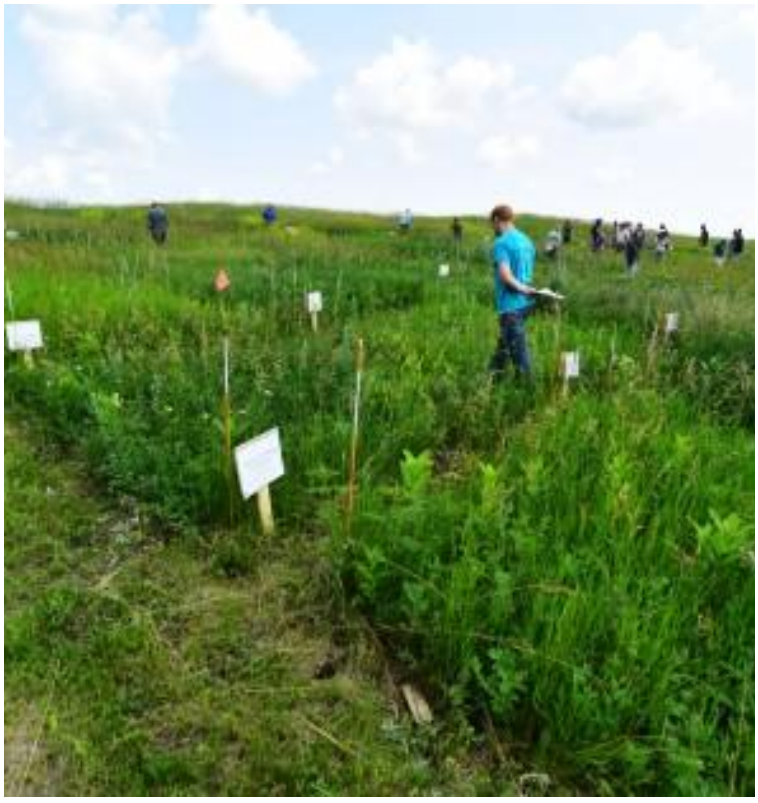
Central Grasslands Research Extension Center

Grazing – Forage – Wildlife – Livestock

2025 Annual Report

NDSU NORTH DAKOTA STATE UNIVERSITY



Summary of the Year

Welcome to the 2025 CGREC Annual Report

The year 2025 grazing season was very similar to 2024. The winter was mild, making for a great calving season. Rainfall events occurred at a regular schedule throughout the summer, receiving 21.4 inches of moisture for the year and 108 percent of normal.

Our grazing program focused on four large scale experiments which included 1) testing heterogeneity-based grazing treatments (patch grazing, patch burn grazing), 2) integrated livestock-cropping system trials, 3) precision grazing using virtual fence, and 4) managing invasive plants (absinth wormwood) and shrubs (western snowberry). 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. The managing invasive plants focused on herbicide options for absinth wormwood and land management options for western snowberry.

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 completed in December 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 $4/lb calf prices, this equates to $84 in added value per acre**
- ✓ Temporally 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%.
    - **Creating an increased calf performance by 0.14 lb/day (4-year average), equating to an increase of $15/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. Eleven private producers adopted the technology in 2025.

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

4) Extension Programming

✓ Extension programming tied to CGREC had 3540 direct contacts at 80 events, with an indirect reach of 1,376,000 people.

- **The state's BQA program is led by our Livestock specialist (Lisa Pederson). This program certified over 300 producers at 12 BQA trainings, and impacted 25,000 head of cattle in 2025, adding over $2.5 million in added value to those North Dakota producers.**

5) Workforce Development

✓ Will graduate 36 PhD and MS graduate students since 2019 from projects conducted at the center or with the center's cattle.

✓ Trained over 110 undergraduate students by providing summer technician positions.

6) Publications

✓ Over the past 5 years there were 89 peer-reviewed journal articles published from research conducted at the center or with our cattle.

Our 2026 annual field day is scheduled for July 7. 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.

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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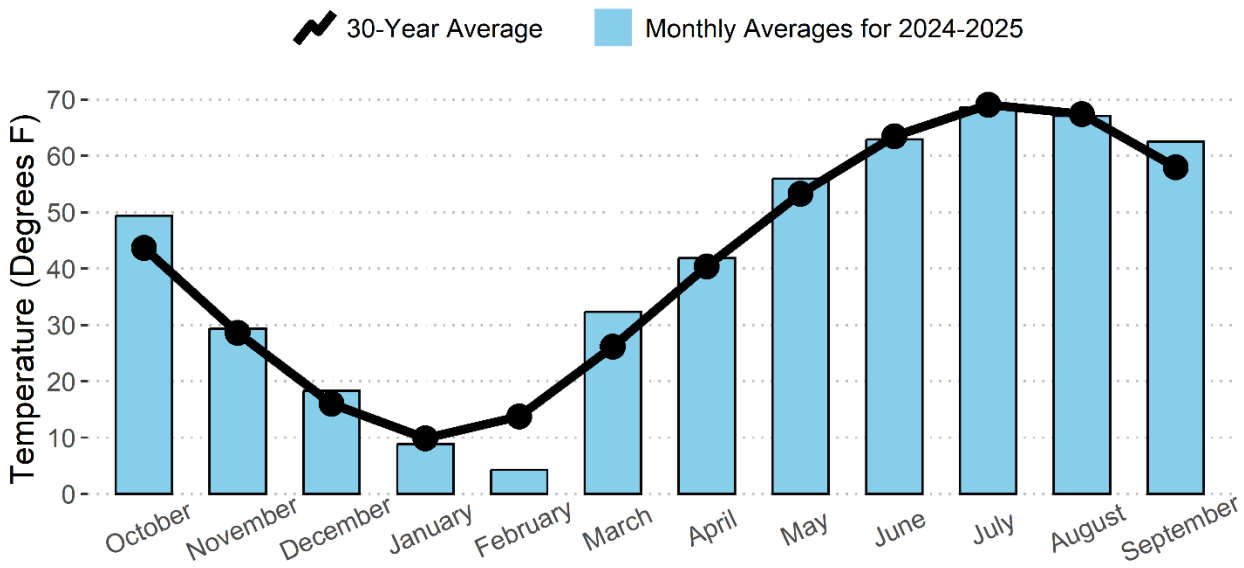
Monthly Temperatures for the 2024-2025 Crop Year



Last spring frost: April 29

Average last spring frost May 13

First fall frost: October 13

Average first fall frost September 22

161 frost free days

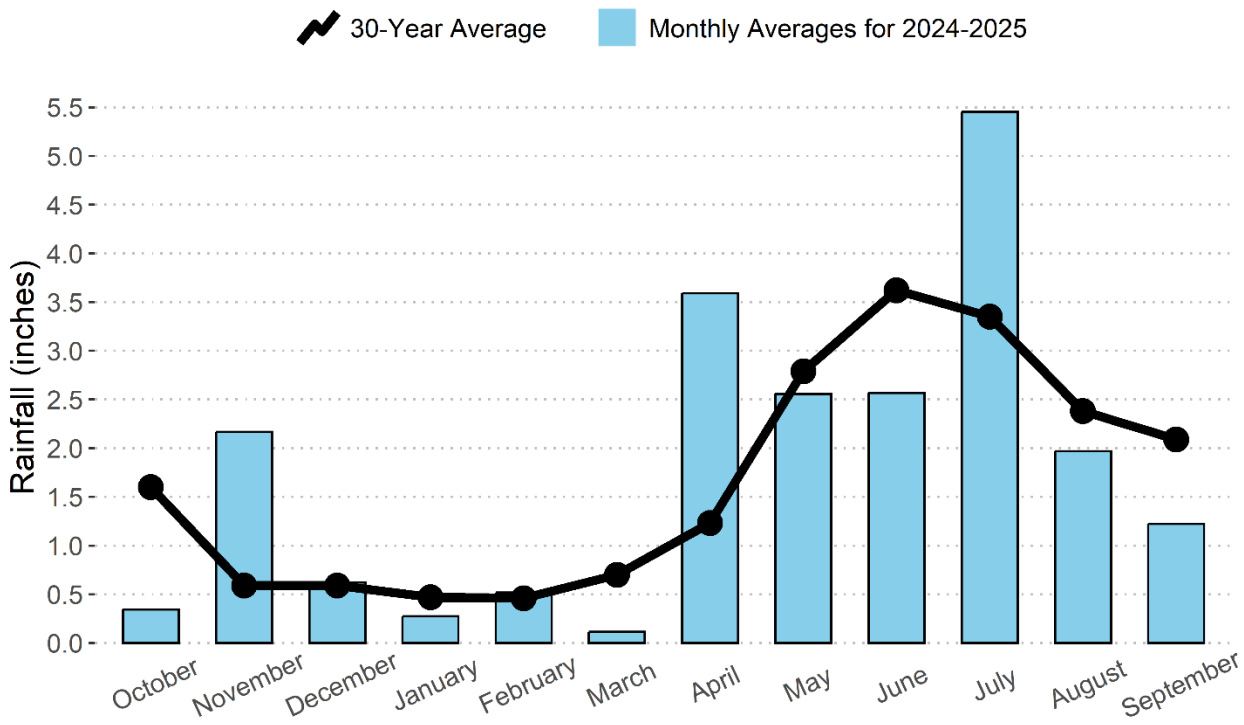
Average 132 frost free days

Month	Average Maximum Temperature[1]	Average Minimum Temperature	Average Temperature	30-year Average Temperature	2024-2025 Deviation from Average
October	62	37	49	43.7	5.3
November	37	21	29	28.6	0.4
December	26	10	18	16	2
January	18	-1	9	9.9	-0.9
February	14	-5	4	13.8	-9.8
March	44	20	32	26.1	5.9
April	52	31	42	40.4	1.6
May	68	44	56	53.3	2.7
June	73	53	63	63.5	-0.5
July	79	59	69	69.1	-0.1
August	77	57	67	67.4	-0.4
September	74	51	63	58	5

