survey (Supplementary Information I). The yield and hay prices remained the same as the hay budget where machinery ownership was assumed.

### ***Assessing the Potential of Other Management Scenarios for the Site***

#### *Rent on the Gain*

Another option to integrate livestock on the land instead of owning cattle is to charge cattle owners rent on the gain for perennial pasture. Therefore, to evaluate the profitability of the grazing system without ownership of the cattle, the rent on the gain scenario was used. The cost of pasture establishment, land tax, fertilizer, and interest remained constant from the enterprise budgets. To calculate revenue, the amount of cattle gain per hectare was needed and a value per kilogram of gain was needed. The gain per hectare was calculated using the ICLS experimental data from 2018 and 2019. The rental rate per kg of gain was determined by using 50% of the value of gain (Childs 2018).

The value of gain was calculated as: (ending - beginning value of the cattle) / (ending - beginning weight).

Revenue per hectare was calculated as: the rental rate per kg of gain * the total kg of gain per hectare of the system.

Net profit was calculated by revenue – total cost.

This scenario included the net profit from the ICLS corn budget to reflect 8-ha in continuous corn production and 12-ha in pasture. (Supplementary Information L)

*Hay Harvest Only Scenario*

A producer may want to incorporate perennial grasses to harvest for hay instead of grazing the pasture. The cost of establishment for this scenario was less than the ICLS hay budget because the cost of fencing and water is not included since no grazing occurred. In this scenario, all 4-ha pastures were harvested for hay once annually. Since the hay in the ICLS was harvested after grazing, the yields used to calculate the revenue for the hay only scenario were the averages from the variety's registration papers. For Liberty an average yield of 18,100 kg $ha^{-1}$ was used (Vogel, Mitchell, Casler, et al. 2014). For Shawnee an average yield of 14,027 kg $ha^{-1}$ was used (Hopkins et al. 1995). For Newell an average yield of 7820 kg $ha^{-1}$ was used (Vogel et al. 2015). The price for Liberty and Shawnee hay was based on the average price in Nebraska in November and December of 2018 or 2019 for fair quality large round bales. The price for Newell was based on the average price for good quality grass hay large round bales in Nebraska during November and December of 2018 or 2019. Smooth bromegrass has better forage quality than switchgrass, therefore, the price for good hay instead of fair was used. The price data for each classification was generated through a custom report from the USDA NASS database. Ownership of the machinery needed to make hay was assumed because owning hay making equipment is more favorable than having hay custom made. The cost of producing hay was calculated using the same crop UNL budgets as the ICLS hay enterprise. However, the hay harvest only scenario was more expensive on a per hectare basis because of the increased hay yields due to the absence of grazing, requiring more materials and hours of equipment use. This scenario included the net profit from the

ICLS corn budget to reflect 8-ha of continuous corn and 12-ha of hay production. (Supplementary Information M)

### ***Sensitivity Analysis***

#### *Grazing Enterprise*

Since cattle markets are subject to fluctuation, we assessed how sensitive the profitability of the grazing enterprise was to the purchase and sale price of the steers. The four groups of cattle evaluated reflected each group of cattle that grazed either Liberty or Shawnee in 2018 or 2019. Both 2018 and 2019 scenarios were used because of the large difference in body weight at grazing initiation. Using the four scenarios allowed us to evaluate if either weight class at grazing initiation produced superior profitability. The start and end weight of the cattle were held constant for each price scenario. Scenarios were simulated by using the average steer feeder price in Nebraska closest to the date of grazing initiation and cessation of the study in 2018 and 2019. 11 years of price data produced 44 scenarios. The steer price data used was from 2009-2019. We first calculated the change in the value of the calf [(sale weight*sale price) - (purchase weight*purchase price)]. The profitability on a per head basis was then calculated by subtracting the cost per head from the increased value of the calf. In order to evaluate what price the cattle would need to be sold at to produce a profit, breakeven prices per head were calculated using the formula: (cost of purchasing steer + cost of producing steer)/weight of the steer. The break-even price per unit of weight was then compared to the price per unit of weight at sale. Breakeven costs can help a producer decide whether or not they should buy cattle, and if they do, what sale price they should insure with livestock risk protection to mitigate downward movement in market prices to maximize the probability of being profitable.

*Bale Hay only Enterprise*

Because hay yields and prices fluctuate, a sensitivity analysis was conducted for profitability of hay production subject to fluctuating yields and market prices. We wanted to identify the lowest price and yield a producer could receive while still being more profitable than continuous corn production. In order to conduct the sensitivity analysis for each perennial grass variety we used a combination of 10 different prices and 11 different yields. The 10 different prices were calculated by taking the base hay price from the original scenario and either increasing (4 prices) or decreasing (5 prices) the price by 5% increments. The change in yield was calculated by taking the base yield from the variety registration papers and either increasing (3 times) or decreasing (7 times) the yield by 5% increments. The cost of production changed as hay yield changed due to the change in variable costs. Variable costs per hectare rise or fall as yields increase or decrease, respectively. Costs were calculated using the same budget template found in Supplementary Information H. The sensitivity analysis allowed us to determine at what yield and price each pasture would stop being more profitable than continuous corn. Knowing the yield and price where there is less profit than continuous corn production can help a producer understand the risk they are taking on by planting perennial grassland for hay production. This sensitivity analysis allows producers to decide if planting a perennial grassland for hay production is a good decision or not.

## Results

### *System Profitability*

We sought to determine if the field-scale model ICLS demonstration site was more profitable than continuous corn on marginal rainfed cropland in eastern Nebraska. In 2018, the diversified ICLS was over 1.5 times more profitable than the continuous corn system (Figure 3-5). However, in 2019 both systems lost money, with the ICLS losing more money than continuous corn (Figure 3-5). These observations indicate that the ICLS can be more profitable than continuous corn production on marginal dryland. However, the stability of profitability is unclear for the ICLS at the field-scale model demonstration site.

In order to detect if there was a difference in profitability between the two switchgrass varieties, data was extrapolated from the 6-ha grazing system for each switchgrass variety to a 12-ha grazing system of a single switchgrass variety. This allowed us to make statements about the profitability of using both switchgrass varieties versus a single switchgrass variety. We found that in 2018, if the site were all Shawnee, the ICLS could have produced greater profits by $826 per 20-ha system than if it were all Liberty or a combination of Shawnee and Liberty (Figure 3-5). But, in 2019 if all the switchgrass was Shawnee, the system lost more money than if it was all Liberty or if it was a diversified system (Figure 3-5). Therefore, we cannot conclude if either switchgrass variety is better suited for the ICLS.

In order to develop the most profitable scenarios, the ownership of both hay and row-crop machinery were compared to custom farming rates for hay and corn production. We found that it was more profitable to sell the corn machinery and custom farm the corn cropland for the ICLS (Supplementary Information B and C). Also, owning hay making equipment was more profitable than custom farming the hay (Supplementary Information H and I). These observations allowed us to determine that using custom farming rates for corn enterprises and ownership of hay machinery for hay enterprises were most favorable for the creation of budgets. Therefore, custom farming costs for the corn production system and ownership costs of hay machinery were used to develop the enterprise budgets.

### *Cost & Revenue Potential*

Different enterprises require different inputs and field operations. Therefore, the difference in cost and revenue potential for each enterprise was compared. Purchasing yearling steers and grazing marginally productive land required twice as much capital as planting the land to continuous corn (Table 3-3). The revenue potential for the grazing system was also double that of continuous corn. The grazing system generated 1.5 times more profit than the continuous corn system in 2018. However, grazing lost more money (\$136 $ha^{-1}$) than growing continuous corn in 2019. The cost for making hay in the diversified system was the lowest because no land taxes or establishment costs were attributed to the hay enterprise. When land taxes and establishment costs are not attributed to hay production, the hay enterprise makes 2.5 times the cost of production in revenue (Table 3-3). These findings indicate grazing enterprises require more capital but have the potential to generate more revenue.

### *Establishment Costs*

It is important to note that ICLS with perennial grasses require additional capital to establish pastures for grazing. In order to assess the cost of establishing perennial grass, establishment cost budgets were developed for each species of perennial grass. Building fence and developing water attributed 55% of the total cost of establishment (Supplementary Information D). This indicates that perennial grass systems for hay instead of grazing may be more achievable because of lower establishment costs.

### ***Alternative Systems***

To explore the profitability of solely producing hay and not grazing, a scenario with only hay production and no fencing or water development establishment costs was conducted. When the perennial grass was harvested for hay each year, the enterprise was profitable each year (Table 3-4). In 2018 and 2019, harvesting hay produced more profit per hectare than planting continuous corn on marginal land (Table 3-4). Another way to reduce input costs associated with ICLS is by not purchasing cattle. Instead of purchasing cattle, cattle could be rented on the gain for the ICLS. Therefore, we sought to explore the profitability of a scenario where producers could rent on the gain, using data from the site in 2018 and 2019. The rent on the gain scenario for the diversified ICLS was not profitable in 2018 or 2019 (Table 3-4). When the rent on the gain scenario was assessed, if the system was all Liberty, then renting on the gain was not profitable in either 2018 or 2019. If the pastures were all Shawnee, the enterprise was profitable in 2018 but not in 2019 (Supplementary Information L). Renting on the gain does not appear to be a viable option for the ICLS in Eastern Nebraska on marginally productive dryland.

### ***Sensitivity Analysis***

#### *Cattle Price & Weight*

In 2018 the grazing enterprise was profitable, but in 2019 it was not. The weight of cattle at grazing initiation varied on average by 104.8 kg $hd^{-1}$ from 2018 to 2019. The year to year variation in weight influenced the price at purchase and sale of the steers. Additional variation was added by weather and forage availability which led to differences in weight gain. Since variability existed among years, the response of the two different grazing systems each year to cattle market fluctuation was evaluated. Therefore, historic cattle price data from Nebraska was used to evaluate the response of each of the four systems to market fluctuation at the time of purchase and sale. To simulate market fluctuation, data from 2009 to 2019 was used for each weight class of cattle in each grazing system. The value of the steer increased from purchase to the time of sale 10 of 11 years for each weight class. The range of increased value was highly variable, between \$34-695 $hd^{-1}$. With 2015 price data the lighter steers decreased in value for both the Shawnee (-\$46 $hd^{-1}$) and Liberty (-\$55 $hd^{-1}$) grazing systems. When the price at sale was greater than the breakeven, the grazing enterprise was profitable. Even though the value of the steer generally increased, the breakeven price of all four systems was lower than the price at sale only 2 of 11 years. When 2013 and 2014 market data was used, the price received at sale was greater than the breakeven price for all four systems. Additionally, when 2017 market data was used, the lighter weight steers in the Liberty grazing system also had a greater price at sale than the breakeven. When 2018 market data was used, the heavier weight steers in both the Liberty and Shawnee grazing systems had a greater price at sale than breakeven. 2014 cattle price data produced profits at least 2.5x greater than other profitable years for all four systems. Of the 44 scenarios produced by the sensitivity analysis, only 11 were profitable. In general, the data from the sensitivity analysis shows that the grazing enterprise is not consistently profitable. Generally, the grazing enterprise was only profitable when cattle prices increased from purchase to sale.

*Hay Yield and Price (Supplementary Information O)*

Baling hay for all three perennial grasses was more profitable than growing continuous corn in 2018 and 2019. Hay yield and price are subject to fluctuation. Therefore, the profitability of each perennial grass was evaluated as yield and price were changed. In order to do this, a sensitivity analysis was conducted. The base yield for the sensitivity analysis was the known average of the cultivar and the price of hay was the average for November and December in NE for 2018 and 2019. The results show that when yield is reduced by 35% and price is reduced by 25%, Liberty and Shawnee pastures baled for hay were more profitable than continuous corn in 2018 (\$95.23 $ha^{-1}$) and 2019 (-\$5.65 $ha^{-1}$). Liberty produced for hay could make 3 times as much profit per hectare when compared to continuous corn production. Additionally, Shawnee produced for hay could make 1.5 times as much profit per hectare when compared to continuous corn production. Similarly, every yield and price combination for the Newell pasture produced profit. However, when hay yield was reduced by 35% in combination with a price reduction of at least 20% the pasture was not as profitable as continuous corn production in 2018. Additionally, a yield reduction of 30% and price reduction of 25% resulted in less profit than continuous corn production in 2018. Only 3 of 110 price and yield combinations made the Newell pasture less profitable than continuous corn in 2018. When the scenarios for Newell were compared to continuous corn production in 2019, every yield and price combination tested was more profitable. These results indicate that a producer planting either of the three varieties or a combination of them on marginally productive land can be more profitable than continuous corn in Eastern NE.

***Productivity & Commodity Pricing***

*Row Crop*

Productivity and commodity pricing play an important role in system profitability. Therefore, we compared the production of the three commodities (corn grain, beef, and hay) and the prices received for the commodities. Corn yield in 2018 was around 1100 kg $ha^{-1}$ greater than in 2019. Corn price was slightly greater in 2019 than in 2018 (Table 3-5). Despite lower prices in 2018, the continuous corn was more profitable than in 2019 because of decreased yields in 2019.

*Perennial Grass Grazing Systems*

In the diversified ICLS grazing system, the cattle gained more weight in 2019 than in 2018 (Table 3-5). In 2018, cattle grazing the Shawnee produced more weight than the cattle grazing Liberty (Table 3-5). However, in 2019, the cattle grazing Liberty produced more beef per hectare (Table 3-5). The cattle at the beginning of grazing in 2019 were 104.8 kg per steer lighter than in 2018 (Table 3-6). The purchase price of the steers was less than the selling price in 2018 versus 2019 (Table 3-5). Because of greater cattle weight at grazing initiation in conjunction with higher prices at selling in 2018, the ICLS was more profitable in 2018 than in 2019. Cattle average daily gain (ADG) in 2018 was greatest on Shawnee, followed by Spring grazing of Newell, then Liberty, with the least ADG from fall grazing of the re-growth of Newell (Table 3-6). In 2019, the greatest ADG was spring grazing of Newell, followed by fall grazing of the re-growth of the Newell, then grazing of the Liberty, with the least ADG from grazing of Shawnee (Table 3-6). Grazing days for the switchgrass varieties were consistent across years (Table 3-6). The spring grazing of Newell was 4 days less in 2019 than in 2018 and the fall grazing of the re-growth of the Newell was 7 days greater in 2019 than in 2018 (Table 3-6). No switchgrass variety was consistently superior in producing animal gains. However, Newell produced adequate daily gains each year.

*Residual Hay Production*

Presumably, Liberty produces greater biomass yields than Shawnee (Vogel, Mitchell, Casler, et al. 2014; Vogel, Hopkins, and Moore 1996). Therefore, we wanted to see which variety produced more residual biomass after grazing. Residual hay production for Liberty was greater than Shawnee residual hay production both years. Both switchgrass varieties had greater residual hay yield in 2018 than in 2019. The hay prices were slightly greater in 2019 than in 2018 (Table 3-5). Hay was more profitable in 2019 than in 2018 because of greater prices. Liberty is better suited as a dual-purpose crop for grazing and biomass production due to greater yield.

## Discussion

The purpose of the economic analysis was to evaluate if the ICLS was more profitable than continuous corn production in Eastern NE on marginally productive cropland. The ICLS consisted of three enterprises: perennial grass grazing, residual hay production, and continuous corn production. Our findings indicate that the ICLS is not consistently more profitable than continuous corn production. In our analysis, the ICLS was more profitable than continuous corn one of two years (Figure 3-5). The year to year variation in the profitability of the grazing enterprise was large (-\$974 – 3231 20-ha$^{-1}$). The variation was caused by market fluctuation and differences in steer weight among years. Therefore, the sensitivity of the grazing enterprise to cattle market fluctuation and steer weight was evaluated. The sensitivity analysis revealed that each grazing system, regardless of cattle price and weight class, typically resulted in a net loss (Supplementary Information N). Therefore, purchasing steers to graze the model ICLS without supplementation is not recommended.

Even though our results indicate that grazing the model ICLS is not consistently more profitable than continuous corn, using alternative perennial grass varieties may be more profitable. In Eastern NE a grazing enterprise with steers grazing big bluestem was more profitable than continuous corn production two-thirds of the time (Mitchell et al. 2005). The increased profitability of big bluestem may be due to greater beef production. Steers grazing big bluestem (454 kg $ha^{-1}$) gained twice as much weight per land area than the proposed ICLS (11.1-210.9 kg $ha^{-1}$) (Mitchell et al. 2005). Greater gains produce more profit with less variability when steers graze Big Bluestem (\$75.19- 404.19 $ha^{-1}$) instead of the ICLS (\$-179.30- 202.9 $ha^{-1}$) (Mitchell et al. 2005). Evidence suggests that big bluestem is likely a better option for perennial warm season grass pasture than switchgrass in Eastern Nebraska because it produces greater cattle gains. Despite other warm-season grass options, switchgrass was selected to be a part of the ICLS. Switchgrass was selected for the ICLS because of the recent interest switchgrass has received for use as a cellulosic biofuel (Mitchell et al. 2016; Mitchell et al. 2010; Vogel, Mitchell, Waldron, et al. 2014). Having multiple uses for a perennial grassland allows the producer to have management flexibility.

For example, switchgrass can be used as a dual-purpose crop. Switchgrass has shown promise as a dual-purpose crop for both cattle production and cellulosic ethanol in Oklahoma. In Oklahoma, steers lightly grazing (2.2 steers $ha^{-1}$) switchgrass for 81 days on average gain 0.83 kg $hd^{-1}$ $d^{-1}$ (Mosali et al. 2013; Biermacher et al. 2017). In addition to grazing, the residual harvested switchgrass produces on average 10.6 Mg $ha^{-1}$ (Mosali et al. 2013; Biermacher et al. 2017). The system management in Oklahoma is near identical to what the ICLS used. However, the steer gains on switchgrass were 25% less than and the residual hay yield was 80% less than the production in Oklahoma (Table 3-6; Table 3-5). The difference in production explains the difference in profitability. In Oklahoma the system made between $232-523 $ha^{-1}$ (Biermacher *et al.*, 2017). The system in Oklahoma produced greater profitability than the ICLS (Table 3-4). Using switchgrass as a dual-purpose crop in Oklahoma is feasible, but not in Eastern Nebraska. This system likely does not work as well in Nebraska because of the reduced growing degree days and limited precipitation resulting in reduced residual biomass growth. However, the system could be more profitable in Eastern NE if the switchgrass is grazed for a shorter duration, leaving more growing degree days to produce greater biomass for residual hay production.

Even though the grazing enterprise did not have reliable profitability, perennial grasslands still offer numerous environmental benefits (Asbjornsen et al. 2014). Therefore, perennial grasslands should still be considered when developing an ICLS. An alternative to purchasing cattle is renting cattle on the gain to graze the pasture. Renting on the gain eliminates the need for additional capital to purchase livestock. Therefore, the profitability of renting on the gain for the grazing enterprise was compared to continuous corn. The results show that renting cattle on the gain was not more profitable than continuous corn production either year (Table 3-4). Renting on an AUM basis also eliminates the need for additional capital to purchase livestock and is an alternative that could be explored as well. However, perennial grasses can also be harvested for hay to be used as cattle feed. Since grazing the ICLS was not consistently profitable, the profitability of producing hay from the perennial grasslands in the ICLS were compared to continuous corn production. The findings indicate that hay production on marginally productive cropland can be more profitable than continuous corn production in Eastern NE (Table 3-4). Furthermore, additional findings indicate that when hay yield and price decrease, baling hay is still more profitable than continuous corn production (Supplementary Information O). Therefore, planting perennial grass varieties for hay production on marginally productive cropland instead of continuous corn in Eastern NE is more profitable. It is well known that perennial forages for hay production can be more profitable than row-crop systems in the Midwest. In Iowa, a diverse 4-yr cropping system including alfalfa for hay production is more profitable than the typical corn-soybean grain system (Liebman et al. 2008). In Iowa, integrated systems with alfalfa hay production and livestock are similar in profit to non-integrated cash crop systems, however, their profitability is more variable (Poffenbarger et al. 2017). The integrated systems also require a greater amount of labor and capital (Poffenbarger et al. 2017). Previous findings in conjunction with our results illustrate that adopting a diversified hay production system instead of a grazing system may be the most secure option for producers in Eastern NE to achieve profitability.

The profitability potential of the ICLS studied was limited because of the grazing system selected. The grazing system for the ICLS was selected to obtain cattle gains from each forage source individually. This was essential so the cattle weight gain potential from grazing the newly developed cultivar Liberty could be evaluated. Liberty was developed for cellulosic ethanol production; therefore, the biomass potential of the cultivar is well known (Vogel, Mitchell, Casler, et al. 2014). However, this was the first grazing research on Liberty so its potential use for grazing was not well known. Alternative grazing systems could produce better outcomes for an ICLS in Eastern NE.

Recommendations for the region suggest that switchgrass should be grazed uniformly in June and July or grazed in June with the re-growth grazed in August (Mitchell and Anderson 2008). The proposed grazing sequences maximize forage quality, which optimize cattle performance. Cattle in the ICLS spent 79-d (June-August) on the Liberty and Shawnee pastures and an average of 46-d on the Newell pasture (Table 3-6). Grazing switchgrass less, and smooth bromegrass more can improve cattle gain. In Central Iowa, cattle in a grazing system with smooth bromegrass (range 72-93-d) and switchgrass (range 27-56-d) gained 53.0-111.8 kg $hd^{-1}$ (Moore et al. 2004). On average, cattle in this system gained 87.14 kg $hd^{-1}$, whereas cattle grazing the ICLS Liberty gained on average 76.5 kg $hd^{-1}$, and cattle grazing the ICLS Shawnee gained on average 79.5 kg $hd^{-1}$ (Supplementary Information F and G). These findings suggest that grazing smooth bromegrass and switchgrass in more timely manners could improve the cattle performance in the ICLS. Additionally, cattle grazing big bluestem instead of switchgrass as the warm-season grass in these systems could produce greater gains (88.62 kg $hd^{-1}$) than switchgrass or the ICLS (Moore et al. 2004). Furthermore, if cattle were to only graze the smooth bromegrass (99.38 kg $hd^{-1}$) all season cattle gain could be maximized (Moore et al. 2004). Despite higher cattle gains from only grazing smooth bromegrass, including a warm-season pasture in the rotation provides a valuable rest to cool-season pastures (Moore et al. 2004). Another reasonable option to improve cattle gain is rotational grazing. Rotationally grazing switchgrass or big bluestem results in 2.76, and

1.81 times greater gain, respectively (George et al. 1997). It is apparent that using different warm-season pasture varieties and/or different grazing systems may improve the profitability potential for an ICLS in Eastern NE. Additionally, to capture animal performance on each component of the ICLS it was necessary to weigh steers after Newell grazing. The weighing process requires 7-d (Watson et al. 2013). This prevented the steers from grazing switchgrass at the peak of forage quality and livestock performance potential.

Another way to improve the profitability potential of an ICLS with steer grazing is to consider different specialized market opportunities. Niche markets exist for different consumer demands; i.e. free-range, locally grown, grass-fed/finished, pasture-raised label claims (Russelle, Entz, and Franzluebbers 2007; Dimitri, Effland, and Conklin 2005; Asai et al. 2018; Parthasarathy Rao P. and Ndjeunga 2005; Entz et al. 2002). These labels provide a premium price to livestock producers for their production practices. For example, grass-finished or pasture-raised labels offer a premium price above cattle market prices (USDA Livestock Poultry and Grain Market News 2020). The premium could make these grazing systems more profitable. Additionally, direct to consumer markets provide additional premiums to the producer through locally raised label claims. Therefore, producers interested in adding grazed perennial grass enterprises should consider pursuing different markets including, locally grown, pasture-raised, and grass-finished protein.

It is important to realize that the economic analyses conducted are limited based on the assumptions made for the analyses. Additionally, the assumptions are based on the actual management of the field-scale model demonstration site. These assumptions determine cost and revenue potential of enterprises and farms. Therefore, it is essential for producers considering an ICLS to develop their own enterprise budgets using their own set of assumptions. Evaluating each producer's individual scenario will result in a more accurate picture of the profitability potential of implementing an ICLS. Evaluating the potential profitability of specific enterprises will help guide producer decision-making.

Future research should evaluate the potential of different grazing systems that maximize forage quality, therefore, maximizing cattle performance. Another research opportunity is to develop a different perennial grass grazing system with more desirable warm-season species to increase cattle performance. Additionally, an annual forage grazing system could be explored to create flexibility for the grower to either grow corn or grow cattle depending on markets and projected profitability. This study can serve as a framework for a producer to use to evaluate their profitability potential of converting to an ICLS.

## Conclusion

Our results indicate ICLS with perennial grass vegetation and continuous corn have the potential to be more profitable than continuous corn on poorly drained cropland in Eastern NE. Incorporating perennial grass for either grazing or hay production in Eastern NE can increase farm profitability on marginal land while improving the farm's environmental impact. Outputs from this research will be used to further develop model ICLS for Eastern NE. The primary purpose of the economic analysis was to evaluate the profitability of the ICLS in comparison to continuous corn production. The ICLS with switchgrass was not consistently more profitable than continuous corn production.

Secondly, we purposed to discover if baling hay only and not grazing the ICLS was profitable. Our evidence suggests that baling hay is not only consistently more profitable than grazing bromegrass and switchgrass, it is also more profitable than continuous corn production in Eastern NE. Our research can help guide future work on developing ICLS for marginal cropland in Eastern NE. It also will serve as a framework to help producers decide if adopting an ICLS is a viable option for their farm.

