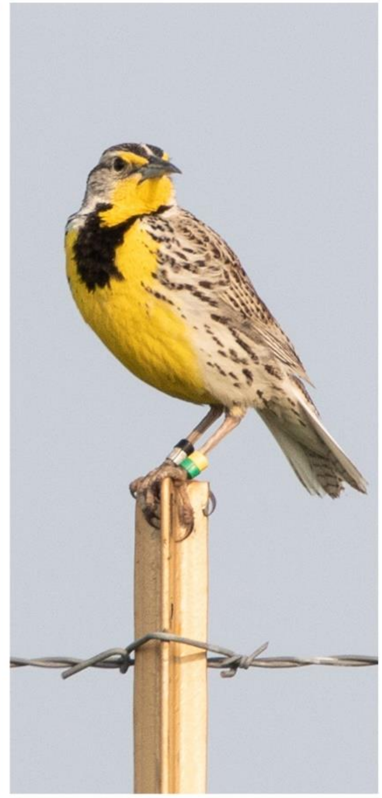
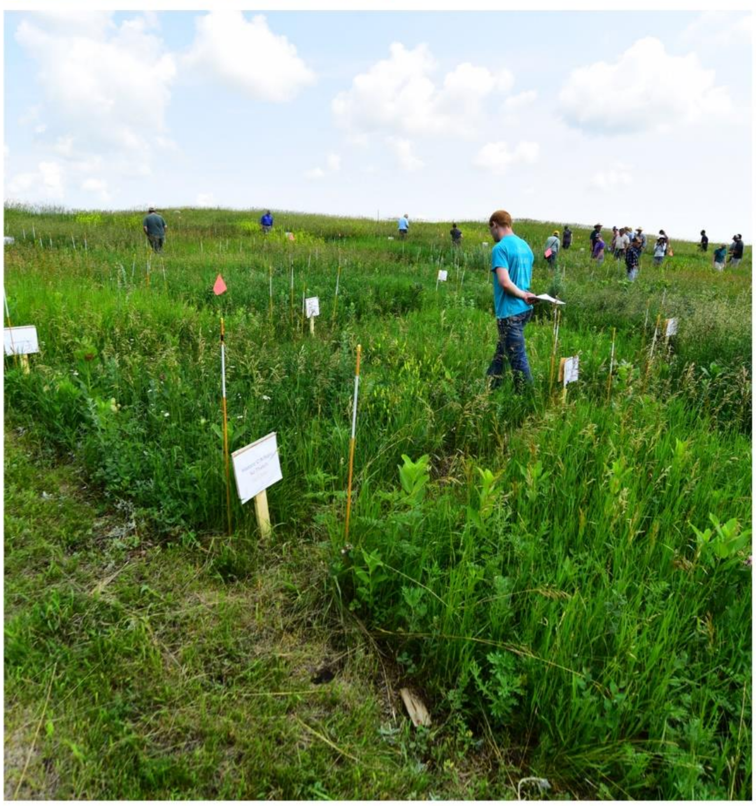
Central Grasslands Research Extension Center

Grazing – Forage – Wildlife – Livestock

2024 Annual Report

NDSU NORTH DAKOTA STATE UNIVERSITY





Summary of the Year

Welcome to the 2024 CGREC Annual Report

The year 2024 grazing season was one for the record books. The winter was extremely mild with less than 20 inches of snow, making for a great calving season. Rainfall events occurred at a regular schedule throughout the summer, receiving over 27 inches of moisture for the year.

Our grazing program focused on three large scale experiments: 1) testing heterogeneity-based grazing treatments, 2) integrated livestock-cropping systems, and 3) precision grazing using virtual fence. The focus of the heterogeneity-based treatments was designed to create different levels of structure and plant diversity across the landscape to see which treatments created better wildlife and pollinator habitat while enhancing livestock performance and production. The integrated livestock-cropping system trials were designed to test the pros and cons of adding livestock grazing on cropland, and test if we can enhance soil health while maintaining or improving crop production. The virtual fencing trials are designed to test the efficacy of the technology and study different grazing strategies on range and cropland.

On an update of our capital projects. We received special funding from the 2021-2023 state legislative session for a new livestock working facility and research complex. We broke ground in 2024 and finished the project in January, 2025. The director's residence was delivered in March 2025 and should be completed in June 2025.

Some impacts from our research projects and Extension programming include:

1) Regenerative grazing using rotational grazing with variable grazing intensities

- ✓ Increased harvest efficiency by cattle of 37.6 percent (4-year average).
  - **Creates added value to the land by 21 lb of beef per acre. At $3/lb calf prices, this equates to $63 in added value per acre**
- ✓ In a single year heavy grazing increased all soil microbiome complexities, with any grazing level enhancing soil storage of total and organic carbon.
  - **Grazing can create healthier soils, better nutrient cycling, and cleaner water**
- ✓ Enhanced conservation of the land

2) Patch-burn grazing

- ✓ Increased forage quality by 25% and mineral concentration by 50 to 100%.
  - **Increasing calf performance by 0.14 lb/day (4-year average), equating to an increase of $14.28/acre in gross revenue**
- ✓ Created the greatest conservation in bird diversity and pollinator habitat.

3) Precision Agriculture (Virtual Fencing)

- ✓ Central Grasslands REC was the first to bring the technology to North Dakota in 2022
  - **We are leaders in the nation testing this technology. We've collaborated with the School of Natural Resource Sciences and Animal Sciences, as well as the Carrington REC, Dickinson REC, Hettinger REC, and 2 private ranches using 23**

herds and almost 3,300 acres. We expect 15 to 20 producers to adopt the technology in 2025.

- ✓ Classic model of research development > Extension programming > Delivery > Adoption

4) Extension Programming

- ✓ Extension programming tied to CGREC had 4,333 direct contacts at 89 events, with an indirect reach of 1,319,105 people.
    - **The state's BQA program is led by our Livestock specialist (Lisa Pederson). This program certified over 300 producers and 15,000 head of cattle in 2024, adding over $1.5 million in added value to those North Dakota producers.**

5) Workforce Development

- ✓ Will have graduated 32 PhD and MS graduate students since 2019 from projects conducted at the center or with the center's cattle.
- ✓ Trained over 100 undergraduate students by providing summer technician positions.

6) Publications

- ✓ Over the past 5 years there were 72 peer-reviewed journal articles published from research conducted at the center or with our cattle.

Our 2025 annual field day is scheduled for July 14. We plan to run two tours, focusing on our integrated livestock/cropping system research. These trials include a new study looking at late season grazing on selected perennial forages, integrating livestock grazing on winter cereals used as a cover crop in a soybean-corn rotation, and using precision grazing with virtual fencing on a trial grazing cover crop-corn rotation to enhance soil health, grain production and livestock grazing efficiency. We plan to finish the tour looking at trials to control absinth wormwood and buckbrush.

Lastly, we said goodbye to our Sandi Dewald on March 5, 2024. She worked at Central Grasslands REC for 30 years and will be truly missed.

We hope to continue serving you for many years. You are always welcome to stop by anytime and see our research or just visit.

Kevin Sedivec, Interim Director

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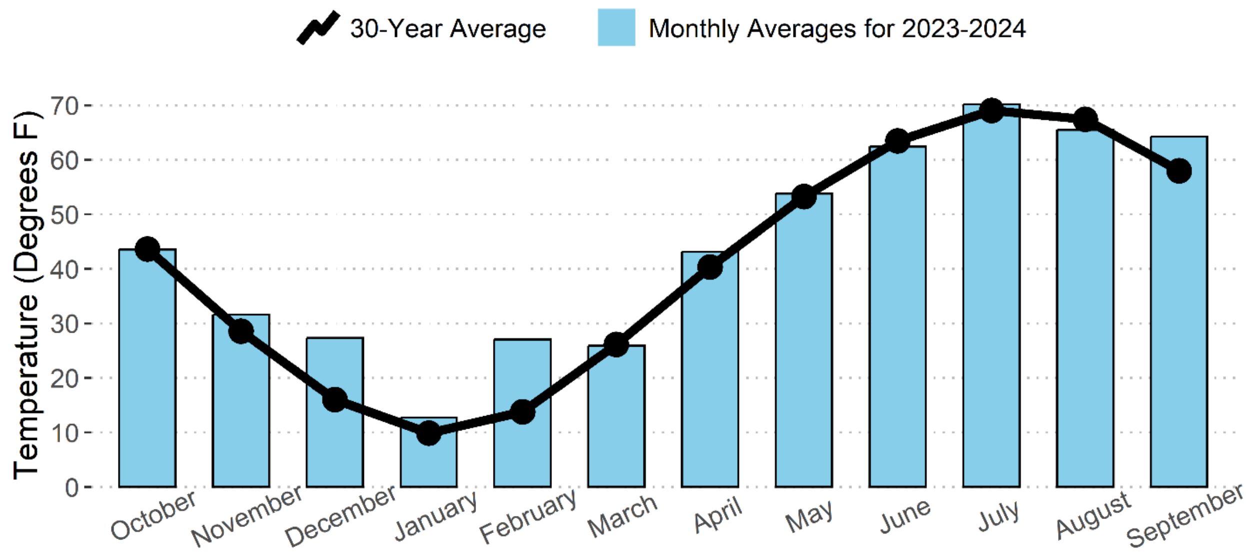
Monthly Temperatures for the 2023-2024 Crop Year



Last spring frost: April 30th (31°F)

First fall frost: October 13 (31°F)

163 frost-free days

Average last spring frost: May 13

Average first fall frost: September 22

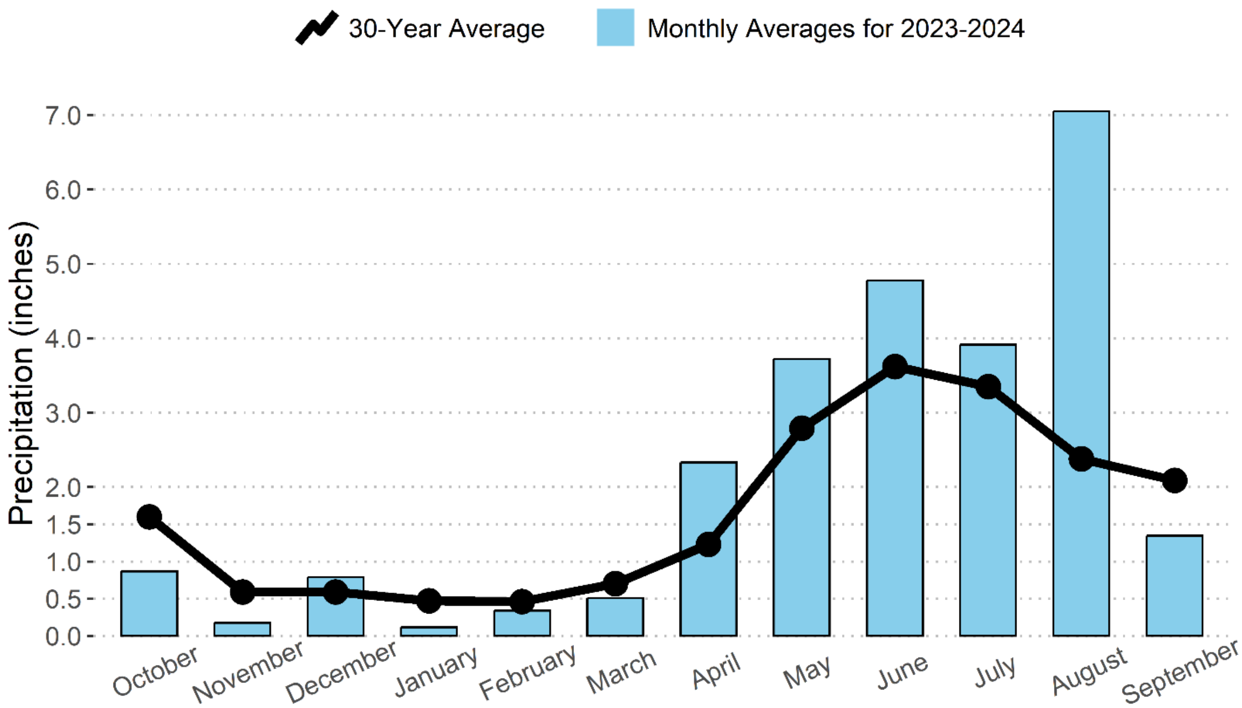
Average: 132 frost-free days

Month	Average Maximum Temperature[1]	Average Minimum Temperature	Average Temperature	30-year Average Temperature	2023-2024 Deviation from Average
October	53	34	43.5	43.7	-0.2
November	41	22	31.6	28.6	3
December	35	19	27.3	16	11.3
January	20	6	12.7	9.9	2.8
February	36	18	27.1	13.8	13.3
March	35	17	25.9	26.1	-0.2
April	54	33	43.1	40.4	2.7
May	65	43	53.8	53.3	0.5
June	73	52	62.4	63.5	-1.1
July	80	60	70.2	69.1	1.1
August	75	56	65.5	67.4	-1.9
September	76	52	64.3	58	6.3

[1] Degrees F

NDAWN, Streeter 6NW

Monthly Precipitation for the 2023-2024 Crop Year



Month	Rainfall[1]	30-year Average Rainfall	Deviation from 30-year Average	Percent of 30-year Average	Snowfall
October	0.87	1.6	-0.73	54.4	0
November	0.17	0.59	-0.42	28.8	17.5
December	0.79	0.59	0.2	133.9	35.5
January	0.11	0.47	-0.36	23.4	0
February	0.34	0.46	-0.12	73.9	7.5
March	0.51	0.7	-0.19	72.9	31.5
April	2.33	1.23	1.1	189.4	0
May	3.72	2.79	0.93	133.3	0
June	4.78	3.62	1.16	132.0	0
July	3.91	3.35	0.56	116.7	0
August	7.05	2.38	4.67	296.2	0
September	1.35	2.09	-0.74	64.6	0
Total	**25.93**	**19.87**	**6.06**	**130**	**92**

[1]Does not include snowfall. [2]Depth in inches
NDAWN, Streeter 6NW; NOAA, Streeter 5NW

Patchy Solutions to Thatchy Problems: Patch-Burn Grazing Reduces Kentucky Bluegrass Thatch and Promotes Plant Diversity

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Summary

Non-native plants invade and degrade rangelands, suppressing native plant diversity. Many rangelands in North Dakota have been invaded by exotic grasses, primarily Kentucky bluegrass (*Poa pratensis*; hereafter 'bluegrass'). Bluegrass invades rangelands and suppresses native plants by accumulating a dense litter mat that over time compresses and degrades into a novel layer between the vegetation and soil profile called thatch. Thatch is considered the main mechanism promoting bluegrass in North Dakota. However, little is known about how thatch impacts native plant diversity. To better understand the relationship between native plants and bluegrass thatch, we collected plant community composition data, as well as thatch depth in 12 pastures managed with either patch-burn grazing (PBG), modified twice-over rest-rotation grazing (MTORG), and season-long grazing (SLG) for three years in south-central North Dakota. We compared how richness, evenness (E_{var}), and diversity (Simpson) changed in response to thatch depth and management practice. We found that thatch depth in PBG was significantly shorter than SLG (1.89 ± 0.11 cm vs. 2.53 ± 0.18 cm) but was not different from MTORG (1.96 ± 0.09 cm). This contrasts existing work which has only shown PBG, and not MTORG, to decrease thatch depth. Richness and diversity varied by treatment with PBG and MTORG having greater richness and diversity than SLG. Additionally, we found that patch-burn grazing resulted in the shortest thatch layer and highest plant species diversity, while season-long grazing had the deepest thatch and lowest diversity. Increasing thatch depth significantly impacted species evenness, showing that increased thatch accumulation leads to a plant community dominated by fewer species, particularly Kentucky bluegrass. This would suggest that the main impact that thatch has on native plant diversity is by limiting how abundant native plant species can be in plant acommunities. Furthermore, this impact may be mitigated by PBG, suggesting that PBG should be used to promote native plant species and negate the negative effects of bluegrass thatch.

Introduction

Invasive species negatively impact rangelands globally (Palit et al., 2021; Pimentel et al., 2001). Invaders alter both ecosystem function and integrity (Gasch et al., 2020). The rapid spread of invasive plants in North America has caused many native rangeland ecosystems to be dominated by exotic species (Toledo et al., 2014), reducing biodiversity (Limb et al., 2018), vegetation structure (Toledo et al., 2014), and altering ecosystem services (Nouwakpo et al., 2019). For example, Kentucky bluegrass (*Poa pratensis* L.) has increased in abundance over the last 40 years, now accounting for up to 60% of all vegetative cover in North Dakota (DeKeyser et al., 2015), decreasing native plant diversity while reducing community structure and ecosystem functioning (Toledo et al., 2014; Hendrickson et al., 2019).

Kentucky bluegrass uses a variety of mechanisms to outcompete native species including the accumulation of litter (Nouwakpo et al., 2019), propagule pressure (Palit et al., 2021), and the build-up of a novel thatch layer (Figure 1; Hendrickson et al., 2019; Nouwakpo et al., 2019). Thatch is formed by litter accumulation over time, which compress older litter into a layer that is comprised of loosely intermingled decaying litter, dead stems, live buds, and portions of the root mat (Figure 1; Kjaer et al., 2024), and is similar to an O-horizon in a soil profile (Berndt et al., 1990; Millar et al., 1966). However, O-horizons are not historically present in the prairies of the northern Great Plains (Millar et al., 1966; DeKeyser et al., 2015). Thus, novel thatch accumulation is thought to be the key factor facilitating Kentucky bluegrass invasion (Hendrickson et al., 2021). However, little is known about how thatch impacts native plant diversity in North Dakota.

Thatch is likely crucial to bluegrass expansion as it can accumulate relatively high levels of lignin in the lower portions of the thatch that interact with the belowground root mass (Hurto et al., 1980), preventing native plant germination (Fowler, 1988; Facelli and Pickett, 1991), altering the soil-surface microclimate (Knapp and Seastedt, 1986), and altering water cycling by increasing runoff (Nouwakpo et al., 2019). Anything that reduces thatch accumulation is also likely to lessen the impact bluegrass has on rangelands. Ideally, land managers would be able to reduce bluegrass thatch and promote biodiversity through existing management practices. Therefore, we measured thatch depth and plant diversity in rangelands invaded by Kentucky bluegrass to assess how different management practices influence plant diversity and thatch accumulation.

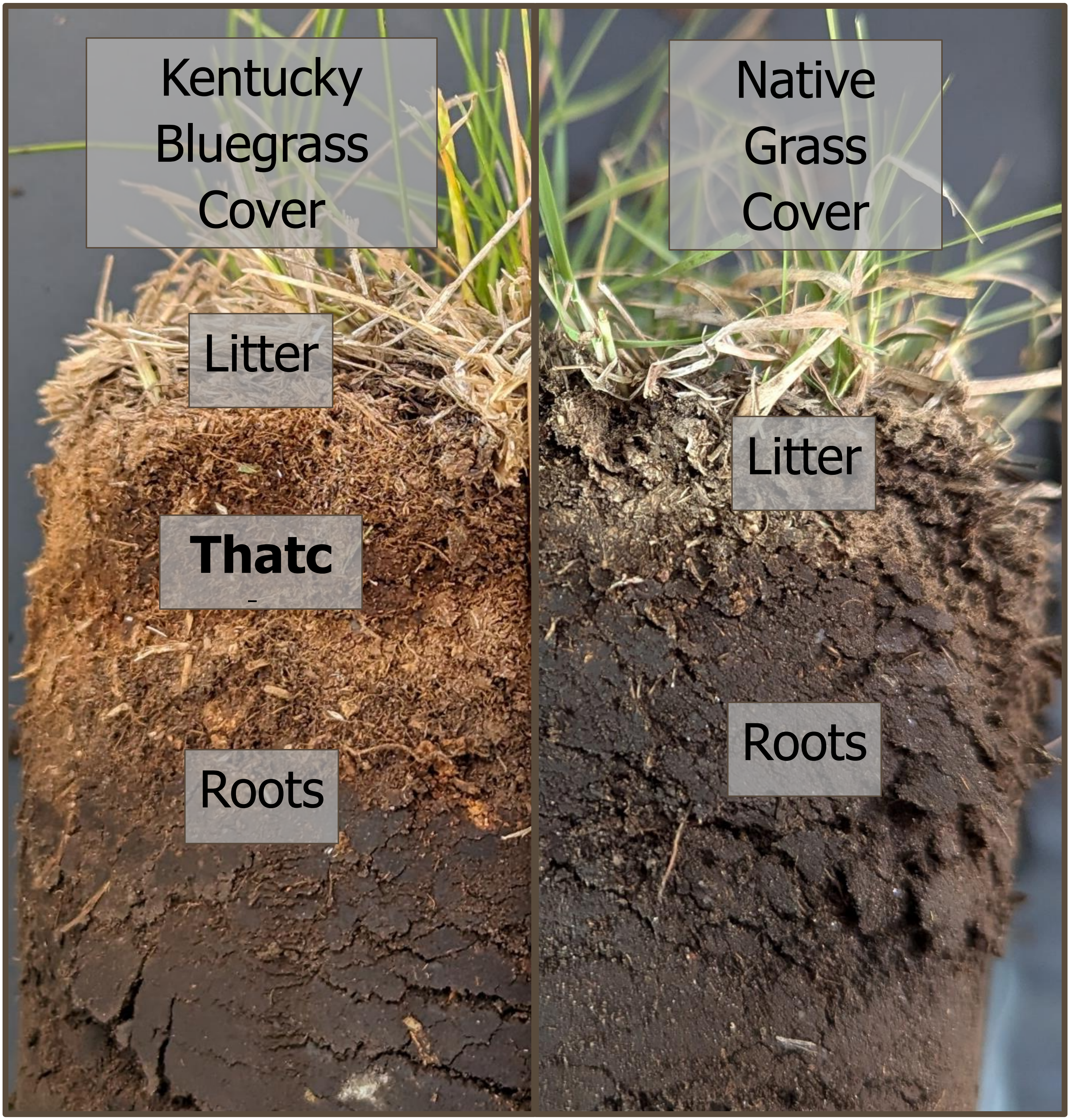

Figure 1. Left: An example of Kentucky bluegrass thatch on top of the soil profile. Thatch is a compressed, decaying mixture of old litter, dead stems, live buds, and portions of the root mat. This thatch layer alters water and nutrient cycling and suppresses native seed germination. In this photo, that is the light brown layer is roughly 3.5 cm (1.5 in) long. Right: An example of a soil profile found in an uninvaded system. There is no thatch layer because native plants do not produce thatch.

Methods and Experimental Design

Site Description

Our study took place at the North Dakota State University, Central Grasslands Research Extension Center in Stutsman and Kidder counties near Streeter, ND. Historically, these sites were mixed-grass prairie consisting of native cool-season grasses, a mix of warm-season grasses and various forbs (Limb et al., 2018). However, changes from historic grazing regimes and fire suppression have allowed bluegrass to invade and dominate these sites (DeKeyser et al., 2015).

Experimental Design

Our study utilized twelve, 65-hectare pastures, four managed with season-long grazing, four with patch-burn grazing, four with a modified twice-over rest-rotation grazing system. All pastures have different grazing histories (see Limb et al. [2018] for an example), but from 2013 until treatment implementation, all pastures were grazed and stocked similarly. We began grazing and burning the season-long and patch-burn grazing pastures in 2017, while grazing began on the modified twice-over rest-rotation pastures in 2018. The season-long pastures were never burned and contained no interior fencing. The patch-burn pastures contained no interior fencing, but one quarter (16 ha) of each pasture was burned each spring. Within a modified twice-over rest-rotation pasture, one herd of cattle was rotated through twice per growing season. These pastures were split into four paddocks using interior fencing resulting in a rested (0% utilization), moderate (20-40% utilization), full (40-60% utilization) and heavy use paddock (>60% utilization). Each year the paddocks change their utilization (e.g., rested becomes moderate, moderate becomes full, full becomes heavy, and heavy becomes rested). We rotated cattle through each pasture (heavy to full to moderate) once from May to July and a second time from August to October.

Data Collection

We collected data after the peak growing season in 2022, 2023, and 2024 along 96 one hundred and ninety-seven foot transects (eight per pasture in season-long, two per burn patch or paddock in patch-burn grazing and modified twice-over rest-rotation) on loamy ecological sites in the grazed treatment pastures (Soil Survey Staff, 2022; USDA NRCS, 2003) to measure thatch depth across treatments. We recorded thatch depth approximately every three feet (n = 31) along each transect using soil cores. Soil cores were collected using a 0.5-inch diameter soil probe to a depth of 20 cm. The length of the thatch layer within each core was recorded to the nearest tenth centimeter. We define thatch as the loosely compacted layer of dead and living stems, litter, and roots that develop between the aboveground biomass and soil surface, which contains the non-thatch bound root mat (see Figure 1; Kjaer et al., 2025). The distinction between aboveground litter and the thatch layer is clear, with the thatch layer beginning where decaying litter is present (Figure 1). This is typically also true for the boundary between thatch and the underlying soil and non-thatch bound root mat, with thatch being orange-brown and the underlying soil being dark brown (Figure 1). In instances where this difference was not visibly obvious, the distinction could be felt with the thatch layer being elastic or pliable under light pressure and the underlying soil and non-thatch bound roots being more rigid.

In addition to thatch depth, we collected data on plant community composition along each transect. We did this by identifying all species present at each sampling point and assigning them a cover value using Daubenmire cover classes (Daubenmire, 1959; Dornbusch et al., 2020). Afterwards, we used this data to calculate plant species richness, evenness, and diversity. Plant species richness is simply the number of unique plant species that occurred along each transect. Plant species evenness is a metric that is used to approximate how abundant all the species along a transect are. Higher levels of evenness would suggest a plant community is made up of many species that all have similar abundances, while lower levels of evenness would indicate a plant community dominated by only one or two species (Smith and Wilson, 1996). Species diversity is a metric that combines both species richness and evenness, a higher value indicates a plant community that is comprised of many, similarly abundant species, while lower values indicate a community with only a few non-dominant species, and one exceptionally dominant species. For this study, data from all years were pooled together prior to analysis.

Data Analysis

We used Generalized Linear Mixed Models (GLMM) to analyze differences in thatch depth, species richness, evenness, and diversity between treatments (Brooks et al., 2017; R Core Team, 2023). GLMM was used to account for random variation that was not intentionally created by design, such as transects accidentally spanning multiple ecological sites and previous land use history (Brooks et al., 2017; Limb et al., 2018).

Results

Thatch depth varied between treatments, but was shortest in patch-burn pastures and longest in season-long pastures ($p < 0.05$; Figure 2). Thatch depth in modified twice-over rest-rotational pastures was shorter than season-long pastures, but thicker than patch-burn grazing pastures (Figure 2).

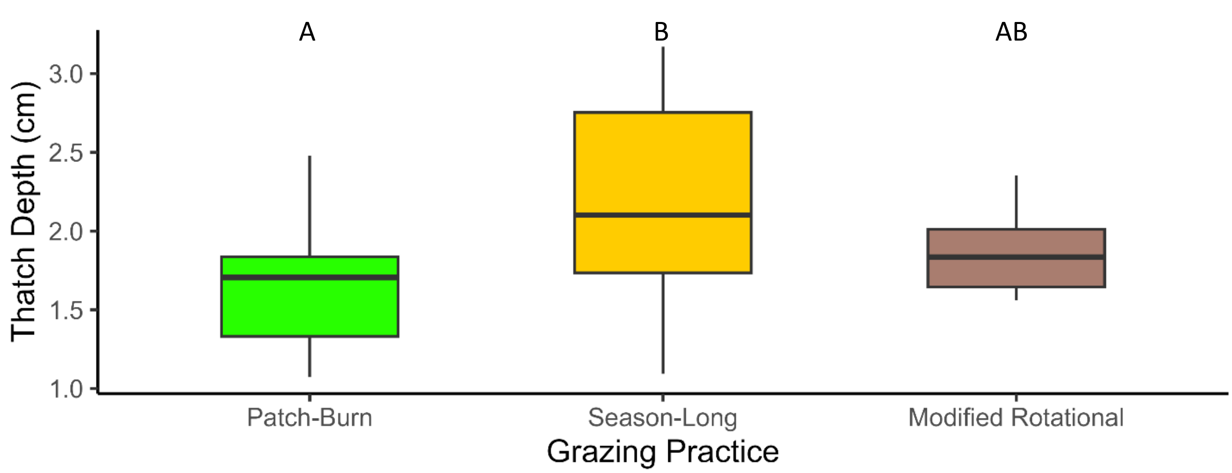

Figure 2. Average thatch depth (cm) between different management practices. Patch-burn grazing (green) resulted in the shortest thatch layer, while season-long grazing (yellow) resulted in the deepest and most variable thatch layer. Thatch depth in pastures managed with modified twice-over rest-rotational grazing (brown) was not significantly different from the other practices.

Patch-burn grazing pastures generally had more plant species than either modified twice-over rest-rotational pastures or season-long pastures (Figure 3). Additionally, season-long pastures consistently had the least number of plant species (Figure 3). However, none of these differences were statistically significant (p = 0.660). Additionally, thatch depth did not impact the number of plant species present in any treatment (p = 0.963; Figure 3).

Species evenness, a measure of plant species abundance, also did not differ between management practices, but was slightly higher in patch-burn grazing pastures than season-long pastures (Figure 4). However, species evenness was significantly impacted by thatch depth (p = 0.005; Figure 4). Specifically, as thatch depth increased, species evenness decreased. In other words, as more thatch accumulated in pastures, the plant community became increasingly dominated by only a handful of species (namely, Kentucky bluegrass).

Plant species diversity was highest in patch-burn grazing pastures, and lowest in season-long pastures (Figure 5). Once again, modified twice-over rest-rotation pastures were more diverse than season-long pastures, but less diverse than patch-burn grazing pastures (p = 0.035; Figure 5). Even though plant diversity in each management practice tended to decrease as thatch depth increased, thatch depth did not significantly impact plant diversity (Figure 5).

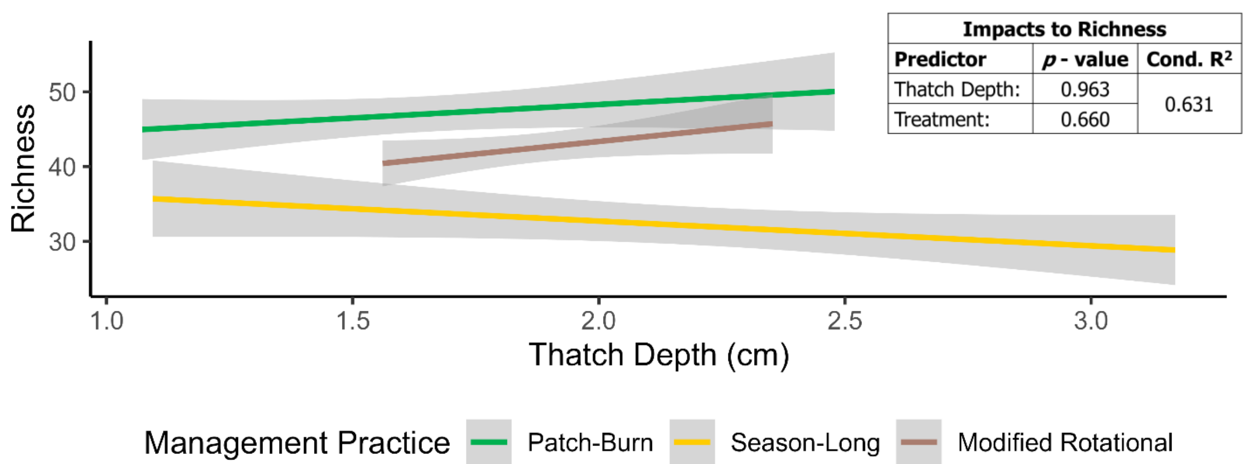

Figure 3. The relationship between plant species richness and thatch depth (cm) under different management practices. Patch-burn grazing (green) had the greatest number of unique plant species, while season-long grazing (yellow) had the fewest. Modified twice-over rest-rotation grazing (brown) was in between the other two practices. However, plant species richness was not significantly different between treatments. Additionally, while it may seem like increases in thatch accumulation led to increases in species richness in patch-burn and modified twice-over rest-rotational grazing, we found that changes in thatch depth did not impact plant species richness.

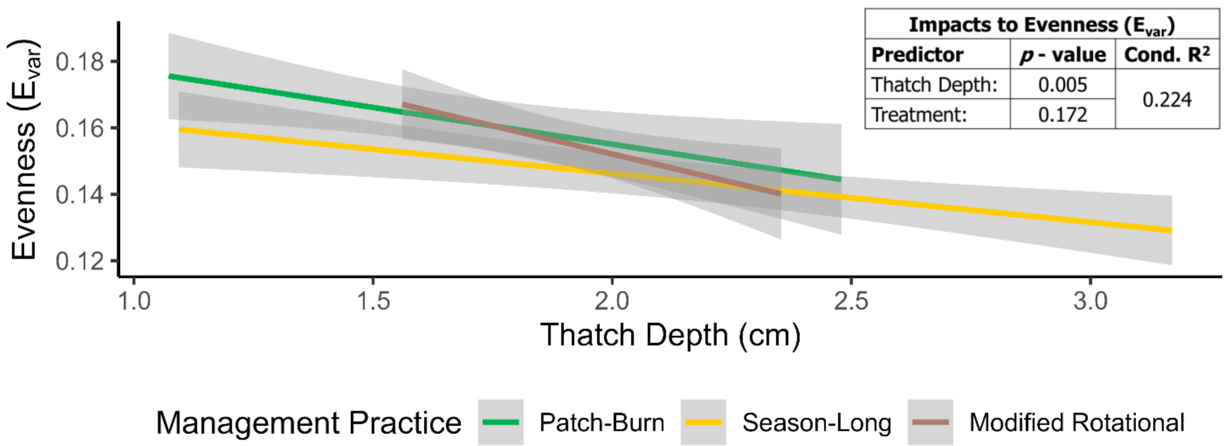

Figure 4. The relationship between plant species evenness (E_{var}) and thatch depth (cm) under different management practices. Species evenness is a measure of how abundant different plant species are in a community. Higher evenness indicates that a plant community is comprised of different species that have relatively similar abundances, while lower numbers indicate the community is dominated by one or two species. Patch-burn grazing (green) had slightly greater evenness than season-long grazing (yellow) and modified twice-over rest-rotation grazing (brown); however, there no differences in species evenness between management practices. Instead, there was a significant negative relationship between plant species evenness and thatch depth. As thatch depth increased, species evenness decreased. Indicating that Kentucky bluegrass thatch accumulation can help create plant communities dominated by only one or two species, namely Kentucky bluegrass.

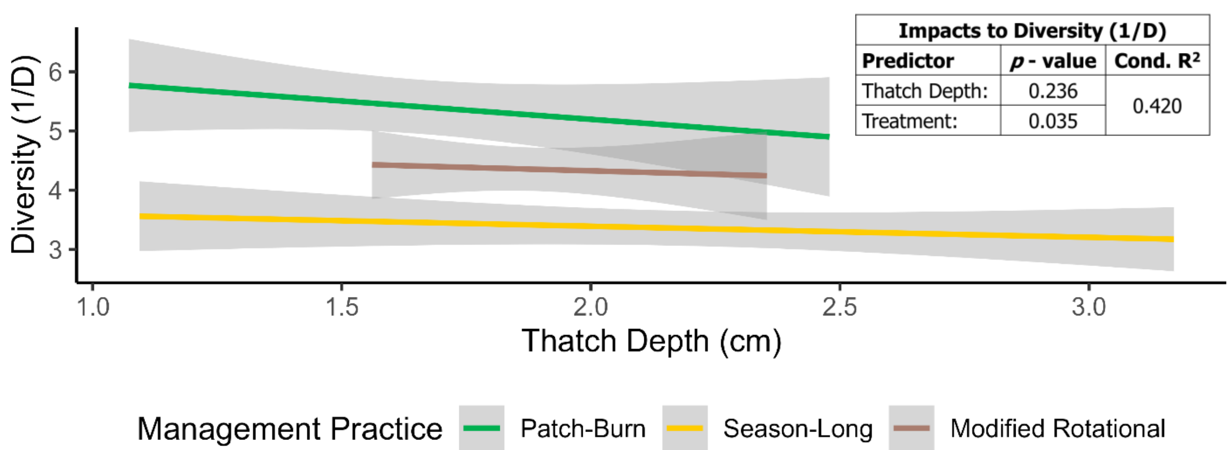

Figure 5. The relationship between plant species diversity (Inverse Simpson's or 1/D) and thatch depth (cm) under different management practices. Species diversity is a metric that combines both species richness and evenness. Higher diversity indices indicate that a plant community is comprised of many different species that have relatively similar abundances, while lower numbers indicate the community only has a few species and is dominated by one or two species. Patch-burn grazing (green) had significantly greater diversity than season-long grazing (yellow), which had the lowest diversity. Modified twice-over rest-rotation grazing (brown) was once again in between the other management practices, but was not significantly different from either practice. Changes in thatch depth did not impact plant species diversity.

Discussion

Kentucky bluegrass invasion in North Dakota has led to a decrease in native plant diversity and landscape-level heterogeneity (DeKeyser et al., 2015; Fuhlendorf et al., 2006; Palit et al., 2021). Previously, it had been thought that Kentucky bluegrass thatch (Figure 1) was the main mechanism promoting bluegrass invasion and leading to a decrease in native plant diversity (Hendrickson et al., 2021; Kjaer et al., 2024; Printz and Hendrickson, 2015). Our results indicate that Kentucky bluegrass thatch does impact native plant communities. Specifically, increased thatch accumulation leads to a plant community that is dominated by one or two plant species, namely Kentucky bluegrass. However, based on our results, we also know that restoring landscape-level heterogeneity through patch-burn grazing can increase plant diversity, helping to compensate for the negative effects of Kentucky bluegrass invasion. Additionally, patch-burn grazing was the only management practice to significantly decrease thatch depth.

Thatch has been thought to be the main driver behind Kentucky bluegrass invasion (Hendrickson et al., 2021; Kjaer et al., 2024; Printz and Hendrickson, 2015). While our results certainly suggest that thatch accumulation negatively impacts plant communities, thatch may not directly impact the plant community as strongly as once thought. Instead, other aspects of Kentucky bluegrass invasion, like litter accumulation or plant competition may be equally or more important that thatch accumulation (Palit et al., 2021; Printz and Hendrickson, 2015). Even still, we know that thatch negatively impacts plant communities, alters water cycling, soil carbon and nitrogen, and the soil-surface microclimate (Hendrickson et al., 2021; Nouwakpo et al., 2019; Sanderson et al., 2017; Toledo et al., 2014). Meaning that thatch may not be the main driver behind Kentucky bluegrass invasion, it’s still an important component of Kentucky bluegrass invasion.