[1]Degrees F

NDAWN, Streeter 6NW

Monthly Precipitation for the 2024-2025 Crop Year



Month	Rainfall[1]	30-year Average Rainfall	Deviation from 30-year Average	Percent of 30-year Average	Snowfall[2]
October	0.34	1.6	-1.26	21.3	0
November	2.17	0.59	1.58	367.8	0
December	0.62	0.59	0.03	105.1	0
January	0.28	0.47	-0.19	59.6	2.5
February	0.52	0.46	0.06	113.0	6
March	0.11	0.7	-0.59	15.7	0
April	3.59	1.23	2.36	291.9	10.6
May	2.56	2.79	-0.23	91.8	0
June	2.57	3.62	-1.05	71.0	0
July	5.45	3.35	2.1	162.7	0
August	1.97	2.38	-0.41	82.8	0
September	1.22	2.09	-0.87	58.4	0
Total	**21.4**	**19.87**	**1.53**	**107.7**	**19.1**

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

Shrub encroachment constraints on rangeland production and the efficacy of management strategies

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Summary

Woody plant encroachment is the process in which grasslands shift to an altered, woody-dominated state and is a major threat to North American grasslands. In North Dakota, western snowberry (*Symphoricarpos occidentalis)* is the most widespread encroaching shrub and is often the target of management practices to improve rangeland productivity and diversity. Despite this, the extent that western snowberry encroachment limits forage production remains unclear, and long-term comparative assessments of different management strategies for reducing western snowberry encroachment and promoting plant diversity are lacking. In this ongoing study, we will determine the relationship between increasing western snowberry cover and herbaceous biomass production. In addition, we will provide a systematic comparison of six different management practices to manage western snowberry: 1) spring prescribed fire, 2) fall prescribed fire, 3) spring mowing, 4) spring and fall mowing, 5) herbicide (2,4-D amine), and 6) high-intensity short duration grazing. Over several years of treatment implementation, we will monitor treatment effectiveness in reducing western snowberry, as well as impacts on the native plant and pollinator communities. Overall, outcomes from this study will provide information on how to best manage snowberry while supporting diverse rangeland communities.

Introduction

Over the past 200 years, encroachment of woody plants into grasslands has increased worldwide (Archer et al. 2017; Van Auken 2000). In the United States, the extent of rangeland lost to encroachment annually is similar to the amount converted to cropland (Morford et al. 2022). Woody encroachment reduces plant species richness (Ratajczak et al. 2012), lowers forage production (Morford et al. 2022), increases wildfire risk (Donovan et al. 2020), and interferes with established plant-pollinator relationships (Kettenbach et al. 2017). The northern Great Plains have experienced relatively lower levels of woody encroachment compared to other grassland regions in the United States, but rates of encroachment have been increasing (Morford et al. 2022). In North Dakota, western snowberry (*Symphoricarpos occidentalis*), most commonly known as buckbrush, is one of the most common encroaching woody plants. Western snowberry is a native rhizomatous shrub that can create dense stands, shading out native grasses, and aggressively resprouts following disturbance (Pelton 1953; Weaver and Fitzpatrick 1934). The shrub also has low palatability to cattle, acts as a physical barrier to grazing, and may lower overall forage production for cattle (Bowes and Spurr 1995; Sbatella et al. 2011).

Herbicides, grazing, prescribed fire, and mechanical mowing have all been tested as management methods for western snowberry. Herbicides, such as metsulfuron methyl and 2,4-D, have demonstrated effectiveness in reducing western snowberry cover, though forb production is often reduced simultaneously (Bowes 1991; Bowes and Spurr 1995). High-intensity short duration grazing has shown inconsistent success in reducing western snowberry patch size, with studies reporting varied outcomes (Bailey et al. 1990; Kirby et al. 1988; Reed et al. 2019), while season-long and rotational grazing have not demonstrated any impact (Kirby et al. 1988). Repeated prescribed fire applications have shown decreases in western snowberry cover and stem density (Anderson and Bailey 1980), while a singular spring burn did not reduce snowberry long term (Anderson and Bailey 1979). Mechanical mowing can reduce western snowberry, particularly with repeat treatments timed to target periods of low belowground carbohydrate reserves (Adams 1983). These studies have shown variable success across different management practices, but some of the effective methods negatively impact the native plant community. Further, many studies only monitored short-term impacts of solitary treatments, which may be an inadequate measure of effectiveness given western snowberry's ability to aggressively resprout following disturbance.

Without systematic, long-term comparisons on the efficacy of different management practices in reducing western snowberry and the corresponding impact on plant and pollinator communities, land managers and producers do not have the needed information to choose a management method that best fits their desired outcomes. Furthermore, although graminoid production increases following reductions in western snowberry (Bowes and Spurr 1995), the relationship between western snowberry encroachment and forage production are unclear. This study addresses both questions, providing information on when and how to best manage western snowberry. Our two main study objectives are to 1) establish the relationship between western snowberry encroachment and herbaceous biomass production, and 2) determine the effectiveness of different brush management methods in reducing western snowberry and promoting a robust plant community that can support a diverse and abundant native bee community.

Methods

Site description

The study was conducted in northern mixed-grass prairie at the Central Grasslands Research Extension Center (CGREC) near Streeter, North Dakota. The region is characterized as a humid continental climate with warm summers and cold winters. Historically, the plant community was a mix of native cool-season and warm-season grasses, with lower levels of forbs and shrubs (Limb et al. 2018). Currently, western snowberry and two invasive cool-season grasses, Kentucky bluegrass (*Poa pratensis)* and smooth brome (*Bromus inermis*), have become the dominant plant species (Limb et al. 2018). The 640-acre study pasture is on loamy to thin loamy soils and is split into sixteen 40-acre paddocks.

Constraints on forage production

We measured herbaceous biomass at different levels of western snowberry foliar cover in four paddocks to determine the relationship between western snowberry encroachment and herbaceous biomass production. Three 25m transects spanning a gradient of western snowberry cover were placed within each paddock, for a total of twelve transects per year. At peak biomass (late July, early August), western snowberry foliar cover was visually estimated in 0.25m^2 frames placed every other meter along the transect and biomass was clipped to functional group (grass, forb, shrub). Litter was removed prior to clipping to only include live biomass, and clipped shrub biomass only included within-year growth. Samples were dried at 60°C and weighed to the nearest .05g. Sampling began in 2025 and will continue in 2026.

To examine the existence of a threshold where increasing western snowberry cover begins to reduce forage production, we followed procedures for determining quantitative benchmarks (Webb et al. 2024) and applied a segmented regression with a mixed effects model using the *segmented* package in R (Muggeo 2008; R Core Team 2021).