**Table 3- 1.** Web soil survey map units.

Table of the total area for each soil map unit at the field-scale model demonstration site from Web Soil Survey.

| Map Unit Symbol | Map Unit Name | Hectares in AOI | Percent in AOI |
|---|---|---|---|
| 3948 | Fillmore silt loam, terrace, occasionally ponded | 2.80 | 13.8% |
| 7105 | Yutan silty clay loam, terrace, 2 to 6 percent slopes, eroded | 4.00 | 19.6% |
| 7280 | Tomek silt loam, 0 to 2 percent slopes | 8.18 | 40.2% |
| 7340 | Filbert silt loam, 0 to 1 percent slopes | 5.38 | 26.4% |

**Table 3- 2.** Herbicide application rate for continuous corn in 2018 and 2019.

List of herbicides, rates, and times of application for the continuous corn in the field-scale model demonstration site.

| Year | Application | Herbicide | Rate L $ha^{-1}$ |
|---|---|---|---|
| **2018** | | | |
| | ***Pre-emergent*** | | |
| | | Atrazine 4L | 2.34 |
| | | Balance | 0.37 |
| | | 2,4-D | 0.58 |
| | ***Post-emergent*** | | |
| | | Roundup Powermax | 2.63 |
| | | Roundup Powermax | 2.34 |
| | | Callisto | 0.18 |
| **2019** | | | |
| | ***Pre-emergent*** | | |
| | | Accuron | 4.68 |
| | | LV6 2,4-D | 0.39 |
| | | Roundup Powermax | 2.34 |
| | ***Post-emergent*** | | |
| | | Callisto | 0.18 |
| | | Roundup Powermax | 1.75 |
| | | Atrazine 4L | 0.58 |

**Table 3- 3.** The revenue, cost, and profit per hectare for each enterprise by year.

Comparison of the cost, revenue, and profit per hectare among each enterprise (corn, grazing, and hay) and the amount of land attributed to each enterprise in each system. The cost and revenue for the ICLS corn production and continuous corn production were determined for each year based on the budgets in Supplementary Information C. The corn yield for each year was the 8-ha field average from the model demonstration site. The cost and revenue for the grazing enterprise were determined for each year based on the budgets in supplementary information F and G. The cattle gains used were the average gain of the cattle in each grazing system. The hay cost and revenue were based on the budgets in supplementary information H and supplementary information J, respectively. The hay yield for each year was based on the residual harvested switchgrass biomass of each variety. The profit per hectare was calculated by subtracting the costs from the revenue for each enterprise. The number of hectares distributed to each enterprise of the Diversified ICLS were based on the actual hectares of the field-scale model demonstration site.

| **2018** | | | | | **2019** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Diversified ICLS | | | | | Diversified ICLS | | | |
| Enterprise: | Corn | Grazing | Hay | Combined Grazing and Hay | Enterprise: | Corn | Grazing | Hay | Combined Grazing and Hay |
| Hectares | 8 | 12 | 8 | 12 | Hectares | 8 | 12 | 8 | 12 |
| Revenue ($ ha$^{-1}$) | 1067.48 | 2232.25 | 136.22 | 2323.06 | Revenue ($ ha$^{-1}$) | 961.69 | 1829.99 | 144.19 | 1926.12 |
| Cost ($ ha$^{-1}$) | 972.25 | 2087.89 | 48.77 | 2120.40 | Cost ($ ha$^{-1}$) | 967.35 | 1971.40 | 46.71 | 2002.54 |
| **Profit ($ ha$^{-1}$)** | **95.23** | **144.36** | **87.45** | **202.66** | **Profit ($ ha$^{-1}$)** | **-5.66** | **-141.41** | **97.48** | **-76.42** |
| | Continuous Corn | | | | | Continuous Corn | | | |
| Enterprise: | Corn | Grazing | Hay | | Enterprise: | Corn | Grazing | Hay | |
| Hectares | 20 | 0 | 0 | | Hectares | 20 | 0 | 0 | |
| Revenue ($ ha$^{-1}$) | 1067.48 | - | - | | Revenue ($ ha$^{-1}$) | 961.69 | - | - | |
| Cost ($ ha$^{-1}$) | 972.25 | - | - | | Cost ($ ha$^{-1}$) | 967.35 | - | - | |
| **Profit ($ ha$^{-1}$)** | **95.23** | **-** | **-** | | **Profit ($ ha$^{-1}$)** | **-5.66** | **-** | **-** | |
| | Newell'-'Liberty'-'Newell' System | | | | | Newell'-'Liberty'-'Newell' System | | | |
| Enterprise: | Corn | Grazing | Hay | Combined Grazing and Hay | Enterprise: | Corn | Grazing | Hay | Combined Grazing and Hay |
| Hectares | 8 | 12 | 8 | 12 | Hectares | 8 | 12 | 8 | 12 |
| Revenue ($ ha$^{-1}$) | 1067.48 | 2167.52 | 181.62 | 2288.60 | Revenue ($ ha$^{-1}$) | 961.69 | 1863.94 | 194.49 | 1993.60 |
| Cost ($ ha$^{-1}$) | 972.25 | 2081.7 | 57.42 | 2119.98 | Cost ($ ha$^{-1}$) | 967.35 | 1967.45 | 55.04 | 2004.14 |
| **Profit ($ ha$^{-1}$)** | **95.23** | **85.82** | **124.2** | **168.62** | **Profit ($ ha$^{-1}$)** | **-5.66** | **-103.51** | **139.45** | **-10.54** |
| | Newell'-'Shawnee'-'Newell' System | | | | | Newell'-'Shawnee'-'Newell' System | | | |
| Enterprise: | Corn | Grazing | Hay | Combined Grazing and Hay | Enterprise: | Corn | Grazing | Hay | Combined Grazing and Hay |
| Hectares | 8 | 12 | 8 | 12 | Hectares | 8 | 12 | 8 | 12 |
| Revenue ($ ha$^{-1}$) | 1067.48 | 2296.97 | 90.81 | 2357.51 | Revenue ($ ha$^{-1}$) | 961.69 | 1796.04 | 93.89 | 1858.63 |
| Cost ($ ha$^{-1}$) | 972.25 | 2094.08 | 40.11 | 2120.82 | Cost ($ ha$^{-1}$) | 967.35 | 1975.34 | 38.38 | 2000.93 |
| **Profit ($ ha$^{-1}$)** | **95.23** | **202.89** | **50.7** | **236.69** | **Profit ($ ha$^{-1}$)** | **-5.66** | **-179.3** | **55.51** | **-142.29** |

**Table 3- 4.** Comparison of net returns for the alternative systems using custom corn operations.

Comparison of the enterprise return per hectare and whole system return in 2018 and 2019. Whole systems were based on 20-ha. The hay and grazing enterprise shared 8-ha of the same land base. The cost and revenue for the ICLS corn production and continuous corn production were determined for each year based on the budgets in Supplementary Information C. The corn yield for each year was based on the 8-ha field average from the model demonstration site. The cost and revenue for the grazing enterprise were determined for each year based on the budgets in supplementary information F and G. The cattle gains for each year were the average gains of the cattle in each grazing system. The hay cost and revenue for the ICLS including grazing were based on the budgets in supplementary information H and G, respectively. The hay yield for each year was based on the residual harvested switchgrass biomass. The hay yield for the hay only scenario is based on the variety's proven yield from their plant registrations. The hay cost and revenue for the hay only scenario is based on the budget table in Supplementary Information M. The rent on the gain scenario was based on the budget in Supplementary Information L.

**Systems Returns Custom Corn Operations**

| | | 'Newell-Liberty-Newell' ICLS | | | 'Newell-Shawnee-Newell' ICLS | | | Diversified ICLS | | | | | Continuous Corn | Rent on the Gain ICLS | | | | | Hay Only ICLS | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Enterprise: | Grazing | Hay | Corn | Grazing | Hay | Corn | 'Newell-Liberty-Newell' Grazing | 'Newell-Shawnee-Newell' Grazing | 'Liberty' Hay | 'Shawnee' Hay | Corn | Corn | 'Newell-Liberty-Newell' Grazing | 'Newell-Shawnee-Newell' Grazing | 'Liberty' Hay | 'Shawnee' Hay | Corn | 'Newell' | 'Shawnee' | 'Liberty' | Corn |
| 2018 | Return per hectare | 85.82 | 124.19 | 95.23 | 202.90 | 50.71 | 95.23 | 85.82 | 202.90 | 124.19 | 50.71 | 95.23 | 95.23 | -30.59 | 28.10 | 124.19 | 50.71 | 95.23 | 377.63 | 602.49 | 857.31 | 95.23 |
| | # of hectares | 12 | 8 | 8 | 12 | 8 | 8 | 6 | 6 | 4 | 4 | 8 | 20 | 6 | 6 | 4 | 4 | 8 | 4 | 4 | 4 | 8 |
| | return to enterprise | 1041.90 | 1005.20 | 770.80 | 2463.30 | 410.40 | 770.80 | 520.95 | 1231.65 | 502.60 | 205.20 | 770.80 | 1927.00 | -185.70 | 170.55 | 502.60 | 205.20 | 770.80 | 1528.20 | 2438.20 | 3469.40 | 770.80 |
| | return to system | **2817.90** | | | **3644.50** | | | **3231.20** | | | | | **1927.00** | **1463.45** | | | | | **8206.60** | | | |
| 2019 | Return per hectare | -103.51 | 139.47 | -5.66 | -179.30 | 55.52 | -5.66 | -103.51 | -179.30 | 139.47 | 55.52 | -5.66 | -5.66 | -126.54 | -164.32 | 139.47 | 55.52 | -5.66 | 477.06 | 763.16 | 1064.85 | -5.66 |
| | # of hectares | 12 | 8 | 8 | 12 | 8 | 8 | 6 | 6 | 4 | 4 | 8 | 20 | 6 | 6 | 4 | 4 | 8 | 4 | 4 | 4 | 8 |
| | return to enterprise | -1256.70 | 1128.80 | -45.80 | -2176.80 | 449.40 | -45.80 | -628.35 | -1088.40 | 564.40 | 224.70 | -45.80 | -114.50 | -768.15 | -997.50 | 564.40 | 224.70 | -45.80 | 1930.60 | 3088.40 | 4309.30 | -45.80 |
| | return to system | **-173.70** | | | **-1773.20** | | | **-973.45** | | | | | **-114.50** | **-1022.35** | | | | | **9282.50** | | | |

**Table 3- 5.** Production and market price of each commodity in 2018 and 2019.

Comparison of the productivity and price of each commodity by year (corn, grazing, and hay). The corn yield, hay yield, and cattle gain were based on production data collected from the site. The corn price was based on the average corn price in Nebraska in October each year. The cattle prices were based on the price closest to the date of purchase and selling for the weight classes of the steers. The data used to calculate this was provided by the Livestock Marketing Information Center (LMIC). The hay prices were the average price of fair quality hay in Nebraska over November and December for each year. The hay prices were generated via a custom report through USDA-NASS.

| | Corn | | Diversified Grazing ICLS | | | 'Newell'-'Liberty'-'Newell' | | | 'Newell'-'Shawnee'-'Newell | | | Liberty Hay | | Shawnee Hay | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yield | Price | Gain | Purchase Price | Selling Price | Gain | Purchase Price | Selling Price | Gain | Purchase Price | Selling Price | Yield | Price | Yield | Price |
| | *kg ha$^{-1}$* | *\$ kg$^{-1}$* | *kg ha$^{-1}$* | *\$ kg$^{-1}$* | *\$ kg$^{-1}$* | *kg ha$^{-1}$* | *\$ kg$^{-1}$* | *\$ kg$^{-1}$* | *kg ha$^{-1}$* | *\$ kg$^{-1}$* | *\$ kg$^{-1}$* | *kg ha$^{-1}$* | *\$ kg$^{-1}$* | *kg ha-1* | *\$ kg$^{-1}$* |
| 2018 | 7551.82 | 0.14 | 97.21 | 2.99 | 3.28 | 81.40 | 2.99 | 3.27 | 113.01 | 2.99 | 3.29 | 2354.45 | 0.08 | 1177.22 | 0.08 |
| 2019 | 6449.49 | 0.15 | 133.87 | 3.81 | 3.26 | 145.30 | 3.81 | 3.26 | 122.43 | 3.81 | 3.26 | 2194.68 | 0.09 | 1059.50 | 0.09 |

**Table 3- 6.** Cattle performance based on forage type for each year.

The cattle gains were based on the data collected from the field-scale model demonstration site. The grazing days were the actual number of days the cattle grazed each pasture. The initial and final body weight was the average of the cattle at the beginning and conclusion of grazing.

| | Grazing Days | Initial BW | Final BW | Average Rate of Gain | Range of ADG | Beef Gain on Pasture |
|---|---|---|---|---|---|---|
| | | *kg* | *kg* | *kg hd $^{-1}$ d $^{-1}$* | *kg* | *kg ha $^{-1}$* |
| **2018** | | | | | | |
| **Spring Newell** | *30* | *393.7* | *410.5* | *0.55* | *-0.56* to *1.19* | *76.0* |
| **Liberty** | *79* | *416* | *448* | *0.41* | *0.21 to 0.70* | *72.5* |
| **Shawnee** | *79* | *413* | *461* | *0.61* | *0.31 to 0.86* | *106.8* |
| **Fall Newell** | *13* | *456.8* | *459.5* | *0.19* | *-1.05* to *1.81* | *11.1* |
| **2019** | | | | | | |
| **Spring Newell** | *26* | *288.9* | *336.1* | *1.81* | *1.17* to *2.95* | *210.9* |
| **Liberty** | *79* | *339.3* | *369.7* | *0.38* | *0.05 to 0.62* | *67.3* |
| **Shawnee** | *79* | *339.7* | *355.6* | *0.2* | *-0.11 to 0.42* | *36* |
| **Fall Newell** | *23* | *362.42* | *379.2* | *0.72* | *0.32 to 1.16* | *73.2* |

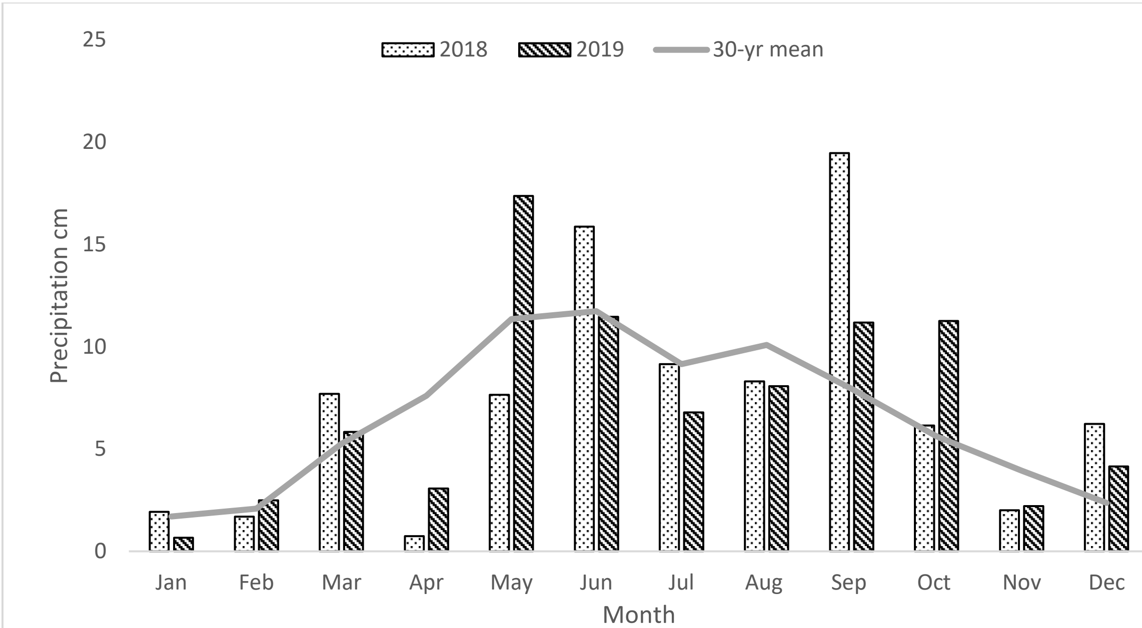


**Figure 3- 1.** Monthly precipitation in Mead, NE.

Precipitation received at Mead, NE for 2018 and 2019. The 30-yr average is for Saunders County, where Mead is located. Data obtained from the High Plains Regional Climate Center.


**Figure 3- 2.** Web soil survey map.

A map of the field-scale demonstration site with the locations of the soil map units.

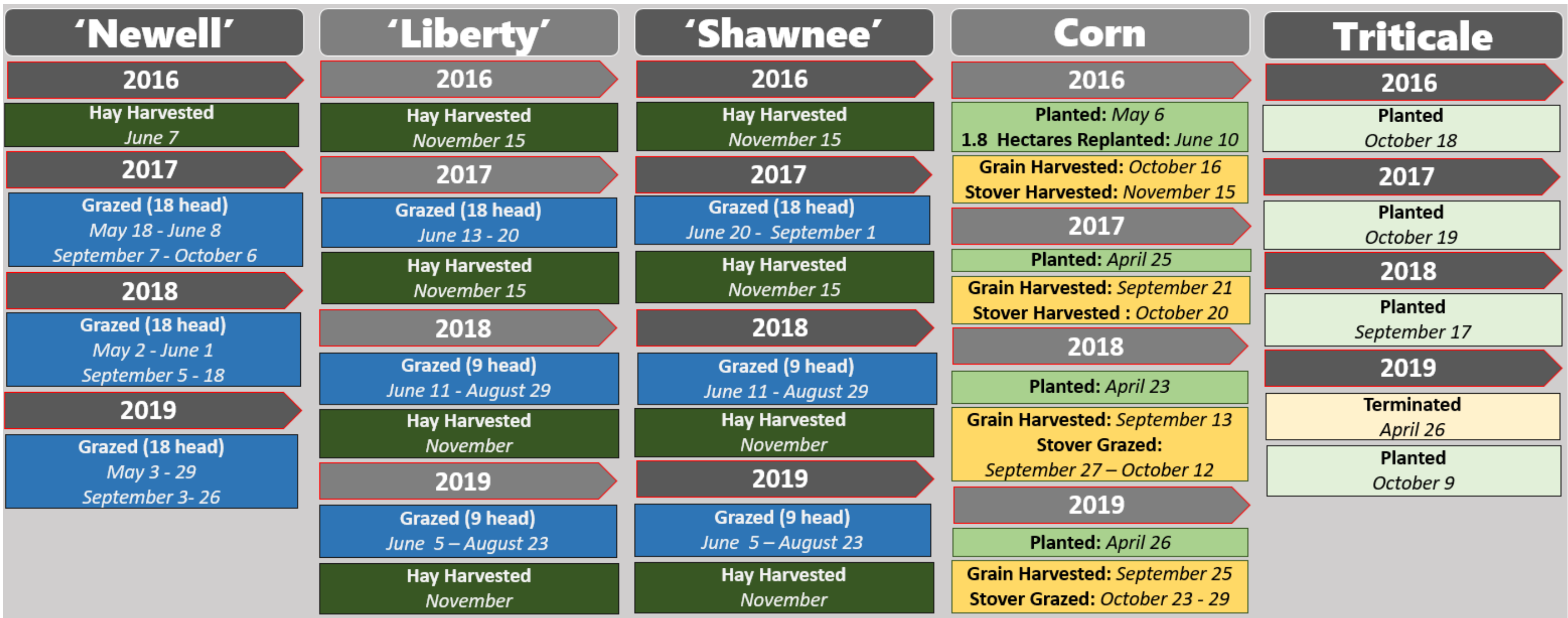


**Figure 3- 3.** Management by component by year.

Outline of how each component of the field-scale model demonstration site was managed each year.

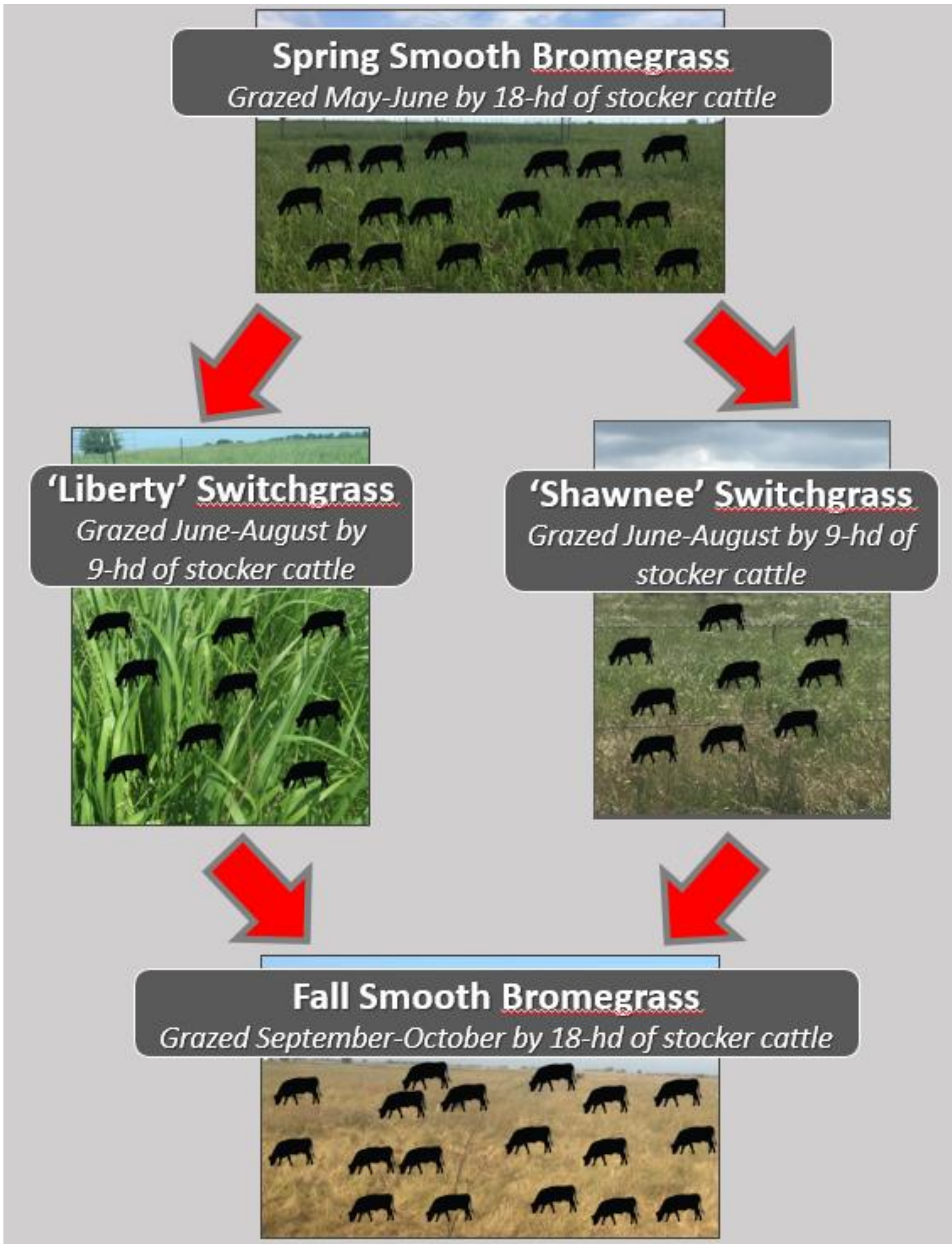


**Figure 3- 4.** Grazing sequence in 2018 and 2019.

Diagram of the grazing systems used in 2018 and 2019. The cattle in the 'Liberty' system grazed the Liberty switchgrass & the cattle in the 'Shawnee' system grazed the Shawnee switchgrass during June-August. The herd was combined to graze the Newell smooth bromegrass in both Spring and Autumn.

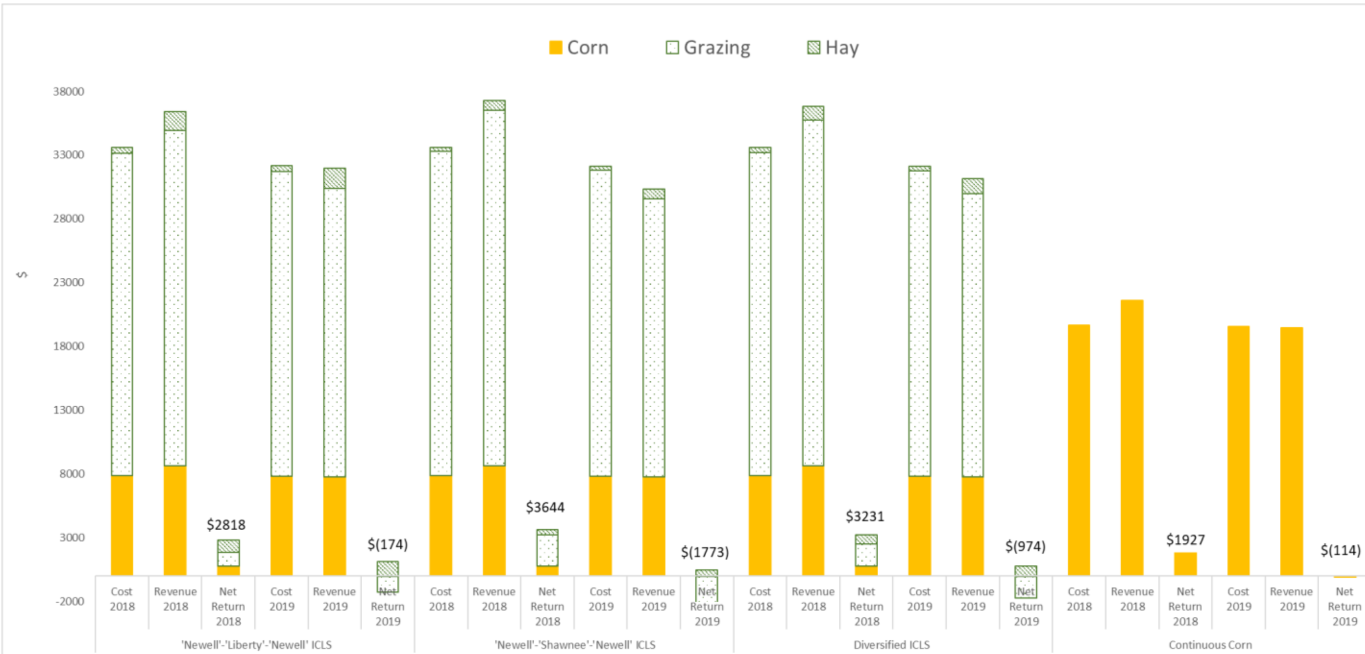


**Figure 3- 5.** The revenue, cost, and net return of systems.

Comparison of the cost, revenue, and net return among each enterprise (corn, grazing, and hay) and the evaluated systems. The yellow bar represents the corn enterprise, the green bar with dots represents the grazing enterprise, and the green bar with diagonal stripes represents the hay enterprise. The cost and revenue for the ICLS corn production and continuous corn production were determined for each year based on the budgets in Supplementary Information C. The corn yield for each year was the 8-ha field average from the model demonstration site. The cost and revenue for the grazing enterprise were determined for each year based on the budgets in supplementary information F and G. The cattle gains for each year were the average gains of the cattle in each grazing system. The hay cost and revenue were based on the budgets in supplementary information H and supplementary information J, respectively. The hay yield for each year was based on the residual harvested switchgrass biomass. The net return was calculated by subtracting the costs from the revenue for each enterprise. The system net return is listed above the net return stacked bar for each year. The system net return is the addition of each of the enterprise net returns. Parentheses indicate negative net returns for the system.