Our results support the idea that restoring landscape-level heterogeneity positively impacts native plant diversity (Duquette et al., 2022; Fuhlendorf et al., 2006, 2006). In our study, using patch-burn grazing positively impacted plant diversity, increasing it compared to season-long grazing. However, this benefit was only present when fire was incorporated as a part of the management practice. When we only used grazing to recreate landscape-level heterogeneity, plant diversity was not different between the modified twice-over rest-rotation grazing practice and season-long grazing. Similarly, patch-burn grazing was the only management practice that led to a decrease in thatch depth. This is likely because burning an area removes the existing litter that would become thatch (Kjaer et al., 2024). After the litter has been removed, cattle focally graze the burned area (Allred et al., 2011; Arterburn et al., 2019), limiting overall biomass accumulation in the area, which then limits the amount of litter that can form, ultimately reducing the amount of thatch that is able to accumulate over time.

Management Implications

Kentucky bluegrass invasion in North Dakota reduces native plant diversity (Toledo et al., 2014). Other factors like litter accumulation, and plant competition may be equally or more important (Palit et al., 2021), but thatch accumulation is still an important driver of Kentucky bluegrass invasion, negatively impacting native plants, water cycling, and soil carbon and nitrogen. Based on our results, management aimed at both reducing the impacts of Kentucky bluegrass and promoting plant diversity should seek to restore landscape-level heterogeneity. Promoting landscape level heterogeneity through grazing alone might appear to benefit plant diversity and decrease thatch accumulation, but it is likely that those trends are due to random chance and are not representative of real changes from management. Instead, restoring landscape-level heterogeneity should be done by incorporating both fire and grazing in a patch-burn grazing framework that removes litter, reduces Kentucky bluegrass thatch and promotes plant species diversity.

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Disturbance & Timing: Effects Exhibited Through Plant Community Change Following Fire and Grazing

Adam Brendemuhl, Esben L. Kjaer, Torre J. Hovick, Miranda Meehan, Benjamin Menapace, Kevin Sedivec

Summary

Rangeland fire is a vital ecological process shaping mixed-grass ecosystems in the Great Plains. Historic disturbance regimes have been altered in recent decades, creating a shift in plant communities. Fire and grazing interactions affect vegetation dynamics, enhance species richness and forage quality, and manage invasive grasses like Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*). Our study investigates the short-term effects of spring and late-summer prescribed fires, paired with grazing, on plant communities. A randomized block design with 96 plots divided into grazed and ungrazed treatments was used to assess the effects of fire season and grazing on vegetation composition, structure, and floral resources. Fires were implemented in the late-summer (late August 2023) and spring (early May 2024) seasons. Cattle were allowed access to grazing throughout the growing season to achieve a moderate degree (40-60%) of use. Data collection included species composition, litter and thatch depth, visual obstruction, vegetative biomass, and floral resource availability. Results from the first full year revealed that fire is able to reduce invasive grasses and enhance species richness compared to unburned plots. Grazing alone decreased brome abundance, while spring fire provided the greatest decrease in bluegrass cover and promoted a more diverse plant community. Grazing without fire provided the least floral resources throughout the season, whereas grazed plots with a late-summer fire provided the largest amount. Preliminary findings suggest that fire and grazing are effective in maintaining invasive grass populations, fostering native species, and improving floral resource availability. Spring fires appear particularly beneficial, reducing invasive grass encroachment and increasing biodiversity amongst plots. Future research will focus on long-term fire return intervals and their influence on rangeland recovery and resilience.

Introduction

Rangeland fire plays an integral role in the formation and maintenance of rangeland ecosystems by creating a varying spatial and temporal disturbance that many native floral and faunal species evolved with (Anderson, 2006). Native American use of fire, and wildfires caused by summer lightning strikes, were the primary causes of historic fires throughout the Great Plains of North America (Komarek, 1967; Higgins, 1986). Fires spreading through landscapes at periodic intervals are influenced by levels of precipitation and the fuel loads present on the landscape (Anderson, 1990: Fuhlendorf et al., 2002). Large mammal grazing also effects fire by removing fuel via foraging or building up fuel through areas that are left ungrazed. The mixed-grass region of the Great Plains consists of a mixture of warm and cool-season plant species and is characterized by historic fire intervals ranging between an average of 5 years or less during drier periods and 10 years or more during periods of higher precipitation or in areas difficult for fire to reach (Zouhar, 2021). Fire is not only beneficial to wildlife species that rely on its ability to promote heterogeneity at different levels within landscapes, but it is also proven to increase livestock performance by creating higher crude protein in recently burned areas, attributing to increased weight gains in cattle (Grant et al., 2010; Hovick et al., 2014; Fuhlendorf and Engle, 2004; Spiess et al., 2020). Land managers who use prescribed fire paired with cattle grazing in a patch-burn system experience benefits such as woody encroachment control, invasive species maintenance, and improved forage quality (Twidwell et al., 2013; McGranahan et al., 2014; Dornbusch et al., 2020; Kjaer et al., 2024). Once paired with grazing, fire improves species richness while promoting floral abundance and resources available for pollinator utilization (Duquette et al., 2022). The results of burns have shown trends in native plant species resilience, as many native plant communities are capable of withstanding rangeland fire events (Vermeire et al., 2014; Gates et al., 2017; Kral-O'Brien et al., 2020). Invasive species like smooth brome (*Bromus inermis* – hereafter: brome*)* and Kentucky bluegrass (*Poa pratensis* – hereafter: bluegrass) continue to invade mixed-grass rangelands and prescribed fires have shown promising results for controlling the abundance of these problematic species. Attempting to control invasive species in a novel ecosystem often brings forth the challenge of discovering techniques and practices that keep invaders maintained while not hindering the growth and diversity of native plant species. Although there are many desired outcomes from using prescribed fire, there is still relatively little research on how fire may impact plant communities when variables such as years since a fire event, the season in which a fire takes place, and the presence or absence of grazing are combined and studied. It has been documented that these factors, once paired with climate and other disturbances, play an important role in determining how a rangeland will recover following a fire event (Fuhlendorf et al., 2009). Further research is needed to understand how disturbance regimes inclusive of fire and grazing will affect plant growth and composition at a community level over various lengths of time.

Our objective in this study is to comprehend the short-term legacy effects of spring and late-summer prescribed fires on northern Great Plains rangelands throughout 6 growing seasons. This project is designed to 1) understand how burning, paired with the season and amount of time since fire, plays a role in the response of the plant community in terms of vegetational production, structure, and cover while we also 2) determine if cattle grazing post-fire has any effect on the composition of plants found on site. Additionally, we are 3) monitoring the amount of floral resource availability to better understand the role disturbances have on local vegetation used by pollinator species.

Methods

We established a block containing 96 10m x 10m plots on a sandy loam site at the Central Grasslands Research Extension Center near Streeter, North Dakota. The block was split in half with 48 plots fenced off to create 48 ungrazed and 48 grazed plots. We randomly assigned treatments to each split block that consisted of spring fire, late-summer fire, or no fire to each plot. We then randomly assigned fire return intervals (0-5 years) to each fire season treatment. All treatments were replicated four times using a complete block design. Yearling angus heifers were placed on pasture between June and November in an attempt to achieve a moderate degree of use (40-60%). We assessed plant species composition using a modified Daubenmire cover class system (Daubenmire, 1959), gathered visual obstruction readings (VOR) using a Robel pole (Robel et al., 1970), and measured litter and bluegrass thatch depth with a soil probe and ruler for each plot. We quantified results from each of the six treatment types before fire implementation (July 2023) and after the completion of fires (July 2024).

Relative cover data was obtained through the use of 10 0.25m^2 frames evenly spaced along two transects running north to south in each plot. Change in species richness, evenness, and diversity were observed and compared for the 6 treatment types (**Table I**) between both seasons (Inverse Simpson's).

Table 1. A list of each type of fire season paired with or without grazing make up each of the 6 treatment combinations used in this study.

Treatment Combinations:
1. No Fire (control) – No Grazing
2. Spring Fire – No Grazing
3. Late-Summer Fire – No Grazing
4. No Fire (control) – Grazing
5. Spring Fire – Grazing
6. Late-Summer Fire - Grazing

Additionally, we gathered total above-ground biomass clippings for randomly selected plots during the peak of the growing season (early September 2024) and monitored floral resources within each plot on a weekly basis between the spring fires and late-summer fires (June-September) of 2024. While implementing the prescribed fires, we recorded the relative humidity, wind direction, wind speed, and approximate burn completion for each plot. Every plot designated as spring and late-summer fires were burned during August 2023 and May 2024 to complete initial fires, establishing a baseline for return intervals. All of the late-summer, 5-year return interval plots (8 total) received fire in early October 2024 due to excess moisture and growth during late-August and September. Since this study is still in its youth we have focused our current results on how the burn season and application of grazing interact to influence plant community characteristics, as more time is needed to determine year return effects.

Results

Precipitation for the 2024 season (69.1 cm total) was approximately 1.5 times greater than the previous year (46.2 cm in 2023), and about 20 cm above the average annual precipitation (49.1 cm) through the last 30 years of recorded data (NDAWN). The approximate burn completion for both spring and late-summer prescribed fires stayed around 85-90% on plots that received fire. Biomass clippings in plots that were grazed by cattle showed smaller amounts for graminoid weights than ungrazed plots but produced much more legume biomass in contrast (**Figure 1**). Results from our Robel pole readings demonstrates the role grazing plays on vegetation density and overall structure, displaying increased VOR measurements in areas left free from grazing between years (**Figure 2**). As expected, any plots that were burned experienced a reduction in litter depth at the soil's surface (**Figure 3**). The only treatment that displayed maintenance of bluegrass thatch was late-summer fire paired with grazing (**Figure 4**).

Spring fires created the greatest positive change in both plant species diversity and richness while unburned plots created the least positive change (**Figures 5**). When compared to plots that received no fire, spring-burned plots displayed a reduction in bluegrass cover (p = 0.0226) (**Figure 6**). Plots receiving both fire and grazing provided the best invasive grass maintenance while ungrazed plots tended to increase invasive abundance. Ungrazed spring fire plots displayed the greatest decrease in bluegrass abundance among treatments. Grazing on its own was contributed to a decrease in brome abundance when compared to plots that did not receive a grazing treatment (p = 0.0176). Control (no fire) plots that were grazed provided the least amount of flower availability throughout the year when compared to the other five treatment combinations (**Figure 7**).

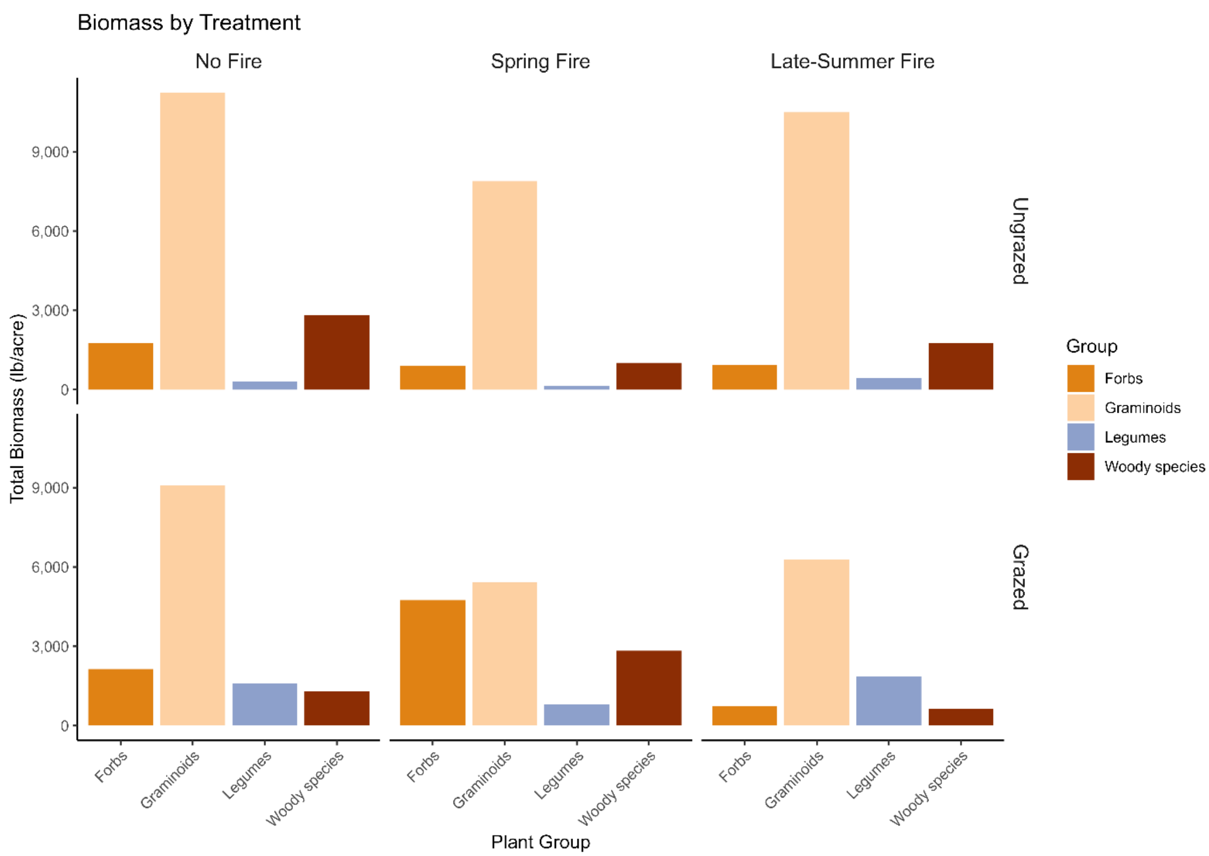

Figure 1. The total biomass in pounds per acre along the y-axis and plant functional group along the x-axis. Each of the six treatment combinations are displayed with their own graph. Data was obtained through random selection of 24 plots – 4 for each treatment combination.

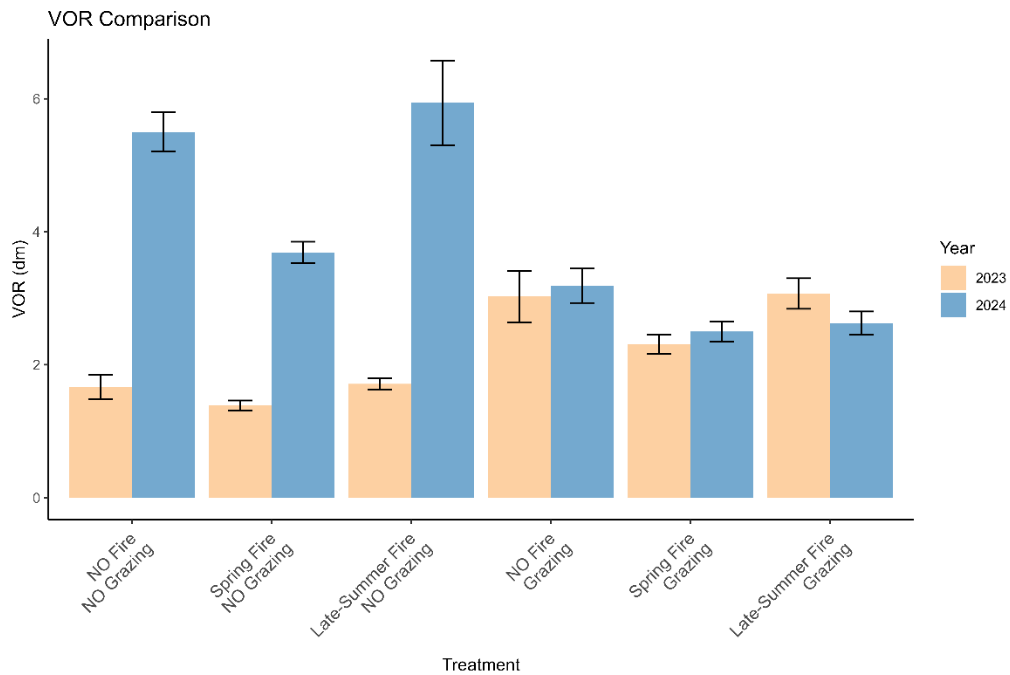

Figure 2. The mean Robel Pole reading in decimeters (y-axis, 1 dm = 10 cm) within each treatment (x-axis) between seasons (colored bars).

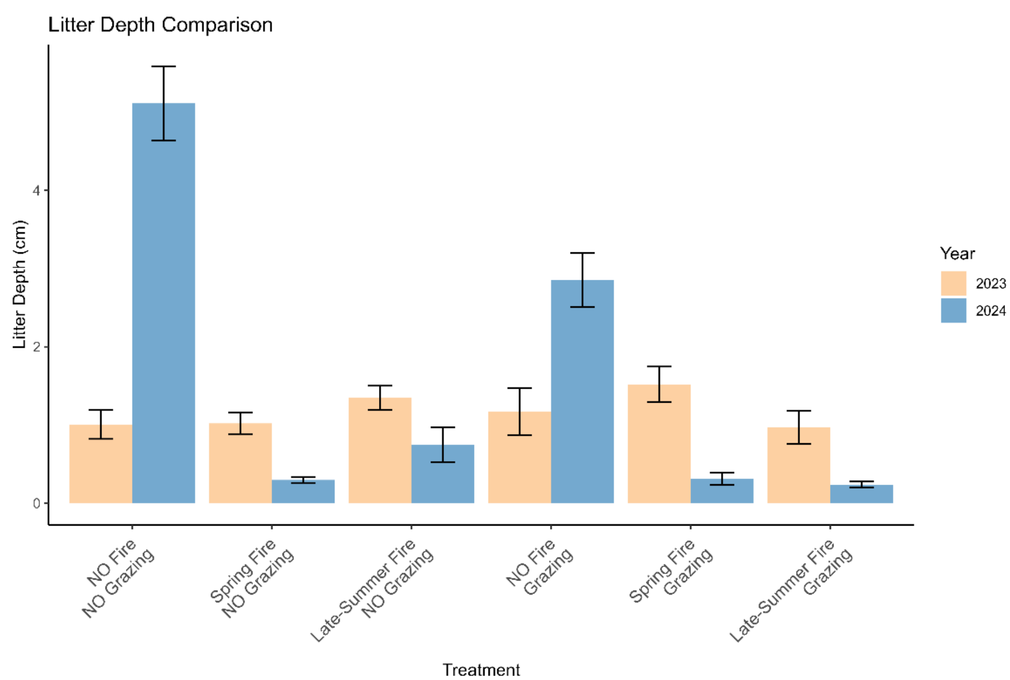

Figure 3. The mean litter depth measurement in centimeters (y-axis) for each treatment (x-axis) between seasons (colored bars).

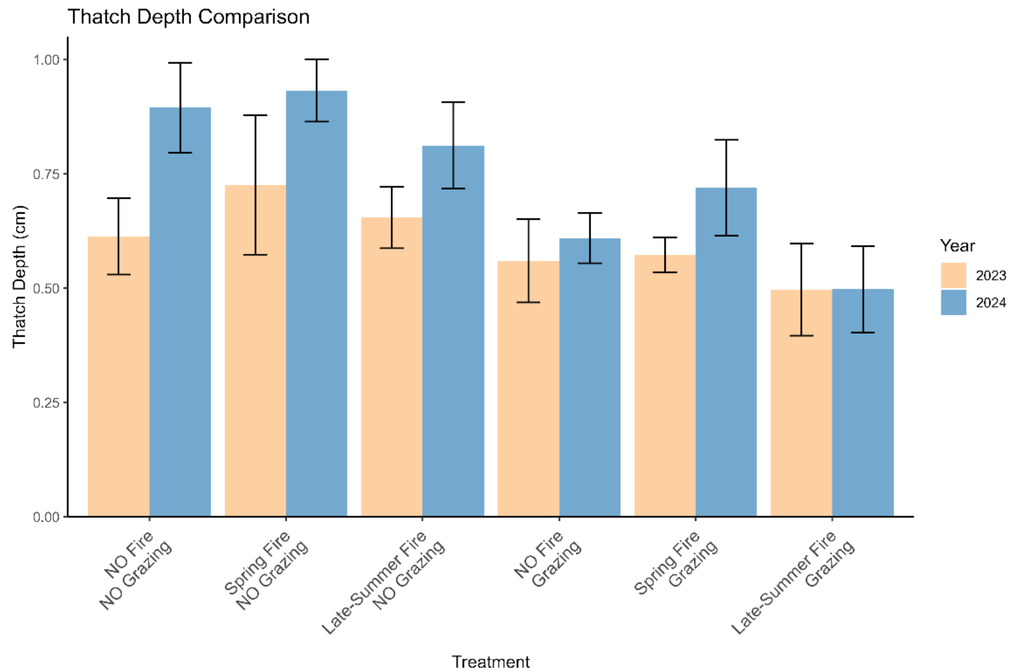

Figure 4. The mean Kentucky bluegrass thatch depth measurement in centimeters (y-axis) for each treatment (x-axis) between seasons (colored bars).

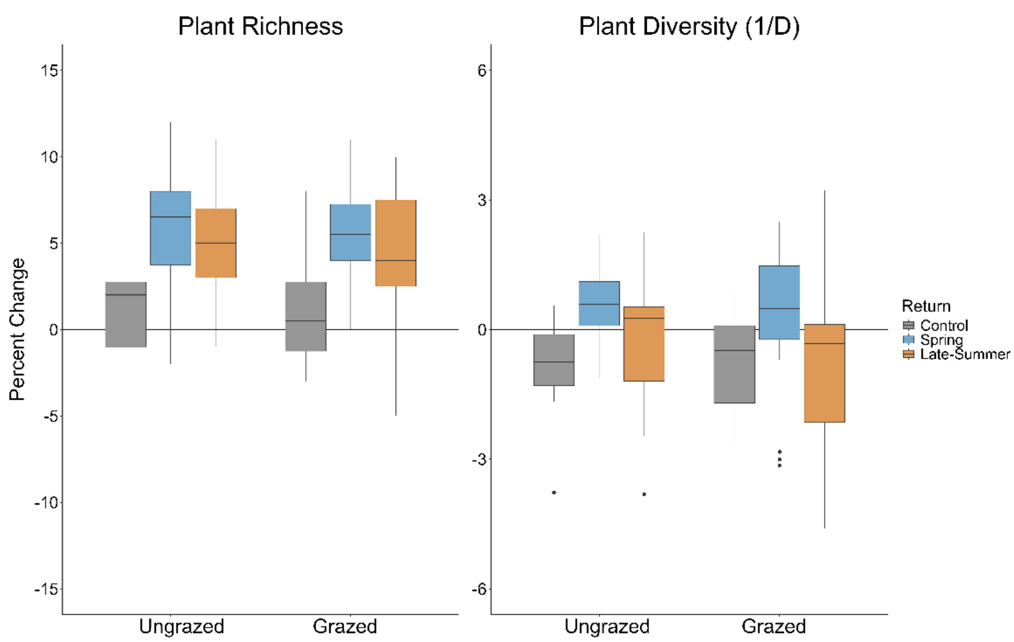

Figure 5. The change in the number of plant species (left y-axis) and the plant diversity index (right y-axis) within grazed and ungrazed plots (x-axis) between seasons (colored bars).

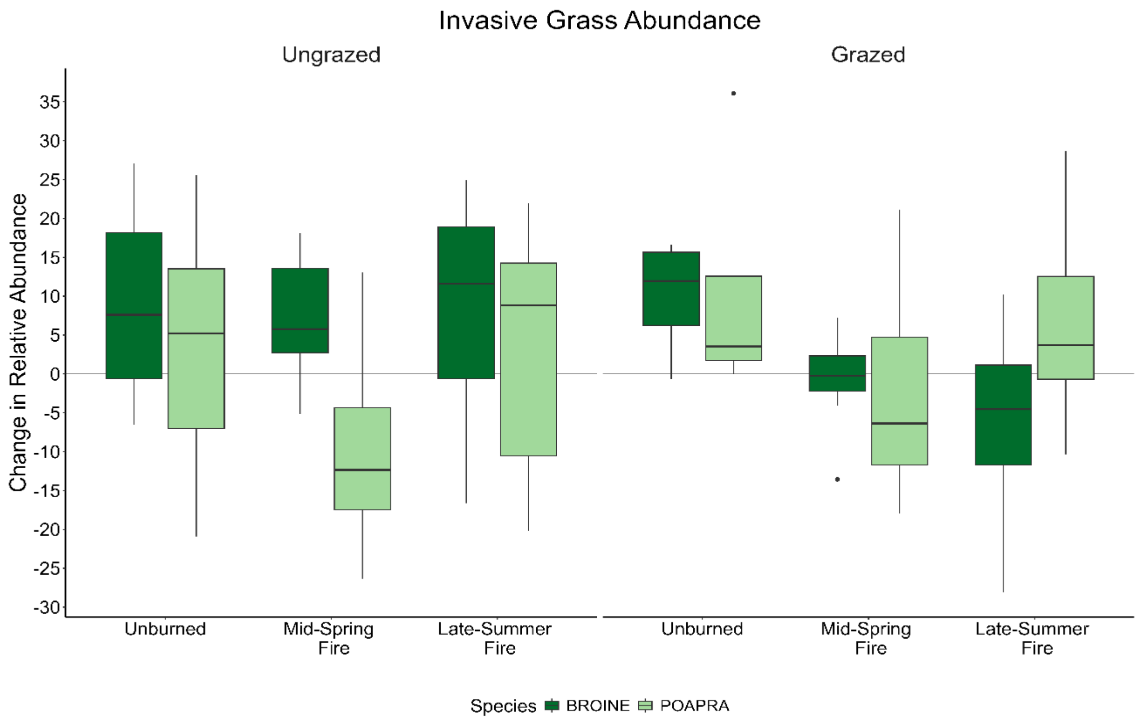

Figure 6. The relative change (y-axis) in the cover values recorded for Kentucky bluegrass (*Poa pratensis* – light green) and smooth brome (*Bromus inermis* – dark green) between the 2023 and 2024 seasons. Treatment combinations are displayed along the x-axis.

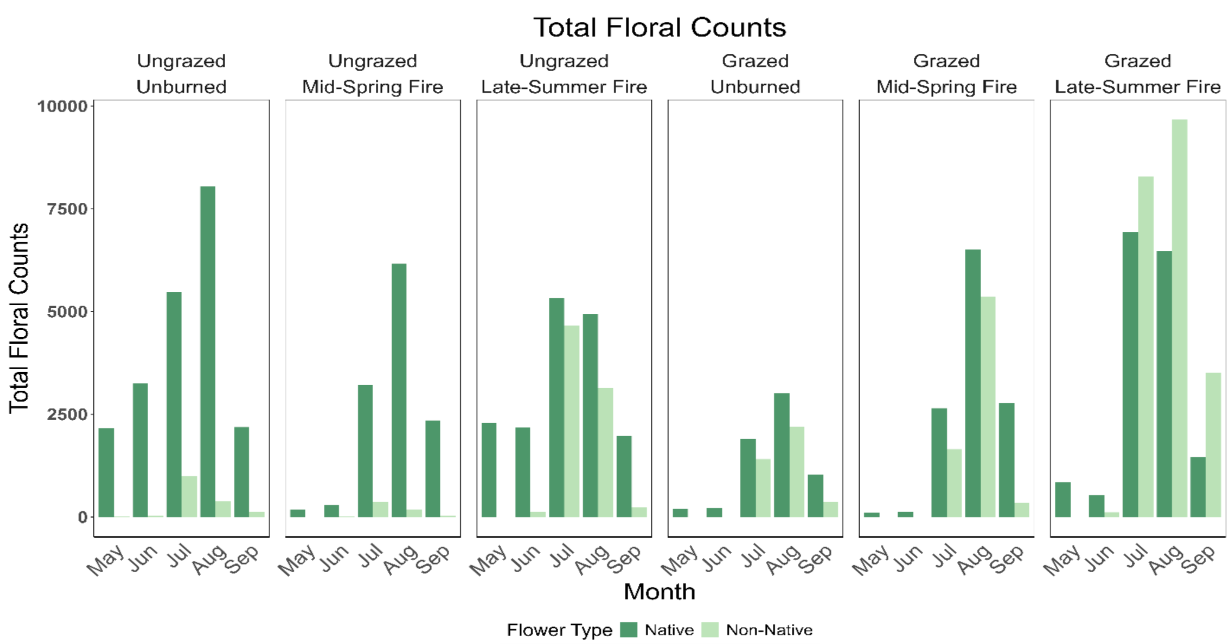

Figure 7. The total amount of flowers observed (y-axis) on a weekly basis for one growing season (2024). Flower totals are separated by treatment type and month observed (both along x-axis). Flower totals are further divided based on native/non-native status by color of bar.

Discussion

Results from our biomass clippings exhibit an influx in legume weight when sampled in plots that were grazed. This is most likely due to greater amounts of the non-native plant black medic (*Medicago lupulina*) growing throughout the lower sections of the plant community canopies, which made up an estimated 60-70% of all legume weights. With additional moisture in 2024 and less canopy cover from taller species like brome and sweet clover due to grazing effects, black medic had a better chance at establishing. We found that grazing without the use of fire lead to the smallest amounts of floral resources available, suggesting that fire can improve the amounts of flowers in burned areas after allowing for regrowth. Different treatment combinations allowed for different flowering windows and amounts for the same species. For example, the flowering process of western snowberry (*Symphoricarpos occidentalis*) varied depending on the season in which the plot was burned. Unburned plots created the earliest available flowers for snowberry, late-summer fires created the most available flowering plants, and spring fires created a longer flowering window.

When compiling results from each aspect of this study, it became evident that lack of rangeland disturbance (fire or grazing) has the potential to increase invasion of non-native grasses. When disturbance was absent, plots displayed a decreased change in plant diversity and the least amount of richness. In the plots where cattle grazing was not implemented, we began to see an increase in brome abundance. Plots that received a grazing and fire treatment were able to maintain or slightly reduce the abundance of brome while also having the potential to maintain bluegrass thatch depth. By not having a disturbance system in place to inhibit invading grasses like brome and bluegrass from further establishing, we begin to see cover of these species increase between years, reducing the abundance of native grasses and forbs through competition. These results agree with a similar study that was completed on site previously (Dornbusch et al., 2020), advocating that patch-burn grazing can help in maintaining bluegrass abundance levels. The largest increase in thatch depth between years came from the subset of plots that were without fire or grazing, agreeing with an additional CGREC study (Kjaer et al., 2024) suggesting that disturbance may be the most efficient way to maintain any thatch layers already present on a rangeland. Based upon our results, spring fires paired with grazing provided the best invasive grass maintenance while promoting plant species richness and diversity, suggesting that early growing season disturbance may be the most beneficial management technique for supporting native plant communities.

Conclusions

Novel rangeland ecosystems create various challenges for land managers attempting to accomplish conservation and livestock production goals. Invasive cool-season grass species have become a widespread problem, creating issues throughout rangelands of the Northern Great Plains. Grasses like Kentucky bluegrass and smooth brome heavily contribute to a reduction in native species diversity, richness, floral resource availability, and overall abundance within native mixed-grass rangeland remnants. Through the use of prescribed fire and cattle grazing, we begin to see maintenance over the abundance of invasive grasses and their reproductive mechanisms. Furthermore, when these types of disturbances are utilized at certain timings throughout the growing season (i.e. spring season fires), we are able to see results that restrict invasive grass expansion while promoting native species diversity. As the study progresses, we strongly anticipate the years since a fire event to play a critical role in future plant community characteristics.

Associated Fact Sheet: Page 117

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Timing of Cattle Grazing to Restore Plant Diversity in a Smooth Brome Invaded Rangeland

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Summary

Rangelands are highly threatened ecosystems, partially due to invasive species. Smooth brome (*Bromus inermis* Leyss.) is an invasive perennial cool-season grass that negatively impacts diversity. Studies suggest grazing may restore diversity, but research on timing is lacking. Smooth brome regenerates after grazing via axillary buds located on the crown. These buds can be quantified to evaluate management or restoration practices. We hypothesized that spring only (SO), fall only (FO), or both spring+fall grazing (SF) would reduce smooth brome, increase native plant diversity, and decrease smooth brome's vegetative regeneration in smooth brome invaded rangeland, relative to non-grazing control (CO). We measured plant community composition and smooth brome's tiller and bud abundance. The SO and SF grazing reduced smooth brome cover and increased non-native forb cover. However, these treatments led to smaller, more numerous, tillers, which may or may not decrease with additional years of grazing. Our results show promise for controlling smooth brome and restoring diversity.

Introduction

Rangeland and grassland ecosystems are highly threatened. Invasive species degrade grasslands. By negatively impacting diversity, especially of native plants, invasive species can alter wildlife habitat, reduce biological community stability, and may decrease livestock production stability (Fuhlendorf et al., 2006; Ellis-Felege et al., 2013; Allred et al., 2014).

Smooth brome (*Bromus inermis* Leyss.) is an introduced, perennial, cool-season (C_3), rhizomatous grass (Otfinowski et al., 2007). Introduced around 1880, smooth brome has been used for a variety of agricultural and conservation purposes (Otfinowski et al., 2007; Ellis-Felege et al., 2013). However, smooth brome has extensively invaded rangelands and grasslands (Otfinowski et al., 2007; Grant et al., 2020). Smooth brome reduces plant diversity due in part to its relatively early initiation of growth, rhizomatous growth form, and prolific production of shoot and litter biomass (Otfinowski et al., 2007; DeKeyser et al., 2013; Grant et al., 2020).

Management methods needed to restore invaded prairie are uncertain, but grazing has some promise. Suppression of fire and removal of grazing animals (idle management) contributed to smooth brome's invasion (DeKeyser et al., 2013; Grant et al., 2020). Therefore, fire and/or grazing may be important for restoring diversity of invaded prairie. Prairie with a long history of grazing had considerably lower abundance of smooth brome compared to idle managed sites (Coleman et al., 2023). The timing and intensity of grazing needed to restore diversity are uncertain and could vary by site, year, and invasion level.

Studies on intense or early-season grazing have shown promise at improving plant diversity but are limited in number (Dornbusch et al. 2020; Hendrickson et al. 2020; Brown et al. 2024). Early-season grazing could remove smooth brome's shoots and increase light availability for later growing native plants (DeKeyser et al., 2013; Holden et al., 2024). Early and repeated grazing may reduce energy reserves used for tillering in smooth brome and prevent its regeneration. Similarly, repeated grazing in the fall may reduce energy reserves that would be used for regeneration the next spring.

Perennial grass shoots regenerate seasonally from belowground buds (Moore & Moser, 1995). Axillary buds are basic parts of plants and accumulate belowground in grasses (Jewiss, 1972; Ott et al. 2019). Each axillary bud has the potential to grow into a new shoot but can remain dormant for extended periods of time (Moore & Moser, 1995; Ott et al. 2019). Thus, the collection of dormant buds is a source for future growth or regeneration and is referred to as the bud bank (Figure 1; Moore & Moser, 1995; Klimešová & Klimeš, 2007; Ott et al., 2019). The bud bank allows plants to persist after disturbance and a larger bud bank generally correspond with greater tolerance to the disturbance (Ott et al., 2019; Hendrickson & Briske, 1997; Qian et al., 2017). This study evaluated the impact of different times of grazing on the bud bank of smooth brome.

Figure 1. Belowground tiller portion of smooth brome's bud bank. One tiller of smooth brome with roots removed and new tillers formed from its belowground buds (left). Dissected tiller of belowground bud bank and new tillers and/or rhizomes formed from buds (right).

We hypothesized cattle grazing in the spring only (SO), fall only (FO), or both the spring and fall (SF) would decrease the abundance of smooth brome, increase native species, and negatively affect smooth brome's vegetative regeneration in a smooth brome-dominated rangeland of the Missouri Coteau compared to a non-grazed control (CO).

Methods

The study was conducted at the NDSU Central Grasslands Research and Extension Center (CGREC) within the Missouri Coteau ecoregion of the northern Great Plains (NGP). The CGREC is categorized as perennial mixed grass prairie. In recent decades, the introduced cool-season grasses smooth brome and Kentucky bluegrass (*Poa pratensis* L.) became dominant species in many areas of the region (DeKeyser et al., 2013; Grant et al., 2020). Environmental conditions were favorable during the study period and precipitation was 85%, 155%, and 172% of the thirty-year average in 2022, 2023, and 2024; respectively (NDAWN, 2024).

The study area (46.7552° N 99.4511° W) was idle managed for at least 26 years. As a result, smooth brome invaded the pasture. Prior to the study cattle had grazed the pasture infrequently at or below a moderate stocking rate (20-40% utilization, or less) primarily in the spring and summer, but occasionally in the fall. Despite the return of grazing, the pasture was highly invaded at the start of the study and plant diversity was low.

We divided the 65-hectare (160-acre) pasture with electric fencing to make four interior paddocks (Figure 2A). Separate cattle herds grazed each paddock in the spring and again in the fall from 2022-2024. Herds consisted primarily of yearling heifers but included non-lactating cows. Each paddock was stocked at the same stocking rate, and degrees of disappearance in the SF treatment was a full use (40-60%). Cattle grazed during the spring period through early July. Cattle returned to the paddocks at the start of September each year and were removed in early-November. Spring turnout each year were 6/1/2022, 5/8/2023, and 5/2/2024.

We randomly placed an experimental block on loamy soils in each paddock at the beginning of the study (2022). Each block consisted of four plots, one for each treatment. We used cattle panels to create exclosures for plots in certain treatments to prevent cattle from accessing those plots. Exclosures were moved between the SO and FO plots, so that cattle could only graze the SO plots in the spring and FO plots in the fall (Figure 2). SF plots were never excluded and open to grazing throughout the study while the CO plots were always excluded to prevent grazing (Figure 2).

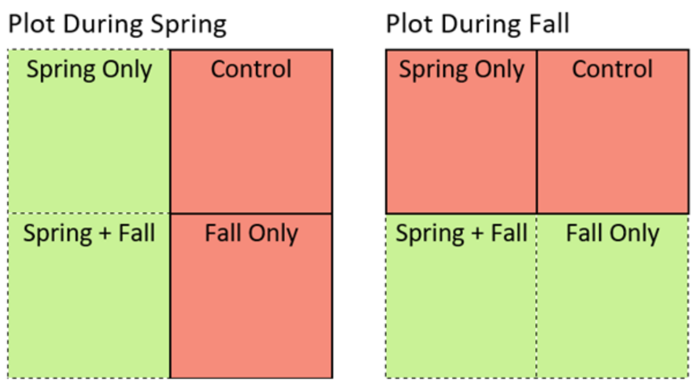

Figure 2. Experimental block design. Example block design during the spring (left) and fall (right). Open (green) plots were free of panels and t-posts. Closed plots (red) were excluded with panels to prevent cattle from grazing. CO plots remained closed to prevent grazing throughout the study, while SO and FO plots were excluded depending on the time of the year. Experimental blocks were randomly placed on loamy soils.