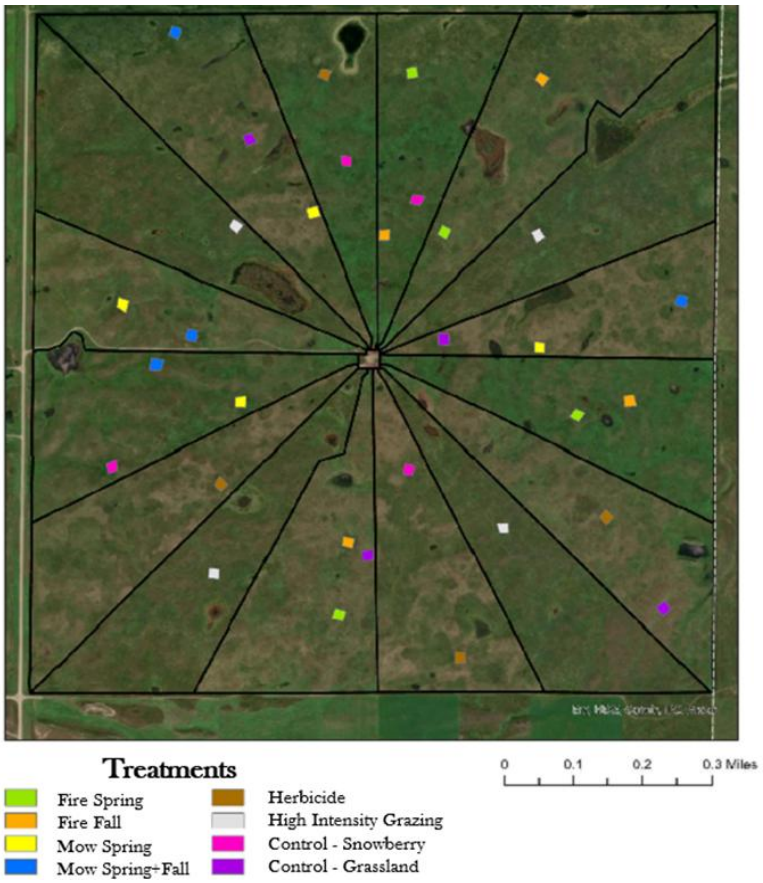

Figure 1. The layout of western snowberry treatment plots within a pasture at the Central Grasslands Research Extension Center. The pasture is 640 acres, divided into sixteen 40-acre paddocks. Each paddock contains no more than three plots. There are six types of treatment plots and two types of control plots, one control with high western snowberry encroachment (Control – Snowberry) and one control without shrub encroachment (Control – Grassland).

Western snowberry management

To compare brush management practices for western snowberry, six practices were implemented as treatments along with two types of control plots – one representative of an encroached grassland site and one of a non-encroached grassland site. All treatments and controls were replicated four times. Treatments were randomly assigned to 25 x 25m plots dominated by western snowberry and will be applied annually for three years (2025 - 2027) (Figure 1). The six treatments are spring prescribed fire, fall prescribed fire, spring mowing, spring and fall mowing, herbicide (2,4-D Amine), and high-intensity short duration grazing (Table 1).

Table 1. Different management strategies implemented in this study with a corresponding description and rationale.

Treatment	**Description**
Spring prescribed fire	Applied in early June to target the drawdown in non-structural carbohydrates after spring growth
Fall prescribed fire	Applied in late August to target the drawdown in non-structural carbohydrates after fruit fill and minimize plant recovery time prior to a killing frost.
Spring mowing	Applied in early June to target the drawdown in non-structural carbohydrates after spring growth.
Spring + fall mowing	Applied in early June and mid-August to target drawdowns in non-structural carbohydrates and minimize plant recovery time prior to a killing frost.
Herbicide (2,4-D Amine)	Applied in mid-June at a rate of 3 quarts/acre. Application timed to target the period where non-structural carbohydrates are transported down into the rhizome system, maximizing herbicide presence belowground.
High-intensity short duration grazing	Twice per year (late spring and early fall), 106 Angus cross cow-calf pair graze a paddock for one week. Grazing is timed to target drawdowns in non-structural carbohydrates and to minimize plant recovery time.

Vegetation sampling

Western snowberry density, western snowberry foliar cover, plant community composition, and vegetation structure were assessed in each plot to evaluate treatment effects on the plant community. Within a plot, 17 – 1m^2 frames were placed every 2.5m along two intersecting transects. Density was assessed by counting western snowberry stems and classifying each stem as mature, new shoot, or dead. Western snowberry cover and plant community composition were determined by ocular plant foliar cover estimations to species.

Foliar cover was measured as the percentage of the ground covered by the vertical projection of aboveground plant material. Vegetation structure was quantified using a Robel pole (Robel et al. 1970). Maximum shrub height and litter depth were measured in each frame. Pre-treatment vegetation sampling occurred in late May and early June of 2025, and annual vegetation sampling occurred in August.

Bee and floral resources

We conducted bee surveys in each plot three times per growing season. Floral visitor surveys, in which the surveyor walks a grid-like path of parallel lines and only captures bees actively pollinating a flower, were used to systematically search the entire plot for 15 minutes. This was followed by a 15-minute visual encounter survey to investigate areas of clumped resources that had the potential to harbor bees that were missed (Tai et al. 2022). The visual encounter survey is a systematic visual search for bees actively pollinating flowers within the plot, where the surveyor meanders throughout a plot to target areas of high activity. Survey times were between 0800 and 1730 hours, with temperatures between 15 and 35 °C and winds below 24 kph (Tai et al. 2022). When a bee was spotted actively foraging a flower, it was netted and identified at the species level (Ulyshen et al. 2023).

Following the bee survey, floral counts were conducted within the plot to establish floral availability. Four parallel lines were walked, each beginning five meters from the edge and measuring approximately 5 meters from the next survey line (Tai et al. 2022). Any flowering plants with a stem that originated within one meter of the walked transect were identified and counted. A flowering plant was defined as any single stem emanating from the ground containing one or more flowering bodies that could feasibly be accessed by a pollinator (Xie et al. 2008). Each species was tallied and recorded as a total number along all four transects.

Preliminary Results

<u>Constraints on forage production</u>

Preliminary results indicate an encroachment threshold at 44.0% western snowberry foliar cover (95% CI: 25.4, 62.6), above which graminoid biomass declines (Figure 2). Prior to this threshold, graminoid biomass was relatively stable at low levels of western snowberry (β_1 = -0.305). Above 44%, graminoid biomass decreased at a higher rate (β_2 = -1.81). Total production, including graminoids, forbs, and shrubs, increased with western snowberry cover (R^2 = .3189, $p < .001$).

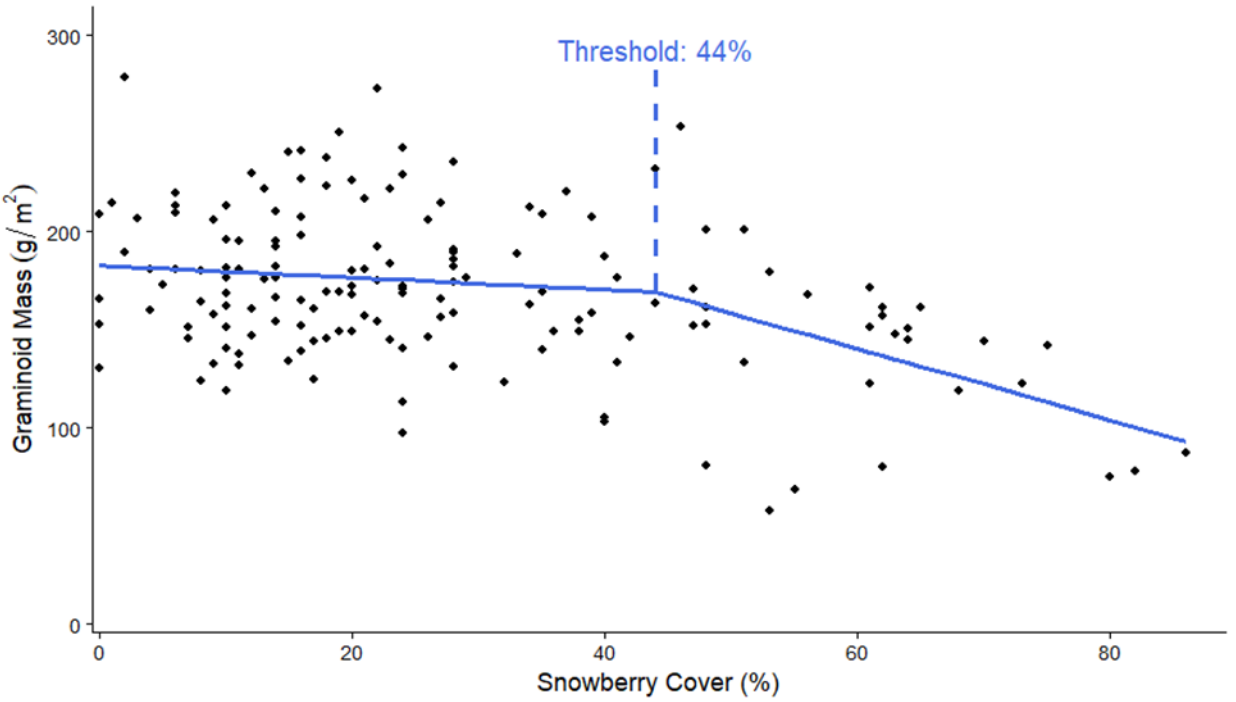

Figure 2. Graminoid biomass at varying levels of western snowberry (*Symphoricarpos occidentalis*) foliar cover with a segmented regression. Preliminary data indicates a threshold at 44.0% western snowberry foliar cover, above which graminoid production is reduced. At cover below 44%, graminoid biomass was relatively stable (β_1 = -0.305). Above 44%, graminoid biomass decreased at a higher rate (β_2 = -1.81).

Western snowberry management

The mean western snowberry cover was 25.7% (SD = 12.3) pre-treatment. Pre-treatment western snowberry density across all study locations was 25.2 mature stems, 4.5 dead stems, and 8.1 new shoots per 0.25m^2. The other common plant species in the study plots were Kentucky bluegrass (63.5% foliar cover) and smooth brome (12.9% foliar cover).