## Supplementary Information

A. Corn budget with machinery ownership for continuous corn system in 2018 and 2019.

**Continuous Corn 2018** UNL Crop Budgets 2019 21-Corn

| Field Operations | Times or Qty | Unit | Labor @ $20.00 /Hr | Fuel @ $2.49 and Lube | Repairs Power | Repairs Imp. | Ownership Power | Ownership Imp. | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|---|---|
| Spray Spring Burndown Herbicide | 1 | | 1.00 | 0.30 | 0.35 | 0.64 | 1.08 | 0.81 | 4.18 | $ 10.33 |
| Spread Fertilizer | 1 | | 1.57 | 0.87 | 0.68 | 0.00 | 2.12 | 0.00 | 5.24 | $ 12.95 |
| Plant No-Till | 1 | | 2.40 | 0.97 | 0.86 | 4.41 | 2.70 | 6.13 | 17.47 | $ 43.17 |
| Spray Herbicide | 2 | | 2.00 | 0.60 | 0.69 | 1.28 | 2.16 | 1.63 | 8.36 | $ 20.66 |
| Combine Dryland Corn | 1 | | 3.14 | 4.30 | 7.31 | 1.53 | 5.84 | 4.33 | 26.45 | $ 65.36 |
| Cart | 120.28 | bu | 1.72 | 0.67 | 0.67 | 1.10 | 2.11 | 0.65 | 6.92 | $ 17.10 |
| Truck | Custom | | | | | | | | | |
| Dry Grain | Custom | | | | | | | | | |
| **Total for Field Operations** | | | 11.83 | 7.71 | 10.56 | 8.96 | 16.01 | 13.55 | 68.62 | $ 169.56 |

| Materials & Services | | Operation Index | Percent Acres Applied | Application Rate | Unit | Applied Price | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|
| Glyphosate w/Surfactant | Herbicide | 1 | 100% | 68 | ounce | 0.12 | 7.97 | $ 19.69 |
| 2,4-D Ester LV4 | Herbicide | 1 | 100% | 0.5 | pint | 2.13 | 1.06 | $ 2.62 |
| 46-0-0 | Fertilizer | 2 | 100% | 125 | lbs N | 0.42 | 52.50 | $ 129.73 |
| Balance Flexx | Herbicide | 2 | 100% | 5 | ounce | 3.70 | 18.50 | $ 45.71 |
| Corn SmartStax RIB Complete | Seed | 3 | 100% | 26.4 | k seed | 3.75 | 99.00 | $ 244.63 |
| Atrazine 4L | Herbicide | 4 | 100% | 1 | quart | 3.25 | 3.25 | $ 8.03 |
| Laudis | Herbicide | 4 | 100% | 2.5 | ounce | 4.45 | 11.13 | $ 27.50 |
| Armezon Pro | Herbicide | 4 | 0% | 14 | ounce | 1.33 | 0.00 | $ - |
| Haul Grain Bushels | Custom | 8 | 100% | 120.28 | bushel | 0.11 | 13.23 | $ 32.69 |
| Dry 2 Points Removed | Custom | 9 | 10% | 120.28 | bushel | 0.08 | 0.96 | $ 2.37 |
| Scouting Dryland Corn | Scouting | | 100% | 1 | acre | 7.00 | 7.00 | $ 17.30 |
| | Crop Insurance | | | | | 25.00 | 25.00 | $ 61.78 |
| **Total Materials & Services** | | | | | | | 239.60 | $ 592.06 |

| | | | | | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|
| **Total listed costs for Field Operations and Materials and Services** | | | | | 308.22 | $ 761.63 |
| Interest on Operations Capital $ 278.66 | cash expense @ | | 5.50% | for 6.0 mo. | 7.66 | $ 18.94 |
| **Total Operating and Use Related Ownership Costs** | | | | | 315.88 | $ 780.56 |
| **Overhead** (accounting, liability insurance, vehicle cost, office expense) | | | | | 20.00 | $ 49.42 |
| Real Estate Opportunity | Dryland (State) | $ 3,100 | per acre @ | 3.00% | 93.00 | $ 229.81 |
| Real Estate Taxes | | $ 3,100 | per acre @ | 1.35% | 41.85 | $ 103.41 |
| **Total Cost per Acre Including Overhead** | | | | | 470.73 | $ 1,163.21 |
| **Total Cost with No Real Estate Opportunity Cost Per Acre** | | | | | 377.73 | $ 933.40 |
| **Revenue Per Acre** | | 120.28 bu per acre | @ | $3.55 per bu | 426.99 | $ 1,055.12 |
| | | $5 per acre | cornstalk rental rate | | 5.00 | $ 12.36 |
| **Total Revenue Per Acre** | | | | | 431.99 | $ 1,067.48 |
| **Return Above All Cost Per Acre** | | | | | -38.74 | $ (95.73) |
| **Return Above All Cost Except Real Estate Opportunity Per Acre** | | | | | 54.26 | $ 134.08 |

Source: https://cropwatch.unl.edu/budgets

**Continuous Corn 2019** UNL Crop Budgets 2019 21-Corn

| Field Operations | Times or Qty | Unit | Labor @ $20.00 /Hr | Fuel @ $2.49 and Lube | Repairs Power | Repairs Imp. | Ownership Power | Ownership Imp. | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|---|---|
| Spray Spring Burndown Herbicide | 1 | | 1.00 | 0.30 | 0.35 | 0.64 | 1.08 | 0.81 | 4.18 | $ 10.33 |
| Spread Fertilizer | 1 | | 1.57 | 0.87 | 0.68 | 0.00 | 2.12 | 0.00 | 5.24 | $ 12.95 |
| Plant No-Till | 1 | | 2.40 | 0.97 | 0.86 | 4.41 | 2.70 | 6.13 | 17.47 | $ 43.17 |
| Spray Herbicide | 1 | | 1.00 | 0.30 | 0.35 | 0.64 | 1.08 | 0.81 | 4.18 | $ 10.33 |
| Combine Dryland Corn | 1 | | 3.14 | 4.30 | 7.31 | 1.53 | 5.84 | 4.33 | 26.45 | $ 65.36 |
| Cart | 102.72 | bu | 1.47 | 0.57 | 0.58 | 0.94 | 1.80 | 0.55 | 5.91 | $ 14.60 |
| Truck | Custom | | | | | | | | | |
| Dry Grain | Custom | | | | | | | | | |
| **Total for Field Operations** | | | 10.58 | 7.31 | 10.13 | 8.16 | 14.62 | 12.63 | 63.43 | $ 156.74 |

| Materials & Services | | Operation Index | Percent Acres Applied | Application Rate | Application Unit | Applied Price | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|
| Glyphosate w/Surfactant | Herbicide | 1 | 100% | 56 | ounce | 0.12 | 6.56 | $ 16.21 |
| Acuron | Herbicide | 1 | 100% | 2 | quart | 15.00 | 30.00 | $ 74.13 |
| 46-0-0 | Fertilizer | 2 | 100% | 125 | lbs N | 0.42 | 52.50 | $ 129.73 |
| 2,4-D Ester LV4 | Herbicide | 2 | 100% | 0.333 | pint | 2.13 | 0.71 | $ 1.75 |
| Corn SmartStax RIB Complete | Seed | 3 | 100% | 26.4 | k seed | 3.75 | 99.00 | $ 244.63 |
| Laudis | Herbicide | 4 | 100% | 2.5 | ounce | 4.45 | 11.13 | $ 27.50 |
| Atrazine 4L | Herbicide | 4 | 100% | 0.25 | quart | 3.25 | 0.81 | $ 2.00 |
| Haul Grain Bushels | Custom | 8 | 100% | 102.72 | bushel | 0.11 | 11.30 | $ 27.92 |
| Dry 2 Points Removed | Custom | 9 | 10% | 102.72 | bushel | 0.08 | 0.82 | $ 2.03 |
| Scouting Dryland Corn | Scouting | | 100% | 1 | acre | 7.00 | 7.00 | $ 17.30 |
| | Crop Insurance | | | | | 25.00 | 25.00 | $ 61.78 |
| **Total Materials & Services** | | | | | | | 244.83 | $ 604.99 |

| | | Total per acre | Total per hectare |
|---|---|---|---|
| **Total listed costs for Field Operations and Materials and Services** | | 308.26 | $ 761.73 |
| Interest on Operations Capital $ 281.01 | cash expense @ 5.50% for 6.0 mo. | 7.73 | $ 19.10 |
| **Total Operating and Use Related Ownership Costs** | | 315.99 | $ 780.82 |
| **Overhead** (accounting, liability insurance, vehicle cost, office expense) | | 20.00 | $ 49.42 |
| Real Estate Opportunity | Dryland (State) $ 3,100 per acre @ 3.00% | 93.00 | $ 229.81 |
| Real Estate Taxes | $ 3,100 per acre @ 1.35% | 41.85 | $ 103.41 |
| **Total Cost per Acre Including Overhead** | | 470.84 | $ 1,163.46 |
| **Total Cost with No Real Estate Opportunity Cost Per Acre** | | 377.84 | $ 933.66 |
| **Revenue Per Acre** | 102.723 bu per acre @ $3.74 per bu | 384.18 | $ 949.34 |
| | $5 per acre cornstalk rental rate | 5.00 | $ 12.36 |
| **Total Revenue Per Acre** | | 389.18 | $ 961.69 |
| **Return Above All Cost Per Acre** | | -81.65 | $ (201.77) |
| **Return Above All Cost Except Real Estate Opportunity Per Acre** | | 11.35 | $ 28.04 |

Source: https://cropwatch.unl.edu/budgets

# B. Corn budget with machinery ownership for ICLS in 2018 and 2019.

**ICLS Corn 2018** UNL Crop Budgets 2019 21-Corn

| Field Operations | Times or Qty | Unit | Labor @ $20.00 /Hr | Fuel @ $2.49 and Lube | Repairs Power | Repairs Imp. | Ownership Power | Ownership Imp. | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|---|---|
| Spray Spring Burndown Herbicide | 1 | | 1.00 | 0.30 | 0.35 | 0.64 | 2.70 | 2.03 | 7.02 | $ 17.35 |
| Spread Fertilizer | 1 | | 1.57 | 0.87 | 0.68 | 0.00 | 2.12 | 0 | 5.24 | $ 12.95 |
| Plant No-Till | 1 | | 2.40 | 0.97 | 0.86 | 4.41 | 6.75 | 15.33 | 30.72 | $ 75.91 |
| Spray Herbicide | 2 | | 2.00 | 0.60 | 0.69 | 1.28 | 5.40 | 4.08 | 14.05 | $ 34.72 |
| Combine Dryland Corn | 1 | | 3.14 | 4.30 | 7.31 | 1.53 | 14.60 | 10.83 | 41.71 | $ 103.07 |
| Cart | 120.28 | bu | 1.72 | 0.67 | 0.67 | 1.10 | 5.28 | 1.63 | 11.06 | $ 27.33 |
| Truck | Custom | | | | | | | | | |
| Dry Grain | Custom | | | | | | | | | |
| **Total for Field Operations** | | | 11.83 | 7.71 | 10.56 | 8.96 | 36.85 | 33.88 | 109.80 | $ 271.32 |

| Materials & Services | | Operation Index | Percent Acres Applied | Application Rate | Unit | Applied Price | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|
| Glyphosate w/Surfactant | Herbicide | 1 | 100% | 68 | ounce | 0.12 | 7.97 | $ 19.69 |
| 2,4-D Ester LV4 | Herbicide | 1 | 100% | 0.5 | pint | 2.13 | 1.06 | $ 2.62 |
| 46-0-0 | Fertilizer | 2 | 100% | 125 | lbs N | 0.42 | 52.50 | $ 129.73 |
| Balance Flexx | Herbicide | 2 | 100% | 5 | ounce | 3.70 | 18.50 | $ 45.71 |
| Corn SmartStax RIB Complete | Seed | 3 | 100% | 26.4 | k seed | 3.75 | 99.00 | $ 244.63 |
| Atrazine 4L | Herbicide | 4 | 100% | 1 | quart | 3.25 | 3.25 | $ 8.03 |
| Laudis | Herbicide | 4 | 100% | 2.5 | ounce | 4.45 | 11.13 | $ 27.50 |
| Armezon Pro | Herbicide | 4 | 0% | 14 | ounce | 1.33 | 0.00 | $ - |
| Haul Grain Bushels | Custom | 8 | 100% | 120.28 | bushel | 0.11 | 13.23 | $ 32.69 |
| Dry 2 Points Removed | Custom | 9 | 10% | 120.28 | bushel | 0.08 | 0.96 | $ 2.37 |
| Scouting Dryland Corn | Scouting | | 100% | 1 | acre | 7.00 | 7.00 | $ 17.30 |
| | Crop Insurance | | | | | 25.00 | 25.00 | $ 61.78 |
| **Total Materials & Services** | | | | | | | 239.60 | $ 592.06 |

| | | per acre | per hectare |
|---|---|---|---|
| **Total listed costs for Field Operations and Materials and Services** | | 349.40 | $ 863.38 |
| Interest on Operations Capital | $ 278.66 cash expense @ 5.50% for 6.0 mo. | 7.66 | $ 18.94 |
| **Total Operating and Use Related Ownership Costs** | | 357.06 | $ 882.32 |
| **Overhead** (accounting, liability insurance, vehicle cost, office expense) | | 20.00 | $ 49.42 |
| Real Estate Opportunity | Dryland (State) $ 3,100 per acre @ 3.00% | 93.00 | $ 229.81 |
| Real Estate Taxes | $ 3,100 per acre @ 1.35% | 41.85 | $ 103.41 |
| **Total Cost per Acre Including Overhead** | | 511.91 | $ 1,264.96 |
| **Total Cost with No Real Estate Opportunity Cost Per Acre** | | 418.91 | $ 1,035.16 |
| **Revenue Per Acre** | 120.28 bu per acre @ $3.55 per bu | 426.99 | $ 1,055.12 |
| | $5 per acre cornstalk rental rate | 5.00 | $ 12.36 |
| **Total Revenue Per Acre** | | 431.99 | $ 1,067.48 |
| **Return Above All Cost Per Acre** | | -79.92 | $ (197.48) |
| **Return Above All Cost Except Real Estate Opportunity Per Acre** | | 13.08 | $ 32.32 |

Source: https://cropwatch.unl.edu/budgets

Ownership costs of machinery are increased by 2.5x to reflect 60% less land planted to corn

**ICLS Corn 2019** UNL Crop Budgets 2019 21-Corn

| Field Operations | Times or Qty | Unit | Labor @ $20.00 /Hr | Fuel @ $2.49 and Lube | Repairs Power | Repairs Imp. | Ownership Power | Ownership Imp. | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|---|---|
| Spray Spring Burndown Herbicide | 1 | | 1.00 | 0.30 | 0.35 | 0.64 | 2.70 | 2.03 | 7.02 | $ 17.35 |
| Spread Fertilizer | 1 | | 1.57 | 0.87 | 0.68 | 0.00 | 2.12 | 0.00 | 5.24 | $ 12.95 |
| Plant No-Till | 1 | | 2.40 | 0.97 | 0.86 | 4.41 | 6.75 | 15.33 | 30.72 | $ 75.91 |
| Spray Herbicide | 1 | | 1.00 | 0.30 | 0.35 | 0.64 | 2.70 | 2.03 | 7.02 | $ 17.35 |
| Combine Dryland Corn | 1 | | 3.14 | 4.30 | 7.31 | 1.53 | 14.60 | 10.83 | 41.71 | $ 103.07 |
| Cart | 102.72 | bu | 1.47 | 0.57 | 0.58 | 0.94 | 4.50 | 1.38 | 9.44 | $ 23.33 |
| Truck | Custom | | | | | | | | | |
| Dry Grain | Custom | | | | | | | | | |
| **Total for Field Operations** | | | 10.58 | 7.31 | 10.13 | 8.16 | 33.37 | 31.58 | 101.15 | $ 249.95 |

| Materials & Services | | Operation Index | Percent Acres Applied | Application Rate | Unit | Applied Price | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|
| Glyphosate w/Surfactant | Herbicide | 1 | 100% | 56 | ounce | 0.12 | 6.56 | $ 16.21 |
| Acuron | Herbicide | 1 | 100% | 2 | quart | 15.00 | 30.00 | $ 74.13 |
| 46-0-0 | Fertilizer | 2 | 100% | 125 | lbs N | 0.42 | 52.50 | $ 129.73 |
| 2,4-D Ester LV4 | Herbicide | 2 | 100% | 0.333 | pint | 2.13 | 0.71 | $ 1.75 |
| Corn SmartStax RIB Complete | Seed | 3 | 100% | 26.4 | k seed | 3.75 | 99.00 | $ 244.63 |
| Laudis | Herbicide | 4 | 100% | 2.5 | ounce | 4.45 | 11.13 | $ 27.50 |
| Atrazine 4L | Herbicide | 4 | 100% | 0.25 | quart | 3.25 | 0.81 | $ 2.00 |
| Haul Grain Bushels | Custom | 8 | 100% | 102.72 | bushel | 0.11 | 11.30 | $ 27.92 |
| Dry 2 Points Removed | Custom | 9 | 10% | 102.72 | bushel | 0.08 | 0.82 | $ 2.03 |
| Scouting Dryland Corn | Scouting | | 100% | 1 | acre | 7.00 | 7.00 | $ 17.30 |
| | Crop Insurance | | | | | 25.00 | 25.00 | $ 61.78 |
| **Total Materials & Services** | | | | | | | 244.83 | $ 604.99 |

| | | | | | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|
| **Total listed costs for Field Operations and Materials and Services** | | | | | 345.98 | $ 854.93 |
| Interest on Operations Capital | $ 281.01 | cash expense @ | 5.50% | for 6.0 mo. | 7.73 | $ 19.10 |
| **Total Operating and Use Related Ownership Costs** | | | | | 353.71 | $ 874.03 |
| **Overhead** (accounting, liability insurance, vehicle cost, office expense) | | | | | 20.00 | $ 49.42 |
| Real Estate Opportunity | Dryland (State) | $ 3,100 | per acre @ | 3.00% | 93.00 | $ 229.81 |
| Real Estate Taxes | | $ 3,100 | per acre @ | 1.35% | 41.85 | $ 103.41 |
| **Total Cost per Acre Including Overhead** | | | | | 508.56 | $ 1,256.67 |
| **Total Cost with No Real Estate Opportunity Cost Per Acre** | | | | | 415.56 | |
| **Revenue Per Acre** | | 102.723 bu per acre | @ | $3.74 per bu | 384.18 | |
| | | $5 per acre | cornstalk rental rate | | 5.00 | $ 12.36 |
| **Total Revenue Per Acre** | | | | | 389.18 | $ 961.69 |
| **Return Above All Cost Per Acre** | | | | | -119.37 | $ (294.98) |
| **Return Above All Cost Except Real Estate Opportunity Per Acre** | | | | | -26.37 | $ (65.17) |

Source: https://cropwatch.unl.edu/budgets

Ownership costs of machinery are increased by 2.5x to reflect 60% less land planted to corn

C. Corn budget with custom farming in 2018 and 2019.

| Custom Rate Corn Budget 2018 | | | | | |
|---|---|---|---|---|---|
| Source | Services | Times or Quantity | Custom Rate | Total per Acre | Total per Hectare |
| 1 | Spray Spring Burndown Herbicide | 1 | 7.16 | 7.16 | 17.69 |
| 2 | Spread Fertilizer | 1 | 5.70 | 5.70 | 14.08 |
| 3 | Plant No-Till | 1 | 19.95 | 19.95 | 49.30 |
| 1 | Spray Herbicide | 2 | 7.16 | 14.32 | 35.39 |
| 4 | Combine | 1 | 36.00 | 36.00 | 88.96 |
| 5 | Haul Grain | 1 | 13.23 | 13.23 | 32.69 |
| 5 | Dry Grain (10% of total acres) | 1 | 0.96 | 0.96 | 2.37 |
| 5 | Crop Insurance | 1 | 25.00 | 25.00 | 61.78 |
| 5 | Scouting | 1 | 7.00 | 7.00 | 17.30 |
| | | | **Total Services:** | 129.32 | 319.56 |
| | **Materials** | **Application Rate per Acre** | **Rate per Unit** | **Total per Acre** | **Total per Hectare** |
| 5 | Glyphosate w/Surfactant | 68 fl oz | 0.12 | 7.97 | 19.69 |
| 5 | 2,4-D Ester LV4 | 0.5 pint | 2.13 | 1.06 | 2.62 |
| 5 | 46-0-0 | 125 lb of N | 0.42 | 52.50 | 129.73 |
| 5 | Balance Flexx | 5 fl oz | 3.7 | 18.50 | 45.71 |
| 5 | Corn SmartStax RIB Complete | 26,400 seeds | 3.75 | 99.00 | 244.63 |
| 5 | Atrazine 4L | 1 quart | 3.25 | 3.25 | 8.03 |
| 5 | Laudis | 2.5 fl oz | 4.45 | 11.13 | 27.50 |
| | | | **Total Materials:** | 193.41 | 477.93 |
| | **Total costs for materials & Services:** | | | 322.73 | 797.48 |
| 5 | Interest on Operations Capital | | 5.5% for 6 mos | 8.88 | 21.93 |
| | | | **Total Operating Expenses:** | 331.61 | 819.41 |
| 5 | Overhead | | | 20.00 | 49.42 |
| 5 | Real Estate Opportunity | $3100 per acre at 3% | | 93.00 | 229.81 |
| 5 | Real Estate Taxes | $3100 per acre at 1.35% | | 41.85 | 103.41 |
| | | | **Total Cost Including Overhead:** | 486.46 | 1202.05 |
| | | **Total Cost with No Real Estate Opportunity Cost:** | | 393.46 | 972.25 |
| | **Revenue** | **Unit** | **Price per Unit** | **Total per Acre** | **Total per Hectare** |
| | 120.28 | bu | 3.55 | 426.99 | 1055.12 |
| | 1 | ac | 5 | 5.00 | 12.36 |
| | | | **Total Revenue:** | 431.99 | 1067.48 |
| | | | **Return Above All Cost:** | -54.46 | -134.58 |
| | | **Return Above All Cost Except** | **Real Estate Opportunity:** | **38.54** | **95.23** |

[1] Spraying Weed Control, boom, rate per acre
Average Rate for Eastern NE Custom Rate Survey 2018
[2] Dry Fertilizer Solid Broadcast, including power, labor & applicator, rate per acre
Average Rate for Eastern NE Custom Rate Survey 2018
[3] Planting Row Crops, no coulters or row cleaning devices, includes no-till, without band applicator, rate per acre
Average Rate for Eastern NE Custom Rate Survey 2018
[4] Combining Dryland Corn, flat rate per acre
Average Rate for Eastern NE Custom Rate Survey 2018
[5] Based on 2019 UNL Crop Budgets
Budget 21-No Till, Continuous Dryland Corn
Herbicide products and rates are the actual applied to the ICLS demonstration site

## Custom Rate Corn Budget 2019

| Source | Services | Times or Quantity | Custom Rate | Total per Acre | Total per Hectare |
|---|---|---|---|---|---|
| 1 | Spray Spring Burndown Herbicide | 1 | 7.16 | 7.16 | 17.69 |
| 2 | Spread Fertilizer | 1 | 5.70 | 5.70 | 14.08 |
| 3 | Plant No-Till | 1 | 19.95 | 19.95 | 49.30 |
| 1 | Spray Herbicide | 1 | 7.16 | 7.16 | 17.69 |
| 4 | Combine | 1 | 36.00 | 36.00 | 88.96 |
| 5 | Haul Grain | 1 | 11.30 | 11.30 | 27.92 |
| 5 | Dry Grain (10% of total acres) | 1 | 0.82 | 0.82 | 2.03 |
| 5 | Crop Insurance | 1 | 25.00 | 25.00 | 61.78 |
| 5 | Scouting | 1 | 7.00 | 7.00 | 17.30 |
| | | | **Total Services:** | 120.09 | 296.75 |

| Source | Materials | Application Rate per Acre | Rate per Unit | Total per Acre | Total per Hectare |
|---|---|---|---|---|---|
| 5 | Glyphosate w/Surfactant | 56 fl oz | 0.12 | 6.56 | 16.21 |
| 5 | 2,4-D Ester LV4 | 0.33 pt | 2.13 | 0.71 | 1.75 |
| 5 | 46-0-0 | 125 lb of N | 0.42 | 52.50 | 129.73 |
| 5 | Acuron | 2 quarts | 15 | 30.00 | 74.13 |
| 5 | Corn SmartStax RIB Complete | 26,400 seeds | 3.75 | 99.00 | 244.63 |
| 5 | Atrazine 4L | 0.25 quart | 3.25 | 0.81 | 2.00 |
| 5 | Laudis | 2.5 fl oz | 4.45 | 11.13 | 27.50 |
| | | | **Total Materials:** | 200.71 | 495.96 |

| Source | Item | | | Total per Acre | Total per Hectare |
|---|---|---|---|---|---|
| | **Total costs for materials & Services:** | | | 320.80 | 792.71 |
| 5 | Interest on Operations Capital | | 5.5% for 6 mos | 8.82 | 21.80 |
| | | | **Total Operating Expenses:** | 329.62 | 814.51 |
| 5 | Overhead | | | 20.00 | 49.42 |
| 5 | Real Estate Opportunity | $3100 per acre at 3% | | 93.00 | 229.81 |
| 5 | Real Estate Taxes | $3100 per acre at 1.35% | | 41.85 | 103.41 |
| | | | **Total Cost Including Overhead:** | 484.47 | 1197.15 |
| | | **Total Cost with No Real Estate Opportunity Cost:** | | 391.47 | 967.35 |

| Revenue | Unit | Price per Unit | Total per Acre | Total per Hectare |
|---|---|---|---|---|
| 102.723 | bu | 3.74 | 384.18 | 949.34 |
| 1 | ac | 5 | 5.00 | 12.36 |
| | | **Total Revenue:** | 389.18 | 961.69 |
| | | **Return Above All Cost:** | -95.29 | -235.46 |
| | **Return Above All Cost Except** | **Real Estate Opportunity:** | **-2.29** | **-5.65** |

[1] Spraying Weed Control, boom, rate per acre
Average Rate for Eastern NE Custom Rate Survey 2018

[2] Dry Fertilizer Solid Broadcast, including power, labor & applicator, rate per acre
Average Rate for Eastern NE Custom Rate Survey 2018

[3] Planting Row Crops, no coulters or row cleaning devices, includes no-till, without band applicator, rate per acre
Average Rate for Eastern NE Custom Rate Survey 2018

[4] Combining Dryland Corn, flat rate per acre
Average Rate for Eastern NE Custom Rate Survey 2018

[5] Based on 2019 UNL Crop Budgets
Budget 21-No Till, Continuous Dryland Corn
Herbicide products and rates are the actual applied to the ICLS demonstration site

D. Pasture amortized establishment costs over a 30 year useful life.

| 'Newell' Smooth Bromegrass Pasture Establishment | | 'Shawnee' & 'Liberty' Switchgrass Pasture Establishment | |
|---|---|---|---|
| [1] Seeding Rate (Kg Ha$^{-1}$) | 5.6 | [1] Seeding Rate (Kg Ha$^{-1}$) | 5.0 |
| [1] Seed Cost ($ Kg$^{-1}$ ) | 22.04 | [1] Seed Cost ($ Kg$^{-1}$ ) | 33.06 |
| **Seeding Cost per Hectare** | **$ 123.55** | **Seeding Cost per Hectare** | **$ 166.80** |
| | **$ ha$^{-1}$** | | **$ ha$^{-1}$** |
| [1] Custom Planting | 39.66 | [1] Custom Planting | 39.66 |
| [1] Pre Herbicide | 16.61 | [1] Pre Herbicide | 16.61 |
| [1] Post Herbicide | 15.81 | [1] Post Herbicide | 15.81 |
| [1] Custom Spray | 37.31 | [1] Custom Spray | 37.31 |
| [1] Interest | 7.76 | [1] Interest | 9.22 |
| [2] Land Charge | 103.41 | [2] Land Charge | 103.41 |
| [3] Water Development | 263.54 | [3] Water Development | 263.54 |
| [4] Fencing | 423.29 | [4] Fencing | 423.29 |
| **Total Cost of Establishment per Hectare** | **$ 1,030.95** | **Total Cost of Establishment per Hectare** | **$ 1,075.65** |
| Assumed Pasture Life (years) | 30 | Assumed Pasture Life (years) | 30 |
| Interest Rate (%) | 5.5 | Interest Rate (%) | 5.5 |
| **Yearly Establishment Cost per Hectare** | **$ 70.93** | **Yearly Establishment Cost per Hectare** | **$ 74.01** |

**Sources**

[1] ISU Ag Decision Maker Converting Cropland to Switchgrass
[2] UNL Crop Budgets, land value $3,100 @ 1.35%
[3] Big Bluestem Pasture in the Great Plains: An Alternative for Dryland Corn
Rob Mitchell, Ken Vogel, Gary Varvel, Terry Klopfenstein, Dick Clark, Bruce Anderson
120 foot well, tank, and solar power
[4] 2018 UNL Custom Rate Survey State Average for Fencing Cost
$9,136 per mile of fence. Cost is based on fencing an 80 acre pasture

E. Newell smooth bromegrass pasture management cost.

| Yearly Management | | | |
|---|---|---|---|
| | **$ ac$^{-1}$** | **$ ha$^{-1}$** | |
| Fertilizer Application | $ 5.00 | $ 12.35 | ISU Ag Decision Maker Converting Cropland to Switchgrass |
| Fertilizer | $ 22.00 | $ 54.34 | ISU Ag Decision Maker Converting Cropland to Switchgrass |
| Interest on Operating Costs | $ 0.90 | $ 2.22 | ISU Ag Decision Maker Converting Cropland to Switchgrass |
| Land Taxes | $ 41.85 | $ 103.37 | |
| **Total costs** | $ 69.75 | $ 172.28 | |

F. Steer budget for Newell-Liberty-Newell grazing system in 2018 and 2019.

**Newell-Liberty-Newell System 2018**

| | | |
|---|---|---|
| **Expenses** | | |
| [1] Average Purchase Weight of Cattle (Kg) | | 392 |
| [2] Price $ kg$^{-1}$ | | 2.99 |
| [3] Number of Cattle | | 9 |
| [3] Hectares of Pasture Grazed | | 6 |
| **Cost of Buying Stockers per Hectare** | **$** | **1,738.01** |
| [4] Interest for Purchasing Cattle @8% for 4 mos | | 46.35 |
| [5] Labor | | 16.65 |
| [5] Vet | | 7.81 |
| [6] Mineral | | 9.04 |
| [7] Transportation | | 13.17 |
| [5] Marketing | | 5.31 |
| **Additional Cost with Owning Yearlings per Hectare** | **$** | **98.34** |
| [8] Amoritized Establishment Cost per Hectare *(weighted average, 4 hectares of switchgrass & 2 hectares of smooth bromegrass)* | | 72.99 |
| [9] Fertilizer per Hectare | | 54.36 |
| [9] Spread Fertilizer per Hectare | | 12.36 |
| [9] Interest on Operating Capital per Hectare | | 2.22 |
| [10] Real Estate Tax per Hectare | | 103.41 |
| **Cost of Pasture per Hectare** | **$** | **245.35** |
| **Total Cost of System per Hectare** | **$** | **2,081.70** |
| **Revenue** | | |
| [1] Average Selling Weight of Cattle (Kg) | | 447 |
| [2] Price $ kg$^{-1}$ | | 3.27 |
| [3] Number of Cattle | | 9 |
| [3] Hectares of Pasture Grazed | | 6 |
| **Total Revenue Per Hectare** | **$** | **2,167.52** |
| **Net Profit per Hectare** | **$** | **85.82** |