We estimated absolute cover of each vascular plant species to examine plant community composition. Absolute cover was measured as the nearest percentage each species made up of the top of the canopy. We sampled at peak production, around the beginning- to mid-July. Four quadrats (1 m^2) were used to sample each plot during 2023 and 2024. Starting from each corner of a plot, we took one large step towards the center and dropped the quadrat. Within each quadrat, we recorded all vascular plant species present and then recorded its absolute cover.

Four permanent 15 cm x 15 cm quadrats were established per plot (16 per treatment) at the beginning of the study to count the number of smooth brome tillers (density). Tiller counting surveys were conducted in the spring and fall to align with tillering patterns of smooth brome. Spring surveys occurred within the week prior to grazing. Since the initial survey in the spring of 2022 occurred prior to any grazing treatments, these data were baseline and used to evaluate baseline conditions, not compare treatment effects. Fall surveys occurred in mid-September, approximately half a month after the start of the fall grazing treatments.

Four smooth brome tillers were collected per plot following each survey to assess the tiller portion of the belowground bud bank. Tillers collected in the spring of 2022 were not used as the FO treatments had not been applied, but the SO and SF treatments had. We restricted our random collection of tillers to certain areas within plots to avoid sampling tillers from the same genetic plant the next year. Tillers were collected no less than three decimeters from permanent tiller density quadrats to avoid unintentionally affecting tillers within quadrats. Tillers were dissected using a dissection scope to expose the bud bank. We recorded number of axillary buds and outgrowth of buds (number of daughter tillers and rhizomes). A dual-staining procedure was used to determine bud viability (Hendrickson and Briske 1997).

Results & Discussion

Grazing during the SF and SO reduced smooth brome cover compared to the CO by creating more numerous but shorter smooth brome tillers (Figure 3A; Figure 4). Grazing during the SF and the FO increased Kentucky bluegrass cover over the CO (Figure 3B). Fall timed grazing likely exacerbated rhizome/tiller production in Kentucky bluegrass as it produces most of its rhizomes in the fall (Etter, 1951; DeKeyser et al., 2015) and defoliation increases its rhizome/tiller production (Toledo et al., 2014). Grazing did not alter the relative cover of native forbs compared to the CO; however, relative cover was greater in the SF and SO treatments than FO grazing (Figure 3C). We believe SO and SF grazing opened the canopy, causing an increase in non-native forbs over the CO (Figure 3D). The primary non-native forbs that increased were Canada thistle (*Cirsium arvense*), alfalfa (*Medicago sativa*), and yellow-sweet clover (*Melilotus officinalis*).

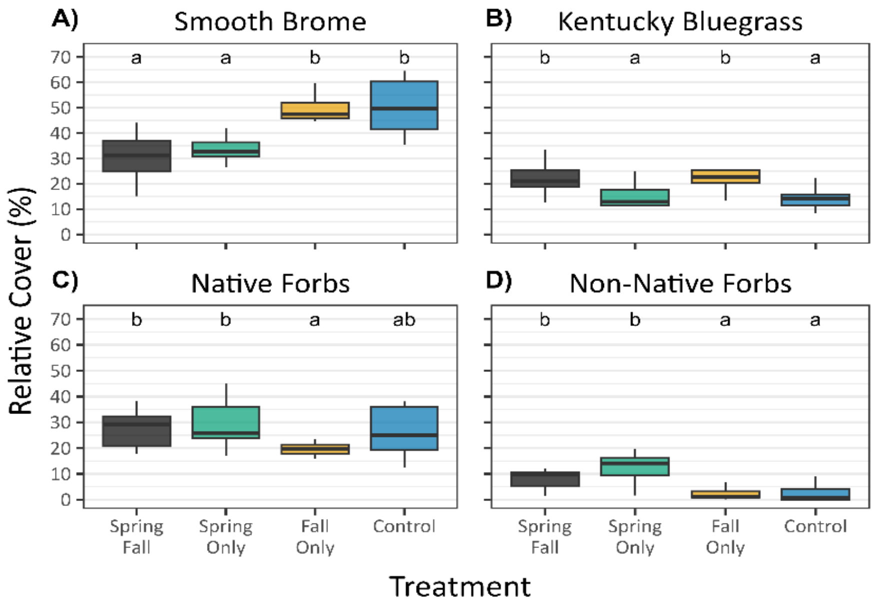

Figure 3. Relative cover of functional groups by treatment. Figure shows results for smooth brome (A), Kentucky bluegrass (B), native forbs (C), and non-native forbs (D). Relative cover on y axis. Significance (p<0.05) is within functional groups, not between functional groups, and is depicted by a different letter between treatments.

We found that grazing during the SF and SO significantly increased tiller density over the CO by the second year of the study (Figure 4). Tiller density was still greater in the SF treatment than the CO by the third year but was no longer greater in the SO treatment (Figure 4E). Grazing in the spring may release apical dominance and increase bud outgrowth/tillering (Otfinowski et al., 2007). It may also increase tillering by increasing light and nutrient availability to juvenile tillers (Ott et al., 2019). In addition, smooth brome grows primarily during the spring (Otfinowski et al., 2007), so increased tillering with greater nutrient availability and adequate sunlight could have exacerbated smooth brome's abundance in these treatments.

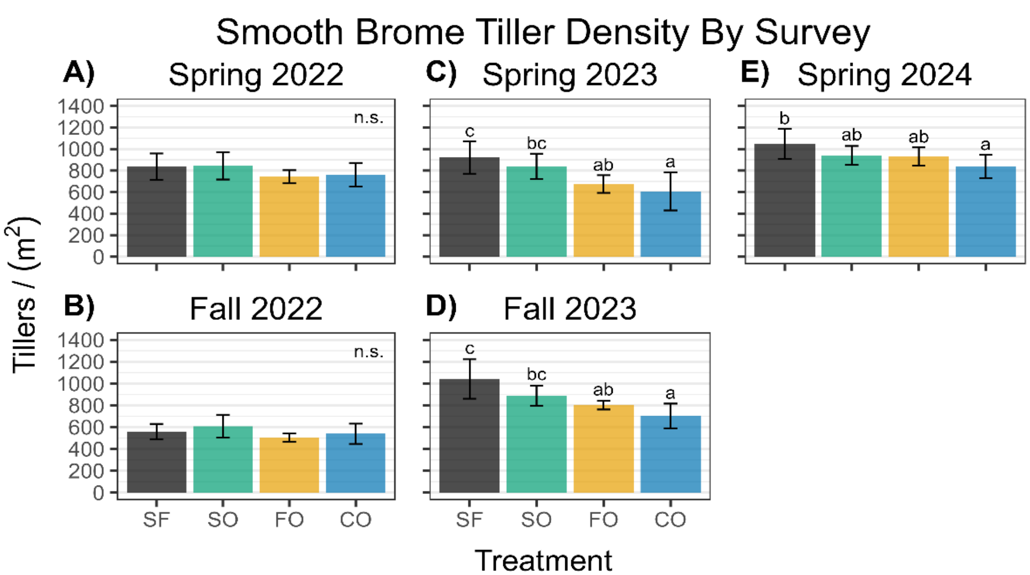

Figure 4. Alive tiller density of smooth brome by grazing treatment during the spring and fall of each year of the study. Alive tillers density during the spring 2022 (A), fall 2022 (B), spring 2023 (C), fall 2023 (D), spring 2024 (E). Data collected during spring of 2022 (A) occurred prior to grazing treatments and are considered baseline data. Distinct letters within a single pane of the figure represents significant difference between treatments (p<0.05).

Our results indicate grazing did not influence smooth brome's bud bank or outgrowth of buds into tillers or rhizomes (Figure 5). Of the alive buds, the vast majority were active and neither the amount of active nor dormant buds per tiller differed between treatments. These findings are similar to another study on juvenile smooth brome tillers (Bam et al., 2022). Therefore, it seems that new tillers did not emerge from the bud bank in our study, even though most tillers emerge from buds in perennial grasslands (Benson & Hartnett, 2006). Thus, tillers may have come from something we had not measured, such as seeds or another portion of the bud bank. Smooth brome produces many buds along rhizomes not just on the bases of tillers. So, by measuring axillary buds only on tiller bases, we may have measured too little of the bud bank to capture any significant results. In the future it may be beneficial to measure other areas of the plant such as the portion along rhizomes, but this requires more time. It remains unclear whether the increased tiller densities from SO and SF grazing are due to seed germination, unmeasured outgrowth of buds, or a combination of both.

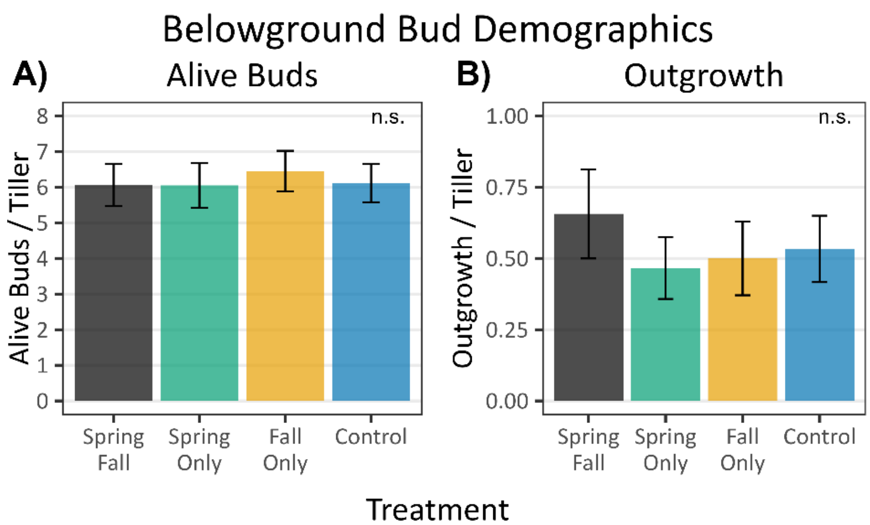

Figure 5. Average belowground alive axillary buds per smooth brome tiller (A) and outgrowth of such buds into new tillers or rhizomes (B).

Increased tillering due to SO and SF grazing may produce favorable or unfavorable results in the future. Increased tillering due to spring timed grazing may persist after additional years of grazing. In fact, Brown et al. (2024) also found that three years of grazing increased tillering. However, results may differ after four or five years. Alternatively, repeated grazing in future years may eventually decrease tiller populations by depleting carbohydrate reserves, depleting the bud bank, reducing the seed bank, and/or promoting other species that outcompete smooth brome (Reynolds & Smith, 1962; Russell et al., 2017). Smooth brome populations may be starting to decline due to SO grazing by the third year of our study (Figure 4C-E). This could be a promising sign for controlling smooth brome with SO grazing and we predict similar outcomes in the future from SF grazing. However, additional years of data are needed to test our predictions.

Studies have shown that grazed rangelands in the NGP have higher diversity and less smooth brome versus ungrazed rangelands (Coleman et al., 2023). Grazing during the SO and SF in our study produced promising results for managing/restoring diversity in smooth brome invaded rangeland but requires further testing. These treatments reduced smooth brome cover and increased non-native forb cover; however, primarily undesirable species. Furthermore, Kentucky bluegrass increased due to SF and FO grazing. Spring timed grazing also increased tiller density, leading to more but smaller smooth brome tillers. Increased tillering could indicate stress from grazing on smooth brome suggesting a future decrease with repeated implementation. However, smooth brome may sustain elevated tiller density due to SO or SF grazing as well. We plan to test whether additional years of our grazing treatments will control smooth brome and restore plant diversity in the coming year.

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Enhancing the profitability of winter rye cover crops through integrated crop livestock systems

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Summary

Cover cropping can provide important soil health benefits; however, the practice incurs additional costs to crop production that may not be recouped within the short-term. Shifting cover crop practices to integrated crop livestock systems by grazing cattle can recoup the costs of winter cover cropping while maintaining soil health benefits of the cover crop. During the 2022-2023 crop season, winter rye yielded enough forage to provide 0.14 animal unit months (AUM) per acre when planted as a cover crop following a German millet hay crop. This fall grazing did not negatively impact spring winter rye stands, which provided 0.66AUM/ac. The 2023 fall winter rye stands were inadequate for grazing following soybean harvest. The only grazing event for the 2023-2024 season occurred in spring, providing 0.23 AUM/ac. Grazing did not alter soil chemical properties or negatively impact soil physical health. Weed suppression by the winter rye was unaffected by grazing. In one of the two years, grazing cover crops generated a return on the cost of cover cropping by extending the grazing season and reducing livestock feed and yardage costs. The cost of establishing a winter cover crop each year was approximately $43/ac and did not generate a positive net effect within the enterprise. In 2023, grazing winter rye in both fall and spring generated a net positive effect of $36.06/ac and spring only grazing generated a net effect of $1.59/ac for the enterprise. The grazing duration in 2024 was shorter, which highlights the impact of AUMs supported by a winter cover crop on offsetting costs. Integrating livestock into cover crop systems can generate a net economic return, but grazing productivity is heavily influenced by the previous crop as well as temperature and precipitation during winter rye seeding.

Introduction

Cover crop practices are a vital tool in managing soil health, however adding a cover crop to a production system increases labor and costs. Despite the potential for increased soil fertility, soil health, and crop productivity, these soil enhancements often fail to recoup the investment of cover cropping. Many producers utilizing cover crops are interested in the soil health and environmental benefits of cover cropping, but the lack of clear economic benefits has created reluctance towards cover crop adoption (Roth et al., 2018; Bergtold et al., 2019). Utilization of forage produced by cover crops may be able to alleviate the concerns regarding the lack of profitability. Machine harvesting of forages can be costly, reducing the return on cover crop investment. Integration of grazing livestock and shifting towards integrated crop livestock systems (ICLS) can further increase the profitability of cover cropping by reducing livestock feed and yardage costs, and extending the grazing season (Adams et al., 1994; Schomberg et al., 2014). The objectives of this study were to: 1) determine the effects of livestock integration and cover crops on soil health, and 2) evaluate the economic impact of shifting crop and cattle enterprises to integrated crop livestock systems.

Materials and Methods

A two-year study was conducted at the Central Grasslands Research Extension Center near Streeter ND. An approximately forty-acre field was divided into nine paddocks and randomly assigned one of three treatments: 1) dual season (fall and spring) grazing (DG), 2) spring only grazing (SG), and 3) control, which was divided into two additional treatments of no graze (NG) or no winter rye (NR). Following fall harvest of the previous cash crop, winter rye was no-till seeded within DG, SG and NG paddocks. Forage biomass was estimated to determine stocking rates, and cattle grazed applicable treatments for the season.

Cover crop performance was evaluated by pre- and post-grazing biomass and absolute ground cover. Absolute ground cover was used to assess erosion risks, which is an important factor in protecting soil health. Additionally, weed cover was evaluated to determine potential increases in weed pressure. Cash crop performance was determined through mid-season staging and stand counts, as well as yield. Cattle performance was evaluated by average daily gain (ADG). Soil physical properties of bulk density and aggregate stability were collected to determine livestock impacts to soil structure.

Production economics were estimated by partial budgeting. A partial budget only focuses on changes to expenses or income within an enterprise. Expenses within the partial budget are a combination of experimental data and estimates from the 2024 North Dakota custom work rates, North Dakota south central region crop budgets, and 2023 custom service rates related to livestock production in Nebraska (McClure et al., 2023; Haugen, 2024; North Dakota State University, 2024).

Results and Discussion

Pre-grazing winter rye biomass did not differ ($P > 0.05$) during either grazing period within DG, SG, and NG. Post-grazing winter rye biomass did not differ ($P > 0.05$) between DG or SG, and both were expectedly less than NG. Pre-grazing percent bare ground did not differ either year. Pre-grazing weed cover was greatest in NR both years, although weed cover increased greatly in DG in 2024 compared to SG or NG. Weed cover did not change following grazing in either year, indicating grazing did not impact the ability for the winter rye cover crop to inhibit annual weed establishment. No differences ($P > 0.05$) were observed for the 2023 soybean yield or 2024 corn silage yield (Figure 1).

Stocking rates were variable between grazing periods. In fall 2022 four cows averaging 992 lbs bodyweight grazed for five days totaling 0.14 animal unit months (AUM) per acre. In spring 2023 nine yearling heifers averaging 690 lbs bodyweight grazed for 16 days totaling 0.66 AUM/ac. The fall and spring grazing periods for the 2022-2023 season supported 0.8 AUM/ac for DG and 0.66 AUM/ac in SG. Grazing did not occur in fall of 2023 due to poor winter rye establishment due to late harvest. In spring of 2024 seven yearling heifers averaging 745 lbs bodyweight grazed for seven days resulting in 0.23 AUM/ac for both DG and SG.

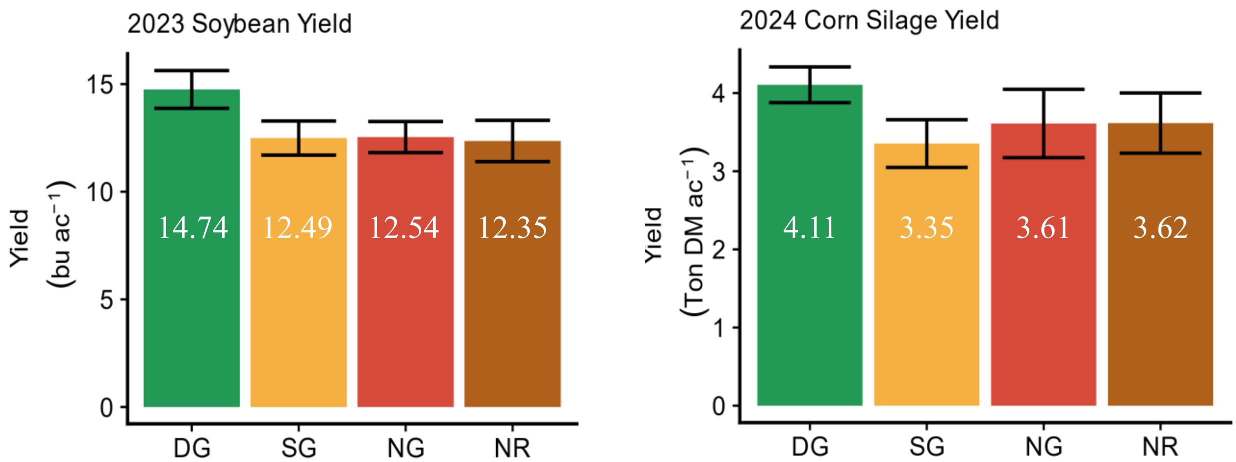

Figure 1. Soybean yield in 2023 and corn for silage yield in 2024. Means are shown in white text in each bar. DG = Dual Graze, SG = Spring Graze, NG = No Graze, NR = No Rye.

Within the NG treatment, adding winter cover crops without grazing to the enterprise resulted in added costs of \$43.05/ac in 2023 and \$42.93/ac in 2024 (Figure 2). Yield did not differ ($P > 0.05$) from no cover crop either year, but the experimental estimated income for each paddock was used, resulting in increased income by \$6.28/ac in 2023 and reduced income by \$0.28/ac in 2024. Integrating livestock resulted in positive net effects to the production enterprise in 2023. In 2023, DG saw the highest net effect of \$36.06/ac, and SG had a positive net effect of \$1.59/ac. In 2024, both DG and SG grazed 0.23 AUM/ac throughout the season. This lower stocking rate resulted in a negative net effect of \$-22.54/ac for both SG and DG treatments. These costs reflect total savings in feed and yardage costs, rather than cost per pound of gain due to the short grazing period limiting acclimation to the new diet and restricting gains. Additionally, estimated income from cash crop yield was used for each treatment, which while not significantly different, did increase income in DG and SG in 2023 and 2024.

Implications

Although variable in net effect, integrated crop livestock systems offer opportunities to generate a return on cover crop establishment. Grazing livestock immediately prior to cash crop seeding does not negatively impact soil structure or crop performance. Livestock average daily gain was lower in grazing livestock than dry lot feeding within this study. However, the short grazing durations likely did not capture potential compensatory gains following the change in diet. Spring grazing of winter cover crops can be a viable strategy to extend the grazing season and reduce feeding costs by beginning grazing earlier in the year.

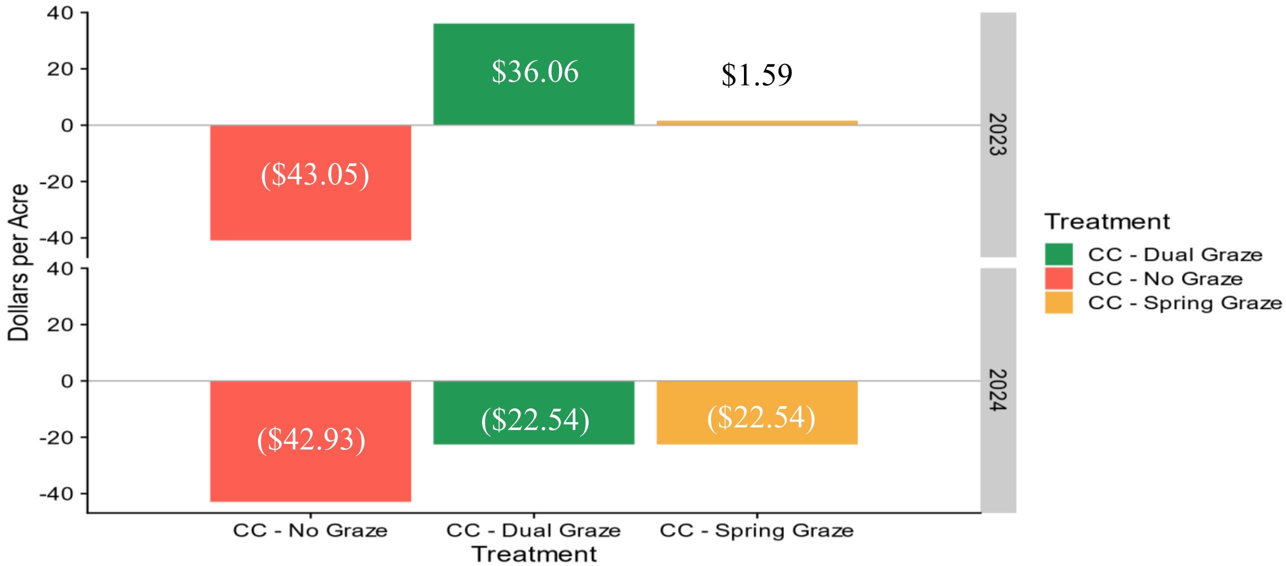

Figure 2. Estimated change to net enterprise income for 2023 and 2024. Changes to income are compared to livestock production utilizing dry lot feeding management without planting cover crops within the cropping operation. Values in parentheses indicate negative values.

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Efficacy of virtual fencing technologies for managing grazing cattle within strip grazing systems

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Summary

Virtual fencing (VF) technologies have seen increasing interest in use as the technology matures. While VF is often advertised for the management of grazing livestock within large pasture settings, the technology offers methods to shift to more intensive grazing strategies without the need for greatly increased labor. This study aims to determine the efficacy of VF and other grazing technologies on the containment of grazing cattle under strip grazing management; as well as evaluate the impacts to forage utilization and stocking rates by shifting to intensive strip grazing management from continuous grazing practices. Pastures at three locations were seeded with a summer annual forage mix and divided into four treatments including virtual fencing (VF), automatic gate (AUTO), manual poly-wire (MAN), and continuous graze (CONT). The VF, AUTO, and MAN treatments were divided into eight sections to allow intensive strip grazing management. Cattle location was recorded from GPS point data and used to determine daily containment. Forage utilization rates were calculated following the removal of cattle. No significant difference was found for cattle containment rates with 77.5% contained by VF, 77.4% contained by AUTO, and 81.0% contained by MAN. Similar containment rates resulted in no difference in forage utilization rates within intensive grazing strategies, although utilization was greater in MAN than CONT. While stocking rates did not statistically differ between treatments, intensive grazing strategies provided an additional eleven days of grazing or up to an additional 0.5 AUM per acre. With similar containment rates and increased forage utilization, VF can be an effective alternative to conventional poly-wire fencing without the increased labor required for intensive grazing practices.

Introduction

Virtual fencing (VF) is a novel wireless technology used for managing the movement of grazing livestock. With VF technologies, a GPS receiver fitted to livestock, typically as a collar, communicates the position of the animal through long range wide area network (LoRaWAN) or cellular data back to a management program on a manager's computer or mobile device. Using this program, the manager remotely establishes borders according to his or her management goals. Auditory or electrical stimulus designed to deter further movement are administered to the animal upon approaching or entering these boundaries.

Many of the drawbacks of conventional fencing can be avoided with VF. Virtual fencing can reduce labor and material costs while providing increased adaptability and flexibility to grazing livestock management (de Avila et al., 2025; Hoag et al., 2025). The ability to quickly shift grazing boundaries allows managers to adapt to changing pasture conditions, weather events, or fires (Boyd et al., 2022). Areas sensitive to grazing disturbance can be easily managed without the need to install and remove physical fencing (Campbell et al., 2019). In addition to comparing costs of VF to the costs of building new fencing, VF technologies become more cost effective on a per use basis, by allowing more intensive grazing strategies without the need for increased labor or materials (Hoag et al., 2025). Moving to more intensive grazing strategies can further increase the value of VF by increasing forage utilization. Forage utilization is increased as intensive grazing practices reduce trampling and wasted forage (Davies-Jenkins et al., 2024). Furthermore, VF can provide animal location data, allowing near-real time monitoring and insights that provide indirect benefits to grazing systems (Antaya et al., 2025).

Much of the current research and applications of VF is used within large-area grazing systems and rangelands. The reduced labor in moving cattle with VF may lead to useful adaptations to smaller scale intensive grazing systems, such as strip grazing within cover crop systems. However, the efficacy and accuracy of VF within smaller areas is unknown. The objectives of this on-going study are: 1) determine the efficacy of VF within small-area strip grazing 2) evaluate the effects to grazing efficiency through different grazing technologies, 3) determine differences in grazing livestock distribution from grazing technologies.

Materials and Methods

A summer annual forage mix containing forage oats (*Avena sativa*), sorghum-sudangrass (*Sorghum × drummondii*), forage pea (*Pisum sativum*), and pasja brassica (*Brassica rapa × napus*) was established at the Central Grasslands Research Extension Center (CGREC) near Streeter, ND; the Carrington Research Extension Center (CREC) in Carrington, ND; and the Beef Cattle Research and Teaching Center (BCRT) in Fargo, ND. Fields were divided into four paddocks ranging from 4-8 acres and randomly assigned one of four treatments: strip graze with virtual fencing (VF), strip graze with automatic gate opener (AUTO), strip graze with manual poly-wire gate (MAN), or continuous grazing (CONT). Each strip graze paddock was divided into eight sections using the assigned grazing technology to create grazing strips ranging

Figure 1. Examples of the grazing technologies used within the study. Cattle fitted with virtual fencing collars (left). Automated gate opener dividing two grazing strips (right). Virtual fencing collars are equipped with GPS devices to determine the location of the animal. The collar emits an auditory or electrical cue to deter the animal from travelling out of assigned boundaries. The automated gate openers are set to a date and time to unlatch and allow the gate to retract.

from 0.5-1 acre (Figure 1). Water and mineral supplement was provided for each paddock. Carrying capacity and forage utilization was determined by clipping eight 0.5 m^2 quadrats within each paddock to determine forage biomass and comparing biomass to an ungrazed check.

All cattle were fitted with VF GPS collars and trained to audible and electrical cues before being randomly assigned to one of four treatments. Audible and electrical cues were disabled for all cattle not assigned to VF. Stocking rates were adjusted at each location to sustain approximately one week of grazing duration in each strip. Within each paddock, ten first-calf heifers grazed at CGREC, eleven cows grazed at CREC, and nine first-calf heifers grazed at BCRT. Cattle grazed each section sequentially. Paddocks were moved independently, with access to the next section allowed once forage utilization was approximately 60-75% by visual estimation. Location data was used from the GPS collars to determine if cattle were successfully excluded from restricted sections. Cattle 0-50 ft past the strip boundary were considered to be within the auditory boundary. Cattle 50-300 ft past the strip boundary were considered to be within the electrical boundary. Cattle greater than 300 ft were unmanaged by VF and considered to be out of strip.

Results and Discussion

Cattle containment did not differ between grazing technologies (P = 0.533), with 77.5% containment for VF, 77.4% containment within AUTO, and 81.4% containment within MAN (Figure 2). Containment varied by location as well as by the individual animal (Figure 3). Additionally, containment rates were often reduced prior to the allocation of the next grazing strip as cattle encroached upon fence lines to seek preferred forages. Escapes prior to the allocation of the new strip were greatest within AUTO. The number of VF cues increased during days when the VF boundary moved, as animals learned where the boundaries were. Audible and electrical cues increased as cattle were motivated to cross boundaries as forage quality and quantity decreased.

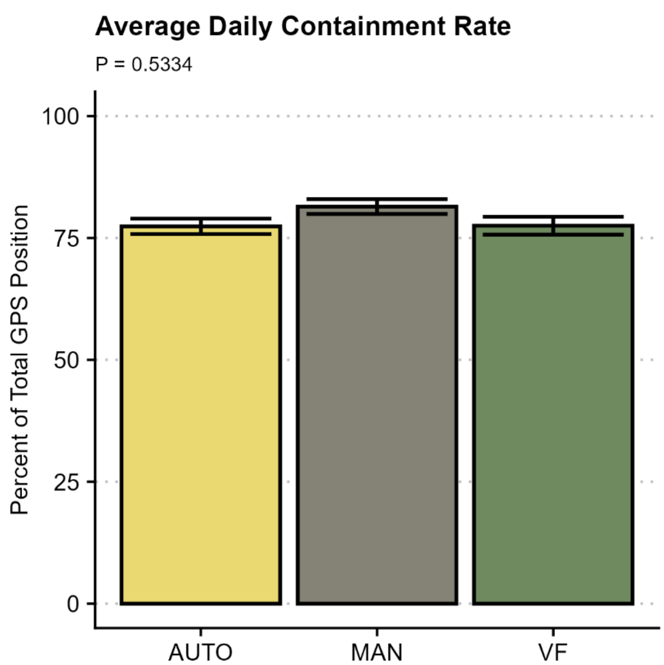

Figure 2. Average containment rate for each grazing technology. Containment rates were calculated by the percent of daily GPS points within the allocated grazing area. AUTO = Automatic gate, MAN = Manual poly-wire, VF = Virtual fence.

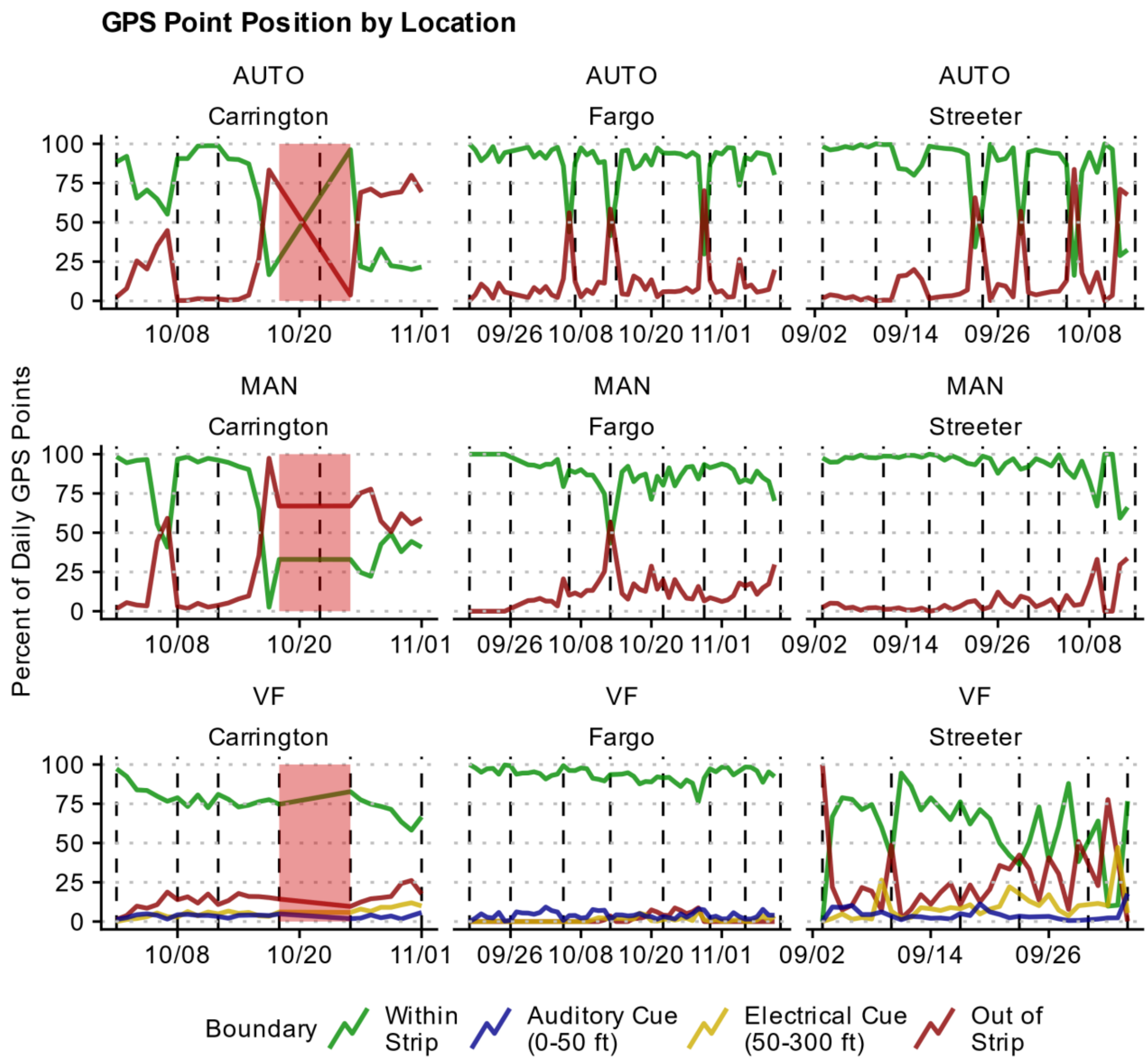

Figure 3. Daily containment rate for each grazing technology for each location. Green lines denote the percent contained points and red lines denote percent out of strip points. Within VF blue lines denote points within the auditory boundary (0-50 ft) and yellow lines denote points within the electrical cue boundary (50-300 ft). The vertical dashed lines denote dates where new grazing strips became accessible for the applicable treatment. Regions shaded in red experienced extended failures in base station connectivity. AUTO = Automatic gate, MAN = Manual poly-wire, VF = Virtual fence, CONT = Continuous graze.

Forage utilization was greatest (P = 0.012) within MAN at 34% which differed from CONT at -15% (Figure 4). The negative utilization in CONT is likely due to the large amount of trampling waste and high variability of remaining biomass. Utilization rates within AUTO and VF did not differ from MAN nor CONT with 25% and 14% respectively. Utilization rates were lower than expected, likely due to highly mature forage reducing palatability late in the grazing period. These differences in utilization did not statistically impact stocking rates (P = 0.094). The average stocking rates across all locations were 2.6 AUM/ac in AUTO, 2.5 AUM/ac in MAN, 2.3 AUM/ac in VF and 2.2 AUM/ac in CONT (Figure 5). While stocking rates did not statistically differ, grazing durations differed at each location. At CGREC, cattle in CONT and VF grazed for 37 days, while AUTO and MAN paddocks grazed for 48 days. Grazing at CREC concluded early due to continued entry to restricted sections increasing trampled forage. All treatments at CREC grazed 35 days, but standing forage within non-allocated strips was greatest in the VF treatment indicating restricted access by grazing cattle. Grazing duration was greatest at BCRT with 49 days in CONT and 60 days in VF, AUTO, and MAN. Across all locations, grazing duration did not statistically vary, although intensive grazing provided an additional eleven days of grazing or up to 0.5 AUM/ac.

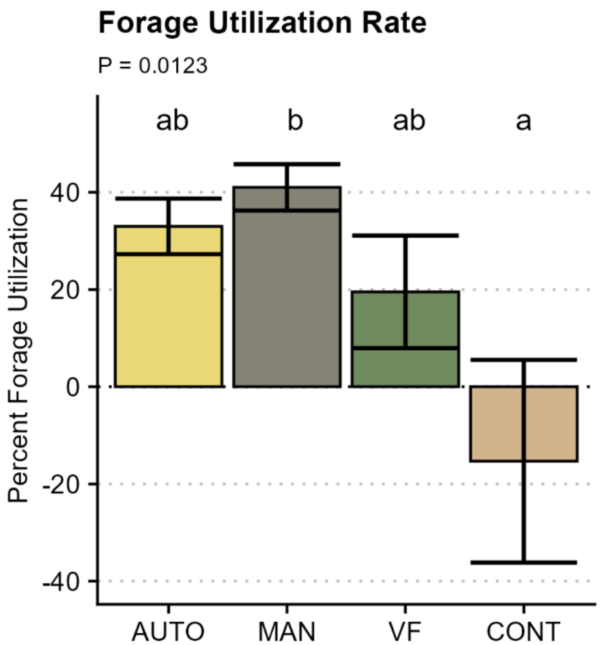

Figure 4. Average utilization rate for each grazing technology across locations. Means not connected by same letter are significantly different P < 0.05. AUTO = Automatic gate, MAN = Manual poly-wire, VF = Virtual fence, CONT = Continuous graze.