Bee surveys resulted in 438 individuals recorded across all transects throughout the season. Preliminary observations from bee surveys showed a large portion of the bees found were honeybees (*Apis mellifera*) and bumblebee species (*Bombus spp.*). We identified at least one species from the five families Apidae, Andrenidae, Colletidae, Halictidae, and Megachilidae. Early results show higher floral use numbers in high-intensity short duration grazing and prescribed fire plots compared to mowing and herbicide. Post-processing and identification are ongoing.

We found 68 floral species across all transects. Some of the most abundant floral species were yellow sweet clover (*Melilotus officinalis*), Canada thistle (C*irsium arvense*), wild licorice (*Glycyrrhiza lepidota*), leadplant (*Amorpha canescens*), western snowberry (*Symphoricarpos occidentalis*), black-eyed susan (*Rudbeckia hirta*), black medic (*Medicago lupulina*), white heath aster (*Symphyotrichum ericoides*), prairie chickweed (*Cerastium arvense*), and stiff sunflower (*Helianthus pauciflorus*).

Discussion

Preliminary data showed a threshold at 44% western snowberry foliar cover, above which graminoid production decreases at a rate of 1.81 g/m^2 per 1% increase in western snowberry cover. In contrast, total production increased with higher western snowberry cover, as higher western snowberry biomass over compensated for reductions in graminoid biomass. This switch in production from graminoids to woody plants indicates limitations in forage availability for cattle with encroachment, as western snowberry has low palatability to cattle (Bowes and Spurr 1995). Moreover, dense western snowberry stands can physically impede cattle grazing, which suggests the threshold at which cattle operations are affected may occur at foliar cover levels below 44%. These preliminary data will be combined with subsequent biomass clipping data to further refine the estimated threshold of western snowberry foliar cover at which forage production declines.

Brush management treatments will continue to be applied through 2027. Preliminary results indicate lower bee and floral abundance in herbicide and mowing plots, suggesting potential trade-offs between reducing western snowberry and maintaining strong pollinator communities. Plant and pollinator communities will continue to be monitored over the course of the study to allow ecologically meaningful differences to emerge beyond immediate treatment effects and clarify whether early responses persist over time.

Western snowberry is a major woody encroacher across North Dakota rangelands that can aggressively resprout following disturbance, complicating management. In addition, some commonly employed brush management strategies may negatively impact native plant and pollinator communities. This study will provide information on management strategies that reduce western snowberry while simultaneously supporting native plant diversity, floral resources, and pollinator communities. Further, by defining the relationship between western snowberry encroachment and forage production, this study will identify thresholds for implementing control practices before negative impacts on cattle production. In summary, this study will provide guidance on how to balance western snowberry management with the maintenance of healthy plant and pollinator communities, supporting both livestock production and long-term rangeland ecosystem function.

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Fire frequency, burn season, and grazing determine plant community attributes in a Northern Great Plains grassland

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Summary

Fire and grazing are central to the evolutionary history of grasslands and support grassland biodiversity and ecosystem functioning. Contemporary alteration and suppression of these disturbance regimes have compromised the ecological integrity of grasslands globally, including the mixed-grass prairies of the Northern Great Plains (NGP). Fire and grazing support diversity, enhance forage quality and quantity, prevent woody encroachment, limit litter accumulation, and help control invasive species. This study investigates the influence of fire frequency, burn season, and grazing on the plant community. This study used a split-plot factorial design of 96 plots, with one split grazed during the growing season and one split ungrazed. All plots were randomly assigned a season of fire (spring or fall) and a fire-return interval (1 thru 5 years or unburned control). Each treatment combination was replicated four times. Fire implementation began in the fall of 2023 and spring of 2024. All plots were sampled for canopy cover, plant biomass, and floral resource availability. In 2024, forage production was lower in the spring burn treatment compared to the fall burn treatment and unburned control. Conversely, all burn treatments, regardless of fire-return interval, had higher biomass than the unburned control in 2025. Plant community composition differed between treatments, with grazing and burn season impacting composition. Two invasive grasses, Kentucky bluegrass (*Poa pratensis)* and smooth brome (*Bromus inermis*), have generally increased since study onset. However, successive fires without grazing reduced Kentucky bluegrass cover and the combination of fire and grazing showed the lowest increases in smooth brome. Total floral resources were higher in fall burns than spring burns or unburned controls. Additional years of this study will better characterize the effects of different fire-return intervals, fire season, and grazing on the plant community. By monitoring these responses, we can better inform land managers on grazing and fire regimes that target their specific management goals for grasslands.

Introduction

The Great Plains grasslands evolved with fire and grazing (Anderson 2006). Historically, fire occurred across these grassland ecosystems, igniting from lightning strikes or Native American sources (Roos et al. 2018). In the northern Great Plains (NGP), most lightning fires occurred in July or August, while Native American-set fires were more common in spring and fall (Higgins 1984; Higgins 1986). The historic frequency of fire in the region — termed the fire-return interval — is estimated to be between 5 and 15 years (Guyette 2015; Wright and Bailey 1982). These fires removed litter (Vermeire et al. 2018), reduced woody encroachment (Miller et al. 2017), supported plant diversity, stimulated nutritious plant regrowth (Fuhlendorf et al. 2011; Vermeire et al. 2018), and promoted environments and resources for herbivores and

pollinators (Duncan et al. 2021). The high forage quality in post-fire vegetation attracted large grazers such as bison (Fuhlendorf et al., 2009; Starns et al. 2019). This interaction of fire and grazing created a dynamic and shifting mosaic that was high in species diversity and structural heterogeneity (Scasta et al. 2016).

Without historical disturbance regimes, the successional trajectory of grassland plant communities continues towards communities dominated by trees, shrubs, and invasive species. In other words, grasslands are fire-dependent ecosystems and require regular fire to persist over long time periods (Axelrod 1985; DeSiervo et al. 2023). However, fire exclusion has altered the NGP ecosystem, and two invasive cool season grasses, Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*), have become dominant due to significant alterations to long-term disturbance regimes (DeKeyser et al. 2015; Limb et al. 2018). These invasive grasses alter grassland structure and productivity (Duquette et al. 2022), reduce the diversity of native vegetation (Gasch et al. 2020), and change fuel loads for future fire events, leading to increased risk of wildfires (Starns et al. 2019). In addition, the lack of disturbance is allowing woody plant encroachment in the NGP, lowering forage production and altering plant communities (Morford et al. 2022). Fire is an ecologically necessary process for grassland resiliency, and restoring fire regimes is crucial for grassland conservation. However, pre-European fire patterns may no longer be suitable for grasslands with highly altered plant communities and fuel accumulation. Burning windows have shifted (Yurkonis et al. 2019), and pressure from invasive grasses, woody encroachment, and a shift in climate may necessitate fire regimes that differ from historical patterns.

In this study, we monitored canopy cover, forage production, and floral resources to characterize the response of mixed-grass prairie plant communities to different fire-return intervals, fire seasons, and grazing. Our study objectives were to 1) characterize how seasonality, fire-return interval, and cattle grazing affect plant community composition and production, and 2) quantify floral resources across fire-return interval, season of fire, and differing cattle grazing intensities

Methods

Site description

Research was conducted at the NDSU Central Grasslands Research Extension Center (CGREC). CGREC is comprised of mixed-grass prairie, consisting of both cool and warm-season grasses and forbs (Limb et al., 2018). Historically, grass species were dominated by western wheatgrass (*Pascopyrum smithii*), green needlegrass (*Nasella viridula*), little bluestem (S*chizachyrium scoparium*), and blue grama (B*outeloua gracilis*). Grass-like sedges (*Carex* sp.), and many forb species, including sages (*Artemisia* sp.), goldenrods (*Solidago* sp.), and asters (*Symphyotrichum* sp.), were also common (Barker and Whitman, 1988; Kjaer et al., 2025; Limb et al., 2018). However, the cool-season invasive grasses Kentucky bluegrass and smooth brome now dominate the plant community (DeKeyser et al., 2015; Limb et al., 2018).

Study design

The study was conducted using a split-plot factorial design, with 96, 10 x 10m plots. One split plot was grazed using a grazing intensity targeted at approximately 40 percent degree of disappearance from May through November, while the other split plot remained ungrazed throughout the study. Within each grazing treatment, plots were randomly assigned a season of fire (spring or fall) and a fire-return interval (1 - 5 years or unburned control). Each combination of grazing, burn season, and fire-return interval were replicated four times. At the beginning of the study, we burned all fall burn plots in August 2023, and all spring burn plots in May 2024, with controls left unburned. Following the initial burn, plots were burned based on their assigned fire-return interval and season.

Data collection

Relative humidity, wind direction, wind speed, and approximate burn completion were collected for each prescribed burn. To determine burn completion, plots were visually surveyed post-burn to estimate the percentage of area consumed by the fire.