**Sources**

[1] Actual average weight of the cattle at the beginning of grazing in May and at the conclusion of grazing in September from the field-scale model demonstration site

[2] Average cattle market price in NE on the date bought or sold (when they went on and off pasture) price data from LMCI

[3] Number of cattle used to graze the system and number of hectares in the actual system

[4] ISU Stocker Cattle Budget

[5] Average cost (2008-2018) in Nebraska, South Dakota, and North Dakota. Reported from FINBIN University of Minnesota

[6] Cost of mineral fed in the field-scale model demonstration site. 2 oz per head per day

[7] UNL 2018 Custom Rate Survey for hauling cattle using a gooseneck trailer. Based on 10 miles from the Eastern Nebraska Research and Extension to Wahoo Livestock Sales

[8] See establishment cost tables

[9] ISU Ag Decision Maker Converting Cropland to Switchgrass

[10] UNL Crop Budgets, land value $3,100 @ 1.35%

## Newell-Liberty-Newell System 2019

| | | |
|---|---|---|
| **Expenses** | | |
| [1] Average Purchase Weight of Cattle (Kg) | | 288 |
| [2] Price $ $kg^{-1}$ | | 3.81 |
| [3] Number of Cattle | | 9 |
| [3] Hectares of Pasture Grazed | | 6 |
| **Cost of Buying Stockers per Hectare** | **$** | **1,626.30** |
| [4] Interest for Purchasing Cattle @8% for 4 mos | | 43.37 |
| [5] Labor | | 16.65 |
| [5] Vet | | 7.81 |
| [6] Mineral | | 9.49 |
| [7] Transportation | | 13.17 |
| [5] Marketing | | 5.31 |
| **Additional Cost with Owning Yearlings per Hectare** | **$** | **95.80** |
| [8] Amoritized Establishment Cost per Hectare *(weighted average, 4 hectares of switchgrass & 2 hectares of smooth bromegrass)* | | 72.99 |
| [9] Fertilizer per Hectare | | 54.36 |
| [9] Spread Fertilizer per Hectare | | 12.36 |
| [9] Interest on Operating Capital per Hectare | | 2.22 |
| [10] Real Estate Tax per Hectare | | 103.41 |
| **Cost of Pasture per Hectare** | **$** | **245.35** |
| **Total Cost of System per Hectare** | **$** | **1,967.45** |
| **Revenue** | | |
| [1] Average Selling Weight of Cattle (Kg) | | 386.12 |
| [2] Price $ $kg^{-1}$ | | 3.26 |
| [3] Number of Cattle | | 9 |
| [3] Hectares of Pasture Grazed | | 6 |
| **Total Revenue Per Hectare** | **$** | **1,863.94** |
| **Net Profit per Hectare** | **$** | **(103.51)** |

**Sources**

[1] Actual average weight of the cattle at the beginning of grazing in May and at the conclusion of grazing in September from the field-scale model demonstration site

[2] Average cattle market price in NE on the date bought or sold (when they went on and off pasture) price data from LMCI

[3] Number of cattle used to graze the system and number of hectares in the actual system

[4] ISU Stocker Cattle Budget

[5] Average cost (2008-2018) in Nebraska, South Dakota, and North Dakota. Reported from FINBIN University of Minnesota

[6] Cost of mineral fed in the field-scale model demonstration site. 2 oz per head per day

[7] UNL 2018 Custom Rate Survey for hauling cattle using a gooseneck trailer. Based on 10 miles from the Eastern Nebraska Research and Extension to Wahoo Livestock Sales

[8] See establishment cost tables

[9] ISU Ag Decision Maker Converting Cropland to Switchgrass

[10] UNL Crop Budgets, land value $3,100 @ 1.35%

G. Steer budget for Newell-Shawnee-Newell grazing system in 2018 and 2019.

## Newell-Shawnee-Newell System 2018

| | | | |
|---|---|---|---|
| **Expenses** | | | |
| [1] | Average Purchase Weight of Cattle (Kg) | | 395 |
| [2] | Price \$ kg$^{-1}$ | | 2.99 |
| [3] | Number of Cattle | | 9 |
| [3] | Hectares of Pasture Grazed | | 6 |
| | **Cost of Buying Stockers per Hectare** | **\$** | **1,750.07** |
| [4] | Interest for Purchasing Cattle @8% for 4 mos | | 46.67 |
| [5] | Labor | | 16.65 |
| [5] | Vet | | 7.81 |
| [6] | Mineral | | 9.04 |
| [7] | Transportation | | 13.17 |
| [5] | Marketing | | 5.31 |
| | **Additional Cost with Owning Yearlings per Hectare** | **\$** | **98.66** |
| [8] | Amoritized Establishment Cost per Hectare | | 72.99 |
| | *(weighted average, 4 hectares of switchgrass & 2 hectares of smooth bromegrass)* | | |
| [9] | Fertilizer per Hectare | | 54.36 |
| [9] | Spread Fertilizer per Hectare | | 12.36 |
| [9] | Interest on Operating Capital per Hectare | | 2.22 |
| [10] | Real Estate Tax per Hectare | | 103.41 |
| | **Cost of Pasture per Hectare** | **\$** | **245.35** |
| | **Total Cost of System per Hectare** | **\$** | **2,094.08** |
| **Revenue** | | | |
| [1] | Average Selling Weight of Cattle (Kg) | | 471 |
| [2] | Price \$ kg$^{-1}$ | | 3.29 |
| [3] | Number of Cattle | | 9 |
| [3] | Hectares of Pasture Grazed | | 6 |
| | **Total Revenue Per Hectare** | **\$** | **2,296.97** |
| **Net Profit per Hectare** | | **\$** | **202.89** |

**Sources**

[1] Actual average weight of the cattle at the beginning of grazing in May and at the conclusion of grazing in September from the field-scale model demonstration site

[2] Average cattle market price in NE on the date bought or sold (when they went on and off pasture) price data from LMCI

[3] Number of cattle used to graze the system and number of hectares in the actual system

[4] ISU Stocker Cattle Budget

[5] Average cost (2008-2018) in Nebraska, South Dakota, and North Dakota. Reported from FINBIN University of Minnesota

[6] Cost of mineral fed in the field-scale model demonstration site. 2 oz per head per day

[7] UNL 2018 Custom Rate Survey for hauling cattle using a gooseneck trailer. Based on 10 miles from the Eastern Nebraska Research and Extension to Wahoo Livestock Sales

[8] See establishment cost tables

[9] ISU Ag Decision Maker Converting Cropland to Switchgrass

[10] UNL Crop Budgets, land value \$3,100 @ 1.35%

## Newell-Shawnee-Newell System 2019

| | |
|---|---|
| **Expenses** | |
| [1] Average Purchase Weight of Cattle (Kg) | 289 |
| [2] Price $ kg$^{-1}$ | 3.81 |
| [3] Number of Cattle | 9 |
| [3] Hectares of Pasture Grazed | 6 |
| **Cost of Buying Stockers per Hectare** | **$1,633.98** |
| [4] Interest for Purchasing Cattle @8% for 4 mos | 43.57 |
| [5] Labor | 16.65 |
| [5] Vet | 7.81 |
| [6] Mineral | 9.49 |
| [7] Transportation | 13.17 |
| [5] Marketing | 5.31 |
| **Additional Cost with Owning Yearlings per Hectare** | **$ 96.01** |
| [8] Amoritized Establishment Cost per Hectare | 72.99 |
| *(weighted average, 4 hectares of switchgrass & 2 hectares of smooth bromegrass)* | |
| [9] Fertilizer per Hectare | 54.36 |
| [9] Spread Fertilizer per Hectare | 12.36 |
| [9] Interest on Operating Capital per Hectare | 2.22 |
| [10] Real Estate Tax per Hectare | 103.41 |
| **Cost of Pasture per Hectare** | **$ 245.35** |
| **Total Cost of System per Hectare** | **$1,975.34** |
| **Revenue** | |
| [1] Average Selling Weight of Cattle (Kg) | 372 |
| [2] Price $ kg$^{-1}$ | 3.26 |
| [3] Number of Cattle | 9 |
| [3] Hectares of Pasture Grazed | 6 |
| **Total Revenue Per Hectare** | **$1,796.04** |
| **Net Profit per Hectare** | **$ (179.30)** |

**Sources**

1. Actual average weight of the cattle at the beginning of grazing in May and at the conclusion of grazing in September from the field-scale model demonstration site
2. Average cattle market price in NE on the date bought or sold (when they went on and off pasture) price data from LMCI
3. Number of cattle used to graze the system and number of hectares in the actual system
4. ISU Stocker Cattle Budget
5. Average cost (2008-2018) in Nebraska, South Dakota, and North Dakota. Reported from FINBIN University of Minnesota
6. Cost of mineral fed in the field-scale model demonstration site. 2 oz per head per day
7. UNL 2018 Custom Rate Survey for hauling cattle using a gooseneck trailer. Based on 10 miles from the Eastern Nebraska Research and Extension to Wahoo Livestock Sales
8. See establishment cost tables
9. ISU Ag Decision Maker Converting Cropland to Switchgrass
10. UNL Crop Budgets, land value $3,100 @ 1.35%

# H. Cost of hay production with ownership of machinery for 2018 and 2019.

**Liberty 2018** UNL Crop Budgets 2019 48-Grass Hay

Operations & Materials Cost

| Field Operations | Times or Qty | Unit | Labor @ $20.00 /Hr | Fuel @ $2.49 and Lube | Repairs Power | Repairs Imp. | Ownership Power | Ownership Imp. | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|---|---|
| Swath/Condition Hay | 1 | | 2.00 | 1.43 | 2.31 | 0.00 | 3.33 | 0.00 | $ 9.07 | $ 22.41 |
| Bale Large Round | 1.05 | ton | 2.31 | 0.86 | 0.91 | 1.13 | 2.83 | 1.09 | $ 9.13 | $ 22.56 |
| Move Large Round | 1.05 | ton | 1.16 | 0.60 | 0.45 | 0.00 | 1.42 | 0.06 | $ 3.69 | $ 9.12 |
| **Total for Field Operations** | | | 5.47 | 2.89 | 3.67 | 1.13 | 7.58 | 1.15 | $ 21.89 | $ 54.09 |

| Materials & Services | | Operation Index | Percent Acres Applied | Application Rate | Unit | Applied Price | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|
| Twine Large Round | Other | 3 | 100% | 1.05 | ton | 0.91 | $ 0.96 | $ 2.37 |
| **Total Materials & Services** | | | | | | | $ 0.96 | $ 2.37 |

| | | | | | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|
| **Total listed costs for Field Operations and Materials and Services** | | | | | $ 22.85 | $ 56.46 |
| Interest on Operations Capital | $ 14.12 | cash expense @ | 5.50% | for 6.0 mo. | $ 0.39 | $ 0.96 |
| **Total Operating and Use Related Ownership Costs** | | | | | $ 23.24 | $ 57.42 |

**Liberty 2019** UNL Crop Budgets 2019 48-Grass Hay

Operations & Materials Cost

| Field Operations | Times or Qty | Unit | Labor @ $20.00 /Hr | Fuel @ $2.49 and Lube | Repairs Power | Repairs Imp. | Ownership Power | Ownership Imp. | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|---|---|
| Swath/Condition Hay | 1 | | 2.00 | 1.43 | 2.31 | 0.00 | 3.33 | 0.00 | 9.07 | $ 22.41 |
| Bale Large Round | 0.9788 | ton | 2.15 | 0.81 | 0.85 | 1.05 | 2.64 | 1.01 | 8.51 | $ 21.03 |
| Move Large Round | 0.9788 | ton | 1.08 | 0.56 | 0.42 | 0.00 | 1.32 | 0.05 | 3.43 | $ 8.48 |
| **Total for Field Operations** | | | 5.23 | 2.80 | 3.58 | 1.05 | 7.29 | 1.06 | 21.01 | $ 51.92 |

| Materials & Services | | Operation Index | Percent Acres Applied | Application Rate | Unit | Applied Price | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|
| Twine Large Round | Other | 3 | 100% | 0.9788 | ton | 0.91 | 0.89 | $ 2.20 |
| **Total Materials & Services** | | | | | | | 0.89 | $ 2.20 |

| | | | | | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|
| **Total listed costs for Field Operations and Materials and Services** | | | | | 21.90 | $ 54.12 |
| Interest on Operations Capital | $ 13.55 | cash expense @ | 5.50% | for 6.0 mo. | 0.37 | $ 0.92 |
| **Total Operating and Use Related Ownership Costs** | | | | | 22.27 | $ 55.04 |

**Shawnee 2018** UNL Crop Budgets 2019 48-Grass Hay

Operations & Materials Cost

| Field Operations | Times or Qty | Unit | Labor @ $20.00 /Hr | Fuel @ $2.49 and Lube | Repairs Power | Repairs Imp. | Ownership Power | Ownership Imp. | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|---|---|
| Swath/Condition Hay | 1 | | 2.00 | 1.43 | 2.31 | 0.00 | 3.33 | 0.00 | 9.07 | $ 22.41 |
| Bale Large Round | 0.525 | ton | 1.16 | 0.43 | 0.45 | 0.56 | 1.42 | 0.54 | 4.56 | $ 11.27 |
| Move Large Round | 0.525 | ton | 0.58 | 0.30 | 0.23 | 0.00 | 0.71 | 0.03 | 1.85 | $ 4.57 |
| **Total for Field Operations** | | | 3.74 | 2.16 | 2.99 | 0.56 | 5.46 | 0.57 | 15.48 | $ 38.25 |

| Materials & Services | | Operation Index | Percent Acres Applied | Application Rate | Unit | Applied Price | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|
| Twine Large Round | Other | 3 | 100% | 0.525 | ton | 0.91 | 0.48 | $ 1.19 |
| **Total Materials & Services** | | | | | | | 0.48 | $ 1.19 |

| | | | | | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|
| **Total listed costs for Field Operations and Materials and Services** | | | | | 15.96 | $ 39.44 |
| Interest on Operations Capital | $ 9.93 | cash expense @ | 5.50% | for 6.0 mo. | 0.27 | $ 0.67 |
| **Total Operating and Use Related Ownership Costs** | | | | | 16.23 | $ 40.11 |

**Shawnee 2019** UNL Crop Budgets 2019 48-Grass Hay

Operations & Materials Cost

| Field Operations | Times or Qty | Unit | Labor @ $20.00 /Hr | Fuel @ $2.49 and Lube | Repairs Power | Repairs Imp. | Ownership Power | Ownership Imp. | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|---|---|
| Swath/Condition Hay | 1 | | 2.00 | 1.43 | 2.31 | 0.00 | 3.33 | 0.00 | 9.07 | $ 22.41 |
| Bale Large Round | 0.4725 | ton | 1.04 | 0.39 | 0.41 | 0.51 | 1.27 | 0.49 | 4.11 | $ 10.16 |
| Move Large Round | 0.4725 | ton | 0.52 | 0.27 | 0.20 | 0.00 | 0.64 | 0.03 | 1.66 | $ 4.10 |
| **Total for Field Operations** | | | 3.56 | 2.09 | 2.92 | 0.51 | 5.24 | 0.52 | 14.84 | $ 36.67 |

| Materials & Services | | Operation Index | Percent Acres Applied | Application Rate | Application Unit | Applied Price | Total per acre | Total per hectare |
|---|---|---|---|---|---|---|---|---|
| Twine Large Round | Other | 3 | 100% | 0.4725 | ton | 0.91 | 0.43 | $ 1.06 |
| **Total Materials & Services** | | | | | | | 0.43 | $ 1.06 |

| | | | | |
|---|---|---|---|---|
| **Total listed costs for Field Operations and Materials and Services** | | | 15.27 | $ 37.73 |
| Interest on Operations Capital $ 9.51 | cash expense @ | 5.50% for 6.0 mo. | 0.26 | $ 0.65 |
| **Total Operating and Use Related Ownership Costs** | | | 15.53 | $ 38.38 |

I. Custom rate hay budgets for 2018 and 2019.

**Shawnee Hay 2018**

| Source | Services | | Custom Rate | Total per Acre | Total per Hectare |
|---|---|---|---|---|---|
| 1 | Mowing & Raking | | 17.60 | 17.60 | 43.49 |
| 2 | Bale | | 9.49 | 9.49 | 23.46 |
| 3 | Move | | 2.00 | 2.00 | 4.93 |
| | | | **Total Cost of Hay:** | 29.09 | 71.88 |
| | **Revenue** | **Unit** | **Price per Unit** | **Total per Acre** | **Total per Hectare** |
| 4 | | 0.525 ton per acre | 70 | 36.75 | 90.81 |
| | | | **Return:** | **7.66** | **18.94** |

[1] Mowing and Raking (Where one rate is quoted or contracted.), rate per acre
State Average UNL 2018 Custom Rate Survey
[2] Baling Large Round Bales Without Net Wrap (average lbs/bale = 1432), based on $13.56 per bale
State Average UNL 2018 Custom Rate Survey
[3] Lifting and Moving Large Round Bales With Tractor (average distance = 1.54 miles), based on $2.85 per bale
State Average UNL 2018 Custom Rate Survey
[4] Yield from ICLS Model Demonstration Site
Hay Price is NE Average in November & December for Fair Grass Hay Large Round Bales
USDA AMS Custom Report Data

**Shawnee Hay 2019**

| Source | Services | | Custom Rate | Total per Acre | Total per Hectare |
|---|---|---|---|---|---|
| 1 | Mowing & Raking | | 17.60 | 17.60 | 43.49 |
| 2 | Bale | | 9.49 | 9.49 | 23.46 |
| 3 | Move | | 2.00 | 2.00 | 4.93 |
| | | | **Total Cost of Hay:** | 29.09 | 71.88 |
| | **Revenue** | **Unit** | **Price per Unit** | **Total per Acre** | **Total per Hectare** |
| 4 | | 0.4725 ton per acre | 80.42 | 38.00 | 93.90 |
| | | | **Return:** | **8.91** | **22.02** |

[1] Mowing and Raking (Where one rate is quoted or contracted.), rate per acre
State Average UNL 2018 Custom Rate Survey
[2] Baling Large Round Bales Without Net Wrap (average lbs/bale = 1432), based on $13.56 per bale
State Average UNL 2018 Custom Rate Survey
[3] Lifting and Moving Large Round Bales With Tractor (average distance = 1.54 miles), based on $2.85 per bale
State Average UNL 2018 Custom Rate Survey
[4] Yield from ICLS Model Demonstration Site
Hay Price is NE Average in November & December for Fair Grass Hay Large Round Bales
USDA AMS Custom Report Data

## Liberty Hay 2018

| Source | Services | | Custom Rate | Total per Acre | Total per Hectare |
|---|---|---|---|---|---|
| 1 | Mowing & Raking | | 17.60 | 17.60 | 43.49 |
| 2 | Bale | | 18.98 | 18.98 | 46.91 |
| 3 | Move | | 3.99 | 3.99 | 9.86 |
| | | | **Total Cost of Hay:** | 40.57 | 100.26 |
| | **Revenue** | **Unit** | **Price per Unit** | **Total per Acre** | **Total per Hectare** |
| 4 | | 1.05 ton per acre | 70 | 73.50 | 181.62 |
| | | | **Return:** | **32.93** | **81.36** |

[1] Mowing and Raking (Where one rate is quoted or contracted.), rate per acre
State Average UNL 2018 Custom Rate Survey

[2] Baling Large Round Bales Without Net Wrap (average lbs/bale = 1432), based on $13.56 per bale
State Average UNL 2018 Custom Rate Survey

[3] Lifting and Moving Large Round Bales With Tractor (average distance = 1.54 miles), based on $2.85 per bale
State Average UNL 2018 Custom Rate Survey

[4] Yield from ICLS Model Demonstration Site
Hay Price is NE Average in November & December for Fair Grass Hay Large Round Bales
USDA AMS Custom Report Data

## Liberty Hay 2019

| Source | Services | | Custom Rate | Total per Acre | Total per Hectare |
|---|---|---|---|---|---|
| 1 | Mowing & Raking | | 17.60 | 17.60 | 43.49 |
| 2 | Bale | | 19.66 | 19.66 | 48.59 |
| 3 | Move | | 4.13 | 4.13 | 10.21 |
| | | | **Total Cost of Hay:** | 41.39 | 102.29 |
| | **Revenue** | **Unit** | **Price per Unit** | **Total per Acre** | **Total per Hectare** |
| 4 | | 0.97875 ton per acre | 80.42 | 78.71 | 194.50 |
| | | | **Return:** | **37.32** | **92.21** |

[1] Mowing and Raking (Where one rate is quoted or contracted.), rate per acre
State Average UNL 2018 Custom Rate Survey

[2] Baling Large Round Bales Without Net Wrap (average lbs/bale = 1432), based on $13.56 per bale
State Average UNL 2018 Custom Rate Survey

[3] Lifting and Moving Large Round Bales With Tractor (average distance = 1.54 miles), based on $2.85 per bale
State Average UNL 2018 Custom Rate Survey

[4] Yield from ICLS Model Demonstration Site
Hay Price is NE Average in November & December for Fair Grass Hay Large Round Bales
USDA AMS Custom Report Data

J. Revenue for Shawnee and Liberty hay production in 2018 and 2019.

**Hay Revenue**

| | Yield ton ac$^{-1}$ | Average Price per Ton | Acres | Revenue per Acre | Revenue per Hectare |
|---|---|---|---|---|---|
| Liberty 2018 | 1.05 | 70.00 | 10.00 | 73.50 | 181.62 |
| Liberty 2019 | 0.98 | 80.42 | 10.00 | 78.71 | 194.49 |
| Shawnee 2018 | 0.53 | 70.00 | 10.00 | 36.75 | 90.81 |
| Shawnee 2019 | 0.47 | 80.42 | 10.00 | 38.00 | 93.89 |

* hay prices are from the average price in November and December for fair grass hay large round bales in Nebraska. Price data is from the USDA AMS Custom Report

K. Comparison of each system with ownership of hay and corn machinery and ownership of hay with custom farming rates for corn production.

**Systems Returns Ownership of All Machinery**

| | | 'Newell-Liberty-Newell' ICLS | | | 'Newell-Shawnee-Newell' ICLS | | | Diversified ICLS | | | | | Continuous Corn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Enterprise: | Grazing | Hay | Corn | Grazing | Hay | Corn | 'Newell-Liberty-Newell' Grazing | 'Newell-Shawnee-Newell' Grazing | 'Liberty' Hay | 'Shawnee' Hay | Corn | Corn |
| 2018 | Return per hectare | 85.82 | 124.19 | 32.32 | 202.90 | 50.71 | 32.32 | 85.82 | 202.90 | 124.19 | 50.71 | 32.32 | 134.08 |
| | Hectares | 12 | 8 | 8 | 12 | 8 | 8 | 6 | 6 | 4 | 4 | 8 | 20 |
| | return to enterprise | 1041.90 | 1005.20 | 261.60 | 2463.30 | 410.40 | 261.60 | 520.95 | 1231.65 | 502.60 | 205.20 | 261.60 | 2713.00 |
| | return to system | | **2308.70** | | | **3135.30** | | | **2722.00** | | | | **2713.00** |
| 2019 | Return per hectare | -103.51 | 139.47 | -65.19 | -179.30 | 55.52 | -65.19 | -103.51 | -179.30 | 139.47 | 55.52 | -65.19 | 28.05 |
| | Hectares | 12 | 8 | 8 | 12 | 8 | 8 | 6 | 6 | 4 | 4 | 8 | 20 |
| | return to enterprise | -1256.70 | 1128.80 | -527.60 | -2176.80 | 449.40 | -527.60 | -628.35 | -1088.40 | 564.40 | 224.70 | -527.60 | 567.50 |
| | return to system | | **-655.50** | | | **-2255.00** | | | **-1455.25** | | | | **567.50** |

## Systems Returns Custom Corn Operations

| | | 'Newell-Liberty-Newell' ICLS | | | 'Newell-Shawnee-Newell' ICLS | | | Diversified ICLS | | | | | Continuous Corn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Enterprise: | Grazing | Hay | Corn | Grazing | Hay | Corn | 'Newell-Liberty-Newell' Grazing | 'Newell-Shawnee-Newell' Grazing | 'Liberty' Hay | 'Shawnee' Hay | Corn | Corn |
| 2018 | Return per hectare | 85.82 | 124.19 | 95.23 | 202.90 | 50.71 | 95.23 | 85.82 | 202.90 | 124.19 | 50.71 | 95.23 | 95.23 |
| | Hectares | 12 | 8 | 8 | 12 | 8 | 8 | 6 | 6 | 4 | 4 | 8 | 20 |
| | return to enterprise | 1041.90 | 1005.20 | 770.80 | 2463.30 | 410.40 | 770.80 | 520.95 | 1231.65 | 502.60 | 205.20 | 770.80 | 1927.00 |
| | return to system | | **2817.90** | | | **3644.50** | | | **3231.20** | | | | **1927.00** |
| 2019 | Return per hectare | -103.51 | 139.47 | -5.66 | -179.30 | 55.52 | -5.66 | -103.51 | -179.30 | 139.47 | 55.52 | -5.66 | -5.66 |
| | Hectares | 12 | 8 | 8 | 12 | 8 | 8 | 6 | 6 | 4 | 4 | 8 | 20 |
| | return to enterprise | -1256.70 | 1128.80 | -45.80 | -2176.80 | 449.40 | -45.80 | -628.35 | -1088.40 | 564.40 | 224.70 | -45.80 | -114.50 |
| | return to system | | **-173.70** | | | **-1773.20** | | | **-973.45** | | | | **-114.50** |

L. Cost of gain calculations and rent on gain scenarios

The cost of gain was calculated using the sale weight, purchase weight, and total cost per head. (Total Cost per Hd)/(Sale weight- Purchase weight). The value of gain was calculated using the sale and purchase price, and the sale and purchase weight of the steers grazing the system.