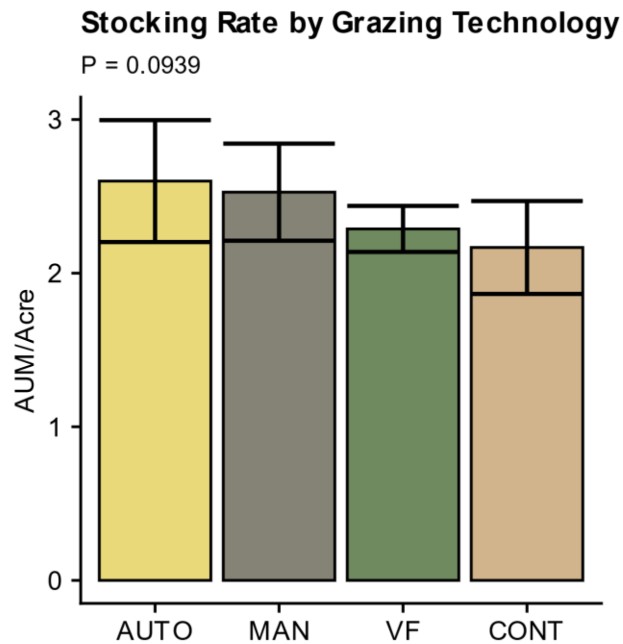

Figure 5. Average stocking rate for each grazing technology. AUTO = Automatic gate, MAN = Manual poly-wire, VF = Virtual fence, CONT = Continuous graze.

Virtual fencing offers an adaptable and flexible strategy for managing grazing livestock with similar efficacy to conventional polywire. Strip grazing can increase forage utilization and stocking rates, creating a more efficient grazing system. The use of VF could aid in the adoption of intensive grazing practices due to the reduced labor required to manage livestock. Additonally, the value generated from alternative VF uses can aid in reducing the cost per use of the technology, increasing the value of the investment in VF infrastructure.

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Using indaziflam for pre-emergence control of absinth wormwood

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Summary

Absinth wormwood (*Artemisia absinthium* L.) is a noxious weed that establishes quickly on disturbed areas. Indaziflam (Rejuvra®) is a preemergence herbicide with long soil residence times that is effective at controlling annual grasses and many broadleaf weeds. We began testing indaziflam in combination with other herbicide treatments to determine the degree of control that indaziflam and other herbicides can have on absinth wormwood. Data will be collected on this study for several years to determine the duration of effect that the treatments have on absinth wormwood and the native plant community.

Introduction

Absinth wormwood infested at least 745,179 acres in the state of North Dakota in 2023 (North Dakota Department of Agriculture, 2023). Absinth wormwood is a perennial noxious weed that spreads by prolific seed production and tillers in disturbed areas. Most chemical control methods labelled for absinth wormwood, such as aminocyclopyrachlor or aminopyralid products, act by disrupting plant growth hormones. Studies have shown that indaziflam, a cellulose biosynthesis inhibitor, can control broadleaf weeds and annual grasses on rangelands. The main goal of this study is to test the efficacy of indaziflam treatments on reducing absinth wormwood. Indaziflam is a preemergence herbicide that kills broadleaf weeds and annual grasses by inhibiting seedling emergence. Therefore, reducing weed seeds in the soil seed bank. The strength of indaziflam as a pre-emergence herbicide is improved by its lengthy residual effects. Many other common pre-emergence herbicides such as picloram, aminopyralid, aminocyclopyrachlor, and imazapic are far more water soluble than indaziflam and therefore have a shorter residence time (Sebastian et al., 2017; Clark et al., 2020). Sebastian et al. (2017) demonstrated that the combined use of indaziflam and other broadleaf herbicides could be effective at reducing weed seeds in the soil seed bank. Reduction of weed seeds in the soil seed bank can release desirable native species from competitive pressure early in the growing season.

An additional goal of this study is to determine how the use of indaziflam in combination with other preemergence herbicides, particularly aminocyclopyrachlor (Method®), changes the duration of control of absinth wormwood. Carter and Lym (2018) have shown that some families of native forbs are resistant to aminocyclopyrachlor at various concentrations. Testing the combination of aminocyclopyrachlor and indaziflam will provide greater insight into the duration of control of absinth wormwood and the resilience of native species to the treatment.

Methods

The study site was selected in early June based on the visual dominance of absinth wormwood. A split plot design with 12 treatments and 1 control was replicated three times.

Each 30 ft^2 (8.59m^2) plot was divided into two subplots; one subplot received the treatment plus indaziflam, and the other received only the treatment. In the case of the control the whole plot received no treatment, but one subplot received indaziflam. Plant community composition and forb stem density was determined at the species level for each subplot within a 1m^2 frame prior to herbicide application. Community composition data was collected according to the canopy cover of each species present in the frame using cover classes (0-1, 2-3, 3-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-95, 95-98, 98-99, 99-100). Stem density of forbs was determined using exact count of each individual per species present in the frame. Herbicide treatments (Table 1) were applied June 14, 2024. The nonionic surfactant Induce® was applied with every treatment at a rate of 0.25% v/v. Indaziflam was applied to each subplot immediately following treatment application at a rate of 73g ai/ha.

In the coming years community composition will continue to be monitored in order to determine the treatment efficacy at reducing the cover of absinthe wormwood.

Table 1. The herbicide treatments utilized in tandem with indaziflam for the control of absinth wormwood.

Common Name	**Trade Name**	**Rate of Application[1]**
Aminocyclopyrachlor	Method®	70g ai/ha
Aminocyclopyrachlor	Method	105g ai/ha
Aminocyclopyrachlor	Method	140g ai/ha
Aminocyclopyrachlor + Chlorosulfuron	Method + Telar XP®	70g ai/ha + 27.8g ai/ha
Aminocyclopyrachlor + Metsulfuron methyl	Method + Escort XP®	70g ai/ha + 22.3 g ai/ha
Aminocyclopyrachlor + 2,4-D Amine	Method + 2,4-D Amine	70g ai/ha + 560g ai/ha
Aminocyclopyrachlor + Chlorosulfuron	Method + Telar XP	105g ai/ha + 41.8g ai/ha
Aminocyclopyrachlor + Metsulfuron methyl	Method + Escort XP	105g ai/ha + 33.4g ai/ha
Aminocyclopyrachlor + 2,4-D Amine	Method + 2,4-D Amine	105g ai/ha + 840g ai/ha
Aminopyralid and Florpyrauxifen-Benzyl	Duracor®	129g ai/ha
Picloram	Tordon 22K®	560g ai/ha
Aminopyralid and 2,4-D Amine	Grazonnext HL®	790g ai/ha

[1]ai/ha = active ingredient per hectare

Preliminary Results

Average percent cover of absinth wormwood in each subplot prior to treatment was 14.5%. On average each subplot contained 33.7 wormwood stems with a standard deviation of 80.7 stems. The chosen study site is otherwise dominated by Kentucky bluegrass (*Poa palustris* L.; 52% cover), smooth brome (*Bromus inermis* Leyss.; 33.9% cover), and western snowberry (*Symphoricarpos occidentalis* Hook.; 21.4% cover). Visual assessment of the treatment effects revealed that absinth wormwood had been reduced on certain treatment areas and totally unaffected on others (Figure 1). It is unclear at this time if absinth wormwood control was improved with the application of indaziflam. Most herbicides used in this study have residual effects and exhibit some preemergence control on broadleaf weeds Therefore, reliable results regarding the control of absinth wormwood cannot be obtained until an additional growing season has passed.

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Figure 1. A subplot where aminocyclopyrachlor was applied at a rate of 105g ai/ha with indaziflam at a rate of 73g ai/ha 10 days post treatment (a). Thirty-nine days post treatment (b) absinth wormwood has increased in areal cover of the plot with no signs of senescence. A subplot where picloram was applied at a rate of 560g ai/ha without indaziflam 10 days post treatment (c). Thirty-nine days post treatment (d) absinth wormwood has senesced and decreased in areal cover.

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Effect of silage additives on chemical composition, fermentation characteristics, and bacterial and fungal communities of corn silage

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Summary

This study was conducted to investigate the effect of silage additives on a) silage composition and fermentation characteristics, and b) bacterial and fungal communities during ensiling and after prolonged aerobic exposure. Whole plant corn was harvested at 33% DM and treated with a) deionized water (control), b) a silage inoculant, and, c) a propionic acid-based additive. The silage inoculant, LB+ Supersile® (Strong Microbials Inc., Milwaukee WI), was applied to supply 1 x 10^5 cfu/g of fresh forage. The acid-based additive, SAVOR® Plus, (KEMIN Industries, Des Moines, Iowa), was applied at 0.5kg/t of fresh forage. The silages were stored in mini silos at ambient temperature (21°C) for 180 days. The main difference between additives was greater concentration of CP, water-soluble carbohydrate, ammonia-N, and lower total acid concentration in silages treated with a propionic acid-based additive relative to inoculant-treated silage. Application of a propionic acid-based additive reduced relative abundance of lactic acid bacteria and yeasts. This effect extended to three weeks after silo opening. More studies are underway to evaluate the effectiveness of silage additives in corn ensiled at different DM contents.

Introduction

Silage additives can be divided into two groups, a) bacterial inoculants that enhance fermentation by increasing numbers of lactic acid bacteria and, b) chemical additives that prevent silage spoilage by minimizing growth of yeasts and preventing silage spoilage. When harvested at optimum DM content, corn is relatively easy to ensile without inoculants but additives that prevent silage spoilage after silo opening are of more interest. Earlier studies examining the effect of additives on silage quality used traditional culturing methods such as plate counts to monitor bacterial and fungal counts. Such methods did not allow monitoring of bacterial and fungal changes within phyla, orders or families and therefore were not able to show microbial succession during silage fermentation (McGarvey et al., (2013). The advent of next-generation sequencing techniques provides the opportunity to estimate the effect of management practices such as DM content at time of ensiling, type of crop ensiled, and addition of silage additives on microbial population shifts in silage (Romero et al., 2017). So far, next-generation sequencing has been used to characterize the effect of silage inoculants on bacterial (Eikmeyer et al., 2013; Romero et al., 2017; Ogunade et al., 2017) and fungal (Romero et al., 2017) communities in silage. This study was conducted to investigate the effect of silage additives on a) silage chemical composition and fermentation characteristics, and b) bacterial and fungal communities during ensiling and after prolonged aerobic exposure.

Methods

Whole plant corn was harvested 33% DM using a two-row Gehl corn chopper that deposited forage directly into a Knight mixer/feed wagon. Approximately 50kg of forage was treated with a) deionized water (control), b) a silage inoculant, and, c) an acid-based additive. The silage inoculant, LB+ Supersile® (Strong Microbials Inc., Milwaukee WI), was dissolved in deionized water and applied to supply 1 x 10^5 cfu/g of fresh forage. The acid-based additive, SAVOR® Plus (KEMIN Industries, Des Moines, Iowa), was applied at 0.5kg/t of fresh forage. Silage inoculant and acid-based additive were sprayed onto forage during mixing. After thorough mixing, four bags (approximately 500g/bag) per treatment were ensiled in 300 x 220 mm vacuum-sealed polyethylene bags (Jarden Consumer Solutions, Boca Raton, FL). Vacuum sealing was accomplished using a commercial sealer (Maxvac 250, LEM Products, West Chester, Ohio, lemproducts.com). All bags were stored at ambient temperature (21°C) for 180 days. Silage samples were submitted to Dairyland laboratories (Dairyland Laboratories Inc., St. Cloud, MN) for chemical analysis and Jonah Ventures laboratory (Jonah Ventures LLC, 5485 Conestoga Ct STE 210 Boulder, CO; https://jonahventures.com) for bacterial and fungal identification.

Results and Discussion

Silage chemical composition

Silage CP concentration was greater (P = 0.001) in corn silage treated with a propionic acid-based additive relative to control and inoculant-treated silage (Table 1). Acid detergent insoluble N concentration was not influenced by treatment. Relative to control and inoculant-treated silages, soluble protein concentration tended to be greater (P < 0.10) in corn silage treated with a propionic acid-based additive (Table 1). Silage WSC concentration was lower (P = 0.001) in control and inoculant-treated silages relative to corn silages treated with a propionic acid-based additive (Table 1). Lower WSC in inoculant-treated and control silage indicates more active microbial utilization of WSC in these silages since WSC are converted into organic acids and lactic acids with the help of lactic acid bacteria (LAB) during ensilage.

Silage fermentation characteristics

Silage pH was lower (P = 0.032) in control and inoculant-treated silages relative to silages treated with a propionic acid-based additive (Table 2). Although silage pH was greater (P < 0.001) in silage treated with a propionic acid based-additive relative to control and inoculant-treated silage, the pH range of all silage treatments was within the normal range (<4%) expected in corn silages (Kung et al. 2018).

Concentration of lactic acid was not influenced by silage treatment. Concentration of lactic acid measured in all treatments in this study, ranging from 6.1 to 6.7%, was within the range of 4 to 7% expected in silages with a moisture content of 60 to 70% (Kung and Shaver, 2001). Acetic acid concentration tended to be greater (P < 0.073) in control and inoculant-treated silages relative to silages treated with a propionic acid-based additive (Table 2). Concentration of propionic acid was not influenced by silage treatment. Butyric acid was not detected in all silages, which indicated low activity from spoilage microorganisms such as *Clostridium* and *Bacillus* spp. (Visser et al., 2007).

Total acid concentration was lowest (P = 0.039) in silage treated with propionic acid-based additive mainly due to relatively lower production of lactic acid in this treatment (Table 2). There was no difference among treatments in lactic acid concentration expressed as a percent of total acid (Table 2). Lactic acid made up more than 70% of total acids which indicated good fermentation. Lactic acid should be at least 65 to 70% of the total silage acids in good silage (Kung and Shaver, 2001). The ratio of lactic acid to acetic acid was not influenced by treatment (Table 2). A lactic acid to acetic acid ratio about 2.5 to 3.0 indicates good silage fermentation (Kung et al. 2018). Concentration of ammonia (%CP) was lower (P = 0.001) in control and inoculant-treated silages relative to silages treated with a propionic acid-based additive (Table 2).

Bacterial community

Next-generation sequencing techniques identified *Firmicutes* and *Proteobacteria* as the predominant phyla, making up approximately 91% of the 16S sequences. Application of a propionic acid-based additive or bacterial inoculant did not impact the relative abundance of *Firmicutes* but there was a tendency (P = 0.11) for greater relative abundance at silo opening (day 0) relative to day 21 (Figure 1A). However, application of a propionic acid-based additive tended (P = 0.058) to reduce relative abundance of *Proteobacteria* relative to control silage and inoculant-treated silage. As well, relative abundance of *Proteobacteria* tended (P = 0.057) be greater at silo opening (day 0) relative to 21 days after silo opening.

Relative abundance of the most prevalent bacterial genera is shown in Figure 1B. Lactic acid bacteria (*Companilactobacillus, Sphingomonas, Leuconostoc, Weissella* and *Methylobacterium-Methylorubrum*) and other genera grouped under others constituted, 40.8% of the 16S sequences, respectively. Application of a propionic acid-based additive reduced (P < 0.001) relative abundance of lactic acid bacteria (LAB) relative control silage and inoculant-treated silages (Figure 1B). Suppression of LAB following application of propionic acid can potentially lead to production of poor-quality silage. However, even with reduction in relative abundance of LAB following application of propionic acid-based additives as shown in this study, there were sufficient numbers of LAB remaining in silage such that were only marginal changes (for example, higher pH and lower total acids) in silage quality.

Fungal community

Three main fungal genera, the predominant of which were *Kazachstania, Nigrospora, Cladosporium,* and *Metschnikowia* were identified in silage treatments. Application of a propionic acid-based additive reduced (P < 0.001) relative abundance of *Kazachstania* relative to control silage and inoculant-treated silage (Figure 2A). Three weeks after silo opening, *Kazachstania* was predominant in control and inoculant-treated silages to the almost total exclusion of other genera (Figure 2A) which showed the effectiveness of the propionic acid-based additive in reducing aerobic exposure.

Four fungal classes, namely, *Saccharomycetes, Tremellomycetes, Dothideomycetes,* and *Sordariomycetes* were identified as the predominant classes in silages. Application of a propionic acid-based additive reduced ($P = 0.008$) relative abundance of *Saccharomycetes* in corn silage (Figure 2B). This effect of the propionic acid-based additive occurred both at silo opening (day 0) but was more pronounce three weeks after silo opening (Figure 2B). Application of a propionic acid-based additive had no effect on *Tremellomycetes*. *Dothideomycetes* and *Sordariomycetes* appeared almost exclusively in corn silage treated with a propionic acid-based additive (Figure 2B).

Next-generation sequencing techniques showed that propionic acid-based additives target yeasts in corn silage and can successfully reduce yeast populations in silage. This effect of propionic acid-based additives extended to three weeks after silo opening suggesting that the additive will significantly reduce spoilage of corn silage exposed to air.

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Table 1. Chemical composition of corn silage treated with a bacterial inoculant or a propionic acid-based preservative.

	Treatment[1]					
	Con	Inoc	Pre	Pre+Inoc	SE	P-value
CP, %	8.52[b]	8.38[b]	9.60[a]	9.21[a]	0.193	0.001
ADIN, %CP	5.30	5.42	5.92	5.30	0.581	0.677
Soluble protein, %CP	62.0	61.5	65.7	64.5	1.17	0.081
WSC[2], %	4.31[b]	4.32[b]	7.05[a]	6.08[a]	0.345	0.001
Starch, %	33.3	31.7	28.9	32.1	2.36	0.355
NDF, %	36.0	37.2	34.1	32.9	1.65	0.110
ADF, %	21.5	22.0	20.8	19.9	1.01	0.283
Lignin, %	2.09[b]	2.04[b]	2.68[a]	2.57[a]	0.106	<0.001

[1]Con, Inoc, Pre, Pre+Inoc = control, bacterial inoculant, preservative, and preservative plus inoculant, respectively.

[2]Water-soluble carbohydrate

[a-c]Means within a row with a different letter differ significantly ($P \leq 0.05$).

Table 2. Silage acidity (pH) and concentration of organic acids, and ammonia in corn treated with a bacterial inoculant or a propionic acid-based preservative.

	Treatment[1]					
	Con	Inoc	Pre	Pre+Inoc	SE	P-value
pH	3.49[b]	3.51[b]	3.82[a]	3.71[a]	0.032	<0.001
Lactic acid, %	6.71	6.57	6.09	6.54	0.291	0.236
Acetic acid, %	1.71	1.89	1.49	1.42	0.164	0.073
Propionic acid, %	0.27	0.28	0.27	0.27	0.016	0.807
Total acids, %	8.69[ab]	8.75[a]	7.84[b]	8.23[ab]	0.283	0.039
Lactic acid, % total acid	77.2	75.1	77.6	79.5	2.039	0.283
Lactic/acetic acid	3.93	3.48	4.22	4.73	0.629	0.312
Ammonia-N, %CP	3.44[b]	3.34[b]	6.53[a]	6.11[a]	0.422	0.001

[1]Con, Inoc, Pre, Pre+Inoc = control, bacterial inoculant, preservative, and preservative plus inoculant, respectively.

[a-c]Means within a row with a different letter differ significantly ($P \leq 0.05$).

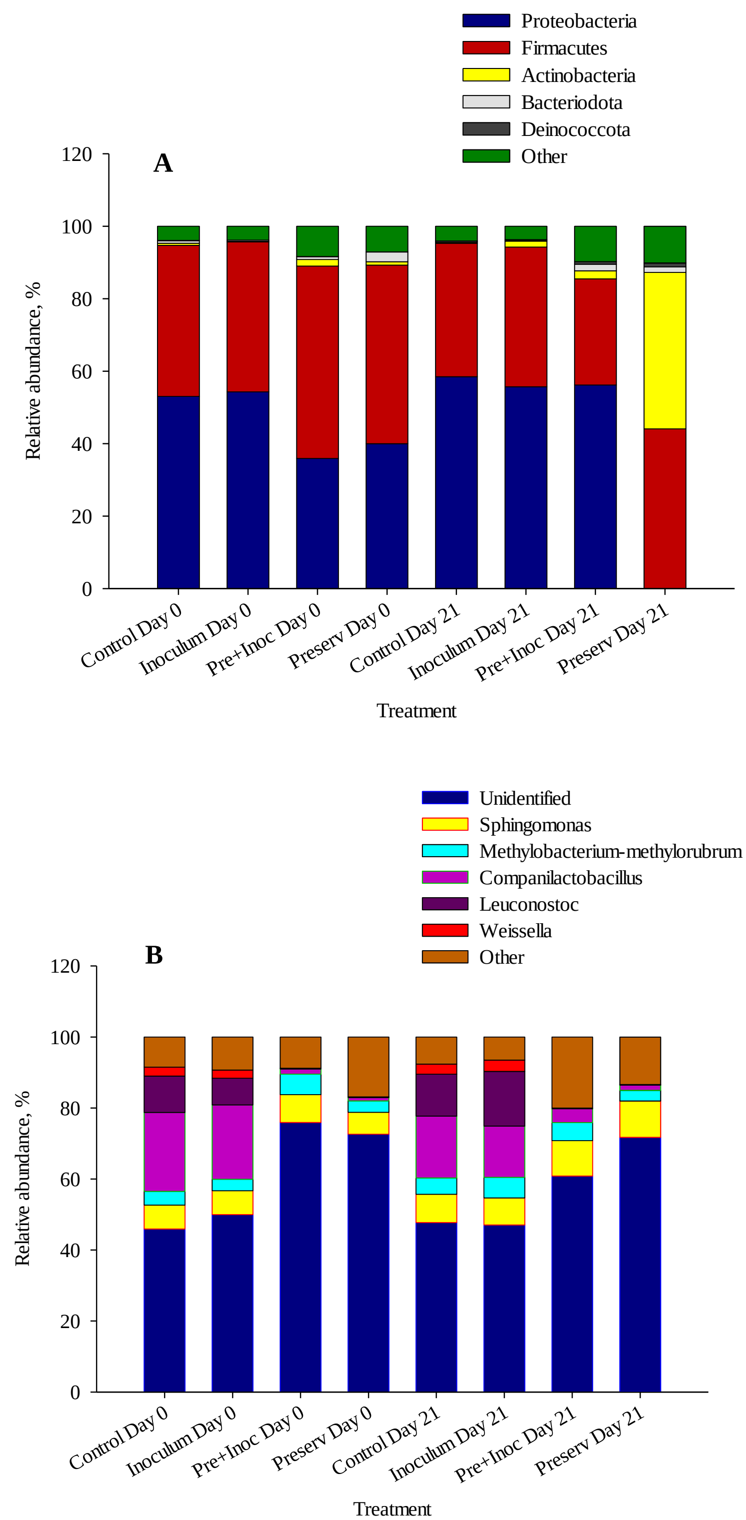

Figure 1. Relative abundance (%) of silage bacterial phyla (**A**) and genera (**B**) at time of silo opening (day 0) and 21 days after silo opening (day 21) in corn silage treated with a bacterial inoculant or a propionic acid-based preservative.

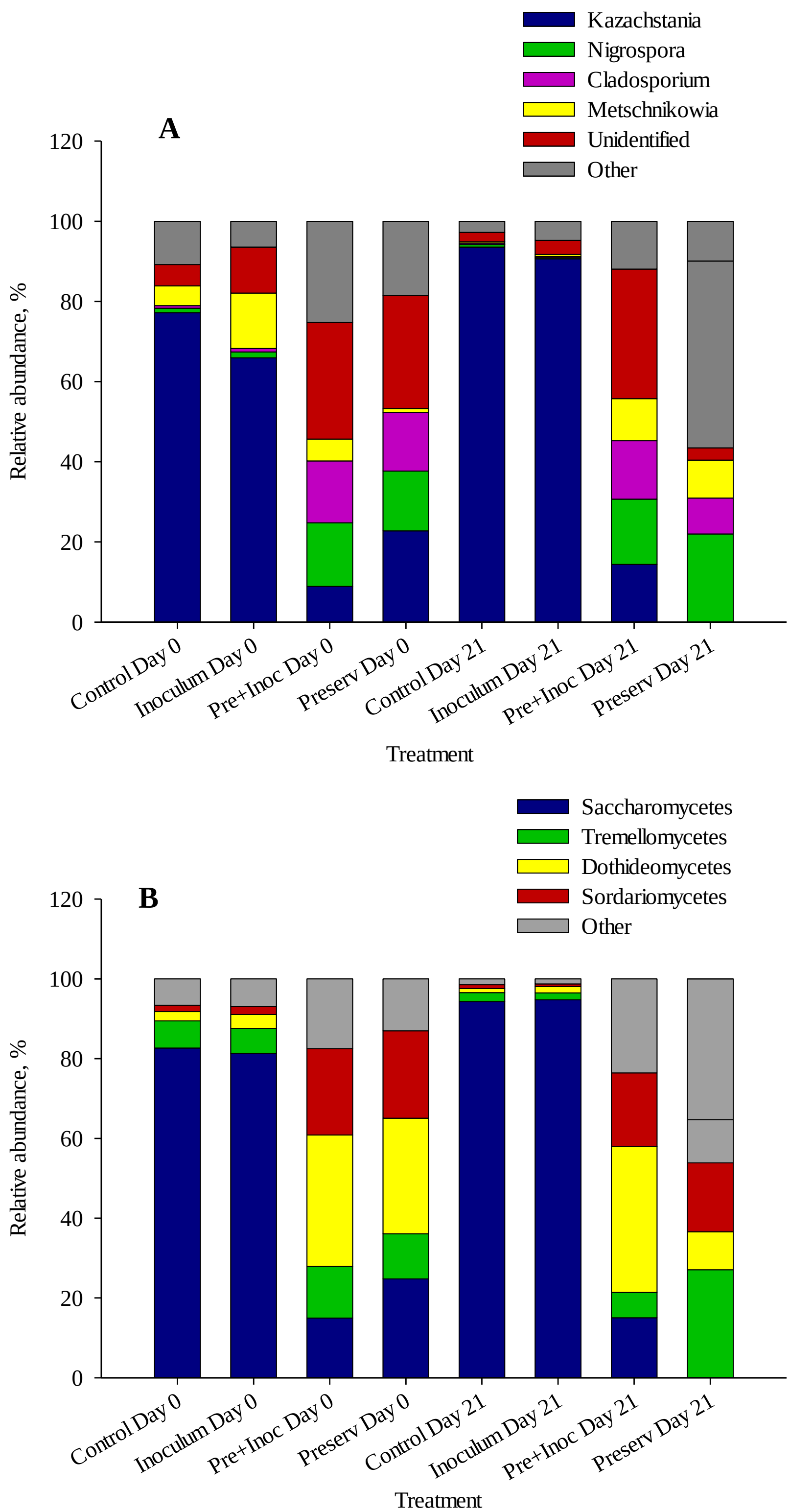

Figure 2. Relative abundance (%) of silage fungal genera (**A**), and class (**B**) at time of silo opening (day 0) and 21 days after silo opening (day 21) in corn silage treated with a bacterial inoculant or a propionic acid-based preservative.

Can a liquid mineral supplement increase forage production, forage quality, and soil nitrogen?

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Summary

Nutri-Graze™ is a product designed to increase forage production by stimulating soil microbial activity. This product was used in conjunction with urea (nitrogen fertilizer) on a grass and alfalfa/grass mixed hayfields. The results of this study suggest neither Nutri-Graze (at 1 pint/acre) or Urea (25 and 50 lb/ac actual N) increase ($p>0.05$) forage production or improve forage quality. Nutri-Graze does not increase ($p>0.05$) soil nitrogen stores by stimulating nitrogen fixing microbes on a grass hay field, nor does it increase forage quality and soil nitrogen on an alfalfa/grass hay field. Urea at 50 lb/ac actual N with and without Nitri-Graze at 1 pint/acre produced greater ($p<0.05$) amounts of forage compared to the control. This result contradicts the findings of previous research. Therefore, the study should be repeated with identical treatments across several years in order to determine if factors such as annual rainfall mask the effects of Nutri-Graze and Urea.

Introduction

Nitrogen (N) compounds are critical for plant growth and are utilized with great success as an agricultural fertilizer. Plants absorb the nitrogenous compounds ammonium (NH_4) and nitrate (NO_3) from the soil. These compounds enter the soil through nitrogen fixation performed by microbes, or when microbes decompose organic matter.

Nutri-Graze is a liquid foliar application designed to increase plant biomass, improve forage quality, and improve soil health by stimulating soil microbial activity. Nutri-Graze contains cobalt, copper, iron and manganese which could provide essential nutrients for soil microbes. Previous studies suggest that Nutri-Graze can improve forage yields by 20-30% (RALCO, 2023). Sedivec and Fitterer (2023) showed 1 pt/acre Nutri-Graze improved forage yields by 44.3% on high production soils and 23.1% on low production soils using 2 pt/acre. The goals of this study will be to determine the potential for Nutri-Graze in combination with urea to increase forage production, forage quality, and soil nitrogen content.

Methods

This study was conducted at NDSU, Central Grasslands Research Extension Center (CGREC) near Streeter, North Dakota. Two study sites were selected on hay fields established in 1988 and 2007. The 2007 hay field was a perennial cool season grass field dominated by smooth brome (*Bromus inermis* Leyss.) and Kentucky bluegrass (*Poa pratensis* L.) (Grass Field) and the 1988 site a mix of alfalfa (*Medicago sativa* L.) and meadow brome (*Bromus biebersteinii* Roem. & Schult.) (Alfalfa/Grass Field). Henceforth, referred to as Grass Field and Alfalfa/Grass

Field, respectively. The experiment was developed using a randomized complete block design with one block located at each study site. Each block contained nine treatments replicated four times. Treatments were assigned to a $9.14m^2$ ($30ft^2$) plot and plot order was randomized within each replicate. The nine treatments applied consisted of a control, which received no enhancement, urea applied at two different rates (25lb/ac and 50lb/ac of actual N), and Nutri-Graze applied at a rate of 1 pint per acre. Three treatments included a second application of Nutri-Graze at a rate of 1 pint per acre one month after cutting each block for hay.

Treatment key:

1. Control
2. 1 application Nutri-Graze
3. 2 applications Nutri-Graze
4. 25lb/ac Urea
5. 25lb/ac Urea + 1 application Nutri-Graze
6. 25lb/ac Urea + 2 applications Nutri-Graze
7. 50lb/ac Urea
8. 50lb/ac Urea + 1 applications Nutri-Graze
9. 50lb/ac Urea + 2 applications Nutri-Graze

Urea and first applications of Nutri-Graze were applied in May 8 (Grass Field) and 13 (Alfalfa/Grass Field), 2024 when grasses were at the 2-3 leaf stage. Biomass samples were collected approximately one month after treatment application when grasses were in the boot stage (first clipping, June 6 and 7, 2025), and again approximately three weeks later when grasses were in the heading stage (second clipping, late June). Soil samples were collected on July 10 to determine total NO_3 and NH_4 content at a depth of 0-6 inches. Each field was completely cut for hay during the week of July 15. On July 29 the second application of Nutri-Graze was applied to treatments 3, 6 and 9. A third biomass sample to assess regrowth and impacts of the second application of Nutri-Graze was collected during the week of September 23.

Biomass was sampled by clipping two subsamples per plot using a $0.25m^2$ frame. After clipping, each sample was dried at 60°C (140°F) for 72 hours and weighed to determine forage production. One of the subsamples from each plot in the second clipping was analyzed for crude protein (CP), acid detergent fiber (ADF), and total digestible nutrients (TDN).

The results of each clipping, soil test, and nutrient analysis were compared across treatments for each field. The data failed the assumptions of a parametric test. Therefore, a Kruskal-Wallis test was used to compare treatments. When the results of the test were significant at the level of $\alpha = 0.05$, a Dunn's multiple comparisons test with p values adjusted using the Holm method was used post hoc in order to determine exactly which treatments differed from each other.

Results and Discussion

Forage Production

There were no differences ($p>0.05$) in total biomass across treatments in the alfalfa/grass field during the first collection period (early June) when smooth and meadow brome were in the boot growth stage. During the first collection in the grass field, the single application of Nutri-Graze produced an average of 1,986lbs/ac of forage which was significantly less than the 3200lbs/ac of forage produced by the urea (50lb/ac actual N) plus Nutri-Graze treatment.

We found no difference ($p>0.05$) in total biomass across treatments during the second clipping (late June) in the Alfalfa/Grass Field when the grass was in the heading stage (Table 1). However, all treatments produced 20 percent or more biomass compared to the control, with the Nutri-Graze producing 32.9 percent more production. There was no difference ($p>0.05$) between the urea rates, and we found adding Nutri-Graze with urea provided no benefit ($p>0.05$) when alfalfa was part of the hay stand (Table 1).

Table 1. Herbage production by treatment on the grass/alfalfa and grass fields when brome was at the heading stage (late June) at the Central Grasslands Research Extension Center near Streeter, ND in 2024.

Treatment	Grass/Alfalfa Field (meadow brome/ alfalfa)		Grass Field (smooth brome)	
	Herbage Production[1] (lb/ac ± SD)	Percent Change from Control	Herbage Production[1] (lb/ac ± SD)	Percent Change from Control
Control	3535.2 ± 934.8^{a}		2094.4 ± 185.5^{a}	
Nutri-Graze	4699.1 ± 517.4^{a}	32.9	2701.0 ± 403.2^{ab}	29.0
Urea (25 lb/ac)	4991.6 ± 1412.9^{a}	41.2	3157.7 ± 727.9^{ab}	50.8
Urea (25lb/ac) + Nutri-Graze	4399.3 ± 767.1^{a}	24.4	3571.6 ± 499.5^{bc}	70.5
Urea (50 lb/ac)	4734.7 ± 941.9^{a}	33.9	3600.1 ± 1334.4^{bc}	71.9
Urea (50lb/ac) + Nutri-Graze	4353.0 ± 692.2^{a}	23.1	4081.8 ± 820.6^{bc}	94.9

[1] Treatments with the same letter were not significantly different at the $p\leq0.05$. Values are the mean production plus/minus the standard deviation.

From the second clipping at the Grass Field site urea applied at 50 lb/acre of actual N with or without 1 pt/ac Nutri-Graze increased ($p\leq0.05$) herbage production compared to the control (Table 1). Although not significant ($p>0.05$), Nutri-Graze alone and Urea (25 lb/ac of actual N) alone increased forage biomass by 29.0 and 50.8 percent, respectively (Table 1). The combination of urea (25lb/ac of actual N) and Nutri-Graze significantly increased herbage production compared to the control ($p\leq0.05$).

We applied a second treatment of Nutri-Graze at 1 pt/ac two weeks after the blocks were cut and put up for hay. Adding a second application of Nutri-Graze did not enhance regrowth in either the Alfalfa/Grass or Grass Field sites in 2024 (Table 2).

These results differ from the conclusions of Sedivec and Fitterer (2023) who found that the application of Nutri-Graze increased ($p \leq 0.05$) forage production compared to the control on loamy soils. Therefore, it is likely that some other covariate influences the effect that Nutri-Graze will have on forage production. One factor may be total annual rainfall. In 2023, the CGREC received 18.2 inches of rain compared to the 27.2 inches received in 2024 (NDAWN 2025). It is possible that rainfall so far above average promotes the growth of the plant to a point that the positive effects of Nutri-Graze and Urea are masked. Another potential covariate in this study was time between spraying and the subsequent rainfall. Rain did not fall at CGREC for 4-9 days after the first application of Nutri-Graze in May (4 days for the alfalfa/grass field, 9 days for the grass field). However, CGREC received 0.89 inches of rainfall within hours of the second application of Nutri-Graze. It is possible that the Nutri-Graze did not have adequate time to be absorbed by the leaf tissue of the plants before being washed off by rainfall. The treatments should be repeated for multiple years in order to determine the impact of precipitation on the efficacy of Nutri-Graze.

Table 2. Herbage production regrowth 56 days following first cutting comparing a second application of Nutri-Graze at 1 pt/ac to the single application of Nutri-Graze and Urea + Nutri-Graze treatments at the Central Grasslands Research Extension Center near Streeter, ND in 2024.

Treatment	Grass/Alfalfa Field (meadow brome/alfalfa)		Grass Field (smooth brome)	
	Herbage Production[1] (lb/ac ± SD)	Percent Change from Single Application	Herbage Production[1] (lb/ac ± SD)	Percent Change from Single Application
Nutri-Graze 1 application	2893.7 ± 631.5^{a}		2033.8 ± 256.9^{a}	
Nutri-Graze 2 applications	2986.4 ± 667.2^{a}	3.2	2101.6 + 281.9^{a}	3.3
25lb/ac Urea + Nutri-Graze 1 application	2954.3 ± 827.8^{a}		2369.2 ± 410.3^{a}	
25lb/ac Urea + Nutri-Graze 2 applications	3089.9 ± 927.7^{a}	4.6	2365.6 ± 488.8^{a}	-0.2
50lb/ac Urea + Nutri-Graze 1 application	3204.1 ± 1027.6^{a}		2529.7 + 717.2^{a}	
50lb/ac Urea + Nutri-Graze 2 applications	3015.0 ± 463.8^{a}	-5.9	2397.7 ± 842.1^{a}	-5.2

[1] Treatments within blocks and fields with the same letter were not significantly different at the $p \leq 0.05$. Values are the mean production plus/minus the standard deviation

Bioavailable Nitrogen in the Soil

The analysis of bioavailable nitrogen in the soil (Figure 2) revealed that no treatments contained significantly different ($p>0.05$) levels of NH_4 or NO_3 in either study field. It can be concluded from these results that both Nutri-Graze and Urea at any application rate had no effect on soil nitrogen under the climate conditions in 2024.