Canopy cover was measured annually on all plots in mid-July to evaluate treatment effects on the plant community. Two transects were placed in each plot with five $0.25m^2$ frames located along each transect. To determine canopy cover, plant cover was estimated at the species level in each frame using a modified Daubenmire cover class (Daubenmire 1959). The modification included assessment for 16 classes (number rankings), each with an assigned percent range.

Beginning in 2024, annual plant biomass measurements were collected on the ungrazed plots during the peak of the growing season (late July, early August). Within a plot, three $0.25m^2$ frames were randomly located, and within-year vegetative growth was clipped and sorted to functional group (graminoids, forbs, legumes, and woody-stemmed plants). Samples were oven-dried at 60°C and weighed to the nearest 0.05g.

Floral resource data was collected during the growing season, between the spring and fall burns. Each plot was sampled once weekly for the total number of flowering plants by species found within the plot. One flowering plant was defined as any stem emerging from the ground with at least one accessible flower. Observers walked in an S pattern to ensure all areas of each plot were covered, and flowering stems were not counted twice. During the same walk, we counted the number of fecal pats in the grazed plots, only recording the pats from the previous week to estimate usage by cattle.

Statistical analysis

We used an analysis of variance (ANOVA) to compare biomass production data between treatments within a year, followed by a Tukey HSD for post-hoc comparisons. Plant community differences between treatments were evaluated using non-metric multidimensional scaling (NMDS) and permutational analysis of variance (PERMANOVA) with a Bray-Curtis distance matrix using the *vegan* package in R (Oksanen et al. 2025; R Core Team 2021). To assess the responses of Kentucky bluegrass and smooth brome, we calculated absolute changes in canopy

cover between 2023 and 2025 and analyzed the data using a linear model with grazing, fire return interval, and burn season as fixed effects.

We analyzed total floral expression using a generalized linear model with a negative binomial distribution, including burn season, fire-return interval, and their interaction as fixed effects. Wald-Chi square tests were used to assess significance.

Results

Burn completion

Burn completion for both the spring and fall burns was consistently higher on the ungrazed plots (spring avg. = 99%, fall avg. = 96.25%) than the grazed plots (spring avg. = 62.5%, fall avg. = 70.5%) in 2025. In the fall burn, when both 1-year and 2-year fire-return interval plots were burned, burn completion was similar between the different fire-return intervals (1-yr avg. = 71%, 2-yr avg. = 70%).

Forage production

Total vegetative biomass was different between treatments ($F_{2,9} = 63.15$, $p < 0.001$) in 2024. The spring burn had lower biomass (2,848 kg/ha ± 126) than both the fall burn (4,372 kg/ha ± 148, $p < 0.001$) and unburned control (4,560 kg/ha ± 64.6, $p < 0.001$; Figure 1). Differences in total biomass between treatments were driven by graminoid biomass ($F_{2,9} = 8.5$, $p = 0.008$; Figure 1). Forb, legume, and woody plant biomass was not different ($p > 0.05$) between treatments in 2024.

The burned treatments, regardless of fire-return interval and burn season, had greater total biomass than the unburned control in 2025 ($F_{1,15} = 5.2$, $p = 0.037$; Figure 2). Graminoid biomass drove the differences in total biomass, as burned plots had greater graminoid biomass than unburned controls ($F_{1,15} = 5.2$, $p = 0.038$) (Figure 2). We found no differences ($p > 0.05$) in graminoid biomass between the spring and fall burn treatments, or 1-year and 2+ year fire return intervals.

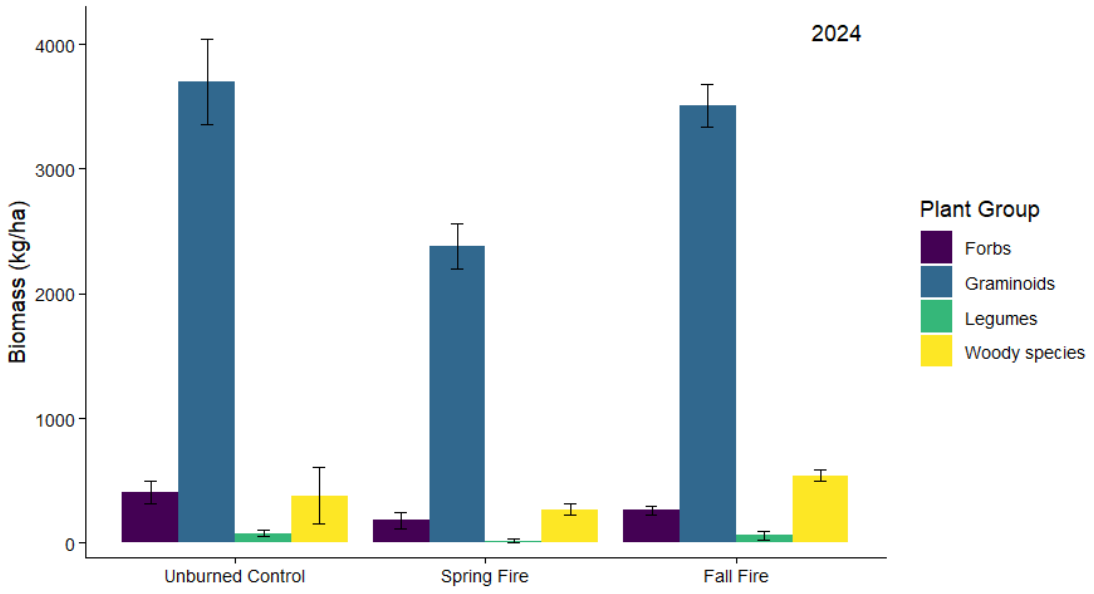

Figure 1. Influence of burn season on plant biomass by functional group in 2024. Mean biomass (kg/ha) was measured for unburned controls, spring burn, and fall burn treatments (n = 4 per treatment). Error bars represent standard error of the mean. All clipped plots were from the ungrazed treatments. Fire-return interval was not compared, as it was the first year following treatment initiation, and treatments receiving prescribed fire had all been burned once.

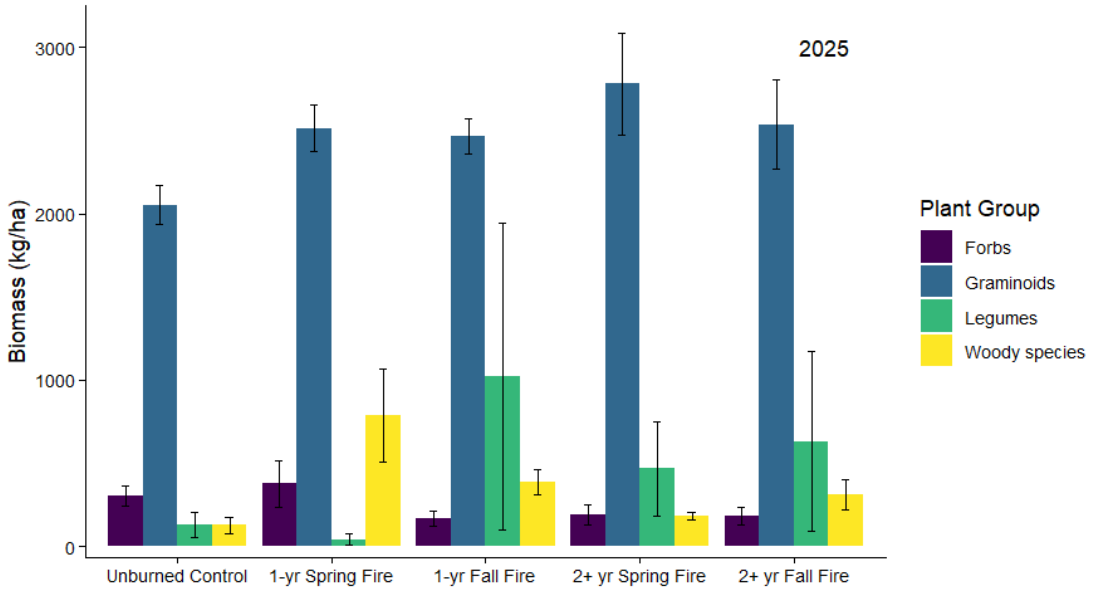

Figure 2. Influence of burn season and fire-return interval on plant biomass by functional group in 2025. Mean biomass (kg/ha) was measured for unburned controls, 1 year fire-return spring burn, 1 year fire-return fall burn, 2+ year fire-return spring burn, and 2+ year fire-return fall burn treatments (n = 4 per treatment). Error bars represent standard error of the mean. All clipped plots were from the ungrazed treatment.