**Cost of Gain**

| | Newell-Liberty-Newell | | Newell-Shawnee-Newell | |
|---|---|---|---|---|
| *Year* | **2018** | **2019** | **2018** | **2019** |
| *Sale Weight (Kg)* | 447 | 386 | 471 | 372 |
| *Purchase weight (Kg)* | 392 | 288 | 395 | 289 |
| *Total Cost ($ $hd^{-1}$ )* | 231.81 | 230.1 | 232.03 | 230.24 |
| **Cost of Gain ($ $Kg^{-1}$)** | **4.22** | **2.35** | **3.04** | **2.79** |

**Rent on Gain Profitability**

| | Newell-Liberty-Newell | | Newell-Shawnee-Newell | | Diversified ICLS | |
|---|---|---|---|---|---|---|
| *Year* | **2018** | **2019** | **2018** | **2019** | **2018** | **2019** |
| *Sale Price ($ $kg^{-1}$ )* | 3.27 | 3.26 | 3.29 | 3.26 | 3.28 | 3.26 |
| *Sale Price ($ $hd^{-1}$ )* | 1461.94 | 1257.18 | 1549.25 | 1211.39 | 1505.60 | 1234.28 |
| *Purchase Price ($ $kg^{-1}$ )* | 2.99 | 3.81 | 2.99 | 3.81 | 2.99 | 3.81 |
| *Purchase Price ($ $hd^{-1}$ )* | 1172.25 | 1096.90 | 1180.38 | 1102.08 | 1176.31 | 1099.49 |
| *Sale Weight (kg)* | 447.37 | 386.12 | 471.42 | 372.05 | 459.39 | 379.08 |
| *Purchase weight (kg)* | 392.47 | 288.11 | 395.19 | 289.47 | 393.83 | 288.79 |
| **Value of Gain (VOG) ($ $kg^{-1}$)** | 5.28 | 1.64 | 4.84 | 1.32 | 5.06 | 1.48 |
| Rental Rate (50% of VOG) | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 |
| Rental Rate ($ kg of $gain^{-1}$) | 2.64 | 0.82 | 2.42 | 0.66 | 2.53 | 0.74 |
| Kg of gain | 54.90 | 98.00 | 76.23 | 82.58 | 65.56 | 90.29 |
| Revenue ($ $hd^{-1}$) | 144.85 | 80.14 | 184.44 | 54.65 | 164.64 | 67.40 |
| Number of Head | 18 | 18 | 18 | 18 | 18 | 18 |
| Revenue per System | 2607.25 | 1442.55 | 3319.86 | 983.74 | 2963.56 | 1213.15 |
| Number of Hectares per System | 12 | 12 | 12 | 12 | 12 | 12 |
| **Revenue ($ $ha^{-1}$)** | 214.75 | 118.82 | 273.45 | 81.03 | 244.10 | 99.92 |
| Cost of Pasture Establishment | 72.99 | 72.99 | 72.99 | 72.99 | 72.99 | 72.99 |
| Land Tax | 103.41 | 103.41 | 103.41 | 103.41 | 103.41 | 103.41 |
| Fertilizer | 66.72 | 66.72 | 66.72 | 66.72 | 66.72 | 66.72 |
| Interest | 2.22 | 2.22 | 2.22 | 2.22 | 2.22 | 2.22 |
| **Total Cost ($ $ha^{-1}$)** | 245.35 | 245.35 | 245.35 | 245.35 | 245.35 | 245.35 |
| **Net Profit ($ $ha^{-1}$)** | -30.60 | -126.53 | 28.10 | -164.32 | -1.25 | -145.43 |
| **Total Cost per System** | 2978.70 | 2978.70 | 2978.70 | 2978.70 | 2978.70 | 2978.70 |
| **Total Profit for System** | -371.45 | -1536.15 | 341.16 | -1994.96 | -15.14 | -1765.55 |

M. Profitability of baling hay only.

| | Liberty | | Shawnee | | Newell | |
|---|---|---|---|---|---|---|
| Yield (kg $ha^{-1}$) | 18100 | | 14027 | | 7820 | |
| Establishment Cost ($ $ha^{-1}$) | 26.76 | | 26.76 | | 23.67 | |
| Fertilization ($ $ha^{-1}$) | 68.94 | | 68.94 | | 68.94 | |
| Land Taxes ($ per $ha^{-1}$) | 103.41 | | 103.41 | | 103.41 | |
| Overhead | 49.42 | | 49.42 | | 49.42 | |
| Cost of Making Hay ($ per $ha^{-1}$) | 288.32 | | 228.33 | | 137.42 | |
| **Total Cost ($ $ha^{-1}$)** | **536.86** | | **476.86** | | **382.86** | |
| *Year* | *2018* | *2019* | *2018* | *2019* | *2018* | *2019* |
| Price ($ $kg^{-1}$) | 0.0771 | 0.0886 | 0.0771 | 0.0886 | 0.0975 | 0.1102 |
| **Revenue ($ $ha^{-1}$)** | **1396.23** | **1604.07** | **1082.04** | **1243.11** | **762.14** | **861.76** |
| **Net Profit ($ $ha^{-1}$)** | **859.37** | **1067.21** | **605.18** | **766.25** | **379.28** | **478.90** |

## N. Sensitivity analysis for cattle price and weight.

| Cost of Purchasing Steer | Purchase Date | Sale Weight | Price at Sale | Revenue from Selling Steer | Sale Date | Change in Value of Steer | # of Steers in System | # of Hectares Grazed | Change in Value of Herd | Change in Value of Herd per ha | Cost of Growing Steers per ha | Profit per ha |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $ hd-1 | 2-May | lb per steer | $ cwt-1 | $ hd-1 | 18-Sep | | | | | | | |
| 815.87 | 1-May | 986.00 | 90.15 | 888.88 | 18-Sep | 73.01 | 9.00 | 6.07 | 657.10 | 108.25 | 343.69 | -235.44 |
| 928.66 | 30-Apr | 986.00 | 104.42 | 1029.58 | 17-Sep | 100.92 | 9.00 | 6.07 | 908.25 | 149.62 | 343.69 | -194.07 |
| 1098.46 | 29-Apr | 986.00 | 126.67 | 1248.97 | 16-Sep | 150.50 | 9.00 | 6.07 | 1354.52 | 223.14 | 343.69 | -120.55 |
| 1246.38 | 4-May | 986.00 | 137.57 | 1356.44 | 21-Sep | 110.06 | 9.00 | 6.07 | 990.56 | 163.18 | 343.69 | -180.51 |
| 1127.70 | 3-May | 986.00 | 142.06 | 1400.71 | 20-Sep | 273.01 | 9.00 | 6.07 | 2457.10 | 404.77 | 343.69 | 61.08 |
| 1489.96 | 2-May | 986.00 | 211.94 | 2089.73 | 19-Sep | 599.77 | 9.00 | 6.07 | 5397.89 | 889.23 | 343.69 | 545.54 |
| 1774.37 | 1-May | 986.00 | 183.41 | 1808.42 | 18-Sep | 34.05 | 9.00 | 6.07 | 306.43 | 50.48 | 343.69 | -293.21 |
| 1212.47 | 29-Apr | 986.00 | 130.33 | 1285.05 | 16-Sep | 72.58 | 9.00 | 6.07 | 653.25 | 107.61 | 343.69 | -236.08 |
| 1352.43 | 5-May | 986.00 | 147.77 | 1457.01 | 15-Sep | 104.58 | 9.00 | 6.07 | 941.26 | 155.06 | 343.69 | -188.63 |
| 1172.25 | 4-May | 986.00 | 148.27 | 1461.94 | 21-Sep | 289.69 | 9.00 | 6.07 | 2607.25 | 429.51 | 343.69 | 85.82 |
| 1213.68 | 3-May | 986.00 | 135.92 | 1340.17 | 20-Sep | 126.49 | 9.00 | 6.07 | 1138.41 | 187.54 | 343.69 | -156.15 |
| | | | | | | | | | | | | |
| 724.15 | 1-May | 851.00 | 96.38 | 820.19 | 25-Sep | 96.04 | 9.00 | 6.07 | 864.36 | 142.39 | 341.15 | -198.76 |
| 843.72 | 30-Apr | 851.00 | 108.32 | 921.80 | 24-Sep | 78.08 | 9.00 | 6.07 | 702.71 | 115.76 | 341.15 | -225.39 |
| 950.47 | 29-Apr | 851.00 | 131.67 | 1120.51 | 23-Sep | 170.04 | 9.00 | 6.07 | 1530.39 | 252.11 | 341.15 | -89.04 |
| 1130.11 | 4-May | 851.00 | 139.60 | 1188.00 | 28-Sep | 57.89 | 9.00 | 6.07 | 520.98 | 85.82 | 341.15 | -255.33 |
| 944.82 | 3-May | 851.00 | 155.56 | 1323.82 | 27-Sep | 379.00 | 9.00 | 6.07 | 3410.99 | 561.92 | 341.15 | 220.77 |
| 1317.63 | 2-May | 851.00 | 230.17 | 1958.75 | 26-Sep | 641.12 | 9.00 | 6.07 | 5770.10 | 950.55 | 341.15 | 609.40 |
| 1674.11 | 1-May | 851.00 | 190.28 | 1619.28 | 25-Sep | -54.83 | 9.00 | 6.07 | -493.48 | -81.29 | 341.15 | -422.44 |
| 1064.70 | 29-Apr | 851.00 | 141.79 | 1206.63 | 23-Sep | 141.93 | 9.00 | 6.07 | 1277.36 | 210.43 | 341.15 | -130.72 |
| 1113.98 | 5-May | 851.00 | 164.52 | 1400.07 | 29-Sep | 286.08 | 9.00 | 6.07 | 2574.76 | 424.16 | 341.15 | 83.01 |
| 1089.98 | 4-May | 851.00 | 151.91 | 1292.75 | 28-Sep | 202.78 | 9.00 | 6.07 | 1824.99 | 300.64 | 341.15 | -40.51 |
| 1096.90 | 3-May | 851.00 | 144.30 | 1227.99 | 27-Sep | 131.09 | 9.00 | 6.07 | 1179.85 | 194.36 | 341.15 | -146.79 |
| | | | | | | | | | | | | |
| 821.53 | 1-May | 1039.00 | 87.10 | 904.97 | 18-Sep | 83.44 | 9.00 | 6.07 | 750.98 | 123.71 | 344.01 | -220.30 |
| 935.11 | 30-Apr | 1039.00 | 101.25 | 1051.99 | 24-Sep | 116.88 | 9.00 | 6.07 | 1051.94 | 173.29 | 344.01 | -170.72 |
| 1106.08 | 29-Apr | 1039.00 | 122.27 | 1270.39 | 16-Sep | 164.30 | 9.00 | 6.07 | 1478.72 | 243.60 | 344.01 | -100.41 |
| 1255.02 | 4-May | 1039.00 | 134.50 | 1397.46 | 14-Sep | 142.43 | 9.00 | 6.07 | 1281.88 | 211.17 | 344.01 | -132.84 |
| 1135.52 | 3-May | 1039.00 | 146.25 | 1519.54 | 20-Sep | 384.01 | 9.00 | 6.07 | 3456.13 | 569.35 | 344.01 | 225.34 |
| 1500.30 | 2-May | 1039.00 | 211.25 | 2194.89 | 19-Sep | 694.59 | 9.00 | 6.07 | 6251.31 | 1029.82 | 344.01 | 685.81 |
| 1786.68 | 1-May | 1039.00 | 181.10 | 1881.63 | 18-Sep | 94.95 | 9.00 | 6.07 | 854.52 | 140.77 | 344.01 | -203.24 |
| 1220.88 | 29-Apr | 1039.00 | 126.76 | 1317.04 | 16-Sep | 96.16 | 9.00 | 6.07 | 865.40 | 142.56 | 344.01 | -201.45 |
| 1361.81 | 4-May | 1039.00 | 141.85 | 1473.82 | 15-Sep | 112.01 | 9.00 | 6.07 | 1008.12 | 166.07 | 344.01 | -177.94 |
| 1180.38 | 4-May | 1039.00 | 149.11 | 1549.25 | 21-Sep | 368.87 | 9.00 | 6.07 | 3319.86 | 546.90 | 344.01 | 202.89 |
| 1222.10 | 3-May | 1039.00 | 133.94 | 1391.64 | 20-Sep | 169.54 | 9.00 | 6.07 | 1525.83 | 251.36 | 344.01 | -92.65 |
| | | | | | | | | | | | | |
| 727.58 | 1-May | 820.00 | 99.28 | 814.10 | 25-Sep | 86.52 | 9.00 | 6.07 | 778.69 | 128.28 | 341.36 | -213.08 |
| 847.71 | 30-Apr | 820.00 | 110.79 | 908.48 | 24-Sep | 60.77 | 9.00 | 6.07 | 546.91 | 90.10 | 341.36 | -251.26 |
| 954.96 | 29-Apr | 820.00 | 134.65 | 1104.13 | 23-Sep | 149.17 | 9.00 | 6.07 | 1342.54 | 221.17 | 341.36 | -120.19 |
| 1135.45 | 4-May | 820.00 | 143.15 | 1173.83 | 28-Sep | 38.38 | 9.00 | 6.07 | 345.43 | 56.91 | 341.36 | -284.45 |
| 949.28 | 3-May | 820.00 | 163.19 | 1338.16 | 27-Sep | 388.88 | 9.00 | 6.07 | 3499.90 | 576.56 | 341.36 | 235.20 |
| 1323.85 | 2-May | 820.00 | 236.68 | 1940.78 | 26-Sep | 616.93 | 9.00 | 6.07 | 5552.33 | 914.67 | 341.36 | 573.31 |
| 1682.02 | 1-May | 820.00 | 199.52 | 1636.06 | 25-Sep | -45.96 | 9.00 | 6.07 | -413.63 | -68.14 | 341.36 | -409.50 |
| 1069.73 | 29-Apr | 820.00 | 142.65 | 1169.73 | 23-Sep | 100.00 | 9.00 | 6.07 | 899.96 | 148.26 | 341.36 | -193.10 |
| 1119.24 | 4-May | 820.00 | 162.72 | 1334.30 | 29-Sep | 215.06 | 9.00 | 6.07 | 1935.55 | 318.86 | 341.36 | -22.50 |
| 1095.13 | 4-May | 820.00 | 159.77 | 1310.11 | 28-Sep | 214.99 | 9.00 | 6.07 | 1934.88 | 318.75 | 341.36 | -22.61 |
| 1102.08 | 3-May | 820.00 | 147.73 | 1211.39 | 27-Sep | 109.30 | 9.00 | 6.07 | 983.74 | 162.06 | 341.36 | -179.30 |

| Year of Price Data | Switchgrass Type | Purchase Weight | Price at Purchase | Cost of Purchasing Steer | Purchase Date | Sale Weight | Price at Sale | Break Even per CWT |
|---|---|---|---|---|---|---|---|---|
| | | lb per steer | $ cwt-1 | $ hd-1 | 2-May | lb per steer | $ cwt-1 | $ cwt-1 |
| 2009 | Liberty | 865 | 94.32 | 815.87 | 1-May | 986.00 | 90.15 | 106.26 |
| 2010 | Liberty | 865 | 107.36 | 928.66 | 30-Apr | 986.00 | 104.42 | 117.70 |
| 2011 | Liberty | 865 | 126.99 | 1098.46 | 29-Apr | 986.00 | 126.67 | 134.92 |
| 2012 | Liberty | 865 | 144.09 | 1246.38 | 4-May | 986.00 | 137.57 | 149.92 |
| 2013 | Liberty | 865 | 130.37 | 1127.70 | 3-May | 986.00 | 142.06 | 137.88 |
| 2014 | Liberty | 865 | 172.25 | 1489.96 | 2-May | 986.00 | 211.94 | 174.62 |
| 2015 | Liberty | 865 | 205.13 | 1774.37 | 1-May | 986.00 | 183.41 | 203.47 |
| 2016 | Liberty | 865 | 140.17 | 1212.47 | 29-Apr | 986.00 | 130.33 | 146.48 |
| 2017 | Liberty | 865 | 156.35 | 1352.43 | 5-May | 986.00 | 147.77 | 160.67 |
| 2018 | Liberty | 865 | 135.52 | 1172.25 | 4-May | 986.00 | 148.27 | 142.40 |
| 2019 | Liberty | 865 | 140.31 | 1213.68 | 3-May | 986.00 | 135.92 | 146.60 |
| | | | | | | | | |
| 2009 | Liberty | 635 | 114.04 | 724.15 | 1-May | 851.00 | 96.38 | 112.13 |
| 2010 | Liberty | 635 | 132.87 | 843.72 | 30-Apr | 851.00 | 108.32 | 126.18 |
| 2011 | Liberty | 635 | 149.68 | 950.47 | 29-Apr | 851.00 | 131.67 | 138.73 |
| 2012 | Liberty | 635 | 177.97 | 1130.11 | 4-May | 851.00 | 139.60 | 159.84 |
| 2013 | Liberty | 635 | 148.79 | 944.82 | 3-May | 851.00 | 155.56 | 138.06 |
| 2014 | Liberty | 635 | 207.50 | 1317.63 | 2-May | 851.00 | 230.17 | 181.87 |
| 2015 | Liberty | 635 | 263.64 | 1674.11 | 1-May | 851.00 | 190.28 | 223.76 |
| 2016 | Liberty | 635 | 167.67 | 1064.70 | 29-Apr | 851.00 | 141.79 | 152.15 |
| 2017 | Liberty | 635 | 175.43 | 1113.98 | 5-May | 851.00 | 164.52 | 157.94 |
| 2018 | Liberty | 635 | 171.65 | 1089.98 | 4-May | 851.00 | 151.91 | 155.12 |
| 2019 | Liberty | 635 | 172.74 | 1096.90 | 3-May | 851.00 | 144.30 | 155.93 |
| | | | | | | | | |
| 2009 | Shawnee | 871 | 94.32 | 821.53 | 1-May | 1039.00 | 87.10 | 101.40 |
| 2010 | Shawnee | 871 | 107.36 | 935.11 | 30-Apr | 1039.00 | 101.25 | 112.33 |
| 2011 | Shawnee | 871 | 126.99 | 1106.08 | 29-Apr | 1039.00 | 122.27 | 128.79 |
| 2012 | Shawnee | 871 | 144.09 | 1255.02 | 4-May | 1039.00 | 134.50 | 143.12 |
| 2013 | Shawnee | 871 | 130.37 | 1135.52 | 3-May | 1039.00 | 146.25 | 131.62 |
| 2014 | Shawnee | 871 | 172.25 | 1500.30 | 2-May | 1039.00 | 211.25 | 166.73 |
| 2015 | Shawnee | 871 | 205.13 | 1786.68 | 1-May | 1039.00 | 181.10 | 194.29 |
| 2016 | Shawnee | 871 | 140.17 | 1220.88 | 29-Apr | 1039.00 | 126.76 | 139.84 |
| 2017 | Shawnee | 871 | 156.35 | 1361.81 | 4-May | 1039.00 | 141.85 | 153.40 |
| 2018 | Shawnee | 871 | 135.52 | 1180.38 | 4-May | 1039.00 | 149.11 | 135.94 |
| 2019 | Shawnee | 871 | 140.31 | 1222.10 | 3-May | 1039.00 | 133.94 | 139.95 |
| | | | | | | | | |
| 2009 | Shawnee | 638 | 114.04 | 727.58 | 1-May | 820.00 | 99.28 | 116.81 |
| 2010 | Shawnee | 638 | 132.87 | 847.71 | 30-Apr | 820.00 | 110.79 | 131.46 |
| 2011 | Shawnee | 638 | 149.68 | 954.96 | 29-Apr | 820.00 | 134.65 | 144.54 |
| 2012 | Shawnee | 638 | 177.97 | 1135.45 | 4-May | 820.00 | 143.15 | 166.55 |
| 2013 | Shawnee | 638 | 148.79 | 949.28 | 3-May | 820.00 | 163.19 | 143.84 |
| 2014 | Shawnee | 638 | 207.50 | 1323.85 | 2-May | 820.00 | 236.68 | 189.52 |
| 2015 | Shawnee | 638 | 263.64 | 1682.02 | 1-May | 820.00 | 199.52 | 233.20 |
| 2016 | Shawnee | 638 | 167.67 | 1069.73 | 29-Apr | 820.00 | 142.65 | 158.53 |
| 2017 | Shawnee | 638 | 175.43 | 1119.24 | 4-May | 820.00 | 162.72 | 164.57 |
| 2018 | Shawnee | 638 | 171.65 | 1095.13 | 4-May | 820.00 | 159.77 | 161.63 |
| 2019 | Shawnee | 638 | 172.74 | 1102.08 | 3-May | 820.00 | 147.73 | 162.48 |

O. Hay sensitivity analysis.

Yellow shaded box represents the base net return calculated using the average 2018 and 2019 hay price with the proven yield from the variety's registration papers. Red box indicates that net return per hectare is less than the net return for continuous corn production in 2018.

**Net Return ($ ha$^{-1}$) for Liberty Hay Production Only**

| | | Price $ Kg$^{-1}$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.0622 | 0.0663 | 0.0704 | 0.0746 | 0.0787 | 0.0829 | 0.0870 | 0.0912 | 0.0953 | 0.0995 | Cost ($ ha$^{-1}$) |
| Yield Kg ha$^{-1}$ | 11747.58 | 288 | 336 | 385 | 434 | 482 | 531 | 580 | 628 | 677 | 726 | 442.61 |
| | 12651.24 | 331 | 383 | 435 | 488 | 540 | 593 | 645 | 698 | 750 | 802 | 455.81 |
| | 13554.90 | 374 | 430 | 486 | 542 | 598 | 654 | 711 | 767 | 823 | 879 | 468.96 |
| | 14458.56 | 417 | 477 | 536 | 596 | 656 | 716 | 776 | 836 | 896 | 956 | 482.15 |
| | 15362.22 | 456 | 520 | 584 | 647 | 711 | 775 | 838 | 902 | 966 | 1029 | 498.61 |
| | 16265.88 | 499 | 567 | 634 | 702 | 769 | 836 | 904 | 971 | 1039 | 1106 | 511.78 |
| | 17169.54 | 542 | 613 | 685 | 756 | 827 | 898 | 969 | 1040 | 1112 | 1183 | 524.95 |
| | 18073.20 | 585 | 660 | 735 | 810 | 885 | 960 | 1035 | 1110 | 1184 | 1259 | 538.15 |
| | 18976.86 | 628 | 707 | 786 | 864 | 943 | 1022 | 1100 | 1179 | 1257 | 1336 | 551.29 |
| | 19880.52 | 671 | 754 | 836 | 918 | 1001 | 1083 | 1166 | 1248 | 1330 | 1413 | 564.49 |
| | 20784.18 | 714 | 800 | 887 | 973 | 1059 | 1145 | 1231 | 1317 | 1403 | 1489 | 577.68 |

**Net Return ($\$$ ha$^{-1}$) for Shawnee Hay Production Only**

| | | Price $\$$ Kg$^{-1}$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.0622 | 0.0663 | 0.0704 | 0.0746 | 0.0787 | 0.0829 | 0.0870 | 0.0912 | 0.0953 | 0.0995 | Cost ($\$$ ha$^{-1}$) |
| Yield Kg Ha$^{-1}$ | 9094.90 | 159 | 197 | 234 | 272 | 310 | 347 | 385 | 423 | 460 | 498 | 406.41 |
| | 9794.51 | 193 | 233 | 274 | 314 | 355 | 396 | 436 | 477 | 517 | 558 | 416.25 |
| | 10494.11 | 226 | 270 | 313 | 357 | 400 | 444 | 487 | 531 | 574 | 618 | 426.16 |
| | 11193.72 | 260 | 306 | 353 | 399 | 445 | 492 | 538 | 584 | 631 | 677 | 436.04 |
| | 11893.33 | 293 | 343 | 392 | 441 | 491 | 540 | 589 | 638 | 688 | 737 | 445.93 |
| | 12592.94 | 327 | 379 | 431 | 484 | 536 | 588 | 640 | 692 | 744 | 797 | 455.81 |
| | 13292.54 | 361 | 416 | 472 | 527 | 582 | 637 | 692 | 747 | 802 | 857 | 464.93 |
| | 13992.15 | 394 | 452 | 510 | 568 | 626 | 684 | 742 | 800 | 858 | 916 | 475.58 |
| | 14691.76 | 424 | 485 | 546 | 607 | 668 | 729 | 790 | 851 | 912 | 972 | 488.77 |
| | 15391.37 | 458 | 522 | 586 | 649 | 713 | 777 | 841 | 905 | 968 | 1032 | 498.61 |
| | 16090.98 | 492 | 558 | 625 | 692 | 758 | 825 | 892 | 959 | 1025 | 1092 | 508.49 |

**Net Return ($ ha$^{-1}$) for Newell Hay Production Only**

| | | Price $ Kg$^{-1}$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.0779 | 0.0831 | 0.0883 | 0.0934 | 0.0986 | 0.1038 | 0.1090 | 0.1142 | 0.1194 | 0.1246 | Cost ($ ha$^{-1}$) |
| Yield Kg Ha$^{-1}$ | 5072.16 | 48 | 74 | 101 | 127 | 153 | 180 | 206 | 232 | 259 | 285 | 347.08 |
| | 5462.32 | 75 | 103 | 132 | 160 | 188 | 217 | 245 | 274 | 302 | 330 | 350.35 |
| | 5852.49 | 99 | 129 | 160 | 190 | 220 | 251 | 281 | 311 | 342 | 372 | 356.97 |
| | 6242.65 | 123 | 155 | 187 | 220 | 252 | 285 | 317 | 349 | 382 | 414 | 363.59 |
| | 6632.82 | 146 | 181 | 215 | 250 | 284 | 319 | 353 | 387 | 422 | 456 | 370.19 |
| | 7022.98 | 173 | 210 | 246 | 283 | 319 | 356 | 392 | 429 | 465 | 502 | 373.47 |
| | 7413.15 | 197 | 236 | 274 | 313 | 351 | 390 | 428 | 467 | 505 | 544 | 380.02 |
| | 7803.32 | 221 | 262 | 302 | 343 | 383 | 424 | 464 | 505 | 545 | 586 | 386.62 |
| | 8193.48 | 245 | 287 | 330 | 372 | 415 | 457 | 500 | 543 | 585 | 628 | 393.24 |
| | 8583.65 | 272 | 316 | 361 | 406 | 450 | 495 | 539 | 584 | 628 | 673 | 396.50 |
| | 8973.81 | 296 | 342 | 389 | 436 | 482 | 529 | 575 | 622 | 668 | 715 | 403.08 |

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# CHAPTER 4

## Soil GHG Emissions are Variable and Management Dependent

### Abstract

The current specialized agricultural production system focused on production of single commodities is facing production, economic, and environmental challenges. Amidst the challenges, researchers have identified Integrated Crop Livestock Systems (ICLS) as a possible solution. Integration can occur through perennial grasslands, cover crop grazing, and crop residue grazing. To explore the potential of ICLS in Eastern Nebraska to mitigate challenges a field-scale model ICLS was established on marginally productive, poorly drained cropland. The ICLS includes 4-ha each of 'Newell' smooth bromegrass (*Bromus inermis* L.), 'Liberty' switchgrass (*Panicum virgatum* L.), and 'Shawnee' switchgrass. The perennial grasslands were grazed by steers in 2017, 2018, and 2019. The ICLS also includes 8-ha of continuous corn (*Zea mays L.*) production. Corn residue was removed by baling in 2016 and 2017 and by grazing in 2018 and 2019. To assess the impact of these livestock integration practices on soil GHG emissions, soil $N_2O$ and $CH_4$ were measured each growing season (2017, 2018, and 2019). Our results indicate that 1) grazing perennial grasslands does not consistently impact soil GHG emissions 2) crop residue and cover crop management may impact soil $N_2O$ emissions and 3) generally continuous corn production results in more soil $N_2O$ emissions than perennial grasslands due to increased synthetic N fertilizer. This research can provide insight for further development and research for ICLS in Eastern NE that minimize soil GHG emissions.

**Introduction**

Farm diversity in the United States has decreased since the conclusion of WWII (Dimitri, Effland, and Conklin 2005; Sulc and Tracy 2007), but specialization of agriculture has met current global food demand. However, the success of specialized agriculture came at a cost. The intensive, specialized systems cause soil erosion, nutrient loss, decreased soil organic carbon, pest resistance, water pollution, and contribute to global greenhouse gas (GHG) emissions (Sulc and Tracy 2007). To address these negative effects, Integrated Crop Livestock Systems (ICLS) have emerged as a potential solution to mitigate GHG emissions. Integrating livestock back onto the land can increase economic and environmental resiliency through diversification (Parthasarathy and Ndjeunga 2005; Devendra and Thomas 2002; Tracy and Zhang 2008). Integration can include livestock grazing annual cover crops, annual crop residues, or perennial grasslands (Sulc and Tracy 2007; Russelle, Entz, and Franzluebbers 2007). Concerns about agriculture's role in GHG emissions among the public and policymakers has risen. Therefore, interest in production practices that mitigate GHG emissions has risen (Seguin et al. 2007). Methods of ICLS show potential for mitigating soil GHG emissions, however, GHG emissions are variable and depend on many factors.

A potential avenue for ICLS in Eastern NE is converting marginally productive cropland to perennial grassland. Non-irrigated, marginally productive cropland provides an opportunity to increase farm profitability and environmental sustainability by diversifying land use through integration of perennial vegetation (Mitchell et al. 2016). Literature has shown that perennial grasslands harvested for biomass can mitigate soil GHG emissions compared to annual row-crop systems. In Italy, converting marginally productive cropland or areas with a surplus of grain production to switchgrass (*Panicum virgatum* L.) production maximized GHG savings (Nocentini and Monti 2019). In the central US, converting cropland used for ethanol production to low input perennial grasslands decreased GHG emissions (Davis et al. 2012). In eastern Nebraska, switchgrass grown for bioenergy production mitigated GHG emissions while continuous corn (*Zea mays* L.) grain production was GHG neutral (Jin et al. 2019).