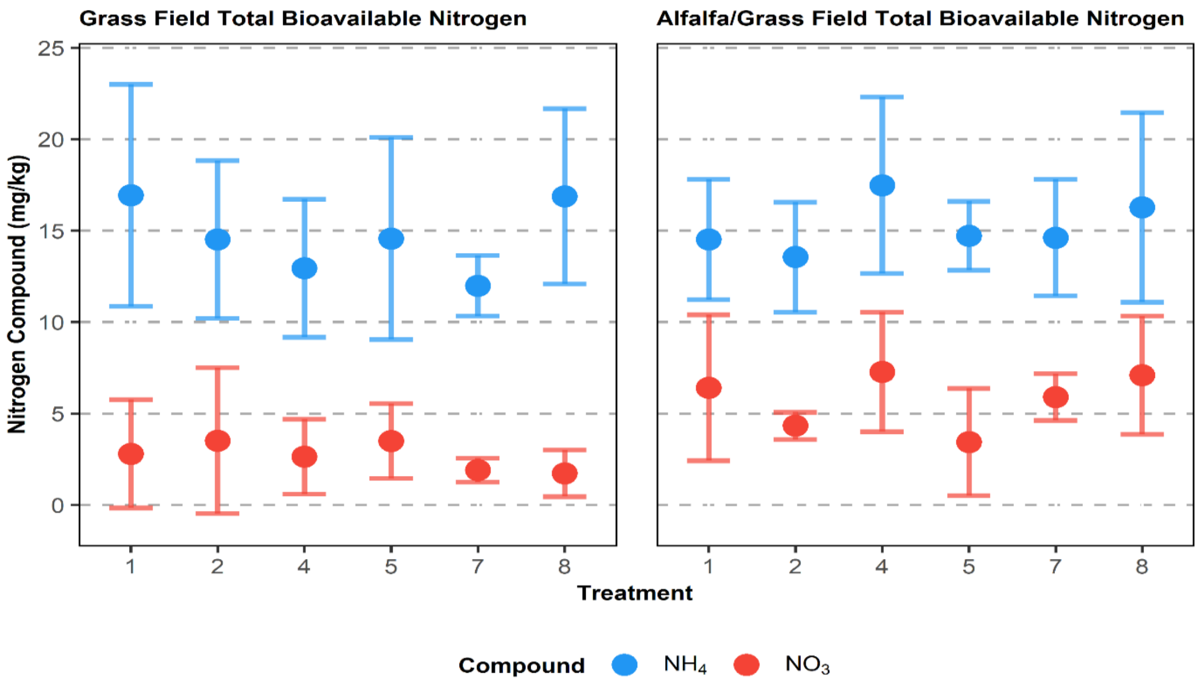

Figure 8. Milligrams of nitrogen compounds NH_4 and NO_3 per kilogram of soil. Points are treatment (see treatment key) means across replicates and within each block. Error bars are one standard deviation. Treatments included control (1), 1 pt/ac Nutri-Graze (2), Urea at 25 lb/ac actual N (4), Urea at 25 lb/ac actual N plus Nutri-Graze at 1 pt/ac (5), Urea at 50 lb/ac actual N (7), Urea at 50 lb/ac actual N plus Nutri-Graze at 1 pt/ac (8).

No increase in soil nitrogen suggests that neither Nutri-Graze or Urea stimulated nitrogen fixing bacteria to fix more nitrogen, or that any nitrogen fixed by the bacteria was quickly taken up by the plants. These results are contradictory to the findings of a previous study which found that the application of Nutri-Graze with manure increased total available nitrogen by 24.3% compared to just manure (RALCO, 2023). This study should be continued in order to confirm that the findings are not the result of climate related factors.

Forage Nutritional Quality

The analysis of plant nutritional components (Figure 3) revealed that no treatments contained significantly different ($p>0.05$) levels of ADF, CP, or TDN in either study field. It can be concluded from these results that neither Nutri-Graze or Urea had an effect on forage nutritional components.

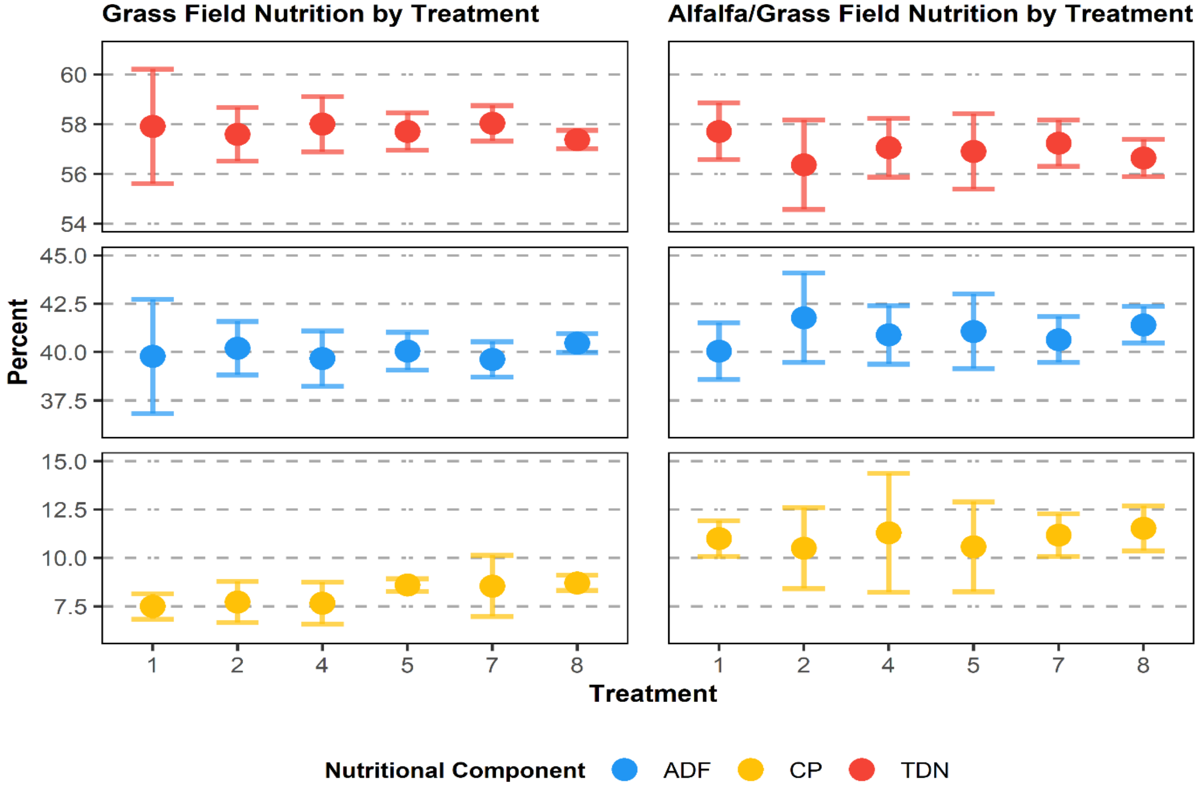

Figure 9. Percent acid digestible fiber (ADF), crude protein (CP), and total digestible nutrients (TDN). Points are treatment (see treatment key) means across replicates and within each block. Error bars are one standard deviation. Treatments included control (1), 1 pt/ac Nutri-Graze (2), Urea at 25 lb/ac actual N (4), Urea at 25 lb/ac actual N plus Nutri-Graze at 1 pt/ac (5), Urea at 50 lb/ac actual N (7), Urea at 50 lb/ac actual N plus Nutri-Graze at 1 pt/ac (8).

The greatest increase in CP as a result of the treatments in this study was approximately 15% on the urea at 25 lb/ac actual N plus Nutri-Graze at 1 pt/ac (5), urea at 50 lb/ac actual N (7), and urea at 50 lb/ac actual N plus Nutri-Graze at 1 pt/ac (8) compared to the control (1) on the Grass Field. However, these differences are statistically insignificant ($p>0.05$). In their 2023 research summary, RALCO reported that Nutri-Graze increased CP by 11.6% in tallgrass prairie (RALCO, 2023). RALCO did not provide statistical analysis to determine the significance of this increase. It is possible that Nutri-Graze may cause a marginal increase in CP levels when used with urea, but more data is needed to prove the statistical significance of the increase.

Implications

With the exception of urea applied at 50 lb/acre of actual N, Nutri-Graze nor urea when applied at the rates in this study did not improve forage production, forage quality, or soil nitrogen in cool season grass forage or cool season grass forage mixed with alfalfa under the climate conditions at CGREC in 2024. The level of precipitation in the summer of 2024 as well as the time between application of Nutri-Graze and rainfall are factors that may have masked the positive effects of Nutri-Graze and urea. More research is needed to determine the effects of Nutri-Graze when paired with urea on cool season grass forage when precipitation is above the annual average.

Associated Fact Sheet: Page 123

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Achieving Diverse Avian Nesting Requirements with Heterogeneity-based Grazing

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Summary

Traditional grazing management focuses on maximizing cattle production through uniform forage utilization, resulting in reduced variation in vegetation structure and composition. This homogenization decreases avian niche diversity, contributing to ongoing declines in grassland bird communities. Recoupling fire and grazing can restore rangeland heterogeneity, but limited regional knowledge and resources for prescribed fire prevent widespread application across the Great Plains. This suggests a need for innovative grazing practices that utilize existing infrastructure to restore heterogeneity.

In 2018, we established a modified rotational grazing system that varies grazing intensity to create heterogeneity across paddocks. Our treatment structure includes four replicates, each split into four paddocks with an assigned grazing intensity based on the degree of disappearance. We assessed the impacts this system had on 1) vegetation structure as well as grassland bird 2) nest survival, and 3) nest densities. We conducted vegetation sampling to quantify vegetation structure and rope dragging to locate nests within paddocks. Nests were subsequently monitored to determine fate. We incorporated vegetation structure and composition measurements taken at each nest into a hierarchical modeling scheme using RMark to assess nest survival.

We found that modifying grazing intensity within a pasture creates heterogeneity in vegetation density while litter depth follows a lag effect based on the previous year's grazing intensity. We found that nest survival of four of the eight species was impacted either directly by grazing or indirectly by changes in vegetation structure associated with grazing. Additionally, nesting density of four species varied among grazing intensities. Responses to grazing and vegetation variables were species-specific, reflecting the importance of heterogeneity when managing for diverse grassland birds.

Our results demonstrate the potential for an alternative grazing practice to restore heterogeneity and improve grassland bird conservation. We recommend land managers incorporate grazing strategies that promote heterogeneity to benefit grassland birds.

Introduction

Rangelands cover approximately 45% of the Great Plains and present an excellent opportunity to improve habitat for imperiled grassland birds (Augustine et al., 2021; Rosenberg et al., 2019). However, approximately 91% of rangelands are privately owned and managed for uniform utilization of forage (Becerra et al., 2017; Robinson et al., 2019). The accompanying reduction in variability in vegetation structure reduces avian niche diversity and contributes to widespread grassland bird declines (Becerra et al., 2017; Rosenberg et al., 2019). Contemporary management for grassland birds focuses on restoring variability in vegetation, referred to as heterogeneity, often employing patch-burn grazing (Fuhlendorf & Engle, 2001; Verheijen et al., 2019). This approach mimics historic disturbance regimes, fire and grazing, that grassland birds evolved alongside (Fuhlendorf et al., 2006).

Despite research showing improved cattle performance with patch-burn grazing, public perception and lack of equipment constrain the application of fire (Clark et al., 2022; Wanchuk et al., 2024). The current lack of alternatives to patch-burn grazing creates the need for innovative methods to promote vegetation structural heterogeneity. In the northern Great Plains, rest-rotation is a common management practice, but it results in uniform vegetation structure (Davis et al., 2020; Whitt & Wallander, 2022). To overcome this, we designed a unique modified twice-over rest-rotation grazing (MTORG) system to restore structural variability to rangeland landscapes. This system would allow land managers to adopt conservation-based management without fire or extensive changes to existing infrastructure.

We hypothesize that avian nesting communities, nest survival, and nest densities will vary across paddocks, with species exhibiting preferences for different types of vegetation structure. Nesting density should be lowest at the extreme ends of this structural gradient because relatively few specialized species, including species of special concern like the chestnut-collared longspur, rely on short vegetation structure (Churchwell et al., 2008). Our objectives are to quantify changes in 1) vegetation structure and the subsequent impacts on 2) nest survival and densities of grassland birds.

Methods

Study Area

The Central Grasslands Research Extension Center (CGREC) is located along the border of Kidder and Stutsman counties in North Dakota. The study area has a temperate, continental climate with an average growing/grazing season (April to September, May to October, respectively) precipitation of 433 mm and average growing season temperatures of 13.6° C (NDAWN, 2025). However, 2021 was a drought year with above-average temperatures (15.4° C) and below-average precipitation (33.3 cm). Temperatures were high but within the normal range in 2022, 2023, and 2024 (13.8, 14.3, 15.2° C, respectively). Precipitation was lower than normal in both 2022 and 2023 but higher than average in 2024 (34.3, 38.5, 55.3 cm, respectively).

Treatment Structure

The modified twice-over rest-rotation grazing (MTORG) system is designed to create heterogeneity in vegetation structure by varying grazing intensities within a pasture. The study system includes four replicates with each replicate split into quarters, herein referenced to as paddocks, based on degree of disappearance. The four paddocks within each of the four experimental replicates and their degree of disappearance are as follows: rested (0%), moderate (20-40%), full (40-60%), and heavy (60+%). Throughout the treatment, a moderate stocking rate (5 year average = 2.34 AUM/ha) has been used with varied lengths of grazing periods to achieve the desired degree of disappearance (Duquette et al., 2022).

Grazing intensity rotates each year, with the rested paddock becoming the moderate paddock, the moderate to full, the full to heavy, and the heavy to rest. Cattle movement within the 65-

hectare pasture is constrained to each paddock (approximately 16 hectares) using interior fencing (Duquette et al., 2022). The system was established in 2018 and completed one full cycle in 2021.

Vegetation Surveys

We measured vegetation structure within each grazing intensity using three 25-m transects in each paddock. Vegetation measurements were taken at 0, 12.5, and 25 m along each transect. Structural measurements included visual obstruction readings (VOR) and litter depth. Vegetation measurements were taken at the end of the breeding season during the first two weeks of August.

Nest Searching/Monitoring

We searched for nests by dragging a 30-m rope with aluminum can bundles attached every 3 m to flush and locate nesting birds (Winter et al., 2003). We repeated this process from 20 May to mid-July from 2021 to 2024. We continued monitoring until the nest was fledged, depredated, or abandoned (Winter et al., 2005). We considered nests successful if they fledged at least one nestling of the same species (Shew et al., 2019). We conducted vegetation surveys at the actual or expected fledge date for successful and failed nests, respectively (McConnell et al., 2017). We measured vegetation using a 0.5-m^2 quadrat centered on the nest bowl using functional group midpoints. We split Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) from the other grasses due to their unique structure and invasiveness (Duquette, 2020). Structural measurements included VOR, vegetation height, and litter depth.

Analysis

We used generalized linear mixed-effects models to compare vegetation structure in each grazing intensity (Brooks et al., 2017). Avian species were divided into functional groups based on habitat preferences. Obligate grassland birds rely exclusively on grasslands for their life history, whereas facultative grassland birds rely on grasslands in conjunction with other habitat types (Vickery et al., 1999). Wetland species are those that rely on wetlands for much of their life history.

We calculated daily survival rates (DSR) which represent the probability that a nest survives from one day to the next (Dinsmore et al., 2002; Laake, 2013). We only included species with more than 30 nests in our analysis. We assessed management and vegetation impacts on nest survival in five steps: 1) temporal, 2) biological, 3) parasitism (songbirds only), 4) grazing, and 5) vegetation structure and composition impacts. We calculated nest densities with a correction for failure before discovery (Arnold et al., 2007) and compared nesting densities among grazing intensities (Hollander & Wolfe, 1973; Saville, 1990).

Results

Objective 1: Vegetation Structure Changes

We found that vegetation density decreased as grazing intensity increased with the tallest and densest vegetation in the rested paddock and the shorter, sparser vegetation in the heavy paddock (Figure 1). In contrast, litter depth followed a lag effect with the deepest litter in the moderate paddock (rested in the previous year) and the shallowest in the rested paddock (heavy in the previous year, Figure 1).

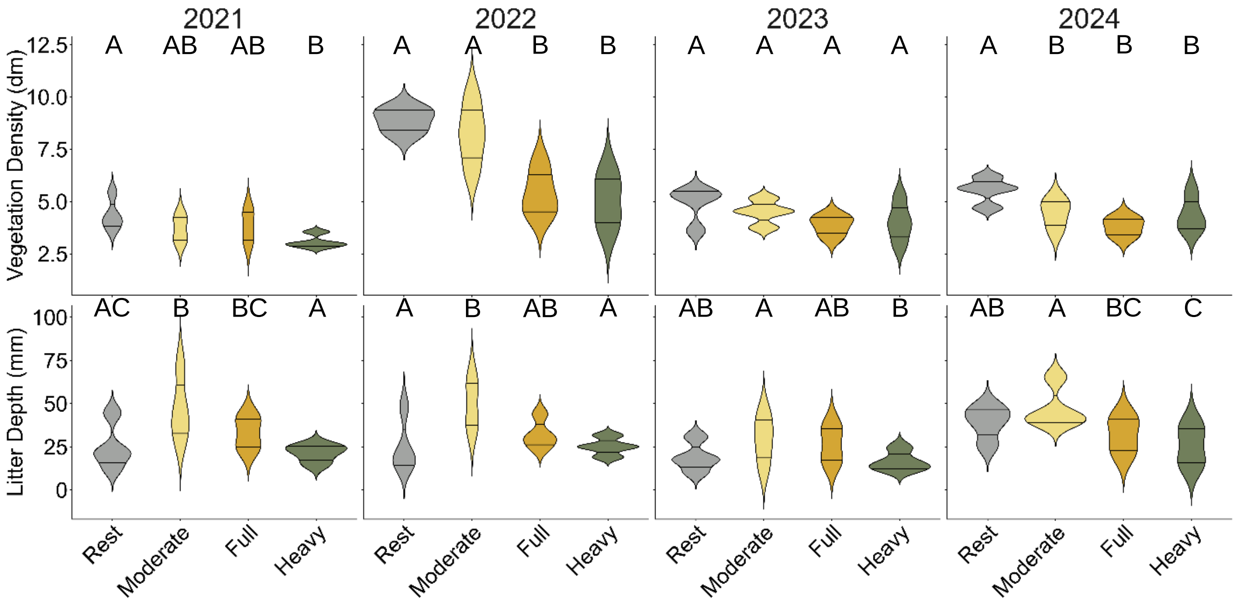

Figure 1. Violin plots showing two vegetation structural measurements taken in a modified twice-over rest-rotation grazing system at the Central Grasslands Research Extension Center in North Dakota. Measurements included litter depth and visual obstruction reading (VOR), a measure of vegetation density, and were taken in August 2021 to 2024 within four replicates of each grazing intensity. Colors represent each grazing intensity, and the shape indicates the distribution of values where wider sections represent the accumulation of data points. Letters indicate statistical significance with shared letters indicating non-significance and unique letters indicating a significant difference.

Objective 2: Avian Nest Survival and Densities

We found a total of 1,602 nests across the three years of the study. This includes a total of 8 obligate and 17 facultative grassland birds as well as 8 wetland-associated birds. Only 11 of the 33 species observed met our minimum requirement of 30 nests for nest survival and density analyses (Table 1).

Table 1. Daily survival rates (DSRs) for birds with more than 30 nests collected at the Central Grasslands Research Extension Center from mid-May to mid-July across 2021 to 2024. DSRs represent the probability that a nest survives from one day to the next. Constant DSR reflects the average DSR across the study period, while yearly DSR represents the DSR for individual years. Stage specific DSR is only included for passerines. Functional groups represent a species dependence on grassland habitat. Obligate grassland birds will exclusively use grassland habitats whereas facultative birds will use other habitats for breeding.

Species	Functional Group	Sample Size	Constant DSR	Year DSR	Stage DSR
Mallard	Facultative	37	0.95	2021: 0.97 2022: 0.96 2023: 0.90 2024: 0.95	N/A
Gadwall	Facultative	106	0.97	2021: 0.97 2022: 0.98 2023: 0.94 2024: 0.97	N/A
Northern Pintail	Facultative	75	0.93	2021: 0.93 2022: 0.94 2023: 0.94 2024: 0.90	N/A
Northern Shoveler	Facultative	34	0.93	2021: 0.86 2022: 0.94 2023: 0.97 2024: 0.91	N/A
Blue-winged Teal	Facultative	131	0.95	2021: 0.97 2022: 0.97 2023: 0.94 2024: 0.90	N/A
Mourning Dove	Facultative	58	0.93	2021: 0.95 2022: 0.96 2023: 0.82 2024: 0.91	Incubating: 0.81 Nestling: 0.98
Clay-colored Sparrow	Facultative	578	0.90	2021: 0.88 2022: 0.92 2023: 0.92 2024: 0.89	Incubating: 0.79 Nestling: 0.95
Western Meadowlark	Obligate	102	0.92	2021: 0.92 2022: 0.93 2023: 0.91 2024: 0.91	Incubating: 0.83 Nestling: 0.96
Red-winged Blackbird	Facultative	159	0.94	2021: 0.92 2022: 0.96 2023: 0.94 2024: 0.93	Incubating: 0.84 Nestling: 0.97
Yellow-headed Blackbird	Facultative	53	0.91	2021: NA 2022: 1.00 2023: 0.97 2024: 0.89	Incubating: 0.79 Nestling: 0.96
Brewer's Blackbird	Obligate	56	0.93	2021: 0.93 2022: 0.99 2023: 0.95 2024: 0.88	Incubating: 0.77 Nestling: 0.98

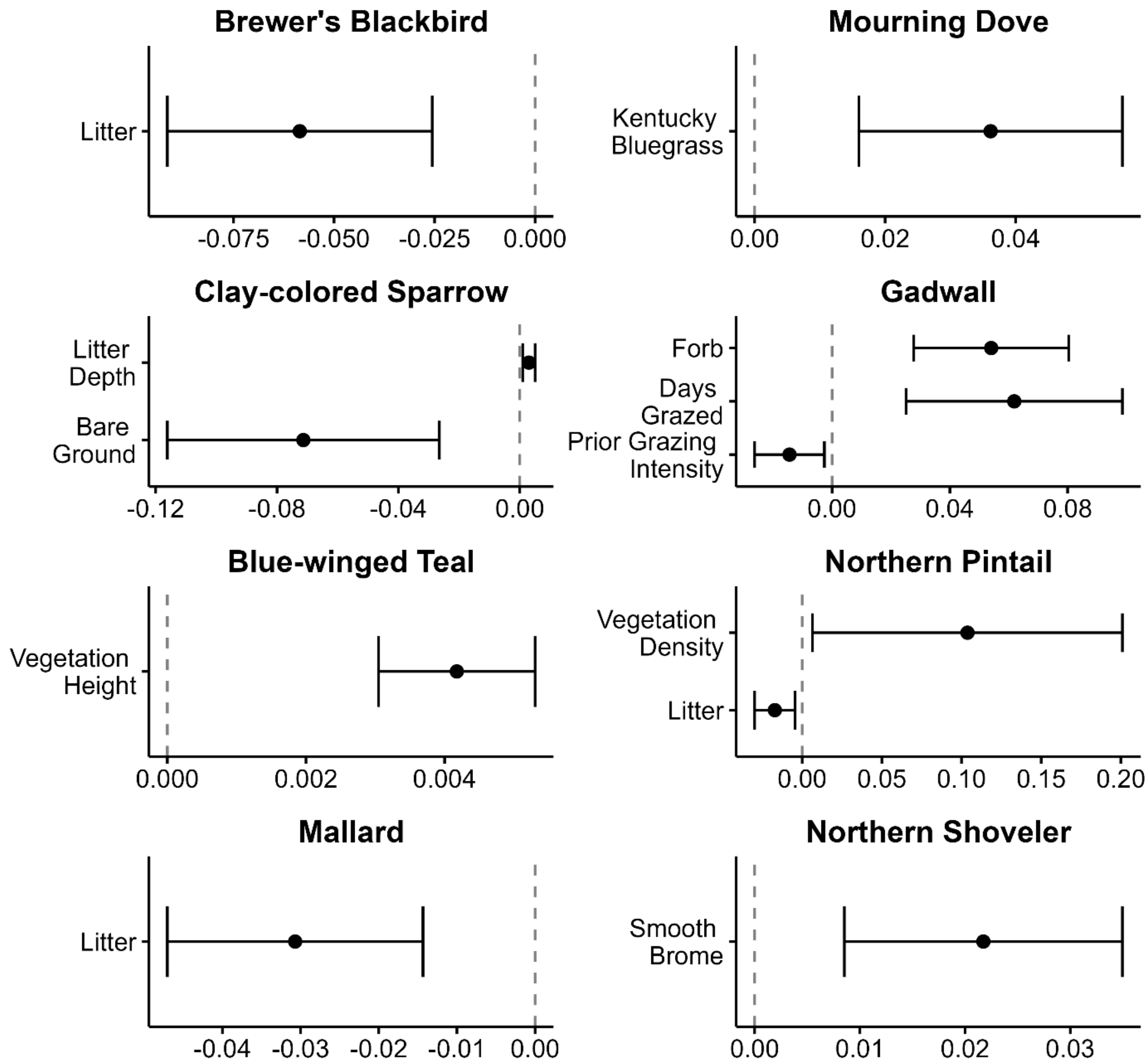

Figure 2. Compositional and structural parameters influencing nest survival for birds with more than 30 nests collected at the Central Grasslands Research Extension Center from mid-May to mid-July across 2021 to 2024. Measurements were taken at the nest location. Values are standardized regression coefficients and lines represent 85% confidence intervals. Values to the right of the dotted line indicate that nest survival increases with that parameter while values to the left indicate nest survival is reduced.

Gadwall were the only species that was directly impacted by grazing with nest survival increasing with the number of days it experiences grazing (Figure 2). However, increasing grazing pressure the previous year resulted in lower nest survival (Arnold, 2010).

The survival of five of our other focal species was associated with vegetation structural variables directly altered by our treatment (Figure 2, Figure 3). Increasing litter cover reduced nest survival for the Brewer’s Blackbird (*Euphagus cyanocephalus*), Mallard (*Anas platyrhynchos*), and Northern Pintail (*Anas acuta*). However, Northern Pintail (*Anas acuta*) nest survival increased with vegetation density. Taller vegetation was associated with higher nest survival for Blue-winged Teal (*Anas discors*). Clay-colored Sparrow (*Spizella* pallida) nest survival increased with litter depth and decreased with increasing bare ground cover. Several species, including the Mourning Dove (*Zenaida macroura*), Gadwall (*Mareca strepera*), and Northern Shoveler (*Spatula clypeata*), nest survival increased with vegetation composition parameters.

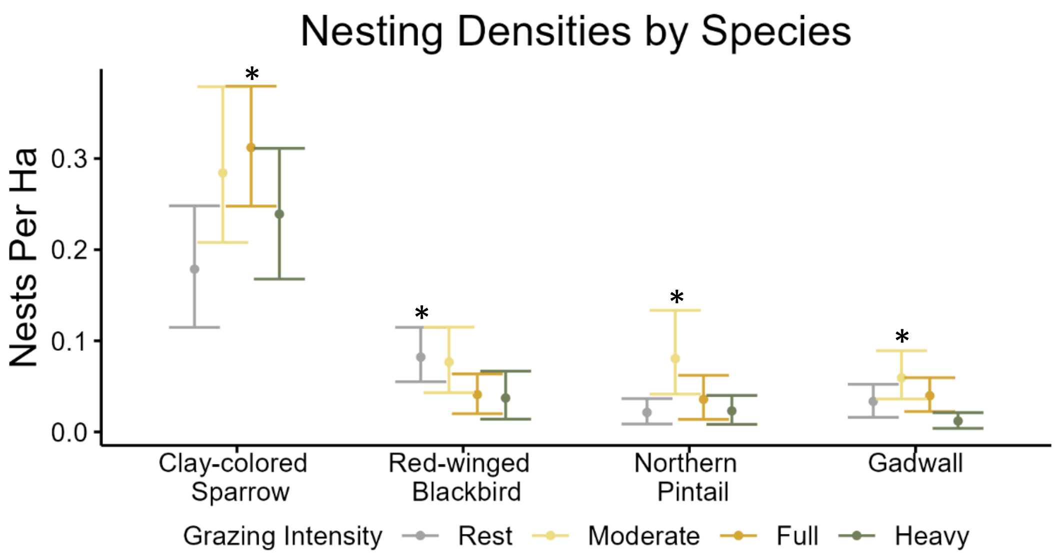

Figure 3. Nesting densities of grassland birds that were significantly different among grazing intensities across a modified twice-over rest-rotation grazing (MTORG) system at the Central Grasslands Research Extension Center from 2021 to 2024. Nesting densities corrected for imperfect detection using daily survival rate and error bars represent bootstrapped 95% confidence intervals. Asterisks indicate grazing intensities with nesting densities significantly ($p < 0.05$) higher than others.

Only four species showed densities that varied among grazing intensities (Figure 3). Clay-colored Sparrow nesting densities were significantly higher in the full paddock compared to rested ($p = 0.02$). Red-winged Blackbird nesting densities were significantly higher in the rested paddock compared to heavy ($p = 0.04$). Northern Pintail nesting densities were significantly higher in the moderate paddock compared to either rest or heavy ($p = 0.03$, 0.02, respectively). Gadwall nesting densities were significantly higher in the moderate paddock compared to heavy ($p = 0.002$).

Discussion

Lower-than-average precipitation early in the 2021 and 2023 field seasons may have impacted the vegetation structural gradient observed between grazing intensities (Derner & Hart, 2007; NDAWN, 2025). Despite these climactic challenges, we were able to identify a consistent gradient in vegetation density across all years but 2023. The reduced structural gradient observed in our vegetation density measurements may result in reduced available niche space which is correlated with lower avian diversity (Coppedge et al., 2008). In contrast, litter depth consistently showed variation attributed to grazing intensity. The changes associated with litter depth followed a lag effect with the previous year's grazing intensity determining litter depth the following year.

Our analysis of nest survival revealed species-specific responses to grazing intensity and changes in vegetation structure. Four out of eight species included in the nest survival analysis were either directly or indirectly impacted by grazing, highlighting the importance of considering species-specific responses in habitat management practices. In the nest density analysis, two more of the eight species showed changes in density either directly or indirectly associated with grazing intensity. The Gadwall was both directly and indirectly impacted by grazing intensity with the highest densities in the moderate paddock and the lowest in the rested, following the same trend as litter depth. The Clay-colored Sparrow nesting densities were also positively impacted by increasing litter depth. This further suggests that maintaining structural variability within a pasture is critical to creating high-quality habitat for diverse species assemblages.

The results of this study can inform grassland bird management in the northern Great Plains and will benefit obligate grassland nesting species that are currently listed as species of concern, including Grasshopper Sparrow (*Ammodramus savannarum*), Chestnut-collared Longspur (*Calcarius ornatus*), Northern Pintail (*Anas acuta*), Upland Sandpiper (*Bartramia longicauda*), and Bobolink (*Dolichonyx oryzivorus*) (Duquette, 2020; Dyke et al., 2015).

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Cascading Effects of Grazing Practices on the Western Meadowlark

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Summary

Rangelands cover almost half of the Great Plains and offer promising opportunities to enhance habitat for imperiled grassland birds. However, ninety-one percent of these rangelands lie in the hands of private landowners, many of whom manage their land for uniform utilization of forage. This reduces habitat quality by altering prey availability, brood parasite abundance, and niche availability for many grassland specialist species. Contemporary grassland bird management advocates for management practices that restore rangeland heterogeneity to improve habitat quality for grassland birds.

We examined the impacts of two heterogeneity-based and one conventional grazing practice on territory size, a proxy for territory quality, of the Western Meadowlark (*Sturnella neglecta*). We delineated territories from mid-May to early June and characterized vegetation structure and composition along 100-meter transects within each territory. We delineated a total of 65 territories from 2022 to 2024 and analyzed the direct and indirect impacts of grazing practice on habitat quality.

Grazing practice did not directly alter territory quality, rather it indirectly impacted territory quality by altering vegetation structure and composition. Vegetation structural variables such as standing litter, vegetation density, and litter depth negatively impacted territory quality whereas laying litter and thatch depth improved territory quality. Among composition variables, forb cover and plant evenness had direct impacts with forb cover negatively impacting territory quality, while invasive grasses like smooth brome and Kentucky bluegrass negatively impacted territory quality. Patch-burn grazing consistently enhanced territory quality by altering vegetation variables that altered territory quality.

Our research suggests that rangeland management decisions have cascading and compounding effects on the wildlife that inhabit these landscapes. These unexpected indirect consequences of management decisions can complicate the incorporation of conservation into working lands. Understanding the complex interaction between grazing practices, vegetation structure, and habitat quality will allow land managers to tailor management to avian conservation goals.

Introduction

Rangelands, covering approximately 45% of the Great Plains, present an excellent opportunity to improve habitat for imperiled grassland birds (Rosenberg et al. 2019; Augustine et al. 2021). However, nearly all rangelands (91%) are privately owned and managed for uniform utilization of forage (Becerra et al. 2017; Robinson et al. 2019). This management approach leads to a reduction in vegetation structure and composition variation, contributing to the widespread decline of grassland bird populations by limiting niche diversity (Sauer et al. 2013; Rosenberg et al. 2019). Contemporary rangeland management strategies for grassland birds advocate for heterogeneous vegetation structure and composition, often employing methods such as patch-burn grazing or rest-rotation grazing (Fuhlendorf and Engle 2001; Campomizzi et al. 2019). These approaches promote vegetation variation more closely aligned with natural rangeland conditions and support a broader range of species' vegetation preferences (Fuhlendorf and Engle 2001). Understanding the direct and indirect impacts of such grazing systems on grassland bird habitat quality is essential for grassland bird conservation in working landscapes.

In the Northern Great Plains, season-long grazing and rotational grazing are common management practices (Whitt and Wallander 2022). Both methods aim to utilize forage uniformly throughout the growing season (Sedivec and Barker 1991; Fuhlendorf and Engle 2001). While season-long grazing utilizes the entire pasture continuously during the growing season, conventional rotational grazing moves cattle between two or more subunits, herein referred to as paddocks, throughout the grazing season (Briske et al. 2008; Whitt and Wallander 2022). Recent research suggests that rest-rotation grazing can be adapted to create heterogeneous pastures by varying the duration each paddock is grazed during the growing season (Duquette and Hovick 2020).

While previous research has explored the impact of grazing practices and vegetation structure on avian diversity, density, and nest survival, understanding the complex, cascading effects requires nuanced investigation (Pillsbury et al. 2011; Hovick et al. 2012; Sandercock et al. 2015). Changes in vegetation from management practices or invasive species may have compounding impacts on wildlife that are potentially stronger than previously reported. We aim to investigate how three management strategies—patch-burn grazing, a modified rotational grazing system, and traditional season-long grazing—affect avian habitat quality.

We hypothesize that treatments resulting in greater heterogeneity in vegetation structure and composition will result in smaller territories (Whitaker and Warkentin 2010). Smaller territory sizes lead to adults spending less time away from the nest and more time caring for nestlings which should result in larger nestling body mass and higher nest success (Wiens et al. 1985; Whitaker and Warkentin 2010; Cooper et al. 2014; Diemer and Nocera 2014). Our objective is to quantify the direct and indirect impacts of grazing intensity on territory size; thereby, providing a deeper understanding of the relationship between grazing practices and avian habitat quality. Notably, this study will be the first to measure the cascading effects of grazing practices on avian habitat quality, adding significant insight to existing literature on the subject.

Methods

Study Area

The Central Grasslands Research Extension Center (CGREC) is located along the border of Kidder and Stutsman counties in North Dakota. The study area has a temperate, continental climate with an average growing/grazing season (April to September, May to October, respectively) precipitation of 433 mm and average growing season temperatures of 13.6° C (NDAWN 2025). Temperatures were high but within the normal range in 2022, 2023, and 2024 (13.8, 14.3, 15.2° C, respectively). Precipitation was lower than normal in both 2022 and 2023 but higher than average in 2024 (34.3, 38.5, 55.3 cm, respectively).

Treatment Structure

The experiment design encompasses four 65-ha replicates, each subjected to one of three treatments: 1) season-long grazing (SLG), 2) patch-burn grazing (PBG), 3) and a modified twice over rest-rotation treatment (MTORG). Stocking rates were maintained between 1.59-2.45 Animal Unit Months/ha for all treatments to achieve a 40 to 50% degree of disappearance.

SLG represents a conventional grazing practice in North Dakota, serving as a baseline for comparison with two heterogeneity-based grazing approaches (Whitt and Wallander 2022). PBG manipulates cattle grazing patterns through the discrete application of fire in spring to a designated quarter of the pasture rather than the use of interior fencing (Coppedge and Shaw 1998; Raynor et al. 2022). In this system, one quarter of the pasture is burned during the dormant season on a 4-year fire return interval. This practice was initiated in 2017 and has been burned every year except for 2022 due to weather constraints. The MTORG system is a unique rotational grazing system which uses interior fencing to divide a pasture into four quarters, herein referenced to as paddocks, including a rested paddock (0% utilization), moderate paddock (20-40% utilization), full paddock (40-60% utilization), and heavy paddock (60+% utilization). The system was established in 2018 and completed one full cycle in 2021.

Banding and Territory Mapping

The Western Meadowlark (*Sturnella neglecta;* WEME), a species of conservation concern in North Dakota, was selected as the focal species for this study (Dyke et al. 2015). An obligate grassland bird, the WEME exclusively relies on grasslands for its life history requirements and is found abundantly across all three treatments (Duquette and Hovick 2020; Duquette 2020). Annual surveys were conducted to locate territorial WEME and previously banded individuals. Specific-target mist-netting with audio lures was used to capture unbanded birds with experienced banders removing birds from the net and banding captured birds with a standard US Fish and Wildlife Service band and a combination of 3 color bands (Ralph et al. 1993).

We created territory maps using a combination of flush- and spot-mapping techniques (Wiens 1969; Fletcher et al. 2003; Jones 2011). The initial visit was based on the location of the individual bird that was banded, and the area was searched until the target bird was flushed. Upon flushing, we marked all flush and landing sites that day until we reached 30-40 locations per bird (Verheijen et al. 2019). We used these points to generate minimum convex polygons and estimate territory area (ha) (Calenge 2006; Cooper et al. 2014; R Core Team 2025).

Vegetation Surveys

We quantified territory vegetation composition and structure using three 100-meter transects placed perpendicular to the longest axis of each territory (Figure 1). Plant communities were sampled every 10 meters starting at 0 and ending at 100 meters (11 quadrats per transect). At each sampling point, we set up a 1-m^2 quadrat and recorded cover of every plant species identified within the quadrat (Daubenmire 1959). Additionally, we took structural measurements including bare ground cover, litter cover and litter depth, thatch depth, and visual obstruction reading (VOR) (Robel et al. 1970).

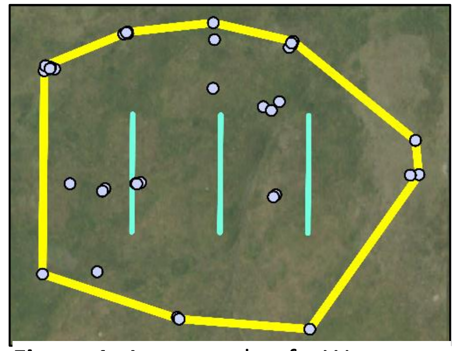

Figure 1. An example of a Western Meadowlark territory. The points represent locations the bird was observed, and the yellow line is the territory boundary. Three 100-meter vegetation survey transects (teal lines) were laid out within each territory.

Statistical Analysis

We averaged all vegetation variables for each territory and relativized them by dividing each percent cover by the total cover within that territory. Simpson's diversity index and E_{var} evenness were then calculated for a territory based on the relativized cover of each species for further analysis. We assessed the direct impact of grazing practice on territory quality and vegetation variables using generalized linear mixed-effects models (Brooks et al. 2017).