Plant community composition

Plant communities differed between the grazed and ungrazed treatments, with grazed plots exhibiting a higher degree of variation than ungrazed plots ($F_{1,90}$ = 8.7, p = 0.004) (Figure 3). Kentucky bluegrass and smooth brome had the highest average canopy cover across all treatments. Compared to pre-treatment data, Kentucky bluegrass cover had increased more in the grazed plots than the ungrazed plots across both fire season and fire frequency ($F_{1,90}$ = 16.1, p <0.001) (Figure 4). The only treatments to show a decrease in Kentucky bluegrass cover were both the spring and fall 1-year fire-return interval in the ungrazed treatment (Figure 4). Smooth brome canopy cover has increased across all treatments since the study began. The combination of grazing with fire, regardless of burn season or return interval, showed lower increases in smooth brome than grazing alone (t_{86} > -3.43, p < .004) (Figure 4).

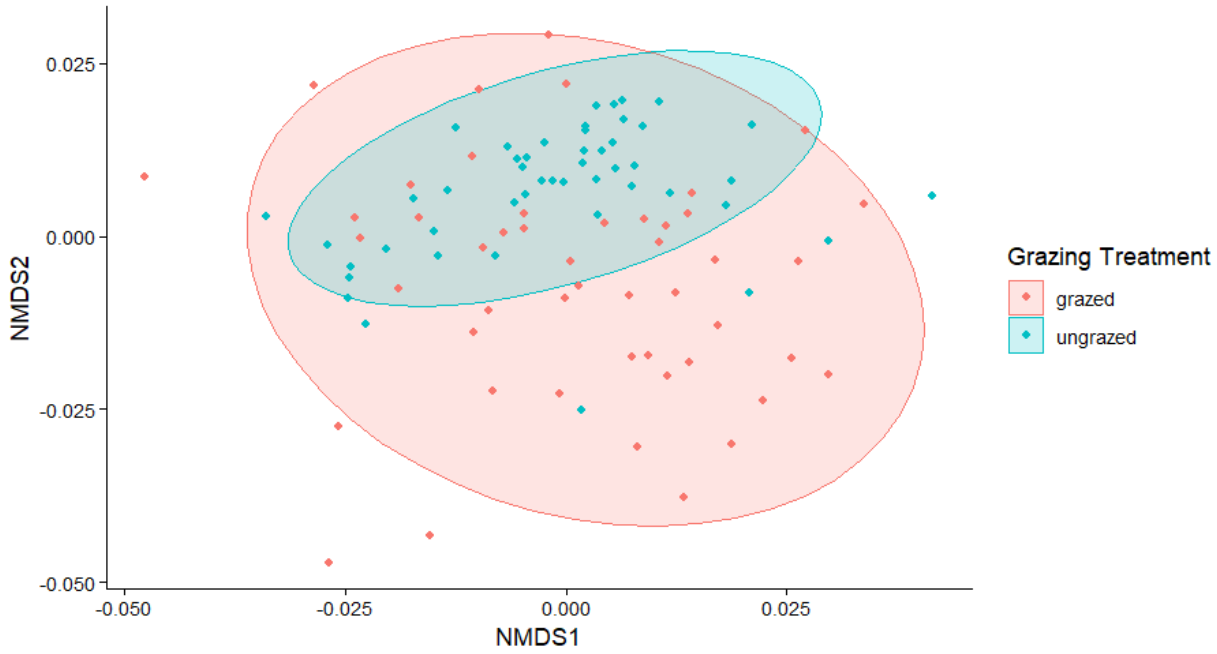

Figure 3. Plant community composition ordination for 2025 (stress = 0.18). The ordination uses non-metric multidimensional scaling with Bray-Curtis distances. Ellipses represent 95% confidence intervals around grazing centroids. Points represent individual plots, shaded based on grazing treatment.

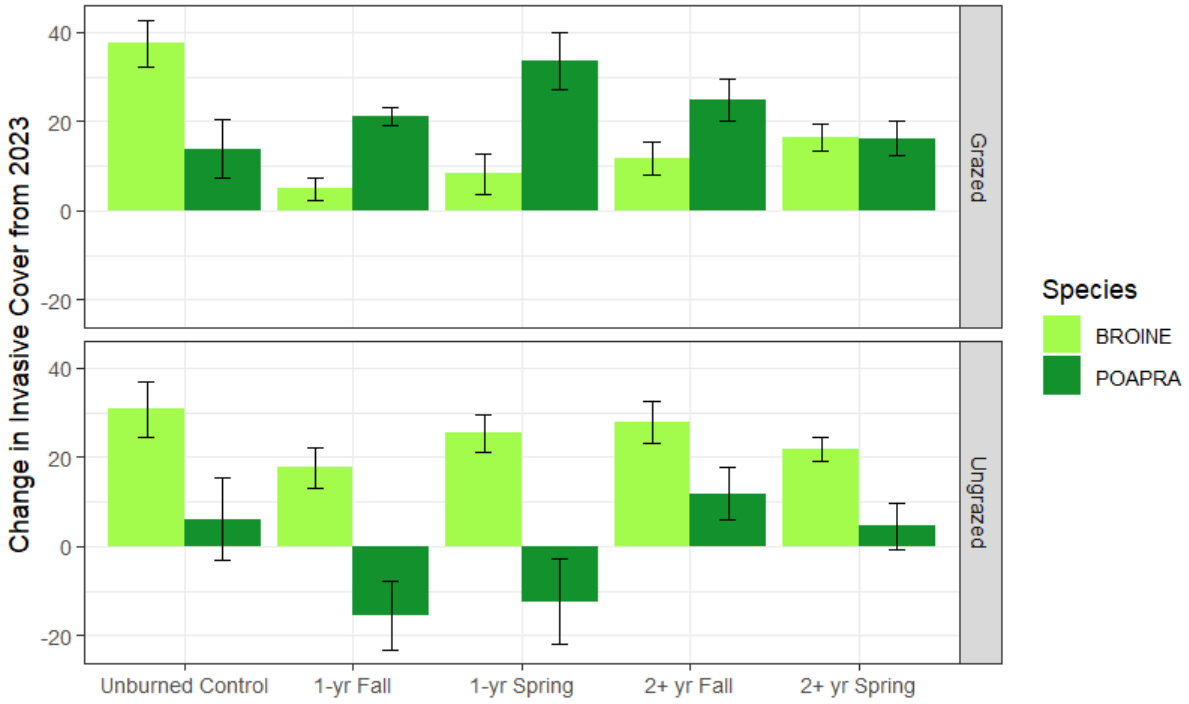

Figure 4. Change in Kentucky bluegrass (Poa pratensis - 'POAPRA') and smooth brome (Bromus inermis - 'BROINE') canopy cover between 2023 and 2025. Data from 2023 was collected prior to treatment initiation while 2025 data was collected following two years of treatment application. Bars are grouped by fire season (spring, fall, control) and fire-return interval (1-year, 2+ years, control). Error bars represent standard error of the mean.

Floral Resources

Peak floral resource availability for both native and non-native species was in July and August for all treatments (Figure 5). Across the entire study area, there was no difference in floral productivity between native and non-native species ($\chi^2 = 0.81$, $p = 0.37$). The season of burn influenced floral expression ($\chi^2 = 17.21$, $p < 0.001$), with fall-burned plots demonstrating higher floral expression (12,886 flowers ± 1990) than plots burned in spring (6,105 flowers ± 943) or unburned controls (6,693 flowers ± 1350).

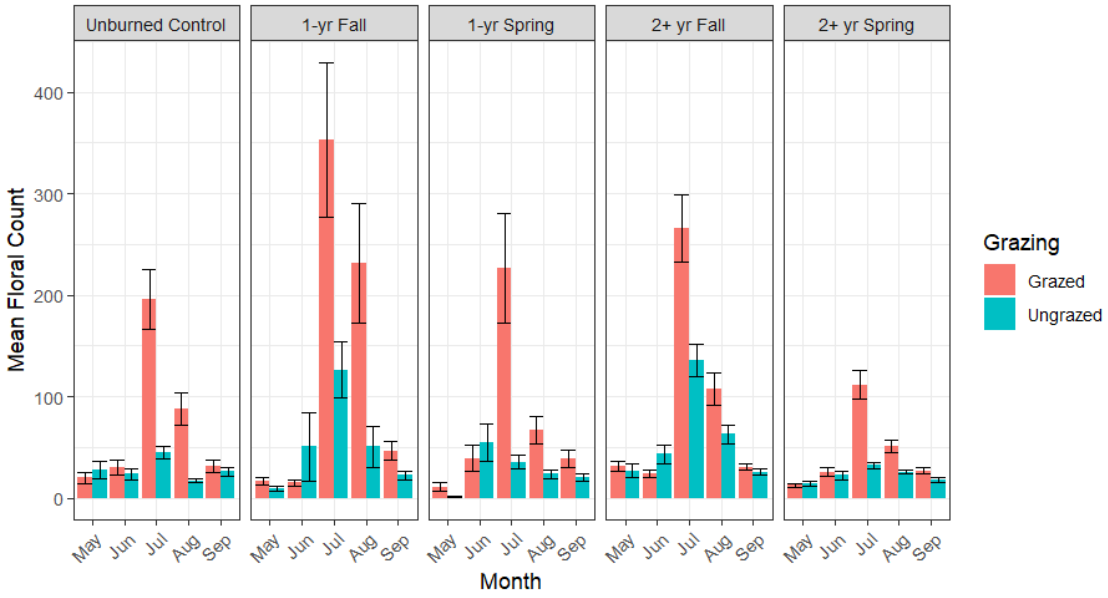

Figure 5. Mean floral count by month for 2025, grouped by the combination of fire season (spring, fall, control) and fire-return interval (1-year, 2+ years, control). Red bars represent grazed treatments, and blue bars represent ungrazed treatments. Error bars represent standard error of the mean.