The result of grazing perennial grasslands on soil GHG emissions is less known and reports inconsistent. Grazing and fertilizing perennial grasslands increased soil nitrous oxide ($N_2O$) emissions in the Northern Great Plains (Liebig et al. 2006) and in New Zealand (Saggar et al. 2008). In contrast, in the southeastern United States, when moderately grazed bahiagrass (*Paspalum notatum* Fluegge) was compared to non-grazed, fewer GHG emissions were observed dependent on location, season, and crop (Gamble et al. 2019) and adaptive multi-paddock grazing in Texas native prairie reduced $N_2O$ and $CH_4$ emissions when compared to continuously grazed prairie or feedlot finishing cattle (Stanley et al. 2018). Because reported impacts of grazing perennial grassland on soil GHG emissions are highly variable and site-dependent, more information is needed to determine how management impacts GHG emissions in grazed perennial grasslands.

Another method of ICLS is cover crop grazing. Cover crops are popular among crop producers and have shown the potential to decrease GHG emissions through reduced fertilizer use. In the Great Plains, use of cover crops decrease soil $N_2O$ emissions (Wegner et al., 2018). In Minnesota, when cover crops were used in a corn-soybean (*Glycine max* Merr.) rotation, soil $N_2O$ emissions were reduced (Bavin et al. 2009). However, researchers indicated that the difference in soil $N_2O$ was likely due to fertilizer rate and source. Anhydrous ammonia applied at higher rates elevated soil $N_2O$ when compared to urea applied at a lower rate (Bavin et al. 2009). Additionally, monocropping increased $N_2O$ emissions because of the increased need for synthetic fertilizer (Abagandura et al. 2019). A meta-analysis evaluating the effect of cover crops on soil $N_2O$ emissions revealed that soil $N_2O$ emissions are highly management dependent (Basche et al. 2014). Data from 26 studies was evaluated. 40% of the studies showed that cover crops reduced $N_2O$ emissions while 60% of the studies showed that cover crops increased $N_2O$ emissions (Basche et al. 2014). Generally, when cover crops were legumes, when residue was incorporated, when precipitation increased, when precipitation was highly variable, or measurements were taken during the crop decomposition phase, $N_2O$ increased (Basche et al. 2014). $N_2O$ emissions are management dependent. Additionally, researchers have called for $N_2O$ measurements throughout the entire year to more accurately capture the net effect of cover crops on $N_2O$ emissions (Basche et al. 2014).

Similar to grazing perennial grasslands the impacts of livestock grazing cover crops on soil GHG emissions is inconsistent. Grazing a winter cover crop increased $N_2O$ emissions compared to a continuous cropping system, likely due to additional fertilizer input used on cover crops (Piva et al. 2014). In Brazil, cover crop grazing mitigated soil GHG emissions when compared to a continuous cropping system (Dieckow et al. 2015), but in South Dakota, grazing annual forages had no impact on soil $N_2O$ or methane ($CH_4$) emissions (Abagandura et al. 2019). Again, more research is needed to develop the best grazing management practices to mitigate GHG emissions.

A more common method of ICLS in Nebraska is cattle grazing corn residue (Schmer et al. 2017; Redfearn et al. 2019). The effect of crop residue grazing on GHG emissions is not well known. Only one study in the Midwest has explored the impact of cattle grazing crop residue on GHG emissions. They found that carbon dioxide ($CO_2$) fluxes were inconsistent with cattle grazing (Tracy and Zhang 2008). However, more studies have been conducted on crop residue removal. Unfortunately, the effect of crop residue removal on GHG emissions is inconsistent. Several studies showed that residue removal had no effect on GHG emissions. In Iowa, residue removal under a no-till corn-soybean rotation did not affect $N_2O$ and $CO_2$ emissions (Johnson and Barbour 2010). Additionally, in Ohio, stover removal under no-till continuous corn production did not affect $CO_2$ emissions (Blanco-Canqui and Lal 2007). Other research has shown that crop residue removal decreased soil GHG emissions. Across the US corn belt, when corn stover is baled, $CO_2$ and $N_2O$ emissions decreased (Jin et al. 2014). Additionally in Eastern NE, corn residue removal decreased $N_2O$ emissions when compared to cropland with retained residue (Jin et al. 2019). However, some studies have shown that retaining residue decreased $N_2O$ emissions. In North Dakota, when residue was retained under a corn-soybean rotation $N_2O$ emissions generally decreased (Wegner et al. 2018). Additionally, residue removal has been shown to increase GHG emissions. In South Dakota, when corn stover was baled in a corn-soybean rotation, $N_2O$ fluxes increased during the following soybean growth phase but did not impact $N_2O$ fluxes during the corn phase (Lehman and Osborne 2016). One meta-analysis suggests that the presence of crop residue stimulates microbial respiration which can deplete oxygen causing an anaerobic environment favoring denitrification and therefore $N_2O$ production (Chen et al. 2013).

The same meta-analysis suggests that residue quality and quantity combined with soil properties could better indicate $N_2O$ emissions (Chen et al. 2013). The impacts of residue removal by baling or grazing on GHG emissions is highly variable and not conclusive. The observed differences in soil GHG emissions among studies has been previously recognized. Soil GHG emissions are highly variable and dependent on management, weather, fertilizer, manure, environment, and soil conditions (Jin et al. 2014; Rakkar et al. 2018; Chen et al. 2013).

We sought to determine if a field-scale ICLS in Eastern NE mitigated soil GHG emissions. The field-scale ICLS demonstration site includes 4-ha each of ‘Newell’ smooth bromegrass (*Bromus inermis* L.), ‘Liberty’ switchgrass, and ‘Shawnee’ switchgrass. In addition, the site includes 8-ha of continuous corn production. The first objective of the study was to determine if grazing perennial grasslands effected soil GHG emissions. The second objective of the study was to determine if grazing or baling corn residue with and without a cover crop influenced soil GHG emissions. The third objective was to evaluate if soil GHG emissions differed between perennial grasslands and continuous corn production.

To evaluate if grazing perennial grasslands influenced soil GHG emissions each perennial grassland contained three pseudo-replicates split into a non-grazed, flash-grazed (grazed for 7-d), and continually grazed exclosure. Soil GHG emissions were recorded for each exclosure throughout three growing seasons (2017-2019). The cumulative $N_2O$ and $CH_4$ emissions were evaluated separately for each growing season. To evaluate if grazing or baling corn residue with and without a cover crop influenced soil GHG emissions, the 8-ha of continuous corn production were split into three replications of 6 different treatment combinations. The 6 different treatments included, no residue removal with no cover crop, no residue removal with a cover crop, residue removal by baling with no cover crop, residue removal by baling with a cover crop, residue removal by grazing with no cover crop, and residue removal by grazing with a cover crop. Soil GHG emissions were recorded for each experimental unit and evaluated for each of the three growing seasons separately. To evaluate the difference between soil GHG emissions for perennial grasslands and continuous corn production, contrast statements between the perennial grassland and continuous corn emissions were conducted for each growing season.

## Materials & Methods

### *Field-scale Model Demonstration Site*

The field-scale demonstration site was located at the Eastern Nebraska Research and Extension Center near Ithaca, Nebraska. The site was established on 20-ha of non-irrigated, marginally productive cropland in 2015. For this study, marginally productive cropland is defined as poorly drained soil. Approximately 40% of the land at the site is classified as somewhat poorly drained (Table 4-1). Soils at the site are silt loams and silty clay loams of soil series common to this region: Tomek (Fine, smectitic, mesic Pachic Argiudoll; 40%), Filbert (Fine, smectitic, mesic Vertic Argialboll; 27%), Yutan (Fine-silty, mixed, superactive, mesic Mollic Hapludalf; 20%), and Fillmore (Fine, smectitic, mesic Vertic Argialboll; 13%) (Table 4-1). The long term average precipitation and air temperature are 74.7 cm and 9.9°C, respectively (NCDC; Station ID Mead 6 S 2020). Weather data for the study was collected from a weather station located 600 m SE of the

ICLS. During the growing season (April-October), in 2017, 2018, and 2019, the site received 675, 537, and 633 mm of rainfall, respectively (Figure 4-1).

At this 20-ha site, 12-ha were planted to perennial grass and 8-ha were planted to continuous corn production in 2015. Of the 12-ha planted to long-term perennial grass, 4-ha each were planted to Newell smooth bromegrass, Liberty switchgrass, and Shawnee switchgrass. Newell smooth bromegrass (Newell) was planted because of the cultivar's increased digestibility when compared to other smooth bromegrass varieties. The increased digestibility leads to higher cattle average daily gains than its' competitor 'Lincoln' smooth bromegrass (Vogel, Mitchell, Waldron, et al. 2014). Liberty switchgrass (Liberty) was planted because it is a lowland ecotype developed for use as a cellulosic bioenergy crop (Vogel, Mitchell, Casler, et al. 2014). Shawnee switchgrass (Shawnee) was planted because it is an upland ecotype that was developed to have improved forage quality, leading to greater potential animal gains (Vogel, Hopkins, Moore 1996). The Newell and Liberty pastures were established in 2015 and Shawnee was established in 2006. Including the two varieties of switchgrass allows for comparison of animal gain and biomass production potential of the varieties. Additionally, including a grazing variety and biomass producing variety of switchgrass offers management flexibility.

***Perennial Grass Grazing Management***

All perennial grass pastures were harvested for hay in 2016 to plan the grazing experiment and allow for adequate plant establishment before grazing. Results for 2016 were not reported because 2016 was considered the establishment year. Each perennial grassland had 3 randomly placed, replicated exclosures. Each exclosure was split into non-grazed, continually grazed, and flash-grazed (Figure 4-4). Each pasture received 56 kg N $ha^{-1}$ each year. In 2017, the Newell smooth bromegrass was grazed in the spring by 18-hd of crossbred yearling steers (mean body wt.=342 kg) for 21 days. The steers were moved to flash graze the Liberty perennial grassland for 7 days to determine the impact of a brief grazing event on biomass yield. Following the flash grazing event, the same steers (mean body wt.=367 kg) grazed the Shawnee switchgrass for 73 days until September 1. The steers were moved back to the Newell to graze the smooth bromegrass re-growth for 29 days. In 2018, 18-hd of crossbred yearling steers (mean body wt.= 393.7 kg) grazed the Newell perennial grassland from May-June. After grazing Newell, the herd was divided. 9-hd (mean body wt.=416.0 kg) of steers grazed the Liberty for 79 days and the other 9-hd (mean body wt.=413.0 kg) of steers grazed the Shawnee for 79 days. At the conclusion of grazing the switchgrass pastures, the herd was recombined and the 18-hd (mean body wt.=456.8 kg $hd^{-1}$) returned to graze the regrowth of the Newell pasture for 13 days. In 2019, 18-hd of crossbred yearling steers (mean body wt.=288.9 kg) grazed the Newell perennial grassland from May-June. After grazing Newell, the herd was divided. 9-hd (mean body wt.=339.3 kg) of steers grazed the Liberty for 79 days and the other 9-hd (mean body wt.=339.7 kg) of steers grazed the Shawnee for 79 days. At the conclusion of grazing the switchgrass pastures, the herd was recombined and the 18-hd (mean body wt.=362.4 kg $hd^{-1}$) returned to graze the regrowth of the Newell pasture for 23 days. The same grazing sequence was followed in 2018 and 2019 to have two years of identical management.

***Row-crop Management***

Each year corn was planted at 65,236 seeds $ha^{-1}$. The field was fertilized with 140 kg $ha^{-1}$ of nitrogen applied as urea (46-0-0) each spring. Pre- and post-emergent herbicide was applied. Herbicide products and rates for each year can be viewed in Table 4-2.

To test how different corn residue management effected soil GHG emissions, 50% of the corn residue was removed by baling on specified plots in 2016 and 2017 (Figure 4-4). In 2018 and 2019, residue was removed by grazing (Figure 4-4). In 2018 grazing began on September 27 and ended on October 12 with 6 steers (459.6 kg $hd^{-1}$) 1.35 $ha^{-1}$. In 2019 grazing began on October 23 and ended on October 29 with 6 steers (379.3 kg $hd^{-1}$) 1.35 $ha^{-1}$. To evaluate the effect of a winter cover crop on GHG emissions during the subsequent growing season, winter hardy triticale was planted on specified plots after corn grain harvest each year (Figure 4-4). Triticale was terminated in spring before corn planting.

***Baseline Soil Sampling***

Baseline soils data were collected when the study was established. Soil samples were collected on June 14, 2016 using a hydraulic sampling system. Two soil cores (3.1 cm DIA) were sampled per perennial grassland plot and three cores were sampled per corn plot. In each plot, cores were separated into six depth increments (0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-90 cm, 90-120 cm) and composited by depth. Soils were air-dried, homogenized, and passed through a 2-mm sieve prior to soil chemical analyses. Soil bulk density was determined by using the volume and dry weights (dried at 105 °C) from the sample cores. Soil electrical conductivity (dS/m) and pH were determined in solution after extraction with deionized water (1:1 soil:water ratio). A subsample of sieved soil was finely ground then analyzed for total carbon and nitrogen (%) using dry combustion. A subsample of sieved soil was sent to a commercial testing lab for determination of exchangeable cations (K, Ca, Mg, Na; mg $kg^{-1}$) (Ward Laboratory; Kearney, NE). Cation concentrations were converted to cmolc $kg^{-1}$ based on corresponding atomic weights and valences, then summed for total base cations. Initial soil properties are displayed in table initial soil properties and were calculated as a weighted average for the 0-30cm depth.

***Soil GHG Emissions***

Soil GHG emissions were sampled from every experimental unit throughout each growing season using the standardized protocols from the USDA-ARS's Greenhouse gas Reduction through Agricultural Carbon Enhancement network (GRACEnet) (Hutchinson and Mosier 1981; Parkin and Venterea 2010; Jin et al. 2017). Vented static chambers were covered with reflective insulation. Both chambers and sampling bases that were installed in the field were built with 20-gage stainless steel. The bases covered an area of 1707 $cm^2$ (52.7 cm x 32.4 cm) and were installed to a soil depth of 5-7 cm so the base height above ground was 5-7 cm. One chamber base was placed within each experimental unit. For the corn, the chamber base was placed in each plot perpendicular to corn rows so the short edge was parallel to the row and the remainder of the base extended into the inter-row area. The base had twice as much area between row compared to inter-row soil microsites. The between-row microsite included the area where fertilizer was applied in the corn. To accommodate field management during the growing season, the bases were removed and then re-installed following completion of the field management activity. To minimize the immediate effects of soil disturbance when bases were reinstalled they were allowed to equilibrate for a minimum of 24 h but typically for 2-4 days before gas sampling (Reicosky et al. 2005). Headspace gas samples were collected via syringes and then injected into evacuated vials at time 0-, 10-, 20-, and 30-min for each sampling event. Samples were taken during the morning of each sampling date to account for diurnal variability and approximate daily average temperature. Sampling occurred repeatedly during the growing season (April-October) each year as weather and staff availability allowed. In 2017, 8 sampling events occurred during the growing season, with one sampling event outside of the growing season, resulting in a total of 348 GS observations. In 2018, 5 sampling events occurred during the growing season, with one sampling event outside of the growing season, resulting in a total of 265 GS observations. In 2019, 9 sampling events occurred during the growing season, with none outside the growing season, resulting in 402 GS observations. Supplementary data collected on each sampling date included air temperature, soil temperature at 15-cm, and soil moisture from 0 to 15-cm depth measured with a handheld time domain reflectometer (FieldScout TDR 300; Spectrum Tech- nologies, Aurora, IL, USA) with a site-specific calibration. Soil bulk density values were used to convert volumetric soil water content to water-filled pore space (WFPS).

A headspace autosampler (CombiPAL; CTC Analytics, Zwingen, Switzerland) connected to a gas chromatograph (450-GC; Varian, Middelburg, the Netherlands) with different detectors for simultaneous measurement of $N_2O$ (electron capture detector), $CH_4$ (flame ionization detector), and $CO_2$ (thermal conductivity detector) was used to measure sample GHG concentrations within 10-d of sample collection. Soil $CO_2$ data is not presented. The fluxes for soil $N_2O$ and $CH_4$ were computed by the linear or quadratic change in the gas concentration in the headspace over time in the enclosed chamber volume (Wagner, Reicosky, and Alessi 1997; Venterea, Maharjan, and Dolan 2011). Additionally, the soil $N_2O$ fluxes were corrected for suppression of the surface–atmosphere concentration gradient (Venterea 2010). Non-zero fluxes were rates greater than (production of gas from soils) or less than (soils consuming gas) the flux detection limit which was calculated by ambient gas concentration, analytical precision, and chamber deployment time (Parkin, Venterea, and Hargreaves 2012). Cumulative growing season $N_2O$ and $CH_4$ emissions for each year were calculated by linear interpolation of daily emissions between sampling dates and summing daily emissions over the growing season.

### ***Statistics***

To determine the effect of grazing and flash grazing on soil GHG emissions of different perennial grass species, cumulative soil GHG emissions from each growing season were calculated and analyzed. The cumulative GHG emissions were evaluated for the perennial grasslands as a pseudo-replicated split plot design where the main effects and treatment interactions of grass species (Newell, Shawnee, Liberty) and grazing management (none, flash, conventional) were tested. To evaluate the effect of corn residue and cover crop management on soil GHG emissions, cumulative soil GHG emissions were calculated and analyzed for each growing season. Cumulative GHG emissions were evaluated for the continuous corn as a randomized complete block design where the stover (baled, grazed, retained) in conjunction with cover crop (with or without Triticale) management was tested. SAS statistical software was used with the PROC GLIMMIX procedure.

Treatment effects on cumulative emissions were analyzed for each growing season because each growing season had different management and a different number of GHG observations. For the corn, residue was removed by baling in 2016 and 2017 effecting 2017 and 2018 emissions. In 2017 and 2018 no grazing occurred so the experimental units that were supposed to be grazed were assigned the retained residue treatment. In 2018, grazing occurred effecting the 2019 GHG emissions. In 2019, the experimental units were evaluated with their original assigned treatment combinations. Although, residue was not removed by baling in 2018, the experimental units with residue baling treatments were considered as experimental units with baled residue because of the previous treatment history in 2016 and 2017. It is important to note that the experimental units with residue grazing were twice the size as the plots with residue retained and residue removed by baling. For the perennial grasslands, grazing management differed from 2017 to 2018 and 2019. In 2017, the Liberty was only flash-grazed and not continually grazed. Therefore, the continually grazed treatments were assigned the flash-grazed treatment. In 2018 and 2019 the original assigned treatment combinations were used.

Normality and homogeneous variance were evaluated using the conditional studentized residuals and the UNIVARIATE procedure in SAS. Significance for main effects and interaction terms were evaluated using a p-value<0.05, and $0.05 < p < 0.10$ were considered marginally significant. Treatment least significant means were reported for the significant main effect or significant interactions.

In order to identify if a difference in soil GHG emissions existed based on land-use (i.e. perennial grassland or annual corn production) the means of the perennial grassland and continuous corn were compared. The means were compared by using contrast statements at the significant main or treatment interaction level for the corn or perennial grasslands using data from the study. Every corn mean was compared to every perennial grassland mean within each growing season. Contrast statements were unbalanced because the most granular level of data was reported. If no significant effects were observed, the overall mean was reported. All reported measured variables are reported as means.

## Results

### *Growing season soil $CH_4$ emissions*

*Perennial Grass*

The observed $CH_4$ emissions were small, but some differences were observed. In 2017, only the species main effect was significant. Therefore, the LS-means are presented at the species level. In 2018 and 2019 the species by grazing interaction was significant. Therefore, the LS-means are presented at the species by grazing interaction level.

In 2017, the Newell smooth bromegrass (BRM) and Liberty switchgrass (LBY) perennial grasslands produced more $CH_4$ than the Shawnee switchgrass (SHN) perennial grassland. The SHN perennial grassland consumed $CH_4$.

In 2018, the non-grazed BRM exclosure produced around double the amount of $CH_4$ as the conventionally and flash-grazed BRM exclosures. However, on the contrary, in 2018, the LBY conventionally grazed exclosure produced over twice as much $CH_4$ as the LBY non-grazed. Additionally, in 2018, there was no difference among grazing treatments for the SHN perennial grassland. Furthermore, in 2018, the LBY conventionally grazed exclosure produced triple the amount of $CH_4$ when compared to the conventionally grazed SHN exclosure. In 2018 SHN and LBY were both grazed for 79-d. In 2018, no differences in flash-grazed treatments across species were observed. In 2018, the BRM non-grazed perennial grassland produced at least 2.5 times more than the LBY and SHN non-grazed perennial grasslands. The BRM was grazed for less time than the LBY and SHN perennial grassland.

In 2019, no differences among the grazing treatments for the LBY and SHN exclosures were observed. In 2019, the BRM non-grazed exclosure produced more than the BRM flash grazed exclosure. In fact, the BRM flash-grazed exclosure consumed $CH_4$. This result also occurred in 2018. In both years, LBY and SHN were grazed for 79-d. For the flash-grazed and non-grazed exclosures there were no significant differences observed among species. The results for soil $CH_4$ emissions are not the same among species in 2017, 2018, and 2019. Additionally, the patterns among years are vague. These results likely indicate that soil $CH_4$ emissions were controlled by soil type and location within the perennial grassland, instead of by grazing and species.

*Corn*

To determine the effect of residue removal by baling and grazing with and without a cover crop on soil GHG emissions, cumulative soil GHG emissions from the growing season were calculated and analyzed. The observed $CH_4$ emissions were small, but some differences were observed. In 2017, treatment was significant. Therefore, the LS-means are presented at the treatment level. In 2018 and 2019 the treatment was not significant. Therefore, the overall mean is presented.

In 2017 when corn residue was baled, and no cover crop was planted, $CH_4$ was emitted from the soil. However, when residue was baled with a cover crop, $CH_4$ was consumed by the soil. Additionally, when stover was retained with and without a cover crop $CH_4$ was consumed. In 2018 and 2019 no treatment effect was observed for $CH_4$ emissions. In 2018 and 2019 the overall corn mean was 0.14 and 0.72 kg C $ha^{-1}$ $yr^{-1}$, respectively.

***Growing season soil $N_2O$ emissions***

*Perennial Grass*

In 2017, no significant main effects or interactions were observed for soil $N_2O$ emissions from the perennial grasslands. The overall mean emissions for the perennial grasslands was 0.81 kg N $ha^{-1}$ $yr^{-1}$. In 2018, a marginally significant interaction was detected between species and grazing. Therefore, the LS-means are presented for each species and grazing combination. In 2019, a significant species main effect was observed. Therefore, the LS-means are presented for each species.

In 2018, the BRM conventionally grazed exclosures produced almost double the amount of $N_2O$ than the BRM flash grazed exclosures. Additionally, the BRM non-grazed exclosure was similar to the BRM conventional and flash grazed exclosures. In 2018 there were no significant differences among grazing treatments in the LBY or SHN perennial grasslands.

In 2018, the BRM conventionally grazed exclosure produced at least 2.5 times more $N_2O$ than the LBY and SHN conventionally grazed exclosures. The BRM perennial grassland was grazed for fewer days than the LBY and SHN perennial grasslands.

Additionally, the non-grazed BRM pasture produced three times the $N_2O$ as the non-grazed SHN pasture. There were no differences among species in the flash grazed treatments. In 2019, the BRM perennial grassland produced 2.5 times the amount of $N_2O$ than the SHN and LBY pasture. Overall, grazing perennial grasslands did not consistently negatively influence soil $N_2O$ emissions.

*Corn*

In 2017 and 2019, the treatment was significant for soil $N_2O$ emissions. Therefore, the LS-means for the emissions of each corn treatment are presented. In 2018, the treatment effect was not significant. Therefore, the overall mean for the corn is presented. In 2017, when residue was retained with a cover crop, $N_2O$ emissions were reduced by at least 2.5 times when compared to plots with retained residue without a cover crop and plots with residue baling with a cover crop. In 2018, there were no differences among treatments. The overall mean emissions for the corn was 4.56 kg N $ha^{-1}$ $yr^{-1}$.

In 2019, grazing with and without a cover crop produced more $N_2O$ than plots with retained residue and a cover crop, plots with baled residue and a cover crop, and plots with baled residue without a cover crop. Although not different, including a cover crop in grazed areas reduced $N_2O$ emissions on average, by half in the grazed treatments.

***Comparison of perennial grass versus corn soil GHG emissions***

*$CH_4$*

In 2017 baling residue with no cover crop produced more $CH_4$ than the LBY and SHN perennial grasslands. However, when residue was baled and a cover crop was included, the corn became a $CH_4$ sink and produced less than the BRM and LBY perennial grasslands. When residue was retained with and without a cover crop the corn field consumed $CH_4$, resulting in the BRM perennial grassland producing more $CH_4$. On the other hand, the SHN perennial grassland consumed 4 more times the $CH_4$ than the cornfield with retained residue and a cover crop.

In 2018, each perennial grassland treatment mean was compared with the overall treatment mean of the corn. The flash and conventionally grazed LBY exclosures produced at least double the amount of $CH_4$ as the continuous corn field. Importantly, the non-grazed BRM exclosure produced 3.5 times more $CH_4$ than the continuous corn field. In 2019, each perennial grassland treatment mean was compared with the overall treatment mean from the corn. No significant differences were detected between the corn-field and perennial grassland treatments. The results from each year indicate that soil type and weather may have influenced the amount of $CH_4$ produced or consumed by the soil more than the crop planted (corn vs perennial grassland).

*$N_2O$*

To evaluate the difference in $N_2O$ emissions between the perennial grassland and corn field contrast statements were made between the means for the significant main effect or at the significant interaction level. In 2017, the corn treatments produced at least 3 times more $N_2O$ than the overall mean of the perennial grasslands.

In 2018 no significant differences were detected between the overall continuous corn and perennial grassland grazing treatments despite the numeric differences. Corn produced at least 4.5 times the amount of $N_2O$ than the perennial grassland. The variability of the data set likely reduced the ability to detect a significant difference.

In 2019, grazing with no cover crop in the continuous corn produced at least 3 times more $N_2O$ than all perennial grass species. Grazing with a cover crop produced 3.5 times more $N_2O$ than LBY and SHN perennial grasslands but produced a similar amount of $N_2O$ to the BRM perennial grassland. When residue was retained with and without a cover crop at least 3 times more $N_2O$ was produced when compared to the LBY and SHN perennial grasslands. However, when compared to the BRM, those corn treatments produced less $N_2O$. Likewise, when baling residue with and without a cover crop was compared to the BRM perennial grassland, they produced less $N_2O$. However, when the baled with and without a cover crop corn treatments were compared to LBY, the corn treatments produced more $N_2O$. These results indicate that perennial grasslands could produce less $N_2O$ than continuous corn.

Overall, the results from 2017-2019 show that perennial grasses have reduced soil $N_2O$ emissions likely due to less synthetic nitrogen fertilizer.

## Discussion

### *Pasture*

Grazing has been shown to increase methane uptake (Gamble et al. 2019), but we found no consistent effects on grazing or grass species on soil $CH_4$ fluxes in the present study. Similarly, there were no consistent effects of grazing or grass species on soil $N_2O$ emissions. Although there was no main or interaction effect of grazing on grassland soil $CH_4$ flux in 2017, the SHN grassland consumed $CH_4$, whereas the LBY and BRM pastures emitted $CH_4$. The observed difference among perennial grasslands may be because the SHN grassland was grazed for 23 more days than the BRM and 66 more days than the LBY grasslands. Generally, $CH_4$ emissions were extremely small and highly variable, making them negligible when considering whole system global warming potential.