We used structural equation modelling to assess the direct and indirect impacts of vegetation on territory quality (Lefcheck 2016). We then removed non-significant pathways until the model could not be simplified any further, based on Akaike's Information Criterion (Shipley 2013). We standardized beta coefficients by dividing them by the standard deviation of the response variable. We used these standardized coefficients to calculate cumulative effect sizes (Lefcheck 2016). Direct effects are represented by the standardized coefficients (standardized β) whereas indirect effects are calculated by multiplying standardized coefficients for each pathway together (Lefcheck 2016). Positive coefficients for a parameter indicate improved territory quality, while negative coefficients indicate reduced territory quality associated with that parameter.

Results

We delineated a total of 65 territories that ranged in size from 1.97 ha to 16.46 ha (mean = 6.31 ha, SD = 2.77 ha). The average territory size was not significantly different between grazing practice ($p > 0.05$). However, the SLG treatment had much greater variability in territory size than either heterogeneity-based treatment (Table 1).

Table 1. Western Meadowlark territory size across season-long (SLG), patch-burn (PBG), and modified twice-over rest-rotation (MTORG) grazing from 2022 to 2024 at the Central Grasslands Research Extension Center. There was no significant difference in average territory size among grazing practices, but SLG had more variable territory sizes than either heterogeneity-based grazing practice.

Grazing Practice	Territory Count	Average Size	Standard Deviation
SLG	22	6.66	3.58
PBG	21	5.96	2.34
MTORG	22	6.30	2.27

The final structural equation model included 11 vegetation variables that directly or indirectly impacted territory quality (Figure 2). When examining structural variables, standing litter cover, vegetation density, and litter depth were the only variables that directly altered territory quality. The cover of standing litter and vegetation density (standardized β = -0.07, -0.05, respectively) both directly reduced territory quality while litter depth had a direct, positive impact on territory quality (standardized β = 0.05). Additionally, laying litter cover and thatch depth had positive, indirect impacts on territory quality (standardized β = 0.04, 0.03, respectively) while litter depth had an indirect, negative impact on territory quality (standardized β = -0.04, Figure 2).

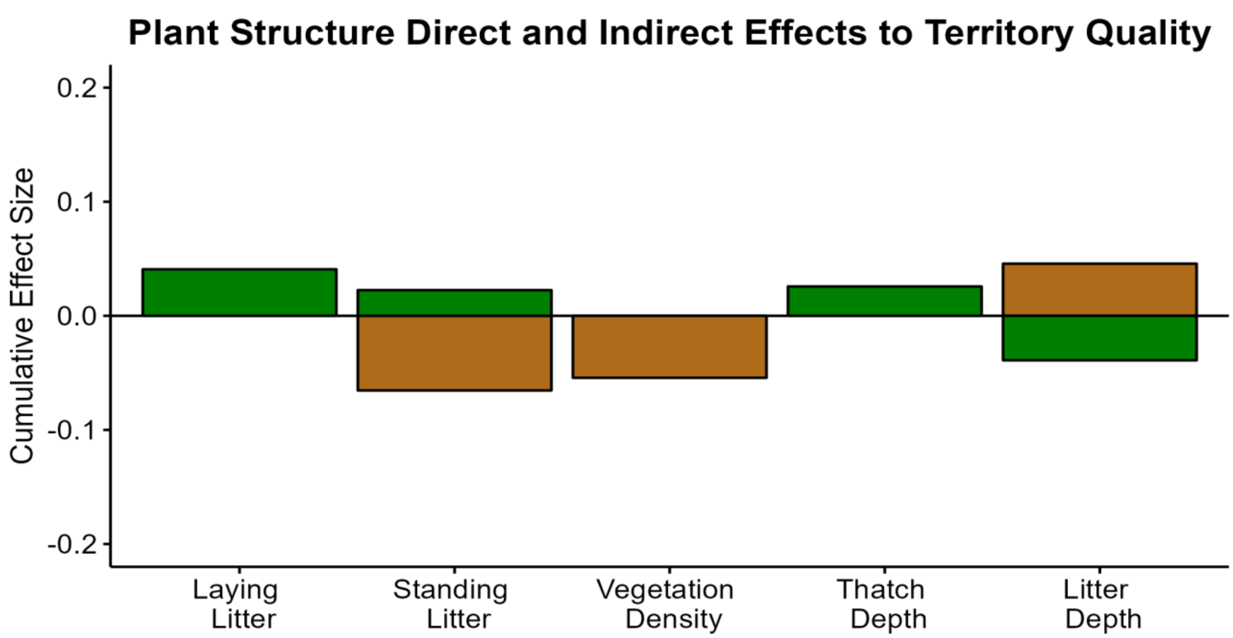

Figure 2. The cumulative effect sizes for each vegetation structural variable on Western Meadowlark territory quality in the final SEM. Brown boxplots represent a direct impact and green boxplots represent an indirect impact on territory quality. Vegetation density was measured with a visual obstruction reading in decimeters, litter and thatch depth were measured in millimeters, and all other variables represent relativized percent cover.

When examining composition variables, plant evenness and percent cover of legumes and woody vegetation were the only variables to directly impact territory quality (Figure 3). Legume cover had a direct, negative impact on territory quality (standardized β = -0.03) while plant evenness and woody cover had direct, positive impacts on territory quality (standardized β = 0.07, 0.04, respectively). Most vegetation composition had negatively, indirect impacts on territory quality including Kentucky bluegrass, smooth brome, woody, and legumes (standardized β = -0.0005, -0.06, -0.06, -0.02, respectively). However, both forb cover and plant evenness had positive, indirect effects on territory quality (standardized β = 0.02, 0.01, respectively). Smooth brome had the strongest negative impact across all variables in the SEM.

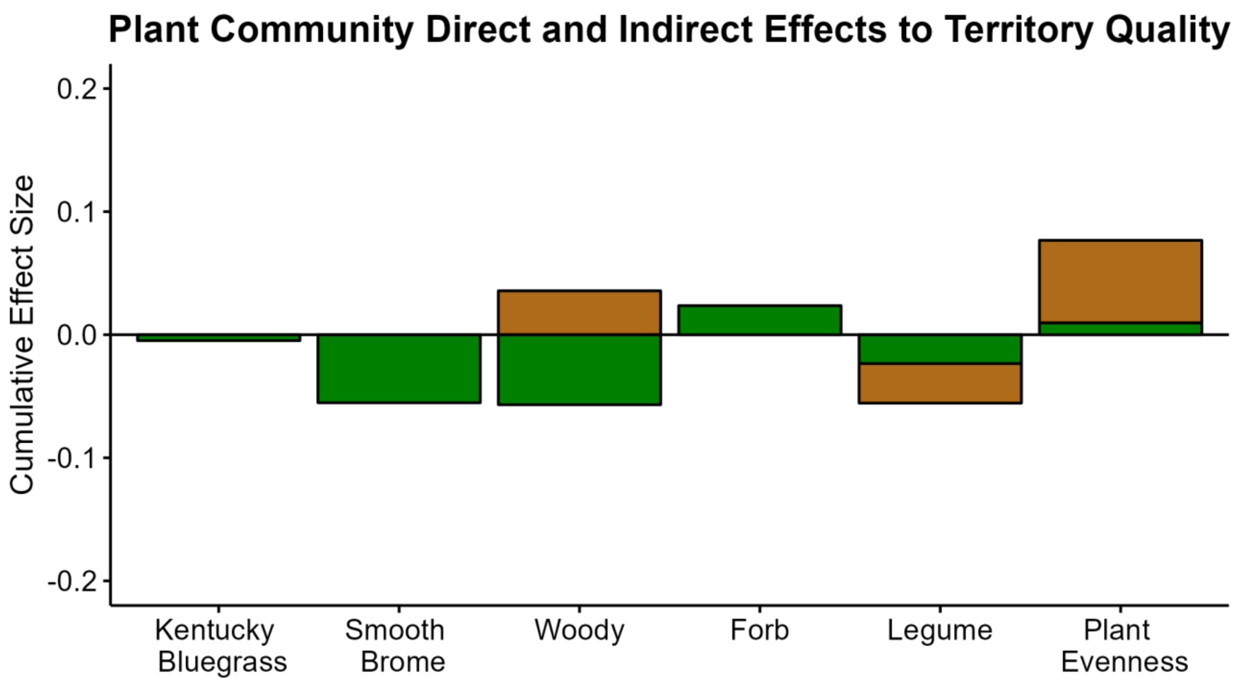

Figure 3. The cumulative effect sizes for each vegetation composition variable on Western Meadowlark territory quality in the final SEM. Brown boxplots represent a direct impact and green boxplots represent an indirect impact on territory quality. Plant evenness was calculated using E_{var} evenness while all other variables represent relativized percent cover.

While grazing practice did not directly impact territory quality, it did alter vegetation structural variables associated with territory quality (Figure 2, Table 2). However, the final impact on territory quality varied by grazing practice. SLG had low amounts of laying litter which reduced territory quality but high amounts of standing litter, improving territory quality. PBG showed less dense vegetation creating higher quality territories but lowered territory quality through shallower litter compared to other grazing practices. The MTORG had more laying litter and deeper litter resulting in higher territory quality. However, the MTORG also had more standing litter, denser vegetation, and deeper thatch than other grazing practices which reduce territory quality.

Table 2. The impact that grazing practice has on territory quality by modifying vegetation structural variables. P represents the impact grazing practice has on each parameter. TQ represents the cascading impact grazing practice has on territory quality by altering each parameter. TQ effects are based on the effect grazing practice has on the parameter and the effect the parameter has on territory quality. As an example, the MTORG had significantly more laying litter than other grazing practices which improved territory quality (+). In contrast, SLG had significantly less standing litter than the MTORG and, since standing litter reduces territory quality, promotes higher quality territories (+). Grazing practices with matching symbols in the TQ column are not significantly different from one another. An = sign indicates no significant difference from other grazing practices.

Grazing Practice	Laying Litter		Standing Litter		Vegetation Density		Thatch Depth		Litter Depth	
	P	TQ	P	TQ	P	TQ	P	TQ	P	TQ
SLG	–	–	–	+	=	=	=	=	=	=
PBG	=	=	=	=	–	+	–	+	–	–
MTORG	+	+	+	–	+	–	+	–	+	+

Table 3. The impact that grazing practice has on territory quality by modifying vegetation composition variables. P represents the impact grazing practice has on each parameter. TQ represents the cascading impact grazing practice has on territory quality by altering each parameter. TQ effects are based on the effect grazing practice has on the parameter and the effect the parameter has on territory quality. As an example, PBG had significantly less Kentucky bluegrass than SLG which improves territory quality (+). In contrast, SLG had higher smooth brome cover than other grazing practices and, since smooth brome reduces territory quality, promotes lower quality territories (–). Grazing practices with matching symbols in the TQ column are not significantly different from one another. An = sign indicates no significant difference from other grazing practices.

Grazing Practice	Kentucky Bluegrass		Smooth Brome		Woody Cover		Forb Cover		Legume Cover		Plant Evenness	
	P	TQ	P	TQ	P	TQ	P	TQ	P	TQ	P	TQ
SLG	=	=	+	–	–	+	=	=	–	+	–	–
PBG	–	+	–	+	–	+	=	=	=	=	+	+
MTORG	+	–	–	+	+	–	=	=	+	–	+	+

In addition to vegetation structure, grazing practice altered vegetation composition and diversity. SLG had increased cover of smooth brome which had the strongest negative impact of any vegetation variables measured. However, SLG showed reduced cover of woody plants and legumes which improves territory quality. PBG had reduced cover of Kentucky bluegrass, smooth brome, and woody plant cover resulting in higher territory quality across all compositional variables. The MTORG did not show a clear trend in altering habitat quality. Increased cover of Kentucky bluegrass, woody plants, and legumes reduced territory quality. However, reduced cover of smooth brome positively impacted territory quality. As expected, the two heterogeneity-based grazing practices showed higher levels of plant evenness which positively impacted territory quality.

Discussion

We found that grazing practice does not directly impact territory quality, rather it has an indirect impact through changes in vegetation composition and structure. Notably, season-long grazing showed greater variability in territory quality than either heterogeneity-based grazing practice. This may indicate that small patches of high-quality habitat exist within traditionally grazed pastures. Prolonged season-long grazing can promote the development of static “grazing lawns” where cattle repeatedly graze the same areas year-after-year, resulting in patches of short-stature vegetation (McNaughton 1984). These grazing lawns may provide fine-scale heterogeneity which may only benefit a small portion of the breeding population, resulting in greater variation in territory sizes.

The relationships we observed between vegetation structure and territory quality align with previous work. Increased vegetation density and litter depth can restrict the mobility of recently fledged young that primarily rely on strong legs to forage and escape predators (Doxon and Carroll 2010; Davis and Lanyon 2020). Additionally, WEME are a ground nesting grassland bird that rely on litter to construct and hide their nests from predators (Baicich and Harrison 2005; Davis and Lanyon 2020). These contrasting habitat requirements may explain the direct and indirect effect observed with litter depth. While some sturdy standing litter can act as perch sites for WEME defending their territory, it also benefits Brown-headed Cowbirds (*Molothrus ater*) which parasitize WEME nests and reduce nest survival (Hull 2000; Churchwell et al. 2008). Woody vegetation also functions as important song perches, but may increase abundance of nest predators and brood parasites (Grant et al. 2004). Vegetation composition, while often overlooked, mainly altered territory quality through changes in vegetation structure, mainly litter depth and vegetation density. Although we lack direct evidence in this study, plant evenness, legumes, and forbs likely impact arthropod abundance and availability which can alter foraging efficiency and potentially lead to changes in nestling survival (Engle et al. 2008).

Although grazing practice did not have a direct effect on territory quality, it exerted an indirect influence by modifying vegetation structure and composition. These findings underscore the importance of adequate disturbance in enhancing grassland bird habitat as all of the vegetation variables that negatively impacted territory quality typically increase with rest (Grant et al. 2004). However, not all grazing practices yielded the same level of habitat improvement. For instance, PBG consistently showed improved territory quality when examining almost every single structural or compositional variable whereas MTORG and SLG only improved territory quality when examining some variables. These results highlight the importance of considering the indirect and cascading effects that grazing practices can have on the wildlife that inhabit these landscapes. Understanding the complex interaction between grazing practices, vegetation structure, and habitat quality will allow land managers to more effectively tailor management to avian conservation goals.

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Four summers of bee surveys: A summary of key findings on bee abundance, community composition, and floral visitation across three grazing regimes

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Summary

Grazed rangelands are important not only for livestock production, but also for supporting managed honey bees and native bee species. We examined the abundance, community composition, and floral visitation of honey bees and native bees in three grazing regimes (modified twice-over rest rotational grazing, patch-burn grazing, and season-long grazing) for four summers (2021-2024). We detected 799 total bees (381 honey bees and 418 native bees) that were caught on flowers. The modified twice-over rest rotational grazing (MTORG) regime consistently had the highest average abundance of both honey and native bees most years. Since 2021, honey bees had a trend of decreasing in abundance each year while native bees increased. We identified 17 bee genera in total and did not see a difference in community composition across the three regimes. However, we found that honey bees were associated with MTORG, and one native bee genus was statistically more abundant in patch-burn grazing (PBG) than season-long grazing (SLG). In terms of floral visitation, honey bees visited 26 flower species while the native bee community visited a total of 44 flowers, with 21 of those species being visited by both honey and native bees. Finally, the percentage of bee visits to native versus exotic floral species in each management were similar for both honey bees and native bees except for in the patch-burn grazing regime where native bees visited native flowers in higher percentages than honey bees did. Our results overall indicate three key preliminary conclusions: the MTORG regime may be particularly beneficial for supporting overall bee abundance in both groups; PBG may better support at least one native bee genus as well as native bee visitation to native flowering plants; and bee diversity is essential for visiting many flowering species and broadly promoting pollination services.

Introduction

Bees are important pollinators that provide essential services to natural and agricultural plant communities (Kremen et al. 2002, Klein et al. 2007, Park et al. 2010). Both honey bees and native bees are vital to native and agroecosystems, but their populations have undergone global declines due to habitat loss, agricultural intensification, and climate change (Brown and Paxton 2009, Potts et al. 2010). Native bees especially require support due to their contribution to long-term crop yield and landowner profit (Garibaldi et al. 2014). Rangelands are a crucial source of pollinator food sources and nesting sites (Black et al. 2011), making these areas critical for pollinator conservation (Cole et al. 2017). If we are to use these lands to efficiently support bee communities, we must explore grazed rangeland management techniques that can create sustainable habitat for bees while also maximizing livestock production.

To contribute to the study of bees across rangeland management methods, we are examining the effects of varying grazing regimes on both honey bee and native bee communities and their floral visitation. All three grazing regimes have rarely been investigated for their effects on bees and there is little research linking bee abundance and diversity along with floral use in the Northern Great Plains. Our three objectives are to examine 1) honey bee and native bee abundance, 2) bee community composition, and 3) floral species visitation by honey and native bees, all across three grazing management regimes.

Methods and Design

Study Site

We collected data at North Dakota State University's Central Grassland Research Extension Center (CGREC) located near Streeter, North Dakota, (46°45'N, 99°28'W). The CGREC is characterized as a mixed-grass prairie and is dominated by western wheatgrass [*Pascopyrum smithii* (Rydb.) Á. Löve], green needlegrass [*Nassella viridula* (Trin.) Barkworth], and blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths] (Limb et al. 2018). It also contains the non-native grass, Kentucky bluegrass (*Poa pratensis* L.) and the native shrub, western snowberry (*Symphoricarpos occidentalis* Hook.) (Limb et al. 2018). The forb community includes many species such as milkweeds (*Asclepias* spp.), goldenrods (*Solidago* spp.), coneflowers (*Echinacea* spp.) and thistles (*Cirsium* spp.).

Grazing Regime Structure

We used three grazing regimes covering approximately 260 hectares each (Figure 1): modified twice-over rest rotational grazing (MTORG), patch-burn grazing (PBG), and season-long grazing (SLG) (Fuhlendorf and Engle 2001). Each regime has four replicates of equal pasture size (65 ha). Within the MTORG, fences are used to create sixteen, 16-ha paddocks. Cattle are rotated twice through these paddocks to generate four replicates of different grazing intensities: heavy (60%+ utilization), full (40-60% utilization), moderate (20-40% utilization), and rested (0% utilization). The PBG is burned on a four-year rotation with a quarter of each pasture being burned every spring (except for the spring of 2022 due to weather). Cattle are free to graze throughout the entire pasture for the season and are not restricted to just the quarter of burned pasture. The SLG treatment acts as a control to reflect common regional management and allows cattle to freely graze throughout the pasture during the season.

Surveys

<u>Transect Bee Surveys</u>

For our surveys, we divided each pasture into 8-ha subplots and placed one 100-m transect in the center of each subplot using ArcGIS. There are 8 subplots in each of the four replicate pastures per regime, giving a total of 32 transect surveys per regime (96 total). All 96 transects were surveyed three times (once in June, July, and August) each summer from 2021-2024. We completed all three rounds of surveys each year except for the final round in August of 2024 in which we only completed 54 out of the 96 surveys. For each survey, we caught all bees within reach (approximately 1 meter on each side of the transect) using a sweep net. All caught bees were lethally collected for identification except for bumble bees (which were photographed and released live). Honey bees were easily identified during the survey and were not caught to save surveyor time. For each observed or caught bee, we recorded the flowering species that the bee was visiting.

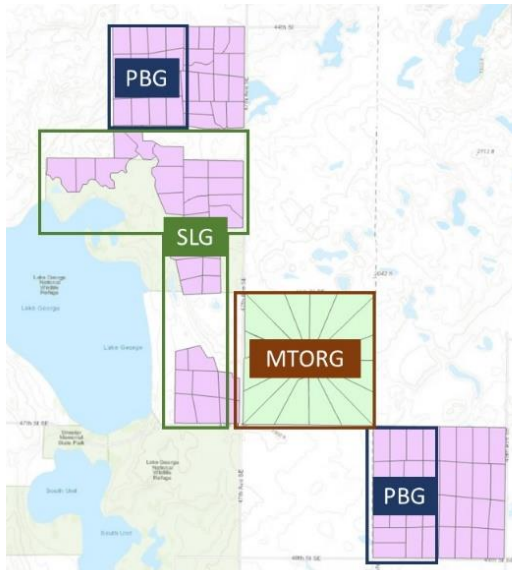

Figure 1. The three grazing regimes used at the CGREC: modified twice-over rest rotational grazing (MTORG, outlined in red), patch-burn grazing (PBG, outlined in blue), and season-long grazing (SLG, outlined in green).

Results

Objective 1: Honey bee and native bee abundance

Across all 4 years, we detected 799 bees on flowering plants. Of those, 381 were honey bees and 418 were native bees. To examine bee abundance across the three grazing regimes (MTORG, PBG, and SLG), we found the average number of bees caught per survey. In short, we took the total number of bees caught in each regime within each year and divided by 24 (because there are 8 transects per replicate pasture that were each surveyed three times each summer). Observationally, we noted that the MTORG regime consistently had the most bees caught for both honey bees and native bees across years (Figure 2a and 2b). Besides the year 2022, honey bees were caught most often in MTORG followed by SLG while native bees were caught most often in MTORG every year. Overall, honey bees had a trend of decreasing in abundance between 2021 and 2024 (Figure 2a) while native bees had an increasing trend over this time period (Figure 2b).

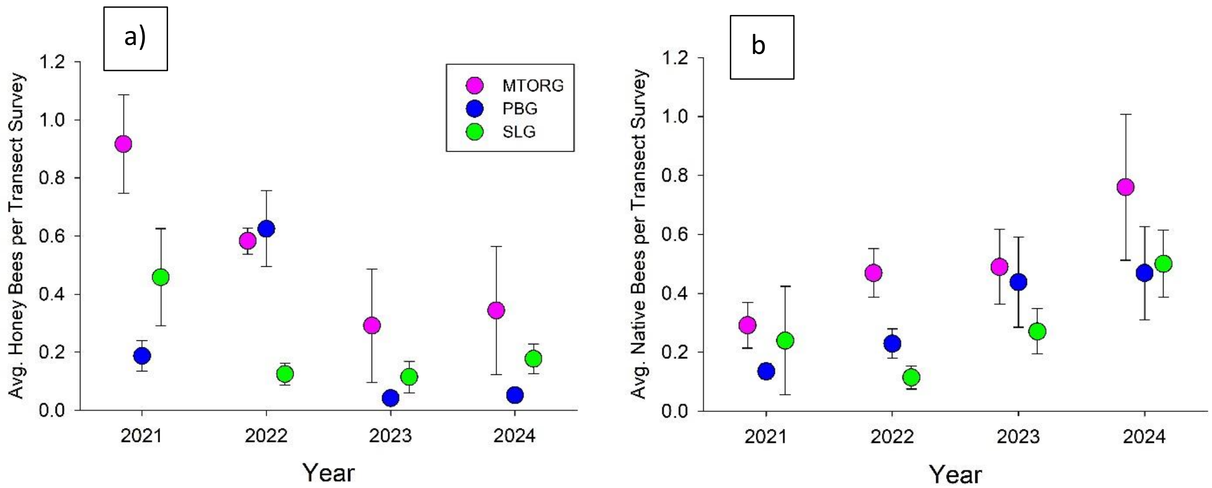

Figure 2. The average abundance of a) honey bees and b) native bees caught per survey with standard error out of the three survey rounds within the three grazing regimes (MTORG, PBG, SLG) during the summers of 2021-2024. We did not finish the final round of surveys for 2024 (54 surveys completed out of 96), so the bee abundance for that year may be higher than represented here.

Objective 2. Bee community composition

We identified our bees to genus (plural genera) to examine if any genera were more abundant within, or associated with, a specific regime across the four years of data collection. We identified 17 genera within five families caught on flowering plants, with four of those genera only having one individual detected (*Sphecodes, Epeolus, Dufourea*, and *Calliopsis*).

To compare composition, we combined all the bees of each genera for all four summers within each regime (Figure 3). We confirmed that composition was similar across all three regimes with a PERMANOVA with the adonis2 function in the "vegan" R package (R Core Team 2024). We used the simper function to compare the average abundance of each genera as well as an indicator species analysis with the multipatt function in the "indicspecies" package to see if any specific genera were associated with any regimes. We found that although genera composition was similar across the three regimes, sweat bees within the genus Agapostemon (Image 1) were more abundant in PBG than in SLG ($p = 0.005$), and honey bees (Image 2) were associated with MTORG ($p = 0.037$).

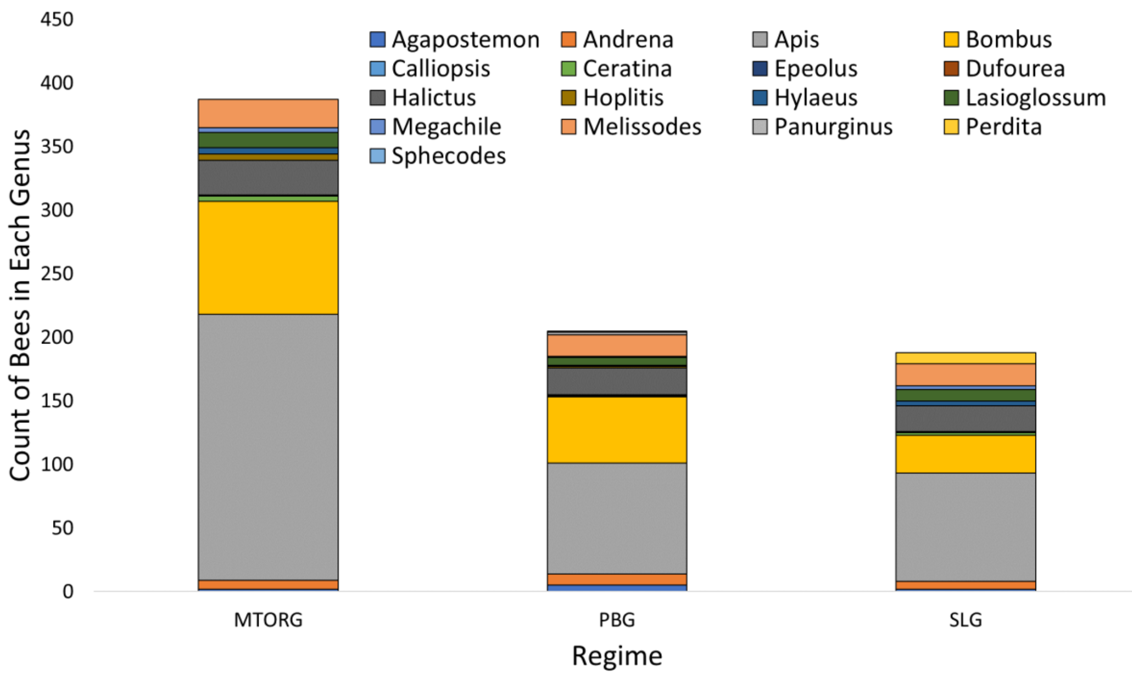

Figure 3. The number of bees caught within each genus in total for all three survey rounds within each grazing treatment (MTORG, PBG, SLG) for all four summers (2021-2024). The gray bars are the genus *Apis,* which are the honey bees. The next most abundant genus is *Bombus,* which are bumble bees.

Image 1. A bee in the genus *Agapostemon*.

Image 2. A honey bee, *Apis mellifera.*

Objective 3. Floral species visitation

Across the four years, honey bees were caught on 26 flowering species, and native bees were caught on 44 flowering species (Table 1). Of those, 21 flowering species were visited by both groups. The four species visited by honey bees, but not native bees, were three native milkweed species (*Asclepias spp*.) and silverberry (*Elaeagnus commutata,* a native shrub with only 1 bee visit). Three of the species visited by honey bees were non-native, or exotic, while native bees visited five exotic species. Within each regime, honey bees and native bees visited native and exotic flower species in roughly the same percentages (Figure 4). However, native bees visited native flowers at a higher percentage in PBG (89% of visits) than honey bees did (74% of visits) (Figure 4).

Table 1. A comprehensive list of the main bee groups detected at CGREC during the transect surveys conducted from 2021-2024 and the flower species that these bees were caught on.

Bee Group	Genera	Native Flowers Visited	Non-native (exotic) Flowers Visited
Honey bees	Apis	Western yarrow, leadplant, oval-leaf milkweed, showy milkweed, common milkweed, field milkvetch, prairie milkvetch, Flodman's thistle, wavy-leaf thistle, purple prairie clover, silverberry, wild licorice, curlycup gumweed, stiff sunflower, hairy false goldenaster, dotted blazing star, Lambert's locoweed, Canada goldenrod, stiff goldenrod, velvety goldenrod, western snowberry, American vetch, ironweed	Absinthe wormwood, Canada thistle, yellow sweet clover
Bumble bees	Bombus	Western yarrow, leadplant, hillside arnica, prairie milkvetch, field milkvetch, Flodman's thistle, white prairie clover, purple prairie clover, wild licorice, curlycup gumweed, blue lettuce, dotted blazing star, false gromwell, Lambert's locoweed, Canada goldenrod, stiff goldenrod, velvety goldenrod, western snowberry, marsh woundwort	Canada thistle, bull thistle, yellow sweet clover
Sweat bees	Lasioglossum Dufourea Halictus Agapostemon	Flodman's thistle, scarlet beeblossom, prairie rose, Canada goldenrod, western snowberry, Maximillian sunflower, western yarrow, leadplant, Canada anemone, field milkvetch, chickweed, Flodman's thistle, wavy-leaf thistle, purple prairie clover, narrow-leaved purple coneflower, blanketflower, curlycup gumweed, stiff sunflower, yellow sweet clover, Lambert's locoweed, Pennyslvania cinquefoil, silverweed, prairie coneflower, prairie rose, Wood's rose, velvety goldenrod, stiff goldenrod, western snowberry, American vetch, bastard toadflax, hairy false goldenaster, lilac penstemon	Common dandelion, yellow salsify, Canada thistle
Small carpenter bees	Ceratina	Canada anemone, blanketflower, curlycup gumweed, western snowberry, American vetch	None
Mining bees	Andrena Calliopsis Panurginus	Leadplant, curlycup gumweed, Lambert's locoweed, stiff goldenrod, Canada goldenrod, western snowberry, narrow-leaved purple coneflower, Maximillian sunflower	Yellow salsify
Longhorn bees	Melissodes	Canada thistle, Flodman's thistle, wavy-leaf thistle, narrow-leaved purple coneflower, curlycup gumweed, Maximillian sunflower, stiff sunflower, hairy false goldenaster, dotted blazing star, prairie coneflower, black-eyed Susan, Canada goldenrod, stiff goldenrod, common dandelion	Canada thistle, common dandelion
Leaf-cutter bees	Megachile	Narrow-leaved purple coneflower, Maximillian sunflower, stiff sunflower, stiff goldenrod, western snowberry	None
Fairy bees	Perdita	Curlycup gumweed	None
Cuckoo bees	Sphecodes Epeolus	Curlycup gumweed, Parlin's pussytoes	None
Mason bees	Hoplitis	Flodman's thistle, blanketflower, yellow sweet clover, American vetch	Yellow sweet clover
Masked bees	Hylaeus	Western yarrow, leadplant, chickweed, narrow-leaved purple coneflower, stiff goldenrod, heart-leaved alexander, prairie rose	None

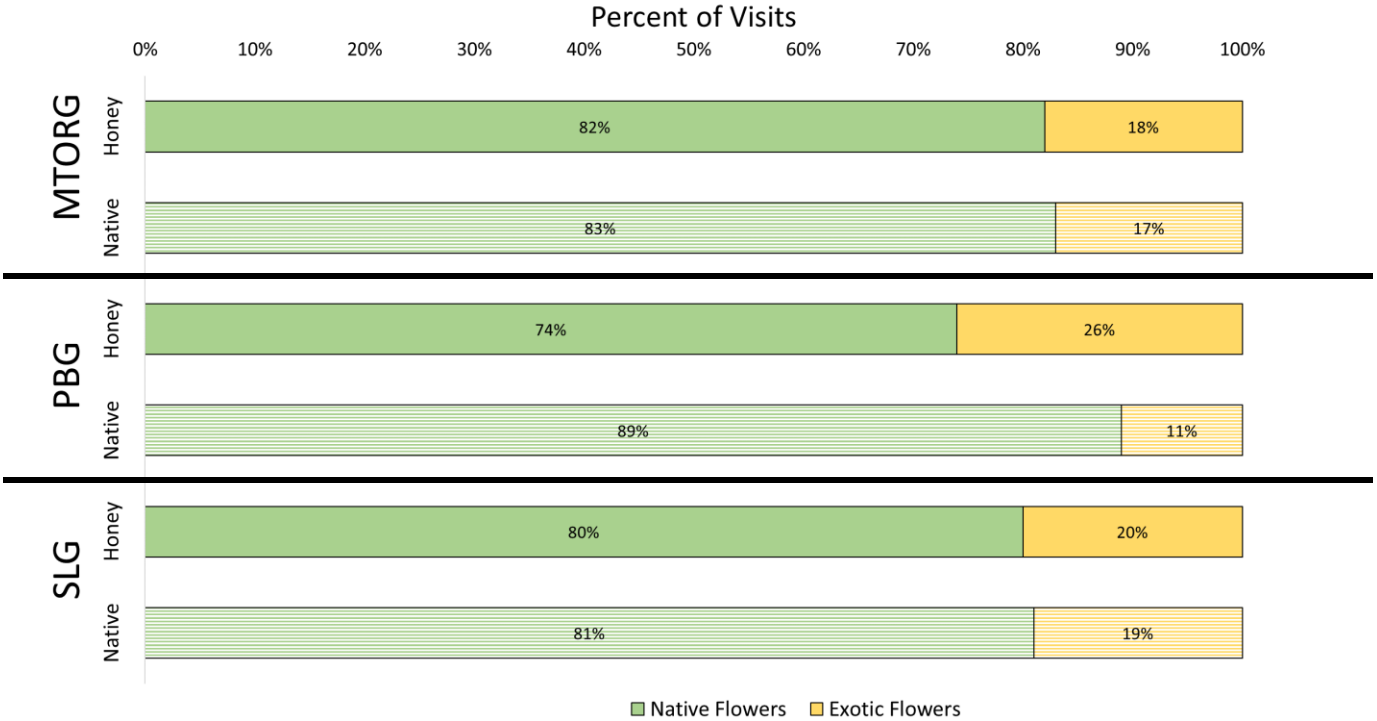

Figure 4. The percentage of honey bee and native bee visits to native flower species and exotic flower species of all three survey rounds within each grazing regime (MTORG, PBG, SLG) across all four summers (2021-2024).

Discussion

We observed that the number of bees caught per survey was consistently highest in MTORG for both honey bees and native bees across our regimes for all four years. However, honey bees had a decreasing trend in abundance while native bees had an increasing trend over all regimes. When we observed the bee genera, we saw that composition was similar across all regimes for the four years of surveying except that honey bees were most associated with MTORG while the native genus, *Agapostemon*, had a higher abundance in PBG than SLG. Finally, we found that honey bees and native bees both visited native and exotic flower species. Native bees visited native flowers in a higher percentage than honey bees in the PBG regime and also visited 18 more floral species than honey bees. Of the 26 flower species that honey bees visited, 21 of those were also visited by native bees.

We originally expected that most bees, both honey bees and native bees, would be most abundant in PBG because of the previous literature supporting that patch-burn grazing can promote a diverse floral community (Ricketts and Sandercock 2016, Duquette et al. 2022). However, there are a few explanations for why MTORG seemingly has the highest abundance each year. For one, even though they can travel long distances, honey bees tend to stay close to their hives. There were commercial bee hives placed near MTORG and two of the SLG replicate pastures each summer. In a separate analysis, we found that 80% of the honey bees we surveyed from 2021-2023 were within 3 km of the hive which encompassed all of MTORG and half of SLG, but did not include any of the PBG pastures. Second, the drought during 2021 seemed to have the worst impact on two of the PBG pastures which barely had any flowering plants or bees at all during that year. The MTORG, and especially the rested pastures, had the most flowers and bees that year. It is therefore crucial that we examine our flowering communities as the next step in conjunction with the weather from each summer to get a better picture as to why we observed that MTORG consistently had the most bees.

Following the drought year of 2021, there seems to be a trend for native bees to increase in all regimes each consecutive year. We expect this as a part of the recovery after the drought where more flowering plants are present. However, we are unsure why the honey bee abundance averages have seemingly decreased. Our next step with this finding would be to first talk to the owners of the commercial hives to rule out that fewer hives were put out each summer before we start attributing the decrease to any other factors.

Finally, our examination of flower species visited by both honey bees and native bees support that both groups effectively visit many native species which comprise the majority of each bee groups' visitations. There is support that honey bees tend to visit exotic species more while some native bees visit native flowering plants more often than exotic (Simanonok et al. 2021, Pei et al. 2023), but in our study, we found that honey bees and all our native bees combined visit exotic species in similar percentages within MTORG and SLG. In PBG, we found that native species made up a greater percentage of visits for native bees than for honey bees which will lead us to examine the floral communities in each regime to better understand this relationship. Additionally, native bees visited all but four of the same floral species as honey bees plus an additional 18 species. This supports that native bee diversity is essential for pollination services to many floral species, especially given that the total abundance of each bee group was fairly similar (381 honey bees to 418 native bees).

Conclusions

Our main findings regarding bee abundance, community composition, and floral visitation have given us valuable insight into how the three grazing regimes support these pollinators across years. To start, we found that honey bees were most associated with the regime closest to their hive and were found visiting four more floral species than the native bee community. We are unsure why they have a decreasing trend when it comes to abundance each year, but we need to further discuss this with the commercial beekeepers who keep these hives on site and explore our floral communities to get a better idea of what may be causing this phenomenon. Next, we can see a trend towards native bee community recovery following a severe drought year as well as similar community composition across regimes and diversity in floral species visitation. Although it is essential to examine these factors at the species level, we can observe that the whole community may have some resilience in using floral resources across all three regimes despite the drought year. However, it has taken three summers to see this trend. Needing multiple years to recover in terms of abundance can be detrimental to native bee communities if extreme weather events become more common in the future. Our results indicate three key preliminary conclusions: the MTORG regime may be beneficial for supporting overall bee abundance in both groups, PBG may better support at least one native bee genus as well as native bee visitation to native flowering plants, and bee diversity is essential for visiting many flowering species and promoting pollination services.