Discussion

Biomass production was different between 2024 and 2025. The spring burn treatments had lower herbage production than the unburned control or fall burn treatments in 2024, indicating grass production was reduced by spring burning. However, the unburned control produced less vegetative biomass than any burned treatments in 2025, regardless of fire-return interval or fire season. Interestingly, the spring fires on a 1-year return interval did not show reduced production relative to any other treatments. Precipitation was above the long-term average in both 2024 and 2025 and did not appear to affect the biomass differences between treatments. However, the spring prescribed burns occurred sixteen days earlier in 2025 compared to 2024, suggesting that spring burns may not reduce within-year forage production if conducted early in the growing season. In conjunction with increased forage quality following fire (Wanchuk et al. 2024), these results would indicate that spring burns should increase livestock production due to higher quality and increased forage production, as long as the burn occurs early in the spring. Biomass clippings will continue over the course of the study to monitor whether the trends observed in 2024 or 2025 persist, and how timing of spring burns affects forage production.

Plant community responses appear to differ based on grazing treatment. While both grazed and ungrazed treatments had similar plant communities pre-treatment, following two years of grazing there was a much greater range of plant communities exhibited in the grazed plots. This is likely due to selective grazing by cattle. Cattle are highly attracted to burned areas (Vermeire et al. 2004), and heavy cattle activity in grazed treatments could create distinct plant communities. Canopy cover of two major invasive grasses, Kentucky bluegrass and smooth brome, was influenced by grazing treatment. Smooth brome showed the lowest cover increase

in grazed and burned plots, suggesting that these two disturbances are needed in combination to control smooth brome invasion. Kentucky bluegrass only showed a reduction in cover relative to pre-treatment data in ungrazed plots with a 1-year fire return interval (2 consecutive years of burn). This indicates it may take successive years of fire to reduce Kentucky bluegrass cover, given the high level of invasion in the region.

The greatest floral resources were observed in July and August, when many grassland species exhibit peak flowering. Our results showed the highest floral resources in the fall burn plots when compared to both the spring and unburned plots, which could point to fall burning as a management strategy for promoting floral availability. Varying fire-return intervals demonstrated no impact on floral resources, suggesting differences may develop over longer timescales. Since fire and grazing interactions are known to have both long and short-term effects on the ecosystem and plant community (Collins and Calabrese 2012; Gordijn and O'Connor 2021), several years of data across multiple different fire intervals will give a clearer picture as to how floral resources respond to fire and grazing.

Conclusion

Fire and grazing have complex interactions that affect herbage production, species composition, and floral resources. While there are trends in vegetation response to various treatments, grassland plant communities responded differently to different fire and grazing treatments. This may suggest tradeoffs in management strategies, with some benefitting one aspect of grassland communities while having neutral or undesirable effects on others. On the other hand, fire has long-term impacts that emerge over years of treatment. As the study continues and all fire-return intervals are implemented, we expect greater differentiation between treatments. By continuing to monitor the effect of different fire and grazing regimes on the plant community, we can characterize these long-term effects of different disturbance regimes. This information can be used to inform fire and grazing management and conserve imperiled grassland ecosystems.

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Using Virtual Fencing to Support Livestock Production and Conservation of Grassland Species

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Summary

Virtual fencing systems utilize digital fence boundaries and global positioning system (GPS)-enabled collars or ear tags to manage movement of grazing animals. Auditory and electrical stimuli are used to keep individual animals within the VF-designated boundaries. While VF technologies are commonly evaluated to determine their effects on livestock production outcomes, an added benefit may be their ability to promote heterogeneity-based grazing patterns. These grazing patterns can help combat biodiversity loss on working landscapes. However, successful grazing management for heterogeneity requires effective cattle containment throughout the grazing period. The objective of this study was to determine VF's efficacy in containing cattle during patch grazing. In 2025, VF collars were deployed at the Central Grasslands Research Center (CGREC) near Streeter, North Dakota. Cattle with VF collars grazed for 133 days between June and October. Four pastures were divided into quadrants using VF and cattle were permitted to graze ¼, then ½, then ¾ of the pastures, excluding ¼. This pattern created a gradient of disturbance by varying grazing intensity over space and time, impacting vegetation structure. Collars sent location data every ~15 minutes, and containment within the VF was calculated as the percentage of all collar location signals from within the VF boundary. The virtual fence containment rate was 74.7% for all cattle (n = 98), ranging from 69.9% to 87.3% between rotations and 57.0% to 86.3% between replications. Pasture, rotation, and individual differences in containment rate were all highly significant ($P < 0.001$), with rotation having the largest impact. While virtual fence containment was effective enough to produce a visual difference in forage production, it did not have statistically significant impacts on forage production or utilization. Average daily gain (ADG) for treatment cows was 0.136 lbs higher than the continuously grazed control cows ($P = 0.01$). ADG for the calves of treatment cows was 0.100 lbs lower than the calves of control cows ($P = 0.58$).

Introduction

Virtual fencing could be an effective tool to implement patch grazing in extensive grazing systems to create heterogeneity, benefiting the conservation of grassland species on multi-use rangelands. These multi-use rangelands are important for maintaining agricultural productivity and are also important habitats for plants, pollinators, birds, and other wildlife. While livestock production and conservation are often viewed as conflicting in their goals, rangeland disturbance via intentionally managed livestock grazing can provide critical benefits for grassland health, biodiversity, and ecosystem services (Derner et al, 2009). Because livestock grazing has such an influential impact on rangeland health and species composition, equipping ranchers with tools and information can help them to graze their livestock in an environmentally-beneficial manner. This is especially important in North Dakota and the Great Plains at large, where the management of private, multi-use land plays a crucial role in conservation efforts.

Virtual fencing is a wireless technology that can be used to manage grazing livestock without physical fencing or in-person herding. Livestock are equipped with GPS-enabled devices in the form of a collar or a smart ear tag. Livestock managers upload or draw their grazing boundaries in the virtual interface, which allows users to track animal location, create and modify virtual pasture boundaries, and herd animals from their computer or mobile device. With this tool, livestock managers can more easily implement grazing plans that enhance biodiversity and maximize ecosystem function and services while also improving forage utilization and future forage availability.

Heterogeneity-based grazing patterns, or those that vary physical disturbance, can enhance biodiversity on working landscapes. Patch grazing is a heterogeneity-based grazing pattern where livestock are allowed access to one section, or "patch," of a pasture, then are granted additional access to another section of pasture while maintaining access to the first, and so forth. Because each pasture section is then grazed for a varying amount of time and at different stages in the plant growth cycle, patch grazing creates variation in the vegetation structure across the pasture and —combined with adequate stocking rates—prevents overgrazing. This varied vegetation structure provides a more diverse habitat for important invertebrates, birds, and other wildlife (Borer et al, 2012; van Klink et al 2015).

Virtual fencing has the potential to be a useful tool for livestock managers to more intensely manage their herds' grazing patterns to both improve forage utilization and environmental health. The objective of this study was to 1) determine VF's efficacy in containing cattle during patch grazing and 2) understand it's impact on forage production, forage utilization, and livestock production.

Methods

This study utilized the Vence virtual fence system as its virtual fence technology for the 2025 grazing period. Four trial replications per year were conducted at Central Grasslands in 2023, 2024, and 2025. Four herds of 20-29 cows were fitted with Vence collars and grazed for an average of 150 days between June and October each year. These Vence collars are battery powered and contain GPS and radio frequency transceiver capabilities. Prior to beginning the study, cattle were placed in a small training pasture for four days in accordance with the Vence system training protocol. This training period ensured that cattle interacted with the virtual fence boundaries often enough to associate the electrical cue with a physical boundary and to learn the directionality of the auditory cue. Cattle were then placed in the four trial pastures. These one-quarter section (160 acres) pastures had physical fencing along the outer perimeter of the pasture and had centralized water access. Within each pasture, virtual fences were created to implement patch grazing. Cattle were assigned to herds by their Vence collar number. Each herd was then assigned a management plan, where virtual fences were scheduled to grant access to set patches according to the grazing plan (Figure 1).