Our results also indicate that grazing perennial grasslands did not have a consistent impact on soil $N_2O$ emissions. Only one of the three growing seasons indicated that grazing and species of grass impacted soil $N_2O$ emissions. Within a species, most grazing treatments were statistically similar. This observation indicates that grazing did not impact soil $N_2O$ emissions. Further evidence suggests that grazing did not impact $N_2O$ emissions. In 2017, no significant species or grazing effect was found despite the management differences among the perennial grasslands. In 2017, the LBY perennial grassland was only grazed for 7-d whereas the BRM and SHN grasslands were grazed for 50-d and 73-d, respectively. This observation indicates that grazing duration may not affect soil $N_2O$ emissions. Further evidence in 2019 suggests that grazing duration did not impact soil $N_2O$ emissions. The perennial grassland with fewer grazing days produced more soil $N_2O$ emissions. The BRM grassland was grazed for 49-d and the SHN and LBY grasslands were grazed for 79-d. Even though the BRM was grazed for 30 less days, the grassland produced more soil $N_2O$ emissions. The minimal differences in the soil $N_2O$ emissions may be since each entire grassland (non-grazed, flash-grazed, and conventionally grazed) received the same level of fertilizer.

Observed increases of soil $N_2O$ in grazed grasslands when compared to non-grazed grasslands are typically due to fertilization. In North Dakota, soil $N_2O$ emissions increase when the pasture is grazed and fertilized when compared to a grazed non-fertilized grassland (Liebig et al. 2006). Additionally, in New Zealand, grazed pastures often exhibit increased soil $N_2O$ when compared to non-grazed grasslands because of increased fertilization and the input of animal dung and urine (Saggar et al. 2008). When grazed perennial grasslands receive nitrogen fertilizer, soil $N_2O$ emissions increase. Interestingly, one study found that grazing perennial grasses can lower $N_2O$ emissions. In the Southeastern United States, cattle grazing bahiagrass at moderate stocking rates either had no impact on soil $N_2O$ or reduced soil $N_2O$ emissions (Gamble et al. 2019). Grazing perennial grasslands has the potential to decrease $N_2O$ emissions, but the result is dependent on fertilizer management. It is also important to note that grazing management, including the duration of a grazing event can impact soil GHG emissions. In Texas, adaptive multi-paddock grazing of native prairie, reduces $N_2O$ and $CH_4$ emissions when compared to continuously grazed prairie (Dowhower et al. 2020).

***Continuous Corn***

Our results suggest that crop residue and cover crop management do not impact soil $CH_4$ emissions but may affect soil $N_2O$ emissions. Two of the three growing seasons indicated that cover crop and residue management did not affect soil $CH_4$ emissions. However, two of the three growing seasons indicated that cover crop and residue management may impact soil $N_2O$ emissions. In 2017, plots with baled residue and a cover crop produced more $N_2O$ than plots with retained residue and a cover crop. This result indicates that residue removal may increase soil $N_2O$ emissions. Additionally, in 2017, plots with retained residue and a cover crop produced less $N_2O$ than plots with retained residue and no cover crop. This result indicates that including a cover crop has the potential to reduce soil $N_2O$ emissions. Despite these treatment differences, in 2018, no treatment effect was detected. However, in 2019, grazing residue increased soil $N_2O$ emissions. Grazed plots produced more $N_2O$ than plots with retained residue and no cover crop and plots with previously baled residue with and without a cover crop. It is important to note that cover crop did not impact $N_2O$ emissions in 2019. The inconsistent results of cover crops reducing GHG emissions is consistent with previous research. This result is supported by previous work in the Great Plains. In South Dakota, cover crops have been proven to decrease $N_2O$ emissions 67% of the time (Wegner et al. 2018). Additionally, a meta-analysis found that the inclusion of cover crops can increase or decrease $N_2O$ emissions (Basche et al. 2014).

Unfortunately, the effect of grazing residue on GHG emissions is not well studied. One study in the Midwest has assessed the effect of grazing residue on GHG emissions. In Illinois when residue was grazed, $CO_2$ effluxes were inconsistent when related to soil compaction and cattle presence (Tracy and Zhang 2008). However, some research has been conducted on the effect of livestock grazing cover crops. These studies may help to gain insight on the effect of grazing crop residue. One study has demonstrated that cover crop grazing mitigates soil $N_2O$ when compared to continuous cropping (Dieckow et al. 2015). Another study has shown that grazing annual forages in South Dakota does not impact $N_2O$ emissions (Abagandura et al. 2019). However, another study revealed an increase in soil $N_2O$ emissions. When an ICLS with cover crop grazing is compared to a continuous cropping system, $N_2O$ emissions increase (Piva et al. 2014). However, researchers believe the observed increase was likely due to additional synthetic fertilizer the grazed cover crop received. Increased synthetic fertilizer generally increases soil $N_2O$ emissions (Bavin et al. 2009; Abagandura et al. 2019).

Our evidence suggests that residue removal may increase soil $N_2O$ emissions. However, our results were not consistent. The inconsistent findings are similar to what reviewers concluded after conducting a global literature review on residue removal. The effect of residue removal on GHG emissions is inconsistent (Rakkar and Blanco-Canqui 2018). In the US, the effect of residue removal on soil $N_2O$ emissions is variable. Under no-till management residue removal in a corn-soybean rotation does not negatively effect $N_2O$ emissions (Johnson and Barbour 2010). Additionally, across the US Corn Belt when stover is baled $N_2O$ emissions decrease (Jin et al. 2014). Furthermore, in Eastern NE, when residue is removed, $N_2O$ emissions decrease (Jin et al. 2019). However, in South Dakota when residue is baled under a corn-soybean rotation $N_2O$ fluxes increase during the soybean growth phase but are not impacted during the corn growth phase (Lehman and Osborne 2016). Clearly, the effect of residue removal on soil GHG emissions is variable. Researchers have concluded that site specific management is essential for GHG mitigation because GHG emissions vary spatially, temporally, and are based on environmental conditions (Jin et al. 2014; Rakkar and Blanco-Canqui 2018).

***Pasture vs Continuous Corn***

Our results suggest that $CH_4$ emissions do not differ among perennial grasslands and continuous cropland. No consistent patterns were observed in $CH_4$ emissions among perennial grasslands and continuous corn through 2017-2019. However, our results indicate that perennial grasslands may reduce soil $N_2O$ when compared to continuous corn production. In 2017, continuous corn produced more $N_2O$ than perennial grasslands.

In 2018, continuous corn produced numerically more $N_2O$ than the perennial grasslands, however, no statistical difference was found. This observation was likely due to the high variability in the corn $N_2O$ emissions. In 2019, 4 of the corn treatments produced more $N_2O$ than 2 of the perennial grasslands. Additionally, 2 of the corn treatments produced more $N_2O$ than one of the perennial grasslands. However, 4 of the corn treatments produced less $N_2O$ than one of the perennial grasslands. This observation indicates that retaining residue with and without a cover crop could reduce $N_2O$ emissions below some perennial grasslands.  Overall, our results were variable and likely dependent on the reduced synthetic N fertilizer input for perennial grasslands when compared to continuous cropland.

Little is known about the difference in GHG emissions between grazed perennial grasslands and cropland. However, it is well known that low-input perennial grasslands managed for bioenergy production can reduce soil GHG emissions. In Italy, if marginally productive cropland or areas with a surplus of grain production were converted to switchgrass production, GHG savings could be maximized (Nocentini and Monti 2019). In the central US, if cropland used for ethanol production was converted to low input perennial grassland, GHG emissions could be reduced (Davis et al. 2012). Additionally, perennial grasslands have the potential to be net GHG sinks. In eastern Nebraska, switchgrass grown for bioenergy production mitigates GHG emissions (Jin et al. 2019). Conversely, continuous corn grain production maintains GHG  emissions (Jin et al. 2019). It is well known that converting cropland to perennial grassland for bioenergy production reduces GHG emissions. However, the impact of grazing perennial grassland on soil GHG emissions is not as well known. Further research needs to expand upon the difference in GHG emissions for grazed perennial grasslands versus continuous cropland.

### *Limitations*

Two limitations existed in this study. The first limitation was that the pasture exclosures were pseudo-replicated, so we were unable to make statements about the effect of species on the GHG emissions. The second limitation was that not every treatment occurred each year. This resulted in unbalanced data for the continuous corn portion in 2017 and 2018 (i.e. the grazed treatments became retained residue). In 2017 the LBY perennial grassland also had unbalanced data. The LBY continually grazed exclosures in 2017 became the same as the flash grazed exclosures because the cattle only grazed the grassland for 7-d.

## Conclusion

Grazing perennial grasses does not consistently have a negative effect on soil $CH_4$ and $N_2O$ emissions. Additionally, crop residue and cover crop management in continuous corn production does not impact $CH_4$ emissions but may impact $N_2O$ emissions. Generally, continuous corn production results in greater $N_2O$ emissions than perennial grasslands because of increased synthetic N fertilizer input. The findings from this research can provide insight for further development and research of ICLS for Eastern NE that minimize soil GHG emissions. Future research should evaluate if certain perennial species and grazing management (duration) result in reduced soil GHG emissions. Additionally, future research should address enteric GHG emissions in conjunction with soil GHG emissions. Evaluating systems GHG emissions will allow for a more direct comparison between ICLS and continuous crop production. Lastly, future research should evaluate the role of cover crop use in reducing soil $N_2O$ emissions when corn residue is grazed.

**Table 4- 1.** Table Web Soil Survey Map Units.

Table of the total area for each soil map unit at the field-scale model demonstration site.

| Map Unit Symbol | Map Unit Name | Hectares in AOI | Percent in AOI |
|---|---|---|---|
| 3948 | Fillmore silt loam, terrace, occasionally ponded | 2.80 | 13.8% |
| 7105 | Yutan silty clay loam, terrace, 2 to 6 percent slopes, eroded | 4.00 | 19.6% |
| 7280 | Tomek silt loam, 0 to 2 percent slopes | 8.18 | 40.2% |
| 7340 | Filbert silt loam, 0 to 1 percent slopes | 5.38 | 26.4% |

**Table 4- 2.** Table Herbicide Application Rate.

List of herbicides, rates, and times of application for the continuous corn in the field-scale model demonstration site.

| Year | Application | Herbicide | Rate L ha-1 |
|---|---|---|---|
| **2017** | | | |
| | ***Pre-emergent*** | | |
| | | Lexar | 4.68 |
| | | Roundup | 2.63 |
| | | 2,4-D | 0.7 |
| | ***Post-emergent*** | | |
| | | Roundup | 2.34 |
| | | Laudis | 0.13 |
| | | Atrazine | 0.35 |
| **2018** | | | |
| | ***Pre-emergent*** | | |
| | | Atrazine 4L | 2.34 |
| | | Balance | 0.37 |
| | | 2,4-D | 0.58 |
| | ***Post-emergent*** | | |
| | | Roundup Powermax | 2.63 |
| | | Roundup Powermax | 2.34 |
| | | Callisto | 0.18 |
| **2019** | | | |
| | ***Pre-emergent*** | | |
| | | Accuron | 4.68 |
| | | LV6 2,4-D | 0.39 |
| | | Roundup Powermax | 2.34 |
| | ***Post-emergent*** | | |
| | | Callisto | 0.18 |
| | | Roundup Powermax | 1.75 |
| | | Atrazine 4L | 0.58 |

**Table 4- 3.** Table Initial Soil Properties.

Initial soil properties for each experimental unit at the ICLS site. Values presented are the weighted average for 0-30cm.

**Initial Soil Properties**

| Species | Grazing | Cover Crop | Bulk density $Mg/m^3$ | E.C. dS/m | p.H. 1:1 soil:H2O | N % | C % | K cmolc/kg | Ca cmolc/kg | Mg cmolc/kg | Na cmolc/kg | Total base cations cmolc/kg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BRM | Continuous | - | 1.32 | 0.51 | 5.36 | 0.15 | 1.66 | 0.78 | 10.29 | 3.30 | 0.10 | 14.46 |
| BRM | None | - | 1.35 | 0.50 | 5.32 | 0.14 | 1.54 | 0.71 | 10.12 | 3.48 | 0.08 | 14.38 |
| BRM | Flash | - | 1.34 | 0.51 | 5.41 | 0.15 | 1.57 | 0.72 | 10.84 | 3.60 | 0.10 | 15.26 |
| | | | | | | | | | | | | |
| SHN | Continuous | - | 1.24 | 0.50 | 5.38 | 0.15 | 1.68 | 0.76 | 12.44 | 3.81 | 0.10 | 17.11 |
| SHN | None | - | 1.16 | 0.48 | 5.38 | 0.14 | 1.65 | 0.66 | 11.22 | 3.30 | 0.10 | 15.28 |
| SHN | Flash | - | 1.23 | 0.54 | 5.50 | 0.14 | 1.61 | 0.70 | 11.78 | 3.94 | 0.10 | 16.52 |
| | | | | | | | | | | | | |
| LBY | Continuous | - | 1.32 | 0.50 | 5.23 | 0.15 | 1.64 | 0.80 | 11.28 | 3.41 | 0.11 | 15.60 |
| LBY | None | - | 1.30 | 0.51 | 5.18 | 0.15 | 1.66 | 0.79 | 10.68 | 3.37 | 0.11 | 14.94 |
| LBY | Flash | - | 1.32 | 0.52 | 5.18 | 0.14 | 1.54 | 0.81 | 11.85 | 3.96 | 0.12 | 16.73 |
| | | | | | | | | | | | | |
| Corn | Grazed | None | 1.33 | 0.51 | 5.18 | 0.15 | 1.66 | 0.75 | 10.37 | 2.94 | 0.11 | 14.17 |
| Corn | Grazed | Triticale | 1.28 | 0.54 | 5.28 | 0.17 | 1.88 | 0.80 | 10.94 | 3.20 | 0.12 | 15.06 |
| Corn | Baled | None | 1.39 | 0.50 | 5.16 | 0.15 | 1.67 | 0.96 | 10.54 | 3.13 | 0.10 | 14.73 |
| Corn | Baled | Triticale | 1.32 | 0.51 | 5.23 | 0.16 | 1.70 | 0.84 | 11.24 | 3.27 | 0.12 | 15.48 |
| Corn | Retained | None | 1.36 | 0.52 | 5.38 | 0.15 | 1.74 | 1.18 | 11.06 | 2.99 | 0.08 | 15.29 |
| Corn | Retained | Triticale | 1.33 | 0.65 | 5.37 | 0.16 | 1.70 | 0.77 | 11.24 | 2.99 | 0.10 | 15.10 |

**Table 4- 4.** Perennial grassland $CH_4$ LS Means.

Average kg of carbon emitted from the soil as $CH_4$ each year of the study in the perennial grassland portion of the study. In 2017 8 observations were recorded, in 2018 5 observations were recorded, in 2019 9 observations were recorded. Means presented are at the significant treatment or main effect level. Treatments with the same letter (A,B,C) are not statistically different and treatments with different letters are statistically different at $P<.05$. P-values between 0.05 and 0.1 were considered marginally significant. BRM is Newell Smooth Bromegrass. LBY is Liberty switchgrass. SHN is Shawnee switchgrass. None is the non-grazed treatment. Conv is the conventionally grazed treatment. Flash is the flash-grazed treatment.

Perennial grassland $CH_4$

| | | | $kg\ C\ ha^{-1}\ yr^{-1}$ | |
|---|---|---|---|---|
| 2017 | | | | |
| | BRM | | 0.17 | A |
| | LBY | | 0.03 | A |
| | SHN | | -0.16 | B |
| | | p-value | 0.0136 | |
| 2018 | | | | |
| | BRM None | | 0.51 | A |
| | LBY Conv | | 0.45 | AB |
| | LBY Flash | | 0.31 | ABC |
| | BRM Conv | | 0.27 | BC |
| | BRM Flash | | 0.26 | BC |
| | SHN Flash | | 0.24 | BC |
| | LBY None | | 0.19 | C |
| | SHN Conv | | 0.15 | C |
| | SHN None | | 0.09 | C |
| | | p-value | 0.0074 | |
| 2019 | | | | |
| | LBY Conv | | 1.72 | A |
| | BRM None | | 1.53 | A |
| | LBY Flash | | 1.17 | AB |
| | BRM Conv | | 1.16 | AB |
| | SHN Flash | | 1.13 | AB |
| | SHN None | | 1.07 | AB |
| | LBY None | | 0.67 | AB |
| | BRM Flash | | -0.28 | B |
| | SHN Conv | | -0.58 | B |
| | | p-value | 0.0611 | |

**Table 4- 5.** Perennial grassland $N_2O$ LS means.

Average kg of nitrogen emitted from the soil as $N_2O$ each year of the study in the perennial grassland portion of the study. In 2017 8 observations were recorded, in 2018 5 observations were recorded, in 2019 9 observations were recorded. Means presented are at the significant treatment or main effect level. Treatments with the same letter (A,B,C) are not statistically different and treatments with different letters are statistically different at P<.05. P-values between 0.05 and 0.1 were considered marginally significant. BRM is Newell Smooth Bromegrass. LBY is Liberty switchgrass. SHN is Shawnee switchgrass. None is the non-grazed treatment. Conv is the conventionally grazed treatment. Flash is the flash-grazed treatment.

| | Perennial grassland $N_2O$ | | |
|---|---|---|---|
| 2017 | | kg N $ha^{-1}$ $yr^{-1}$ | |
| | Overall | 0.81 | |
| 2018 | | | |
| | BRM Conv | 0.98 | A |
| | BRM None | 0.64 | AB |
| | SHN Flash | 0.53 | BC |
| | BRM Flash | 0.45 | BC |
| | SHN Conv | 0.39 | BC |
| | LBY Flash | 0.30 | BC |
| | LBY None | 0.27 | BC |
| | SHN None | 0.19 | C |
| | LBY Conv | 0.17 | C |
| | p-value | 0.0537 | |
| 2019 | | | |
| | BRM | 5.48 | A |
| | SHN | 1.93 | B |
| | LBY | 0.99 | B |
| | p-value | 0.0003 | |

**Table 4- 6.** Corn $CH_4$ LS means.

Average kg of carbon emitted from the soil as $CH_4$ each year of the study in the corn portion of the study. In 2017 8 observations were recorded, in 2018 5 observations were recorded, in 2019 9 observations were recorded. Means presented are at the significant treatment or main effect level. Treatments with the same letter (A,B) are not statistically different and treatments with different letters are statistically different at P<.05. P-values between 0.05 and 0.1 were considered marginally significant. Bal is residue removal by baling. RTN is residue retained. GRZ is residue removal by grazing. NoCC is no cover crop was included. CC is cover crop was included.

Continuous Corn CH4

| 2017 | | kg C $ha^{-1}$ $yr^{-1}$ | |
|---|---|---|---|
| | Bal/NoCC | 0.24 | A |
| | RTN/NoCC | -0.04 | B |
| | RTN/CC | -0.05 | B |
| | Bal/CC | -0.14 | B |
| | p-value | 0.0502 | |
| 2018 | | | |
| | Overall | 0.14 | |
| 2019 | | | |
| | Overall | 0.72 | |

**Table 4- 7. Corn $N_2O$ LS means.**

Average kg of nitrogen emitted from the soil as $N_2O$ each year of the study in the corn portion of the study. In 2017 8 observations were recorded, in 2018 5 observations were recorded, in 2019 9 observations were recorded. Means presented are at the significant treatment or main effect level. Treatments with the same letter (A,B) are not statistically different and treatments with different letters are statistically different at P<.05. P-values between 0.05 and 0.1 were considered marginally significant. Bal is residue removal by baling. RTN is residue retained. GRZ is residue removal by grazing. NoCC is no cover crop was included. CC is cover crop was included.

Continuous Corn $N_2O$

| | | | |
|---|---|---|---|
| 2017 | | kg N $ha^{-1}$ $yr^{-1}$ | |
| | Bal/CC | 7.75 | A |
| | RTN/NoCC | 6.79 | A |
| | Bal/NoCC | 6.72 | AB |
| | RTN/CC | 2.59 | B |
| | p-value | 0.0759 | |
| 2018 | | | |
| | Overall | 4.55 | |
| 2019 | | | |
| | GRZ/NoCC | 15.89 | A |
| | GRZ/CC | 8.65 | A |
| | RTN/CC | 3.96 | AB |
| | RTN/NoCC | 3.27 | B |
| | BAL/CC | 1.75 | B |
| | BAL/NoCC | 1.72 | B |
| | p-value | 0.0807 | |


**Figure 4- 1.** Figure Web Soil Survey Map**.**

A map of the field-scale modern demonstration site with the locations of the soil map units.

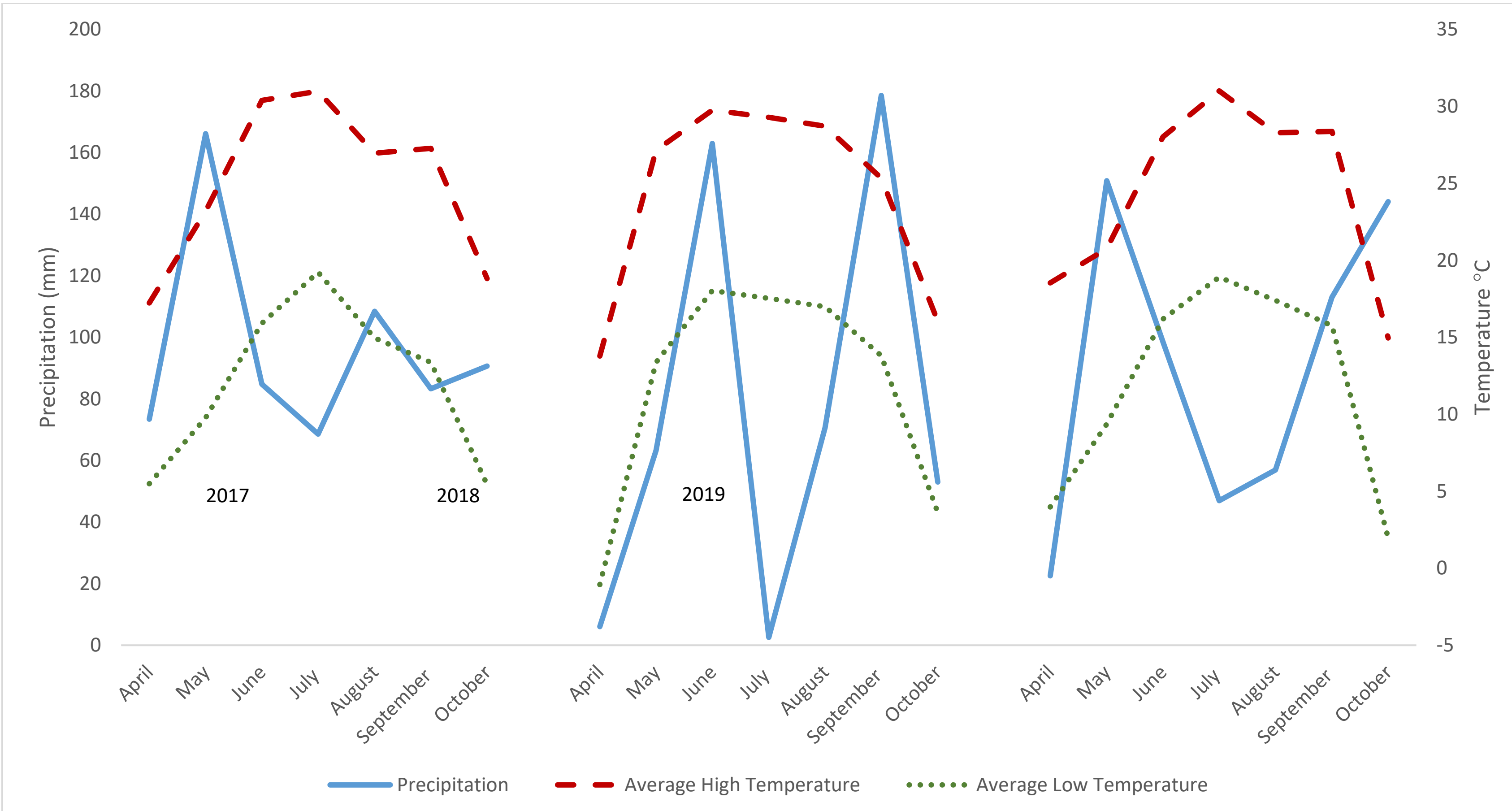


**Figure 4- 2.** Average precipitation, high and low temperature during growing season.

Average precipitation and high and low temperature for each month in the growing season for 2017, 2018, and 2019. Weather station located 600m SE of the ICLS site.

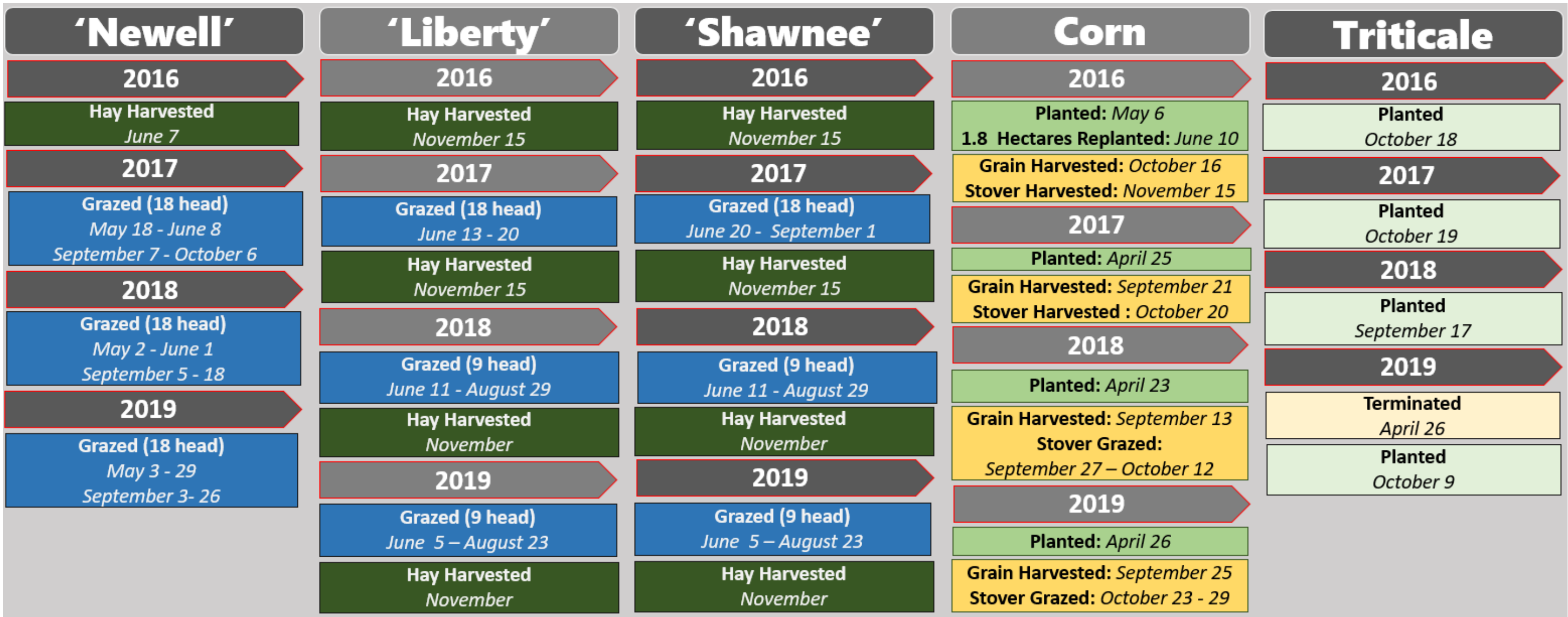


**Figure 4- 3.** Figure management by component by year.

Outline of how each component of the field-scale model demonstration site was managed each year.