Associated Fact Sheet: Page 125

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Informing avian conservation through assessment of community dynamics across different grazing strategies

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Summary

Global grassland loss has resulted in a myriad of ecological consequences, including biodiversity loss and a reduction in ecosystem services. Therefore, conservationists and producers must prioritize alternative land management strategies which simultaneously address producers' needs and conservation goals. Innovative technology, such as virtual fence, may help achieve these goals. However, given the recent emergence of this new technology, there is a need to evaluate its effectiveness in achieving management goals. Our objective was to compare vegetation structure and avian community composition between different grazing strategies (i.e., season long, patch-burn grazing, modified-twice over rest rotational grazing and (virtual) patch-grazing) and within patches of virtual fence treatments (Rested, Light, Moderate, Heavy). We found that virtual fence-managed patch grazing effectively generated a gradient of vegetation structure within management units. Additionally, we determined the abundance of obligate grassland bird species in the heavy grazed patch to be significantly less than both the moderate and rested patches. The combination of results indicates treatment-created heterogeneity translated to differences in grassland bird use, suggesting species specific preference. As we continue to measure the efficacy of virtual fencing and its application to heterogeneity management, our results will help to inform producers and conservation agencies about this new technology and its potential to serve production and conservation.

Introduction

Globally, rangeland ecosystems provide crucial services valued by both producers and conservationists. Rangelands, defined as uncultivated land dominated by grasses, forbs, shrubs, and bare ground (Alkemade et al., 2013), represent 61% of all terrestrial land in the United States (Fuhlendorf & Engle, 2001), which provide 70% of the required annual forage for cattle production in the U.S. (Fleischner 1994). Simultaneously, rangelands are essential for the conservation of grassland birds and other grassland dependent organisms (Fuhlendorf et al., 2006; Hovick et al., 2015). However, given society's dependency on livestock, management of rangelands has become focused on livestock production and moderate use that results in homogeneous vegetation structure (Fuhlendorf & Engle, 2001) rather than conservation-minded grazing that results in structural heterogeneity (Fuhlendorf et al. 2012). As a result, rangeland biodiversity, specifically grassland bird populations, are experiencing declines due to a lack of variable structure and composition (Sauer et al., 2013). To bridge the gap between producer needs with those of conservationists, alternative heterogeneity-based land management strategies need to be implemented to promote conservation and production in working lands (Keyser et al., 2020).

Historically, rangelands within the Great Plains region experienced disturbances such as spatially patchy wildfire and vast roaming herds of grazing bison (*Bison bison*) across the landscape (Fuhlendorf & Engle, 2001). These disturbances created heterogeneous landscapes, diverse in both structure and composition (Fuhlendorf et al., 2006). The resulting range of vegetative structure and composition has influenced the evolution of species which inhabit rangeland ecosystems through fostering conditions exploitable through specialized and generalized use (Duchardt et al., 2016).

Heterogeneous rangeland systems provide much needed vegetation structure which supports a full suite of grassland-dependent bird species, with individual species having varying affinities for structure. (Coppedge et al., 2008; Kim et al., 2008; Sliwinski and Koper, 2015; Ahlering and Merkord, 2016). For example, chestnut-collared longspur (*Calcarius ornatus*) prefer shorter and sparser vegetation structure, (Davis et al., 1999; Fritcher et al., 2004; Sliwinski and Koper, 2015), while the savannah sparrow (*Passerculus sandwichensis*) prefer structure which is moderate in height and patchy in density (Sliwinski and Koper, 2015). Accordingly, as we observe the decline of heterogeneity across rangelands, we also observe a dramatic decline in grassland bird populations (Sauer et al., 2013; Duchardt et al., 2016). These trends are primarily attributed to land conversion and the alteration of natural disturbance processes in rangelands (Fuhlendorf & Engle, 2001; Duquette et al., 2022). For these reasons, the identification and implementation of appropriate land management strategies which consider the needs of grassland birds is vital to their survival as a guild (Powell, 2006).

Efforts have been made to devise alternative management strategies which address the needs of producers and conservationists alike. Alternative land management strategies often focus on structural and composition variation and are collectively referred to as heterogeneity-based strategies. Accordingly, they have been designed to restore the structural heterogeneity to rangelands by mimicking a return to historic disturbance processes (Fuhlendorf and Engle, 2001; Vold et al., 2019). One such alternative land management strategy of particular interest to conservationists and producers alike involves the implementation of virtual fence technology. An emergent technology which has been in continuous development for over a decade (Boyd et al., 2022), virtual fence implements computer-programmed boundaries to do the work of a standard fence with the added benefit of mobility (de Avila et al., 2025). Here we use virtual fence to mimic a patch-grazing strategy to promote structural and compositional heterogeneity through altering cattle behavior to achieve variation in grazing intensity. However, due to its novel nature, little is known about the application of virtual fence for the purposes of conservation, and field testing is required.

Our study evaluated the influence of a virtual fence to create patch-grazing on the grassland bird community composition and abundance as compared to other management strategies. The specific objectives of this study are:

1) Evaluate avian community composition across four different grazing strategies.

2) Quantify structural variation in plant community resulting from patch-grazing using virtual fence technology to indicate its ability to create heterogeneity.

3) Calculate grassland bird functional group abundance across patches resulting from patch-grazing using virtual fence technology.

Methods

Study Site

We conducted our study at North Dakota State University's Central Grassland Research Extension Center (CGREC) located near Streeter, North Dakota, (46°45'N, 99°28'W). The CGREC is characterized as a mixed-grass prairie and is dominated by western wheatgrass [*Pascopyrum smithii (Rydb.) Á. Löve*], green needlegrass [*Nassella viridula (Trin.) Barkworth*], and blue grama [*Bouteloua gracilis (Willd. ex Kunth) Lag. ex Griffiths*] (Limb et al. 2018). Additionally, native shrub, western snowberry (*Symphoricarpos occidentalis Hook.*) and non-native invasive grasses, such as kentucky bluegrass (*Poa pratensis L.)* and smooth brome (*Bromus inermis*) maintain a firm presence (Limb et al., 2018). The forb community includes many species, such as milkweeds (*Asclepias spp.*), goldenrods (*Solidago spp.*), coneflowers (*Echinacea spp.*), and thistles (*Cirsium spp.*).

Treatment

Our study assessed the avian abundance across four grazing management treatments: twice-over modified rest-rotational grazing (MTORG), patch-burn grazing (PBG), season-long grazing (SLG), and patch-grazing using virtual fencing (VF) (Figure 1). Each treatment has four replicate pastures, approximately 65 hectares(ha) in size. Pastures were divided equally into four patches (~16 ha). Each patch had 2 randomly placed 100m transects, placed > 75m from pasture and patch boundaries.

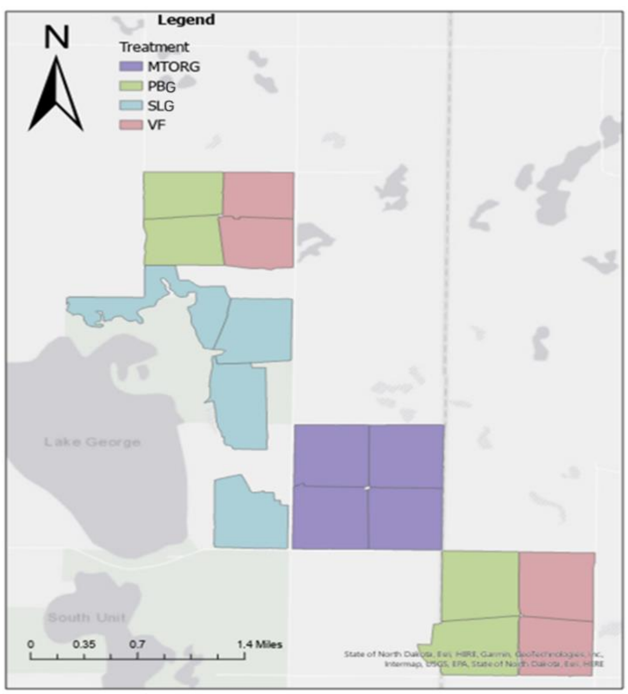

Figure 1. A map of the Central Grasslands Research Extension Center (CGREC), the grazing treatments pertaining to this study, and their arrangement on the landscape.

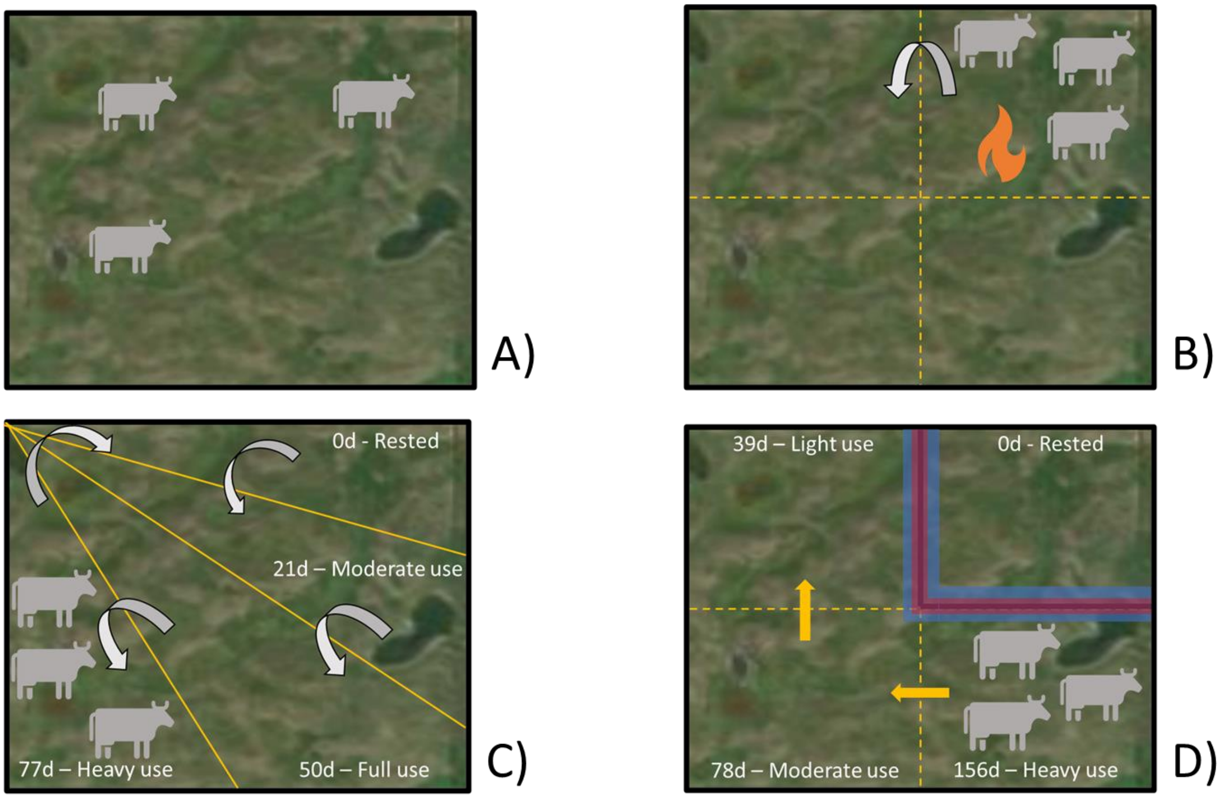

Figure 2. Pictured above are four grazing strategies utilized within this study. A) season-long grazing, B) patch-burn grazing, C) Modified twice-over rest-rotational grazing, and D) virtual fence influenced patch grazing. The dashed lines represent conceptual patch boundaries. The solid lines represent internal fencing. The blue bars indicate audio stimulus zone. The red bars indicate electric stimulus zone. The arrows indicate the rotation of treatment specific disturbance regimes over time. (Modified from Duquette et al., 2022).

Data Collection

<u>*Avian Survey*</u>

We conducted avian visual and auditory detection surveys along 100m within our management units transects from the last full week in May to July 15th, from a ½ hour before sunrise until 10:00 am on days without precipitation or high winds (>20 kph) (Diefenbach et al. 2003; Pavlacky et al; 2017; Duquette et al., 2022). Upon detection (visual or auditory) we recorded a bird's species, sex, behavior, and perpendicular distance to the transect. To maintain accurate estimates of distance as well as to ensure proper identification, detections greater than 50m were censored from the survey (Hovick et al., 2015; Duquette et al., 2022).

<u>*Vegetation Survey*</u>

We conducted vegetation surveys to quantify variation in vegetation structure along each 100m transects within our management units. On each side of the transect, a 0.5m^2 quadrat was used to assess the vegetative community every 25 meters (10 quadrats/transect, offset by 15 meters from the transect). Vegetation was divided into functional groups with the exception of Kentucky bluegrass and Smooth brome. We used cover class midpoints for each of the functional groups to quantify vegetation, and litter depth measurements were taken in the northeast corner of the quadrat (Daubenmire 1959). Additionally, we measured vegetation structure with Robel poles, quantifying visual obstruction in each cardinal from 4 m away at a height of 1 m (Robel 1970).

Statistical Analysis

All statistical analyses were conducted within R version R4.4.1 (R Core Team 2024). We used generalized linear models (GLM) for each objective.

We divided avian species into functional groups based on habitat preferences. Obligate (OBL) grassland birds rely exclusively on grasslands, while facultative (FAC) grassland birds rely on other habitat types in addition to grasslands (Vickery et al., 1999). We calculated average grassland bird abundance by taking the maximum count observed on each transect surveyed, for each observed species, for the duration of the 2024 survey season. A GLM was used to determine whether treatment (SLG, PBG, MTORG, VF) had an effect on average grassland bird abundance. Furthermore, a GLM was used to determine whether patch-grazing intensity (Rested, Light, Moderate, Heavy) within the VF treatment had an effect on average grassland bird abundance.

We calculated average vegetation density by averaging Robel visual obstruction readings (VOR) at the patch level within the VF treatment. A GLM was used to determine whether patch-grazing intensity had an effect on average vegetation density resulting from patch-grazing using virtual fence technology.

Preliminary Results

<u>*Objective 1:*</u> Evaluate avian community composition across four different grazing strategies.

We observed the MTORG grazing strategy to have greater ($p<0.05$) facultative species (FAC) abundance when compared to SLG and PBG (Figure 3). We observed greater ($p<0.05$) obligate (OBL) species abundance in PBG and VF when compared to MTORG. Additionally, obligate species abundance was greater ($p<0.05$) in PBG when compared to SLG. We observed no differences in either OBL or FAC abundances across PBG and VF.

<u>*Objective 2:*</u> Quantify structural variation in plant community resulting from patch-grazing using virtual fence technology to indicate its ability to create heterogeneity.

We observed lower ($p<0.05$) average vegetation density in the Heavy patch grazing intensity when compared to the remaining patches (i.e., Rested, Light, Moderate) (Figure 4). This indicates that the vegetation structure within the Heavy patch was short and sparse by comparison to the other patches. A developing gradient in vegetation structure can be observed across all patches, suggesting varying levels of heterogeneity are being created. While we observed differences among the remaining patches (i.e., Rested, Light, Moderate) they did not significantly differ ($p>0.05$).

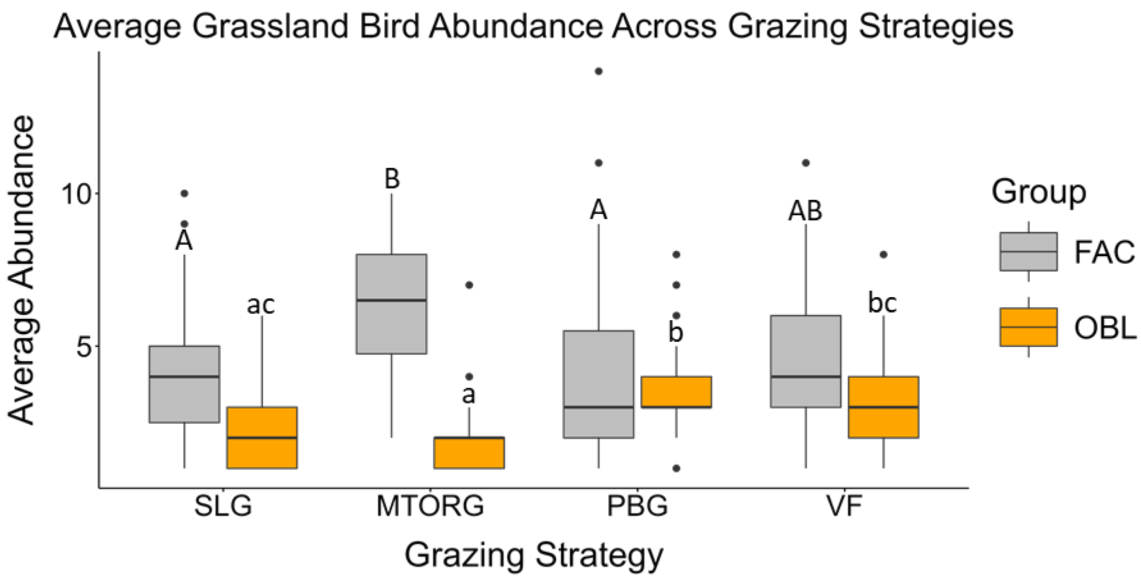

Figure 3. Average abundance of facultative (FAC) and obligate (OBL) avian species within each grazing strategy from visual and auditory surveys conducted from late May through mid-July of 2024. Significance (p<0.05) is indicated by the letters above each column with capital and lowercase letters assigned to differing groups.

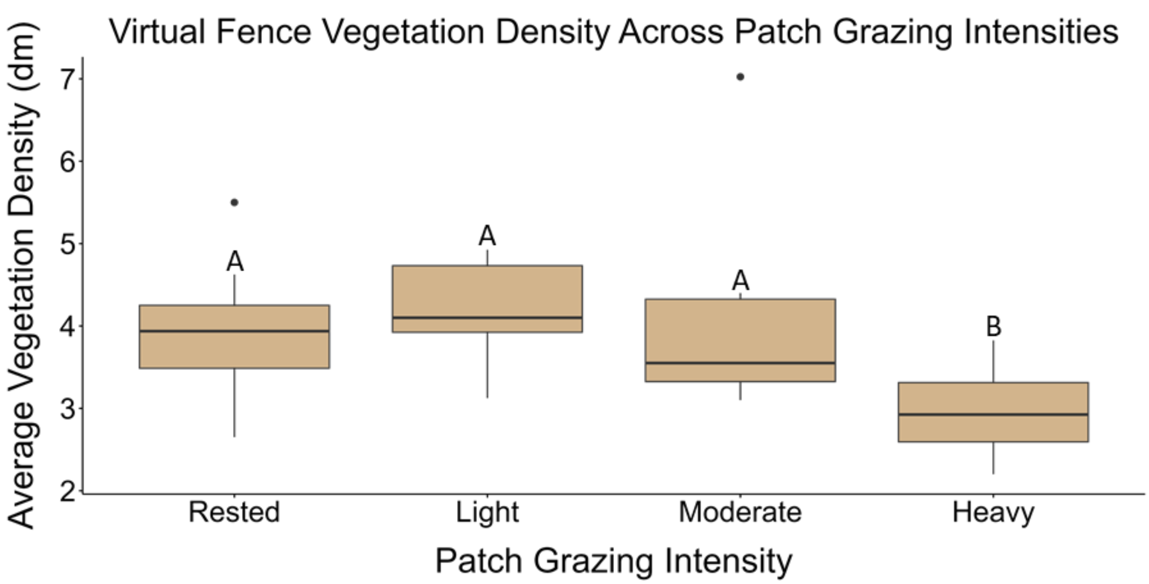

Figure 4. Average vegetation density (dm) based on visual obstruction reading (VOR) vegetation surveys conducted in during peak growing season (late June to early July) within a patch-grazing strategy utilizing virtual fence technology to influence grazing behavior. Patches are labeled according to the grazing intensity they received. Significance (p<0.05) is indicated through a difference in letters above each column.

Objective 3: Calculate grassland bird functional group abundance across patches resulting from patch-grazing using virtual fence technology.

While we observed differences in facultative (FAC) species abundance across patch grazing intensities, none of these differences were found to be significant ($p>0.05$) (Figure 5). Alternatively, we observed fewer ($p<0.05$) obligate (OBL) species in the Heavy patch than in the Rested and Moderate patches.

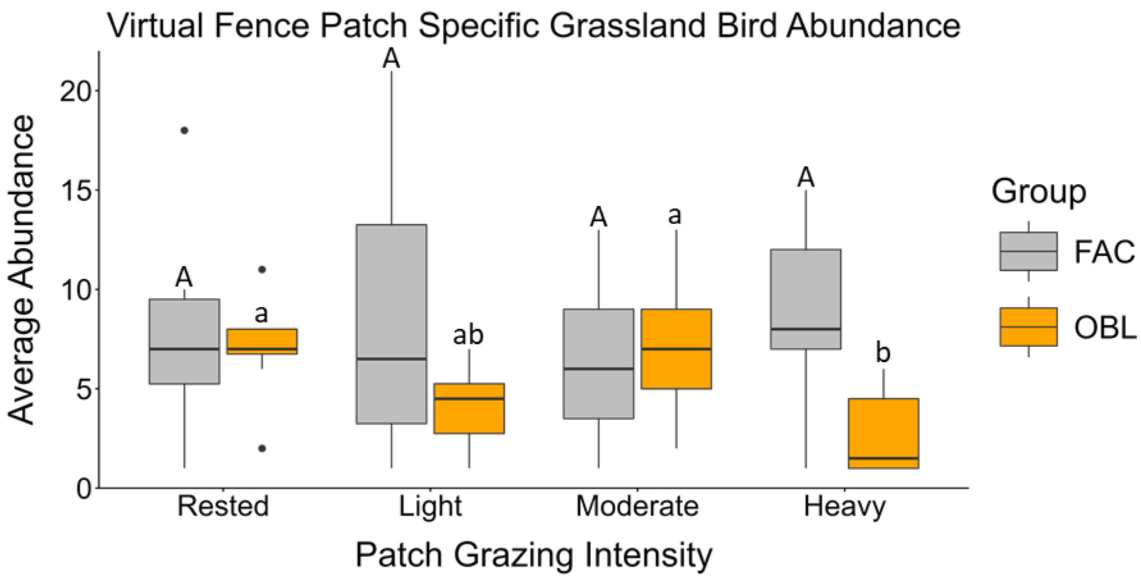

Figure 5. Average abundance of facultative (FAC) and obligate (OBL) avian species from late May through mid-July of 2024, observed within a patch-grazing strategy utilizing virtual fence technology to influence grazing behavior. Patches are labeled according to the grazing intensity they received. Significance ($p<0.05$) is indicated by the letters above each column with capital and lowercase letters assigned to differing groups.

Discussion

In the 2024 field season, we evaluated the average abundance of grassland birds across grazing strategies to determine the influence of grazing strategy on the grassland bird community. Though we observed both facultative and obligate grassland bird species, we are primarily interested in obligate species due to conservation concerns. Our preliminary results show that the average abundance of obligate grassland birds was greatest in the patch-burn grazing (PBG) and patch-grazing strategy utilizing virtual fence (VF). PBG is seen as an effective heterogeneity-based land management strategy which restores structural heterogeneity to rangelands (Fuhlendorf and Engle, 2001), and enhances grassland bird species diversity (Fuhlendorf et al., 2006). As such, it is encouraging to see that a patch-grazing strategy influenced by virtual fence technology has the potential to be similarly effective with regard to observed average obligate species abundance.

In the patch-grazing strategy using virtual fence technology, we identified a slight gradient in vegetation structure. This indicates the creation of heterogeneity, with short - sparse vegetation observed in the Heavy patch and tall - dense vegetation in the Rested patch.

Our findings demonstrate the effectiveness of the virtual fence technology to influence livestock grazing behavior while mimicking a patch-grazing strategy, resulting in each patch receiving a different grazing intensity. This generation of structural heterogeneity increases the availability and/ or quality of breeding habitat for grassland birds (Fuhlendorf et al., 2006; Gregory et al., 2010; Holcomb et al., 2014). In turn, this has the potential to increase avian biodiversity (Knopf, 1996), particularly for those obligate grassland bird species which have affinities for grassland habitats with specific structural characteristics (Cody 1985; Knopf, 1996; Fuhlendorf & Engle 2001).

Within the patch-grazing strategy using virtual fence technology (VF), we observed obligate grassland bird species in all of the patch grazing intensities (i.e., Rested, Light, Moderate, Heavy). We observed the greatest average abundance in the Rested and Moderate patches and significantly fewer in the Heavy patch. When assessed in conjunction with the results of the vegetation density within the VF grazing strategy, we determined that obligate grassland bird species utilized structure along the entire vegetation structure gradient (short and sparse – tall and dense).

More specifically, specialist species are often seen to select for either extreme of this gradient, while generalist species tend to have affinities for structure which falls somewhere in between the two extremes (Fuhlendorf et al., 2006, Augustine and Baker, 2013, Hovick et al., 2015). As such, we can infer that a patch-grazing strategy influenced by virtual fence technology is capable of generating suitable structure for both generalist and specialist obligate grassland bird species.

Conclusion

The future of this study will include an additional season of data collection, further informing our conclusions. We will also perform analysis to determine species specific use within the patch-grazing strategy using virtual fence technology. As we continue to measure the efficacy of virtual fencing and its application to heterogeneity management, our results will help to inform producers and conservation agencies about this new technology and its potential to serve production and conservation.

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High-Forage vs. High-Concentrate Diets Fed to Beef Heifers During Pregnancy and the Impacts on Feeding Behavior and Feed Efficiency in the Dam and Morphometric Characteristics of the Male Offspring

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Take-home Message

Feeding pregnant beef heifers a high-concentrate diet reduces feed intake, improves gain:feed ratio and decreases calving ease compared to a high-forage diet without affecting calf vigor at birth or calf body weight and measurements up to 60 days of age.

Summary

The study assessed the impact of feeding a high-concentrate (HC) diet compared to a high-forage (HF) diet to gestating replacement heifers from 15 days pre-breeding through calving. Specifically, the areas of interest evaluated were dam feeding behavior and feed efficiency, calf body measurements and birth weights, and calf body weight to 60 days of age. By design, there was no difference in average daily gain (ADG; $P = 0.50$) as HF and HC dams were strategically managed for the same targeted ADG of 1 pound/heifer/day in the first two trimesters of gestation and 1.75 pounds/heifer/day in the third trimester of gestation; however, the gain:feed ratio was greater in HC dams than HF dams ($P < 0.01$). Altered feeding events included a greater number of visits and meals in HF dams compared with HC dams ($P < 0.01$). Time eating per visit was greater in HC dams than HF dams ($P < 0.01$), but HF dams spent more time eating per meal and per day ($P \leq 0.02$) than HC dams. Dry matter intake (DMI) per day was greater in HF dams than HC dams ($P < 0.01$), but HC dams had greater DMI per visit and DMI per meal ($P < 0.01$) and an increased eating rate ($P < 0.01$) compared with HF dams. Additionally, calving ease was greater in HF dams than HC dams ($P = 0.03$). No effect of maternal diet was observed ($P \geq 0.12$) for dam body weight at calving, calf birth weights, calf vigor at birth, or calf body weights and body measurements at 24 h of age. The results may provide support for producers to make management decisions regarding development of pregnant heifers when forages are limited, and alternative feed sources are under consideration.

Introduction

Replacement heifers are crucial to the beef production system as they provide a source of genetic improvement to the herd every year. Nutritional management of heifers during pregnancy is essential because heifers have demands for growth and maintenance while also establishing and maintaining a pregnancy, developing a fetus and producing milk for the calf after parturition (NASEM, 2016). Nutrient partitioning focuses primarily on the basal metabolism and growth of the dam and secondly on fetal development and pregnancy maintenance (Short et al., 1990). This is why proper nutrition of the dam is vital for producing healthy calves. Studies show that maternal nutrition during pregnancy can impact fetal programming (Wu et al., 2004). Fetal/developmental programming is the phenomenon in which environmental factors affecting the dam can also influence the fetus in utero, leading to molecular and physiological changes with consequences for growth, metabolism and fertility in the offspring's postnatal life (Barker, 2004; Hammer et al., 2023). This experiment evaluated how feeding a high-concentrate diet to the dam throughout pregnancy not only affected feeding behavior and feed efficiency of the dam, but also body measurements and body weights of the calves.

When forage is limited, alternative supplementation could be used in limited amounts to meet nutrient requirements. This experiment utilized two diets: one consisting of 25% concentrate and 75% forage (HF), and the other consisting of 25% forage and 75% concentrate (HC). The diets were fed to gestating beef heifers to target a specific daily gain of 1 pound/heifer/day in the first two trimesters of gestation and 1.75 pounds/heifer/day in the third trimester of gestation. The objectives were to evaluate the impacts of developing pregnant beef heifers on a high-forage or high-concentrate diet from 15 days prebreeding through calving on feeding behavior and feed efficiency of the dam and morphometric characteristics of the male calves through 60 d of age.

Procedures

Crossbred Angus heifers (n = 119; initial body weight [BW] 748.9 ± 72.8 lbs.) approximately 13 months of age sourced from the NDSU Central Grasslands Research Extension Center (CGREC) arrived at the North Dakota State University Beef Cattle Research Complex (BCRC) in May 2023. Heifers were fitted with radio frequency identification tags (RFID) and trained to consume feed from the Insentec (Hokofarm Group B.V., Marknesse, The Netherlands) roughage intake control (RIC) bunk system. During the training period, all heifers consumed a common forage diet composed of 65% winter wheat/blended hay, 20% corn silage, 5% corn grain and 10% premix (HF; Table 1). Heifers were blocked by initial BW and randomly assigned to receive either a high-forage diet (HF; n = 60) of 75% forage and 25% concentrate or a high-concentrate diet (HC; n = 59) of 25% forage and 75% concentrate prior to breeding (Table 1). Heifers were grouped by BW and diet assignment, then placed into one of six pens. The HF heifers remained on the diet provided at the beginning of the experiment throughout gestation. Over four weeks, the HC treatment group was stepped up from the HF diet to a diet containing 75% concentrates. Both HF and HC groups received their final diets 15 days prebreeding throughout gestation. The HC diet was composed of 15% winter wheat/blended hay, 20% corn silage, 55% corn grain and 10% premix (HC; Table 1). Heifers in both HF and HC groups were managed strategically to target BW gains of 1 pound/heifer/day. This was achieved by collecting BW measurements every other week and adjusting individual feed allotments accordingly. In the third trimester of gestation through parturition, feed allocations for pregnant heifers were adjusted to achieve target BW gains of 1.75 pounds/heifer/day.

Table 1. Feed ingredient percentages in a high-forage and a high-concentrate diet fed to heifers 15 d pre-breeding through gestation.

	Treatment	
Item	HF	HC
Ingredient % DM		
Winter wheat/blended hay	65	15
Corn silage	20	20
Corn grain	5	55
Premix[1]	10	10

[1]The premix consists of dried distiller's grain plus soluble, limestone, salt, urea, Monvet 90 Monensin Granule, trace mineral (Feedlot Trace Hubbard), vitamin A, vitamin D, vitamin E and exclusively in the high-concentrate diet, dicalcium phosphate.

The roughage intake control (RIC) feeding system controls intake as well as monitors feeding behavior. Each bunk has a scale that monitors how much weight is being taken out as animals are eating. Electronic ear tags allow the system to track each animal for daily feed consumption, time spent eating and number of visits to the bunk. Further calculations using these variables allowed for a comprehensive evaluation of feeding behavior including visits per day, meals per day, time eating per visit, time eating per meal, time eating per day, dry matter intake (DMI) per day, DMI per visit, DMI per meal and eating rate. Calculations of gain to feed ratio (G:F) and average daily gain (ADG) throughout the experimental period were calculated using BW gains recorded every other week and feed intake data from the Insentec system. Feed intake and feeding behavior variables were averaged across the 266-d collection period that started at breeding and stopped when the first dam calved. Feed efficiency variables were calculated from 15 d pre-breeding throughout gestation.

At approximately 14 months of age, heifers were synchronized using a seven-day Select Synch + CIDR protocol (Lamb et al., 2010) and artificially inseminated with male-sexed semen from a single sire in June 2023. At d 35 and d 65 after insemination, transrectal ultrasound was used to determine pregnancy status and fetal sex. Forty-six heifers were confirmed pregnant with male fetuses (HC: n = 22; HF: n = 24) and subsequently maintained on treatment diets through calving in March 2024.

Dams and neonatal calves were weighed at birth prior to suckling. Calves were assigned a vigor score of 1 through 5 (1 = healthy calf and 5 = stillborn) and a calving ease score of 1 through 5 (1 = no assistance required and 5 = cesarean). Dams and calves were then paired in an indoor maternity pen for approximately 24 h. At 24 h, calves were weighed, body measurements were recorded and pairs were returned to group pens. Body measurements included chest circumference, abdominal circumference, crown rump length, shoulder hip length, hip height and hip width (Table 3). Calf BW was collected at d 15 and approximately d 30 and d 60 after birth. At approximately 61 d post-calving, pairs were transported to the CGREC and managed as a single group on pasture until weaning.

Statistical Analysis

Data were analyzed using the MIXED procedure of SAS 9.4 (SAS INST. Inc., Cary, NC) with individual animal serving as the experimental unit. Repeated measures were used to evaluate dam feeding behavior and calf BW gain postnatally. No significance was found in the TRT x Day interaction of calf BW gain, so main effects of treatment and day were reported. Dam weight at calving, calf weight pre-suckling and calf morphometric variables recorded at 24 h were analyzed with the main effect of maternal diet at a single point in time. Results are reported as least square means (LSMEANS) with the standard error of the mean. Significance was considered at P-values ≤ 0.05 and tendencies declared at $0.05 < P \leq 0.10$.

Table 2. Feed intake and feeding behavior of gestating beef heifers averaged across the 266-d collection period during gestation.

	Treatment			
Item	HF	HC	SE[1]	*P*-value[2]
Feeding Events, per d				
Visits[3]	31.7	12.8	0.31	<0.01
Meals[4]	5.84	3.14	0.044	<0.01
Time Eating, min				
Per visit	5.57	6.68	0.085	<0.01
Per meal	22.3	21.8	0.22	0.02
Per day	113.2	55.4	0.64	<0.01
Dry matter intake				
Per day, lb	16.6	14.2	0.05	<0.01
Per visit, oz	13.8	25.8	0.28	<0.01
Per meal, oz	52.5	81.4	0.63	<0.01
Eating rate, oz/min	2.43	4.48	0.022	<0.01
Measures of feed efficiency				
ADG, lb	1.28	1.30	0.033	0.50
G:F, lb	0.17	0.21	0.006	<0.01

[1]Standard error of the mean.
[2]*P*-values consider differences between HF and HC treatments across rows.
[3]Visit is any entry to the bunk detected by electronic ear tag.
[4]Meal is a feeding event that may consist of multiple visits but is bound by a period of 7 minutes with no feeding activity on either side.

Table 3. Weights of calves at birth and 24 h after birth and dams at calving, calf body measurements, and calving ease and vigor score following birth.

	Treatment			
Item	HF	HC	SE	*P*-value[1]
Weights				
Birth weight, lb	69.8	69.3	2.80	0.87
24-hour weight, lb	72.3	71.1	2.77	0.68
Dam weight at calving, lb	1046.1	1067.7	27.54	0.44
Calf morphometrics				
Chest circumference, in	29.41	29.31	0.411	0.82
Abdominal circumference, in	29.17	28.75	0.625	0.51
Crown rump length, in	30.05	30.97	0.570	0.12
Shoulder hip length, in	13.45	13.24	0.441	0.63
Hip height, in	28.05	27.50	0.340	0.12
Hip width, in	4.50	4.32	0.208	0.39
Ease and vigor score				
Calving ease[2]	1.02	1.45	0.187	0.03
Calf vigor[3]	1.46	1.64	0.330	0.59

[1] *P*-values consider differences between HF and HC treatments across rows.
[2]Calving ease score assigned during parturition. 1=no assistance, 2=assisted, easy pull, 3=assisted, difficult pull or mechanical assistance, 4=abnormal presentation, 5=cesarean section.
[3]Calf vigor score assigned prior to parturition. 1=normal calf, 2=weak calf that nursed without assistance, 3=weak calf assisted to nurse and lived, 4= weak calf assisted to nurse and died, 5=stillborn.

Results and Discussion

By design, there was a strategic effort to keep ADG equal between HF and HC treatments, and results indicated no difference in ADG between HF and HC dams ($P = 0.50$). Dry matter intake (DMI) per visit ($P < 0.001$) and DMI per meal ($P < 0.001$) were greater in HC dams compared to HF dams. However, HF dams had greater total DMI per day ($P < 0.001$) than HC dams, which can be explained by the greater number of visits to the bunk ($P < 0.001$) and meals ($P < 0.001$) the HF dams had compared to the HC dams. Although HC dams consumed less total dry matter compared to HF dams, G:F ($P < 0.001$) was greater in HC dams than HF dams. Seemingly, the nutrient-dense concentrate feed comprising the HC diet allowed HC dams to put on more weight while consuming less feed. Time eating per visit ($P < 0.001$) was greater in HC dams than HF dams; however, HF dams spent more time eating per meal ($P = 0.02$) and per day ($P < 0.001$) compared with HC dams. Eating rate ($P < 0.001$) was greater in HC dams than HF dams, being nearly doubled. The HC diet was less bulky than the HF diet, presumably allowing the HC heifers to consume feed faster. Feed behavior assessment can be used as a measure of performance in regard to feed efficiency.

Calving ease was greater in HF dams than HC dams (P = 0.03); however, there was no difference in calf vigor (P = 0.59) between HF and HC calves. Calf BW through 60 d of age was not impacted by the interaction of maternal diet x day (P = 0.45; Figure 1). Additionally, maternal gestational diet did not cause differences in BW between calves born to HF and HC dams (P = 0.71). Expectedly, there was an increase in BW in both HF and HC calves with time (P < 0.001). However, BW of HC and HF dams was not impacted at time of calving (P = 0.44; Table 3). There were no differences in calf body measurements at 24 h of age, including chest circumference, abdominal circumference, crown-rump length, shoulder-hip length, hip height and hip width ($P \geq 0.12$).

These data show that a HC diet can be implemented in feeding replacement beef heifers throughout gestation. Feeding a HC diet improves feed efficiency, indicating heifers are reaching their gains while consuming less feed. The improvement in feed efficiency is highlighted by the equal ADG in HF and HC dams but a greater G:F in HC dams. Depending on the availability and cost of forage and concentrate feeds, limit-feeding concentrates in the diet may be a cost-effective method to reach nutrient requirements for gestating beef heifers. As seen in the results, feeding a HC diet does not impact calf BW or calf body measurements, but there is a decrease in calving ease in HC dams, which may be a concern depending on producer calving systems. Continuing to study effects on male calves later in life is important for further understanding of feeding strategies that may allow producers to make decisions regarding feed efficiency in dams and offspring.