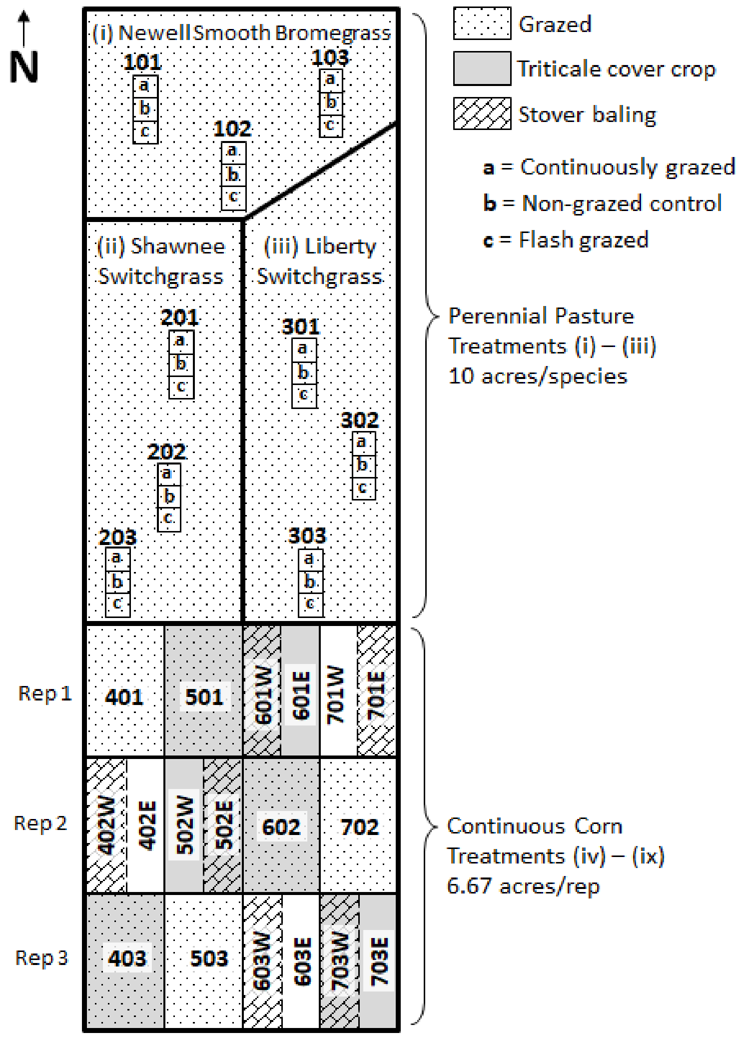


**Figure 4- 4.** Treatment map.

Treatment layout for the ICLS. Corn residue grazing only occurred in Autumn of 2018 and 2019. Stover was only baled in 2017 and 2018. Liberty was only flash grazed in 2018.

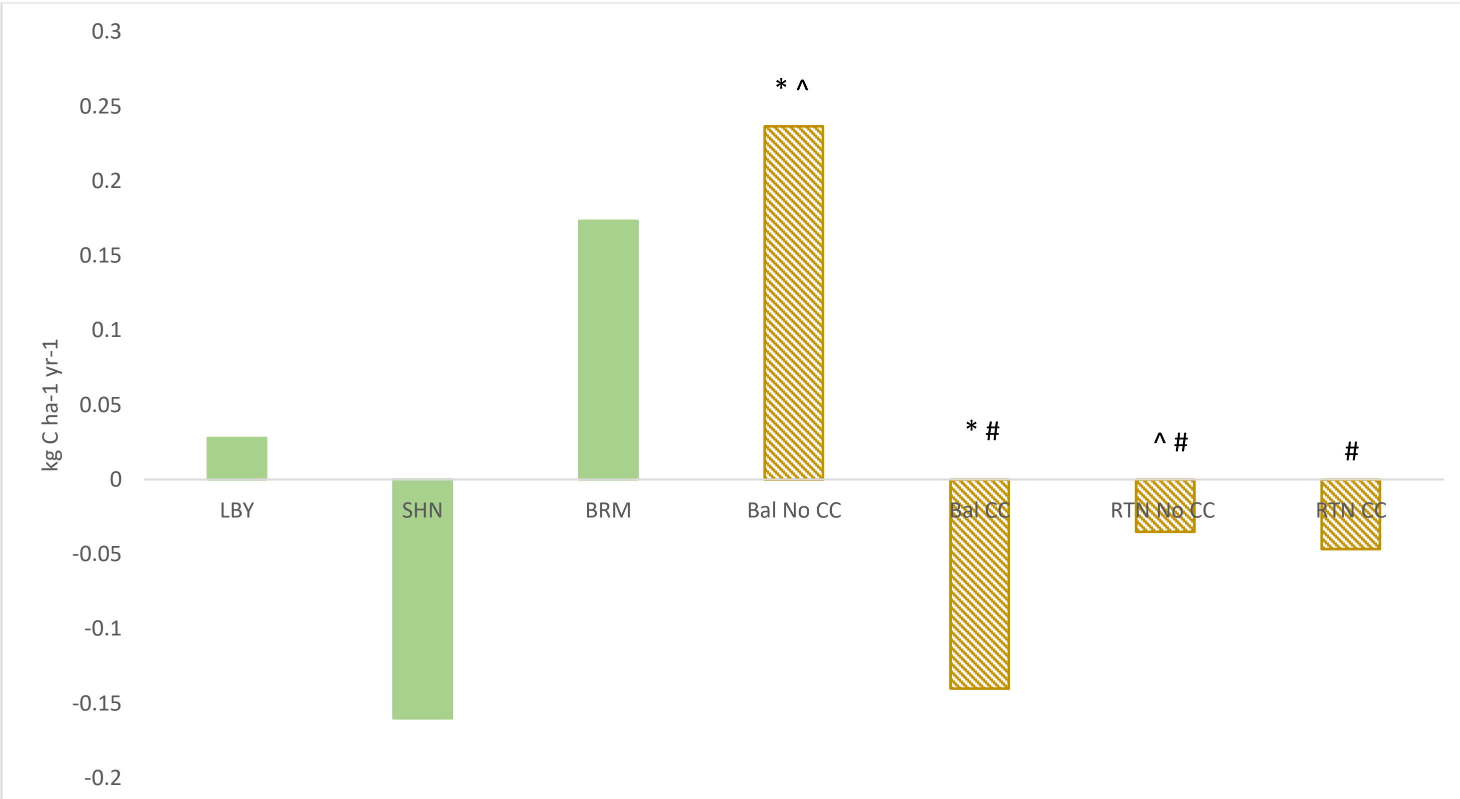


**Figure 4- 5.** 2017 $CH_4$ emission contrasts.

Average kilograms of carbon emitted from the soil as $CH_4$ during the growing season in 2017 for each significant treatment or main effect. Soil GHG emissions were measured 8 times per season Contrasts between perennial grassland and corn treatments were performed using a P<0.05. * denotes corn treatment mean is significantly different from LBY mean. ^ denotes corn treatment mean is significantly different from SHN. # denotes corn treatment mean is significantly different from BRM. Bal is residue removal by baling. RTN is residue retained. NoCC is no cover crop was included. CC is cover crop was included. BRM is Newell Smooth Bromegrass. LBY is Liberty switchgrass. SHN is Shawnee switchgrass.

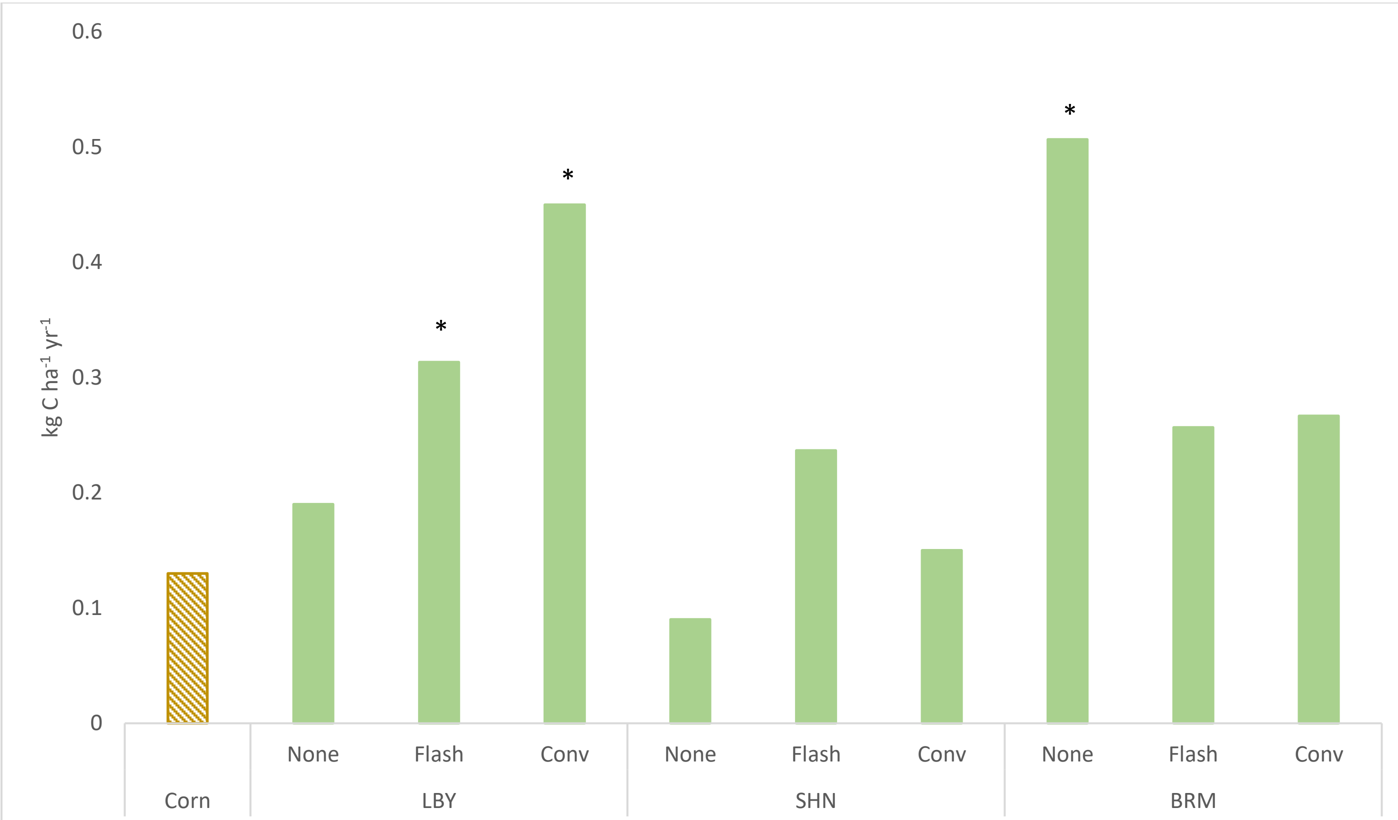


**Figure 4- 6.** 2018 $CH_4$ emission contrasts**.**

Average kilograms of carbon emitted from the soil as $CH_4$ during the growing season in 2018 for each significant treatment or main effect. Soil GHG emissions were measured 5 times per season Contrasts between perennial grassland and corn treatments were performed using a $P<0.05$. * denotes perennial grassland treatment mean is significantly different from corn mean.  BRM is Newell Smooth Bromegrass. LBY is Liberty switchgrass. SHN is Shawnee switchgrass. None is the non-grazed treatment. Conv is the conventionally grazed treatment. Flash is the flash-grazed treatment.

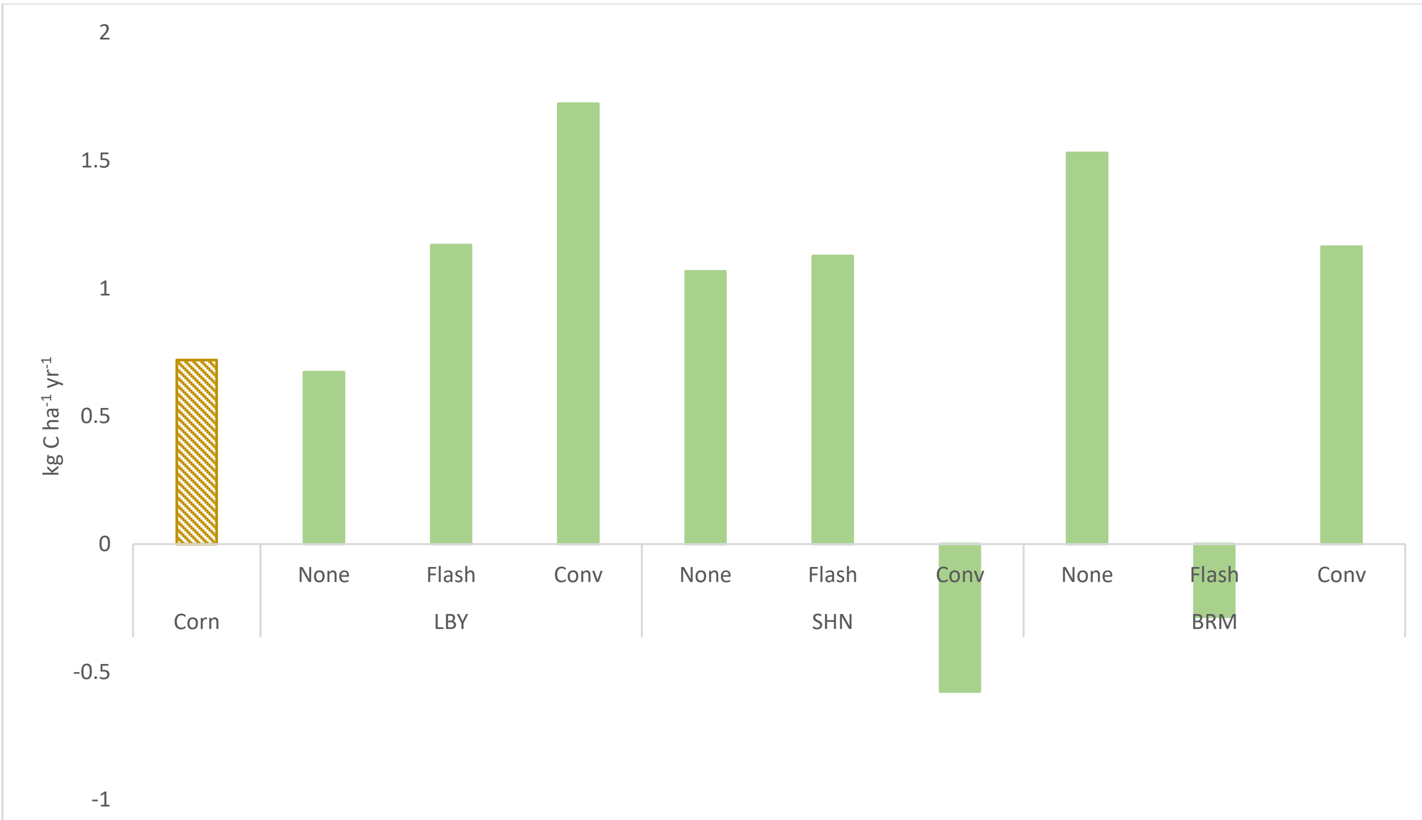


**Figure 4- 7.** Figure 2019 $CH_4$ emission contrasts

Average kilograms of carbon emitted from the soil as $CH_4$ during the growing season in 2018 for each significant treatment or main effect. Soil GHG emissions were measured 9 times per season Contrasts between perennial grassland and corn treatments were performed using a $P<0.05$. No perennial grassland treatments were significantly different from the continuous corn mean. BRM is Newell Smooth Bromegrass. LBY is Liberty switchgrass. SHN is Shawnee switchgrass. None is the non-grazed treatment. Conv is the conventionally grazed treatment. Flash is the flash-grazed treatment.

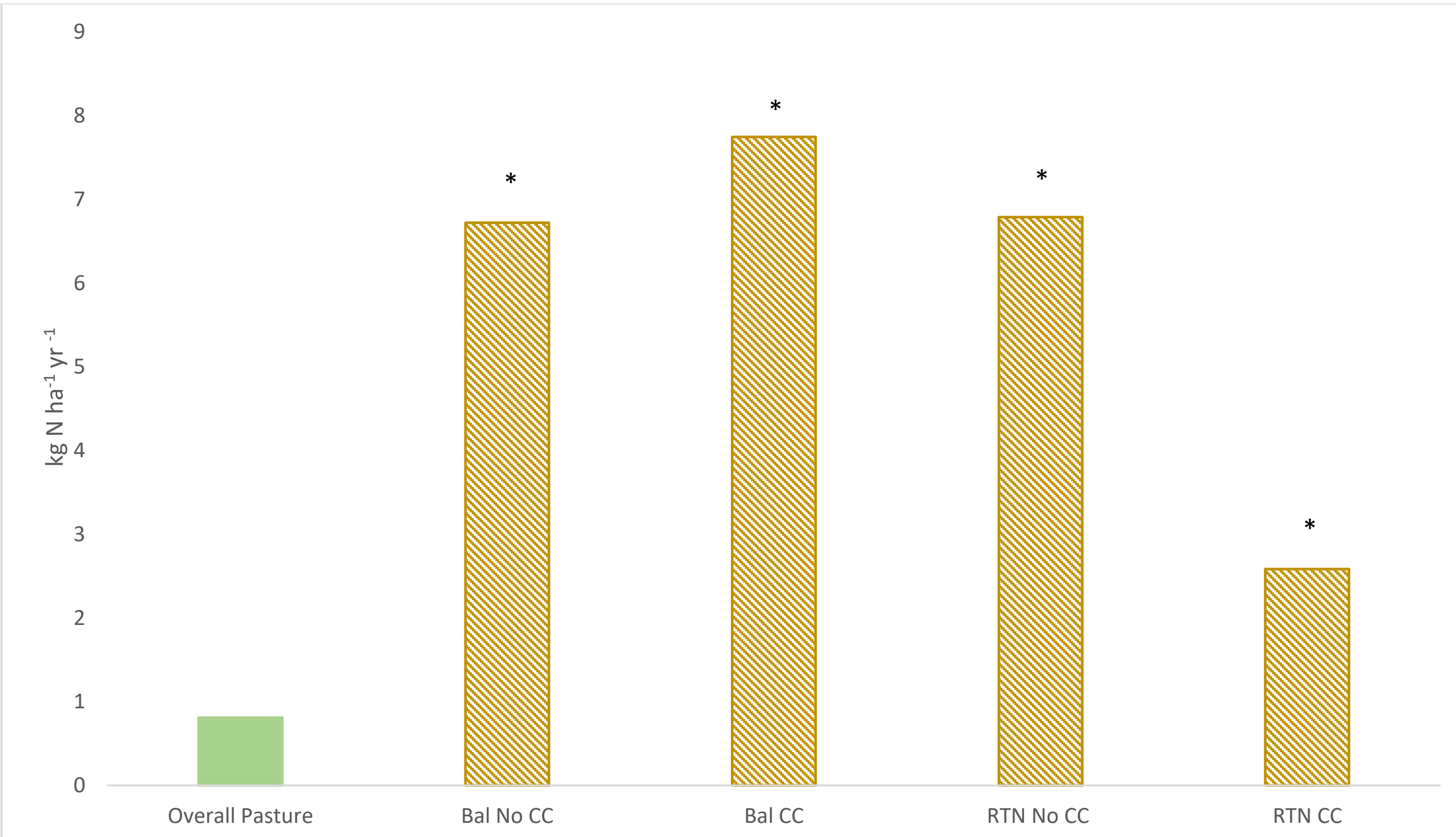


**Figure 4- 8.** 2017 $N_2O$ emission contrasts.

Average kilograms of nitrogen emitted from the soil as $N_2O$ during the growing season in 2017 for each significant treatment or main effect. Soil GHG emissions were measured 8 times per season Contrasts between perennial grassland and corn treatments were performed using a $P<0.05$. * denotes corn treatment mean is significantly different from overall perennial grassland mean.  Bal is residue removal by baling. RTN is residue retained. NoCC is no cover crop was included. CC is cover crop was included.

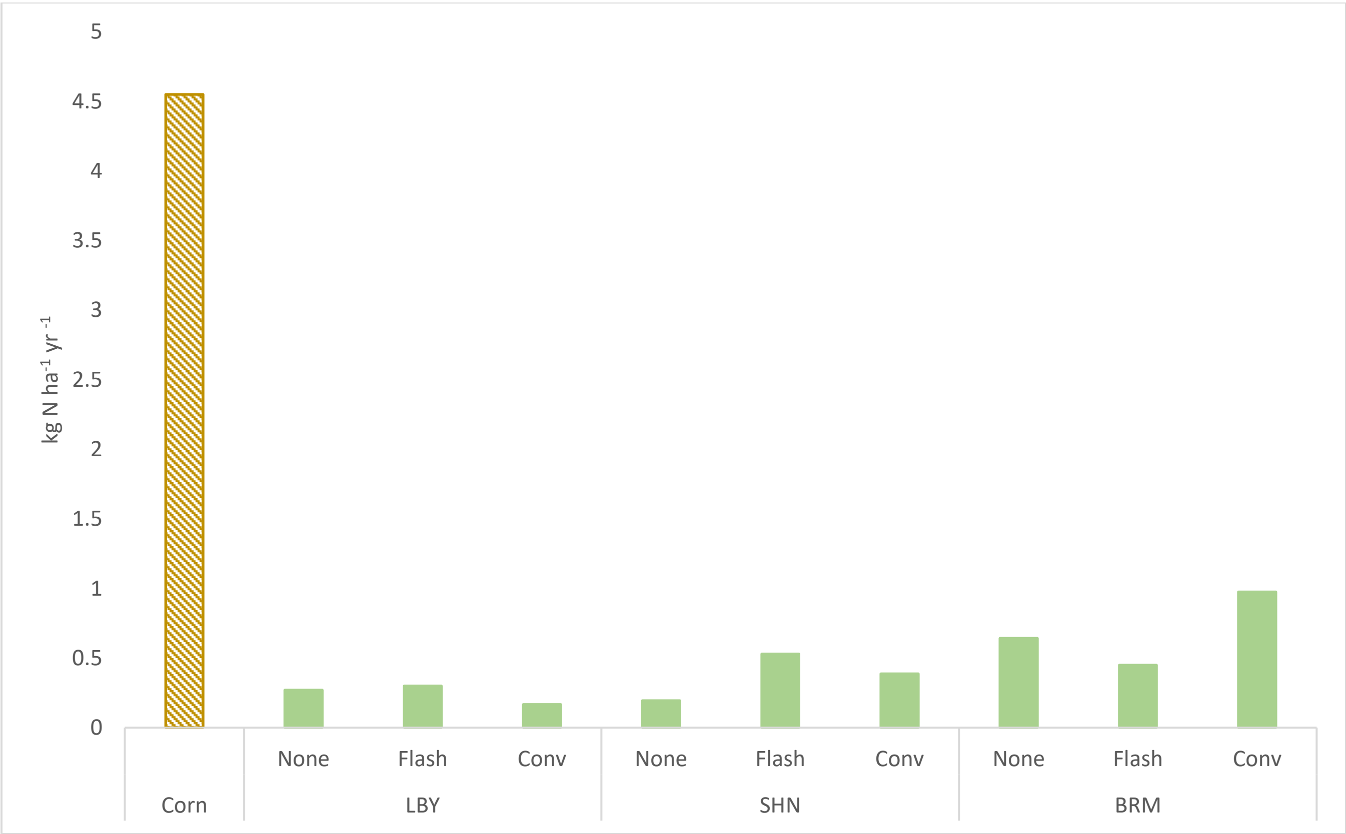


**Figure 4- 9.** 2018 $N_2O$ emission contrasts.

Average kilograms of nitrogen emitted from the soil as $N_2O$ during the growing season in 2018 for each significant treatment or main effect. Soil GHG emissions were measured 5 times per season Contrasts between perennial grassland and corn treatments were performed using a $P<0.05$. No means were significantly different. BRM is Newell Smooth Bromegrass. LBY is Liberty switchgrass. SHN is Shawnee switchgrass. None is the non-grazed treatment. Conv is the conventionally grazed treatment. Flash is the flash-grazed treatment.

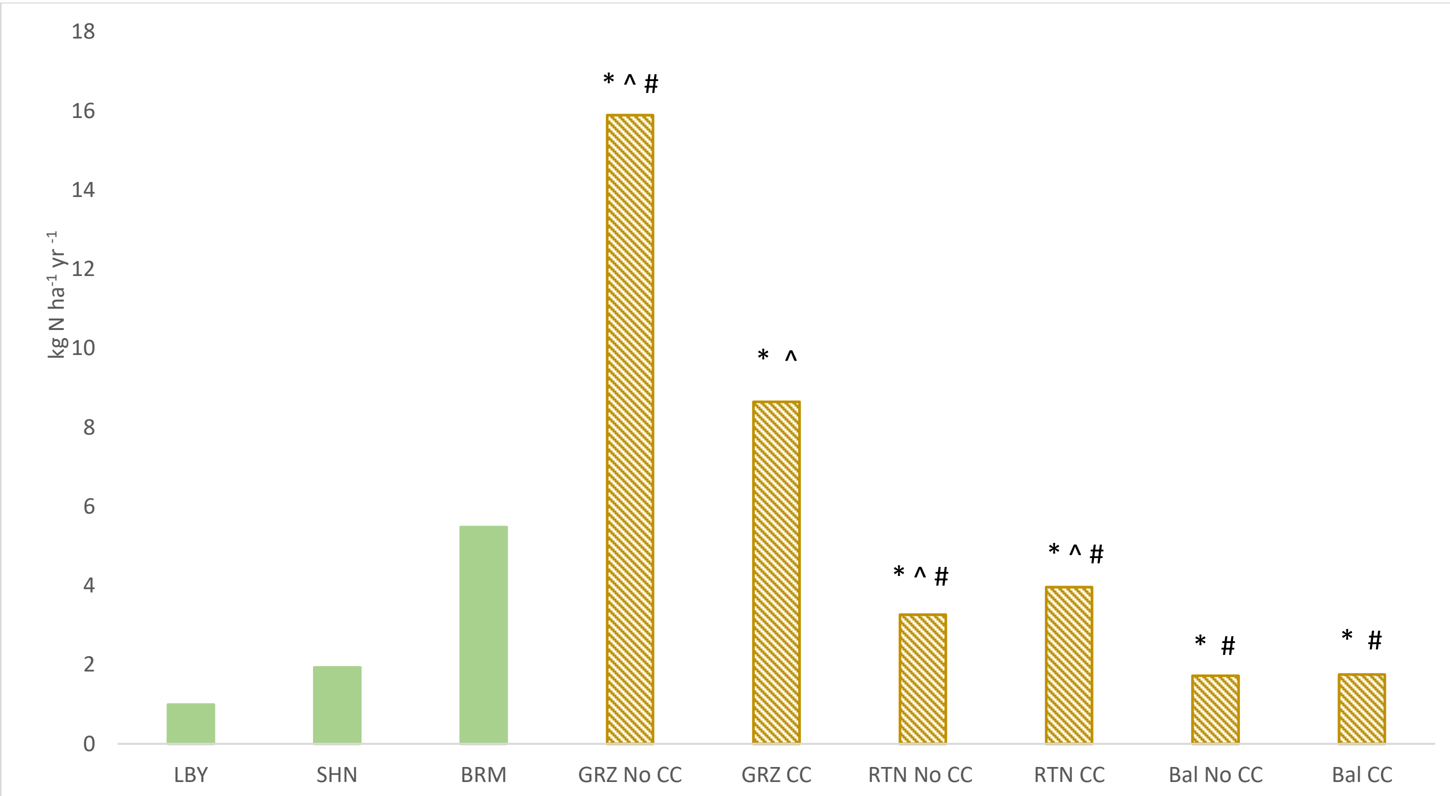


**Figure 4- 10.** 2019 $N_2O$ emission contrasts.

Average kilograms of nitrogen emitted from the soil as $N_2O$ during the growing season in 2017 for each significant treatment or main effect. Soil GHG emissions were measured 9 times per season Contrasts between perennial grassland and corn treatments were performed using a P<0.05. * denotes corn treatment mean is significantly different from LBY mean. ^ denotes corn treatment mean is significantly different from SHN. # denotes corn treatment mean is significantly different from BRM. BRM is Newell Smooth Bromegrass. LBY is Liberty switchgrass. SHN is Shawnee switchgrass. Bal is residue removal by baling. RTN is residue retained. GRZ is residue removal by grazing. NoCC is no cover crop was included. CC is cover crop was included

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