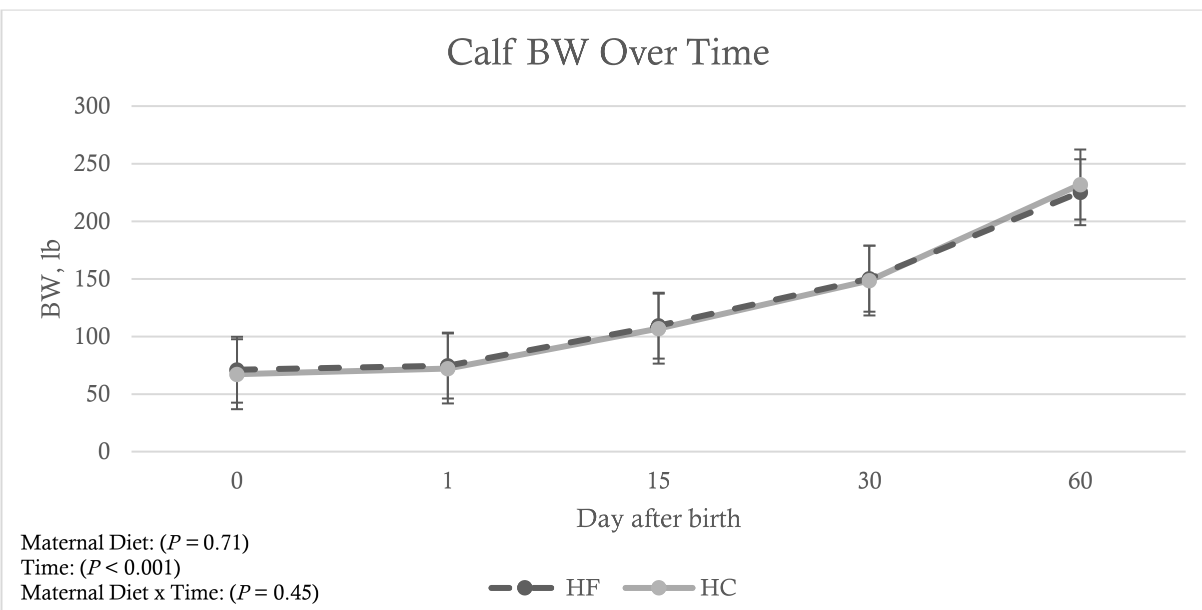

Figure 1. Calf weights at day 0, 1, 15, 30 and 60 of bull calves born to dams fed a HF or HC diet.

Acknowledgements

The authors thank the United States Department of Agriculture National Institute of Food and Agriculture's Agriculture and Food Research Initiative (award number 2022-67016-37092), the North Dakota Corn Council, Zoetis Animal Health (Parsippany, NJ), and STGenetics (Navasota, TX) for funding and product support. The authors also thank the staff, technicians, and students at the Central Grasslands Research Extension Center and the Beef Cattle Research Complex for their assistance.

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Disturbance & Timing: Effects Exhibited Through Plant Community Change Following Spring and Late-Summer Fire with Grazing

Rangeland fire is a vital ecological process shaping mixed-grass ecosystems in the Great Plains. Historic disturbance regimes have been altered in recent decades, creating a shift in plant communities. Fire and grazing interactions affect vegetation dynamics, enhance species richness and forage quality, and manage invasive grasses like Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*). Our study investigates the short-term effects of spring and late-summer prescribed fires, paired with grazing, on plant communities. A randomized block design with 96 plots divided into grazed and ungrazed treatments was used to assess the effects of fire season and grazing on vegetation composition, structure, and floral resources. Fires were implemented in the late-summer (late August 2023) and spring (early May 2024) seasons. Cattle were allowed access to grazing throughout the growing season to achieve a moderate degree (40-60%) of use. Data collection included species composition, litter and thatch depth, visual obstruction, vegetative biomass, and floral resource availability. Results from the first full year revealed that fire is able to reduce invasive grasses and enhance species richness compared to unburned plots (**Figure 1 & Figure 2**). Grazing alone decreased brome abundance, while spring fire provided the greatest decrease in bluegrass cover (**Figure 1**) and promoted a more diverse plant community (**Figure 2**). Grazing without fire provided the least floral resources throughout the season, whereas grazed plots with a late-summer fire provided the largest amount (**Figure 3**). Preliminary findings suggest that fire and grazing are effective in maintaining invasive grass populations, fostering native species, and improving floral resource availability. Spring fires appear particularly beneficial, reducing invasive grass encroachment and increasing biodiversity amongst plots. Future research will focus on long-term fire return intervals and their influence on rangeland recovery and resilience. (see the full 2024 Annual Report for additional research results)

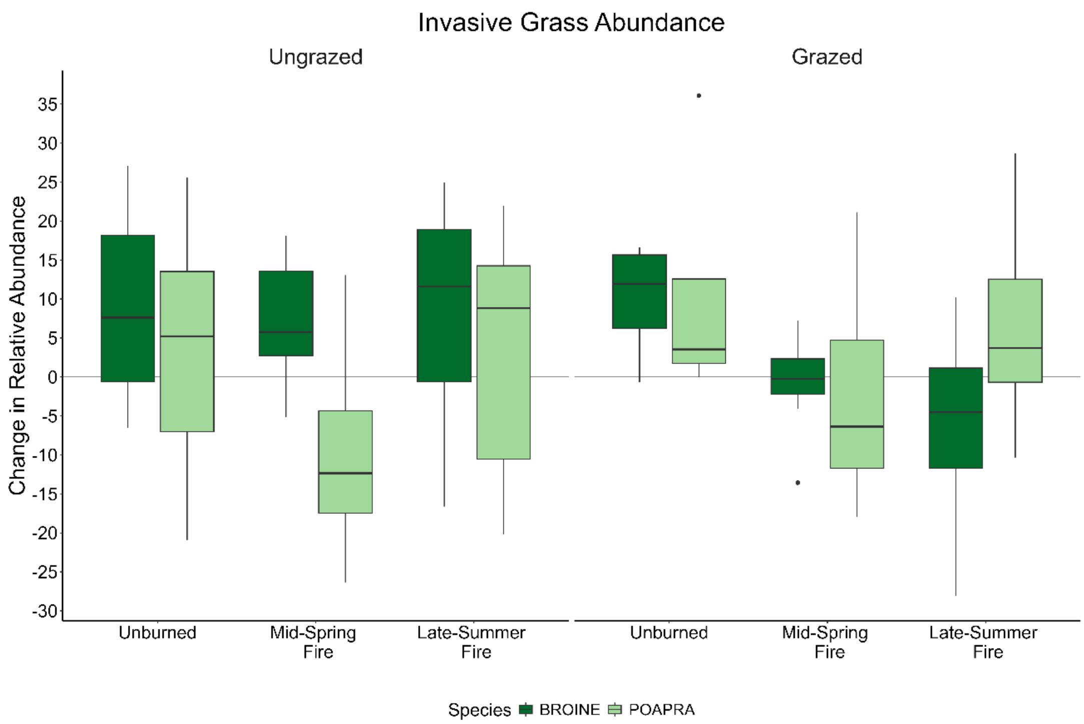


Figure 1. The relative change (y-axis) in the cover values recorded for Kentucky bluegrass (*Poa pratensis* – light green) and smooth brome (*Bromus inermis* – dark green) between the 2023 and 2024 seasons. Treatment combinations are displayed along the x-axis.

Fact Sheets

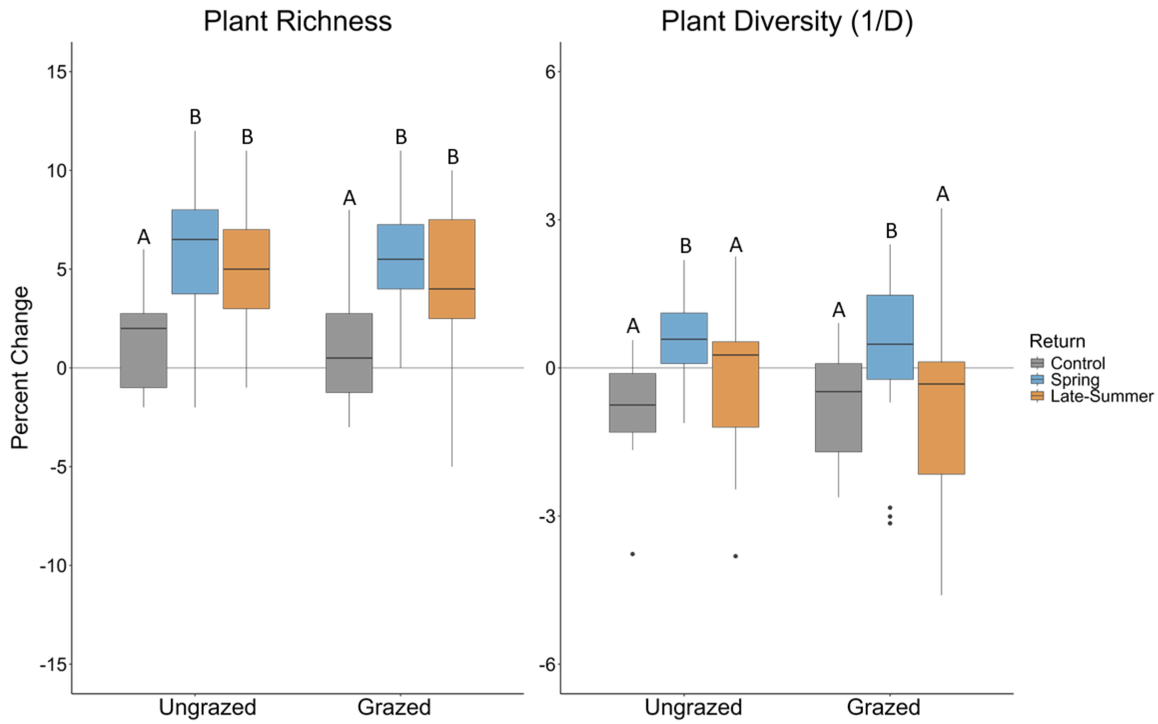


Figure 2. The change (y-axis - left) in the number of plant species and the plant diversity index (y-axis – right) within grazed and ungrazed plots (x-axis) between seasons (colored bars).

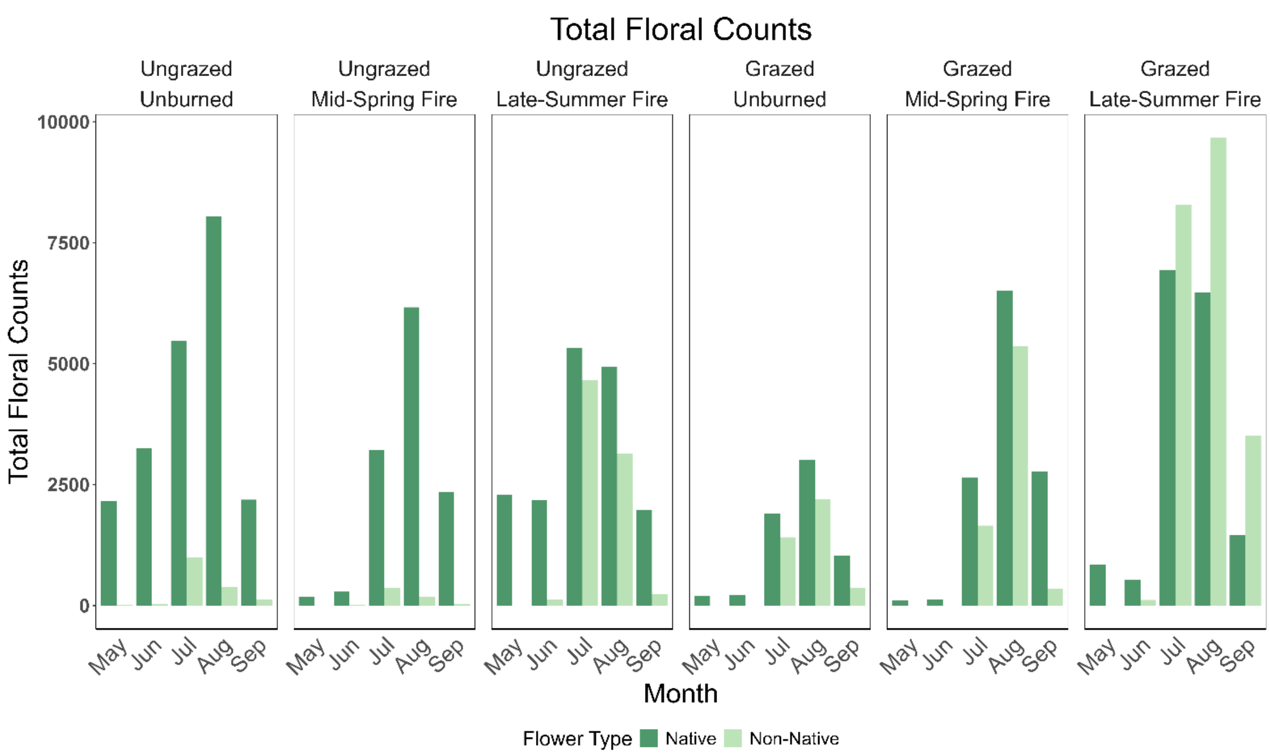


Figure 3. The total amount of flowers observed (y-axis) on a weekly basis for one growing season (2024). Flower totals are separated by treatment type and month observed (both along x-axis). Flower totals are further divided based on native/non-native status by color of bar.

Fact Sheets

Timing of Cattle Grazing to Restore Plant Diversity in a Smooth Brome Invaded Rangeland

Zachary Johnson, Shawn DeKeyser, Kevin Sedivec

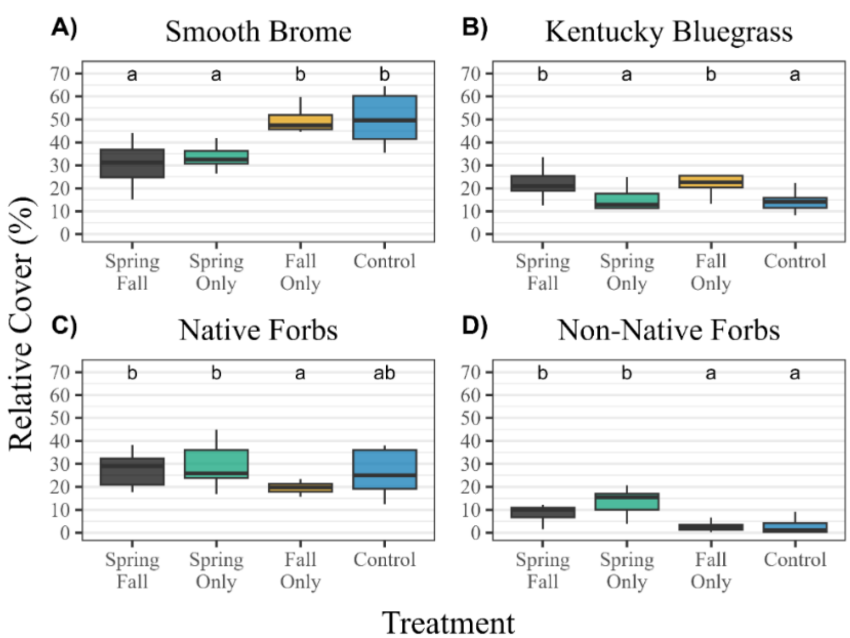
Background

- Rangeland ecosystems are highly threatened.
- Invasive species further threaten rangelands.
- Smooth brome (*Bromus inermis* Leyss.) is a highly invasive grass that reduces biodiversity.
- Rangelands with decades of no fire or grazing often become invaded.
- Intense grazing during the spring and/or fall shows some promise for restoring plant diversity of smooth brome invaded rangelands.
- Plants can regrow after being grazed from collection of belowground buds (bud bank).
    - Species with larger bud banks are typically more grazing tolerant.

Hypothesis

Cattle grazing in the spring only, fall only, or both the spring and fall (spring+fall) would decrease the abundance of smooth brome, increase native species, and negatively affect smooth brome's vegetative regeneration in a smooth brome-dominated rangeland of the Missouri Coteau compared to a non-grazed control.

Results



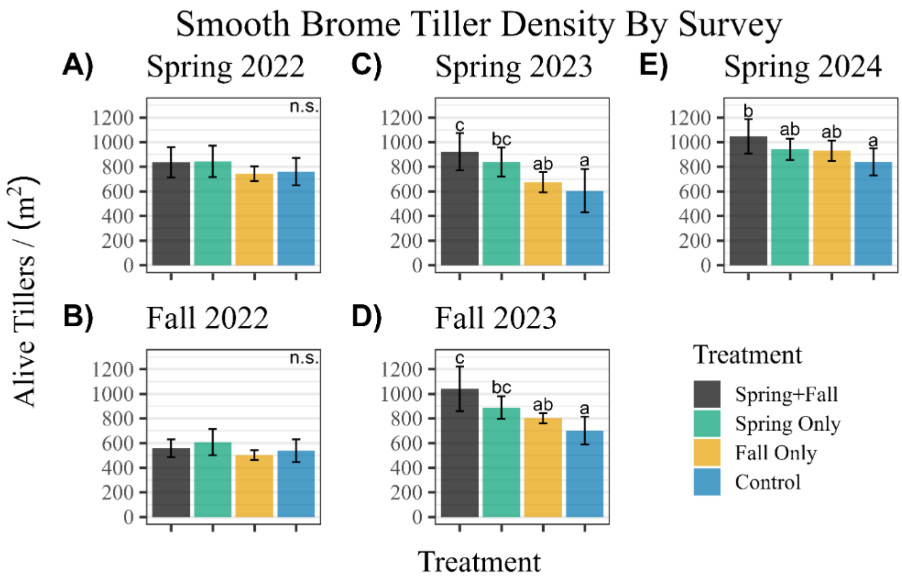
Grazing during the spring only and spring+fall:

- Decreased smooth brome cover
- Increased non-native forbs cover.

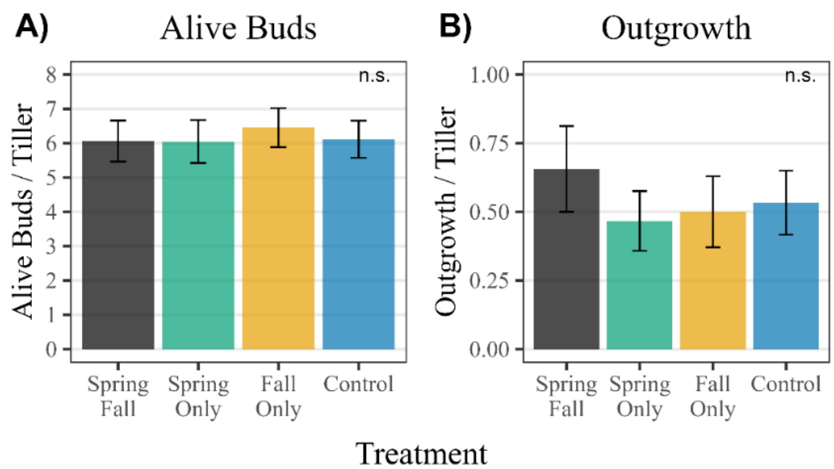
Grazing during the fall only and spring+fall:

- Increased invasive Kentucky bluegrass cover.

Fact Sheets



- Grazing during the spring only and spring+fall increased smooth brome tiller (stem) density in 2nd year of study
- Tiller density in spring only plots was no longer greater in 3rd year
- Grazing did not significantly affect bud banks of smooth brome, or outgrowth of buds into shoots



Discussion

- Partial support for our hypothesis.
- Spring only and spring+fall grazing:
    - Decreased the cover of smooth brome but not its tiller or bud abundance.
    - Increased non-native forb cover but not native cover.
        - Increases in non-native forbs were primarily yellow sweet clover (*Melilotus officinalis*), alfalfa (*Medicago sativa*), and Canada thistle (*Cirsium arvense*).
- Grazing during the fall only and spring+fall:
    - Increased invasive Kentucky bluegrass cover.
- Increased smooth brome tiller density may:
    - Suggest grazing is stressing smooth brome and could lead to future decreases.
    - Suggest smooth brome would remain tolerant of grazing.
    - Additional year of data will be collected.

Central Grasslands Research Extension Center

Enhancing the profitability of winter rye cover crops through integrated crop livestock systems

Joshua Wianecki, Miranda Meehan, Katrina Kratzke, Lindsay Chamberlain Malone, Kevin Sedivec, Zachary Carlson

Introduction

Cover cropping is an important tool for conserving soil health, however the costs associated with cover cropping may not be recovered directly through soil health benefits. Integrated crop livestock systems offer strategies to recover these added costs within the short-term.

Erosion Control

Live plant cover, residue, and root mass provided by winter cover crops aid in erosion control by resisting erosion during high wind or precipitation events. Additionally, cover crops can enhance physical soil structure through increased soil aggregation.

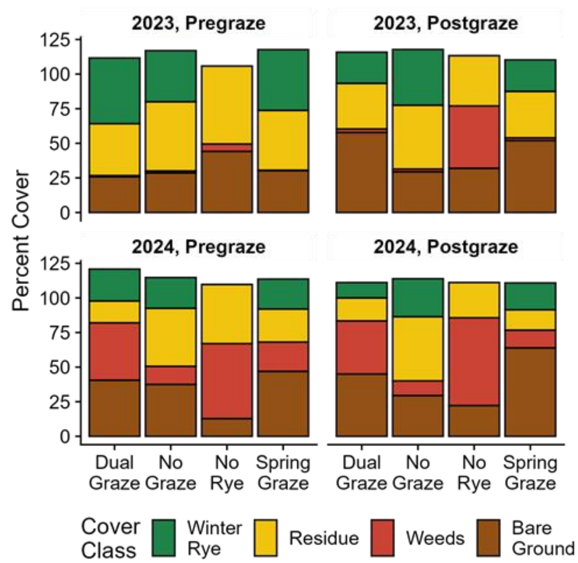


Figure 1. Absolute ground cover pre- and post-grazing for the 2023 and 2024 spring grazing periods.

Figure 2. Differences in weed establishment within grazed winter rye (top) and fallow paddock (bottom).

Weed Prevention

Winter cover crops create competition against annual weed species, reducing weed establishment prior to cash crop seeding. Grazing the winter cover crop did not impact weed cover, and all treatments with a winter rye cover crop greatly reduced weed cover by up to 89% compared to fallow

Central Grasslands Research Extension Center

Integrating Livestock

While biomass produced by winter cover crops is often planted only for soil health purposes, winter cover crops can provide a valuable spring forage resource. In this study, winter rye provided over 1,000 lbs of dry matter per acre prior to termination. This resulted in up to 0.8 animal unit month (AUM) per acre throughout the cover crop season.

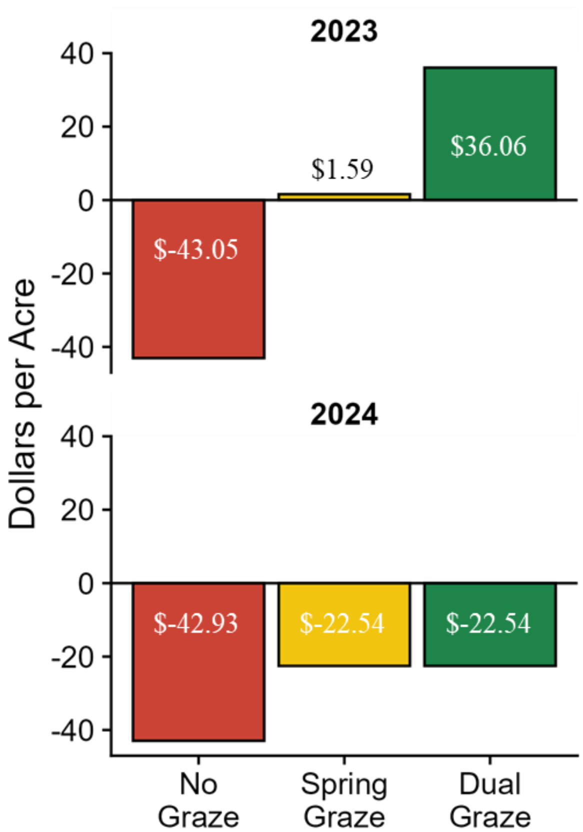


Figure 4. Estimated net economic effect for incorporating a winter rye cover crop without grazing (no graze), and with grazing (spring graze or dual graze) within a crop and livestock production enterprise.

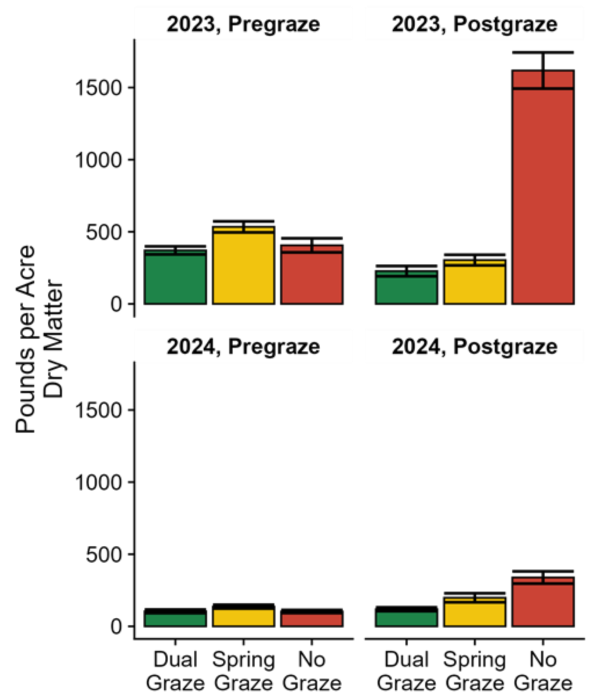


Figure 3. Forage biomass on dry matter basis pre- and post-grazing for the 2023 and 2024 spring grazing periods.

Economics

Establishing a cover crop added $43/ac in additional costs both years. Winter cover crop grazing allowed grazing to start earlier in the season, reducing winter feeding and housing costs. In one of two years of this study, grazing resulted in a positive net economic effect when cover cropping as an integrated crop livestock system. This effect is dependent on AUMs produced which will be variable depending on cropping cycle and climatic factors.

Can a liquid mineral supplement increase forage production, forage quality, and soil nitrogen?

Nutri-Graze™ is a product designed to increase forage production by stimulating soil microbial activity.

Can Nutri-Graze, when combined with different rates of urea, increase forage production, forage quality, and soil nitrogen content?

Table 1. Mean biomass with standard deviation in a mixed grass/alfalfa field and grass field when grasses were in head stage (late June). Different letters in the same column denotes significance.

Treatment	Grass/Alfalfa Field (meadow brome/ alfalfa)		Grass Field (smooth brome)	
	Herbage Production (lb/ac ± SD)	Percent Change from Control	Herbage Production (lb/ac ± SD)	Percent Change from Control
Control	3535.2 ± 934.8[a]		2094.4 ± 185.5[a]	
Nutri-Graze	4699.1 ± 517.4[a]	32.9	2701.0 ± 403.2[ab]	29.0
Urea (25 lb/ac)	4991.6 ± 1412.9[a]	41.2	3157.7 ± 727.9[ab]	50.8
Urea (25lb/ac) + Nutri-Graze	4399.3 ± 767.1[a]	24.4	3571.6 ± 499.5[bc]	70.5
Urea (50 lb/ac)	4734.7 ± 941.9[a]	33.9	3600.1 ± 1334.4[bc]	71.9
Urea (50lb/ac) + Nutri-Graze	4353.0 ± 692.2[a]	23.1	4081.8 ± 820.6[bc]	94.9

- Nutri-Graze had no effect on biomass in the late growing season after being cut for hay and being applied a second time.
- Nutri-Graze had the greatest impact on biomass when grass hay was in the heading stage.
    - Nutri-Graze + 25lb/ac Urea, Nutri-Graze + 50lb/ac Urea, and 50lb/ac Urea alone all produced significantly more biomass than the control (Table 1).

Nutri-Graze and Urea had no effect on forage nutritional quality.

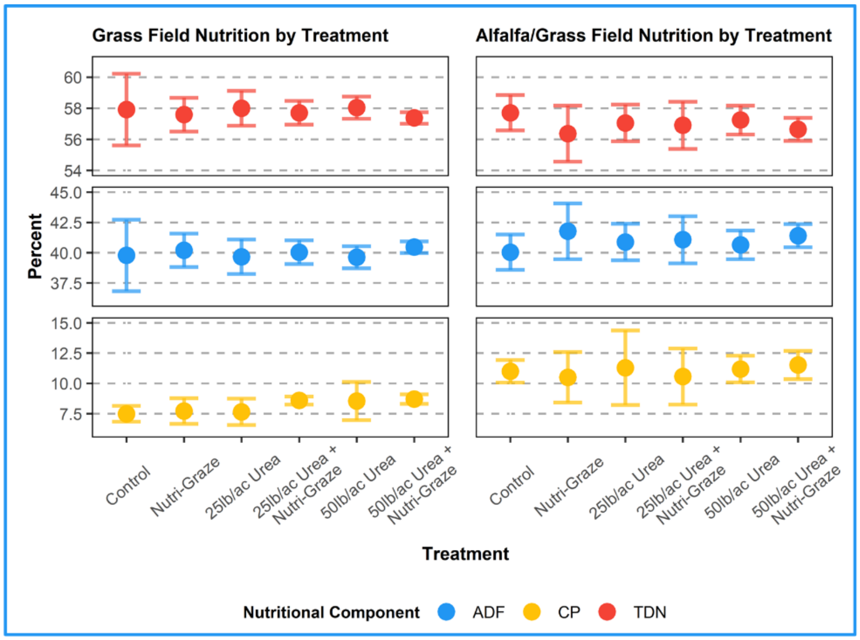


Figure 1. Percent acid digestible fiber (ADF), crude protein (CP), and total digestible nutrients (TDN). Points are treatment means, error bars are one standard deviation.

Nutri-Graze and Urea had no effect on soil nitrogen.

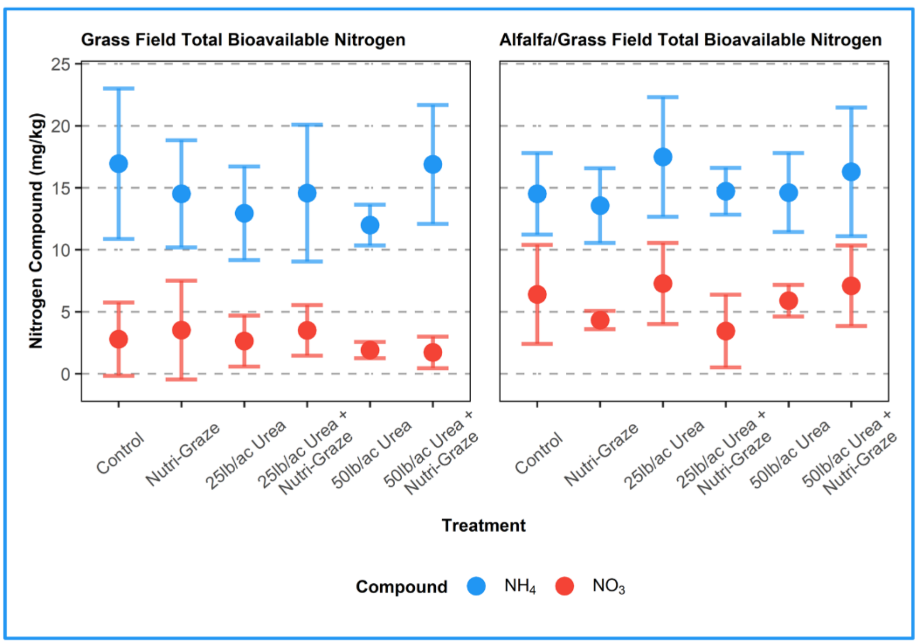


Figure 2. Milligrams of nitrogen compounds NH^4 and NO^3 per kilogram of soil. Points are treatment means, error bars are one standard deviation.

Conclusions:
Nutri-Graze alone has no impact on forage biomass, forage nutritional quality, or soil nitrogen.
The results contradict the findings of previous studies. Higher than average growing season rainfall may have masked the effects of Nutri-Graze and Urea.

Honey bee and native bee communities in three grazing regimes 2021-2024

Bethany Roberton[1], Jason Harmon[1], Torre Hovick[1], Kevin Sedivec[1,2], and Ben Geaumont[3]

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SIGNIFICANCE

Rangelands are a crucial source of pollinator food sources, making these areas critical for bees. If we are to use this land to efficiently support bee communities, we must explore grazed rangeland management techniques that can **create sustainable habitat for bees.**

BEE ABUNDANCE

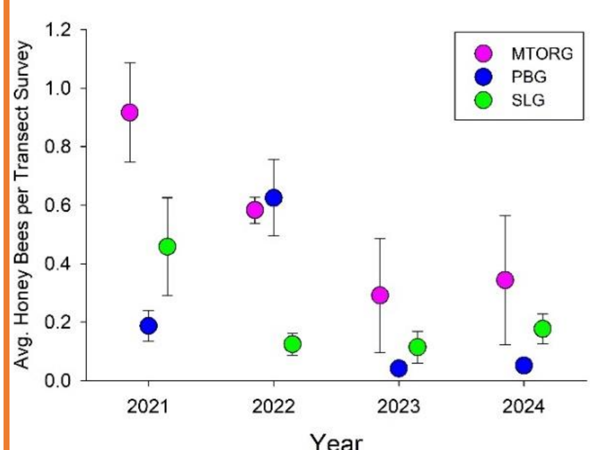
- 799 bees (381 honey bees and 418 native bees) were caught on flowers during 1,110 sweep net surveys in four years.
- The MTORG consistently had the most honey bees and native bees which may have been due to the proximity of the honey bee hives and the flowering resources available during the drought of 2021.
- Honey bees have a decreasing trend in average bees caught per survey while native bees have an increasing trend over the four years.

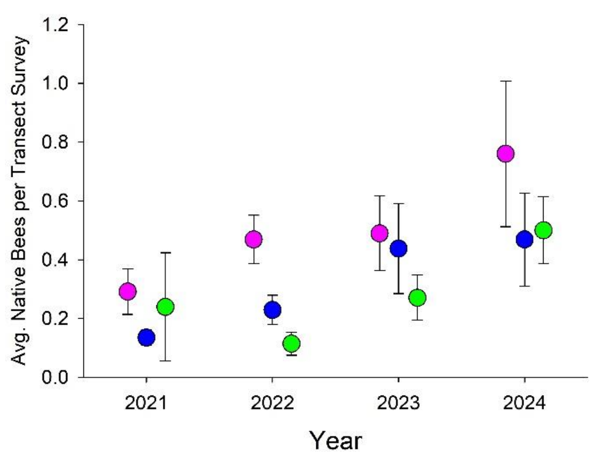
Grazing Regimes

MTORG = Modified Twice Over Rest Rotation Grazing

PBG = Patch Burn Grazing

SLG = Season Long Grazing



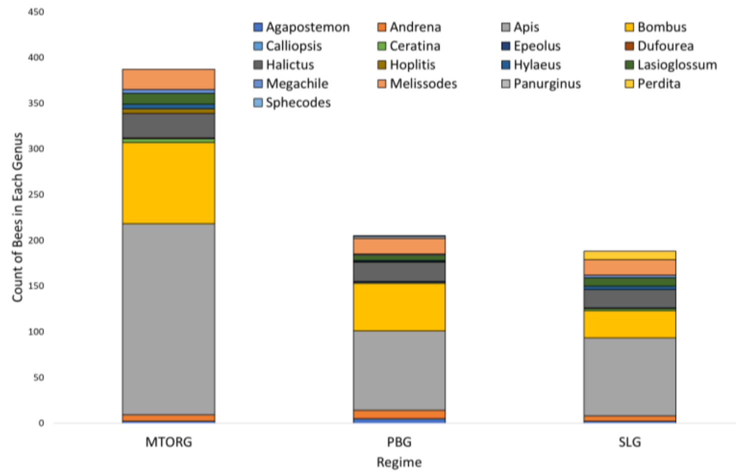


The average abundance of a) honey bees and b) native bees caught per survey with standard error within the three grazing regimes (MTORG, PBG, SLG) during the summers of 2021-2024.

BEE COMMUNITY COMPOSITION

- 17 bee genera were identified across 5 families.
- Four genera only had 1 bee surveyed in total.
- Two genera are cuckoo bees (lay their eggs in the nests of other bees).
- Honey bees were most associated with the MTORG regime.
- One genus of sweat bees (*Agapostemon*) was more abundant in PBG than SLG.

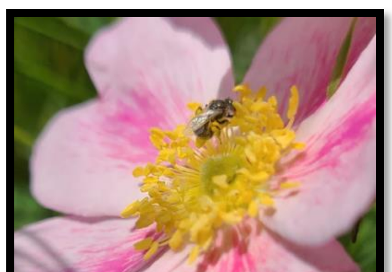
Agapostemon spp.



The number of bees caught within each genus in total for all three survey rounds within each grazing treatment (MTORG, PBG, SLG) for all four summers (2021-2024). The gray bars are the genus *Apis,* which are the honey bees.

VISITED FLOWER SPECIES

Stiff Goldenrod
Solidago rigida



Prairie Rose
Rosa arkansana

Flodman's Thistle
Cirsium flodmanii

- 49 total flower species visited.
- Honey bees were caught on 26 species (21 overlapped with native bees).
- Native bees were caught on 44 species.
- Native bees visited native flowers at a higher percentage than honey bees in PBG.
- The most visited flowers were native thistles, goldenrods, coneflowers, dotted blazing star, prairie rose, curlycup gumweed, western snowberry, sunflowers, milkvetches, and purple prairie clover as well as exotic yellow sweet clover, dandelions, and yellow salsify.

KEY POINTS

1) The MTORG regime may be beneficial for supporting overall bee abundance in both groups.
2) PBG may better support at least one native bee genus and native bee visitation to native flower species.
3) Bee diversity is essential for visiting many flowering species and promoting pollination services.

CGREC Staff and Advisory Board

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Lacey Kreft	Office Manager
Timothy Long	Beef Herdsman
Cody Wieland	Manager of Operations, Livestock Technician
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The CGREC annual field day will be held on July 14, 2025 and open to the public

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