Collars contain a radio frequency transceiver and communicated location data with a solar-powered gateway tower, centered between clusters of pastures at each study site, through long-range wide area network (LoRaWAN) transmissions every 15 minutes. These devices utilize GPS location data to determine the position of the animal and administer relevant auditory and

electrical cues to the animals as necessary. Management cues were administered first as auditory tones when an animal entered the predetermined 49-foot warning zone to let them know they were approaching a virtual fence. The cue then shifted to an electrical cue of 800 volts if the animal crossed over the virtual fence into the 246-foot shock zone.

Initially, cattle were permitted to graze one quadrant of their assigned pasture before gaining access to the second and third quadrants in average 50-day intervals (Figure 1). Grazing period intervals were determined by visually-determined forage availability approaching 50 days since the start of the grazing period to account for differences in forage availability across pasture quadrants. In subsequent years, pasture quadrants will be grazed in accordance to a Heavy > Moderate > Low > Rest grazing intensity rotation. This patch grazing pattern was designed to create a gradient of disturbance by varying grazing intensity over space and time, ultimately impacting vegetation structure and therefore insect and bird populations.

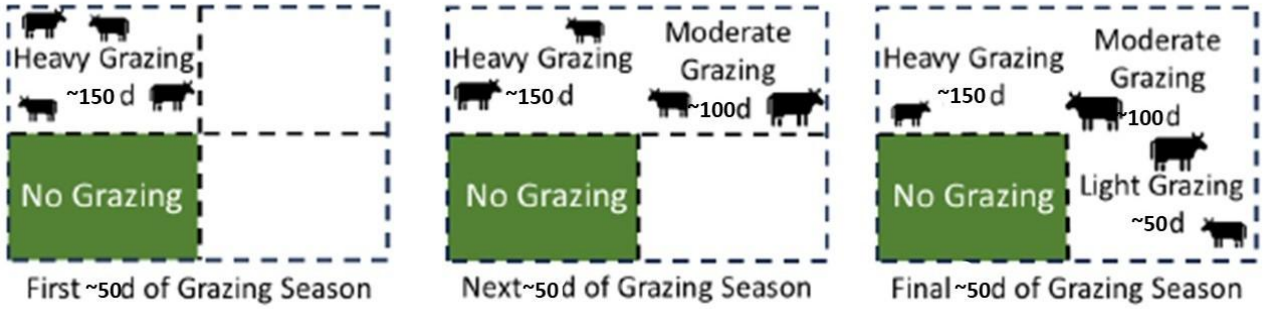

Figure 1. Cattle patch grazed ¼, then ½, then ¾ of the pasture. Cattle were considered contained if they were within the approved quadrants and escaped if they crossed out of the virtual boundary.

Containment rate was defined as the percentage of all location data points within the designated virtual fence boundaries during the grazing period. Containment rates were calculated for each collared animal, pasture, virtual fence boundary, rotation period, and overall.

At one site in each pasture quadrant, five 0.25m^2 quadrats were clipped within a grazing exclosure to calculate forage production (kg/ha). An additional five quadrats were clipped outside the exclosure at half of the sites to calculate forage utilization at the end of the grazing season. All grasses and forbs within a five-meter frame were clipped, dried, and weighed. Dry weights were converted to pounds per acre. Forage utilization for those pasture quadrants that had exclosure control values was calculated as 1-((treatment forage production)/(control forage production)). Differences in forage production between treatment quadrats with controls and those without for each pasture were measured and used to calculate forage utilization for those sections.

Lastly, pre- and post-grazing weights were collected for collared cows and their calves, as well as cows and calves that were continuously grazed during the same period, to determine whether patch-grazing managed via virtual fence had any impact on livestock production. This data was used to calculate average daily gain for the animals and compared against the average

daily gain of cow/calf pairs grazed continuously during the study period in neighboring pastures at CGREC.

Results

The virtual fence containment rate was an average of 74.7% across study sites at CGREC for 2025. Between study sites, the virtual fence containment rates ranged from 57.0% to 86.3% for the entire grazing period. The average containment rate across study sites was 76.1% for the first rotation period, 69.8% for the second rotation period, and 87.3% for the third rotation period. Individual animal containment rates ranged from 47.9% to 100%. Pasture, rotation, and individual animal differences all had a significant impact on containment rates between treatment groups ($P < 0.001$). The containment rate for the grazing period is similar to average containment rates for 2023 and 2024, but the containment rates varied between years for grazing rotation periods. In 2023, containment was 84.3% overall, 90.2% in Q1, 85.6% in Q2, and 73.1% in Q3. In 2024, containment was 77.7% overall, 68.6% in Q1, 79.8% in Q2, and 81.4% in Q3 (Figure 2).

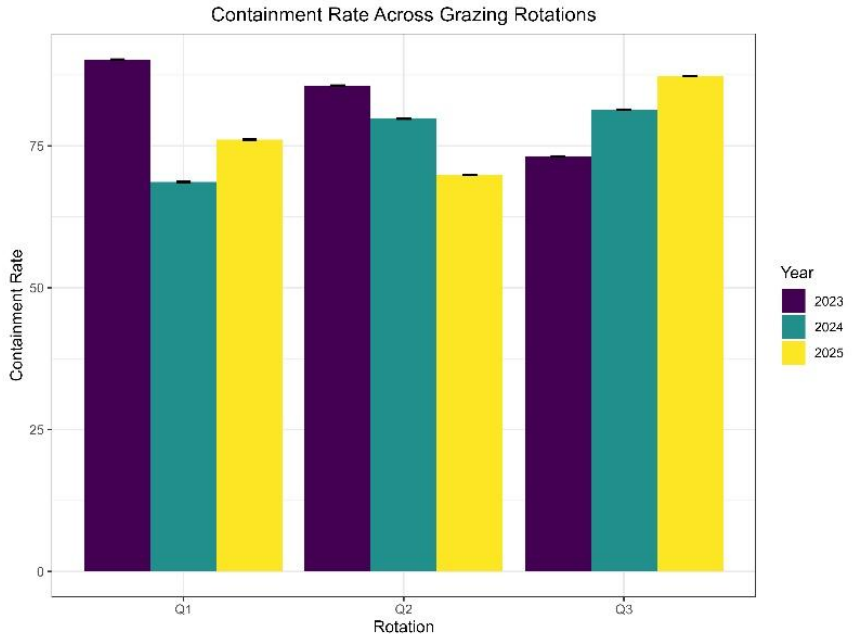

Figure 2. Containment rate for each grazing rotation for each year. $P < 0.001$.

While virtual fence containment was effective enough to create differences in forage structure, forage production was not different between patches. Average forage production was 3,285 kg/ha under heavy grazing intensity, 3,007 kg/ha under moderate grazing intensity, 3882 kg/ha under low grazing intensity, 2,252 kg/ha where rested, and 6,114 kg/ha for control sites (Figure 3). Average forage utilization for grasses was 47.4% under heavy grazing intensity, 51.8% for moderate grazing intensity, 39.0% for light grazing intensity, and 36.7% for the rested patches (Figure 4). Note that calves were able to graze in the rested quadrants and there were instances of cattle escaping the virtual fence to graze in rested quadrants, impacting utilization.

All forbs utilization rates across treatments were negative (-6.8% to -327.4%), as many of the control sites were crowded with grasses and had very few or no forbs compared to grazed patches.

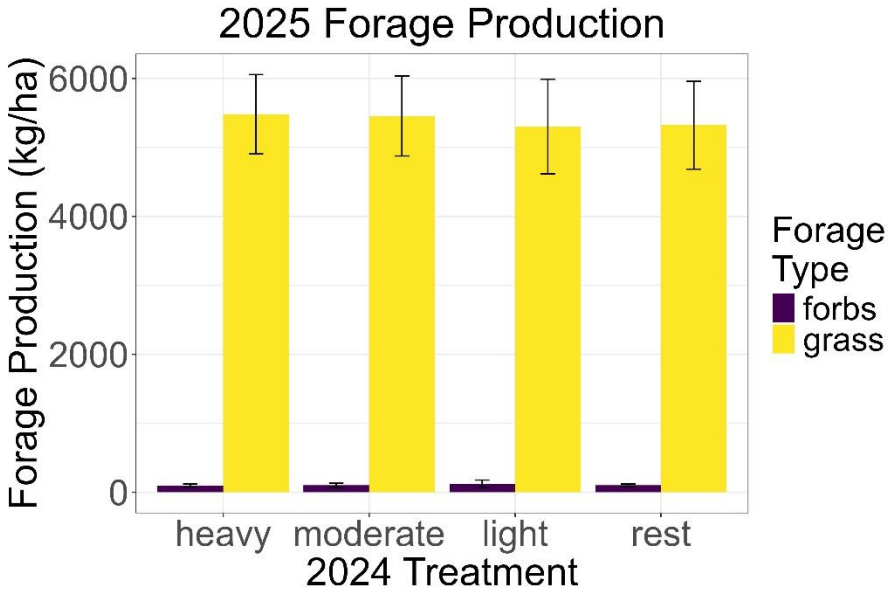

Figure 3. Average forage production for 2025. Error bars represent standard error. P > 0.05.

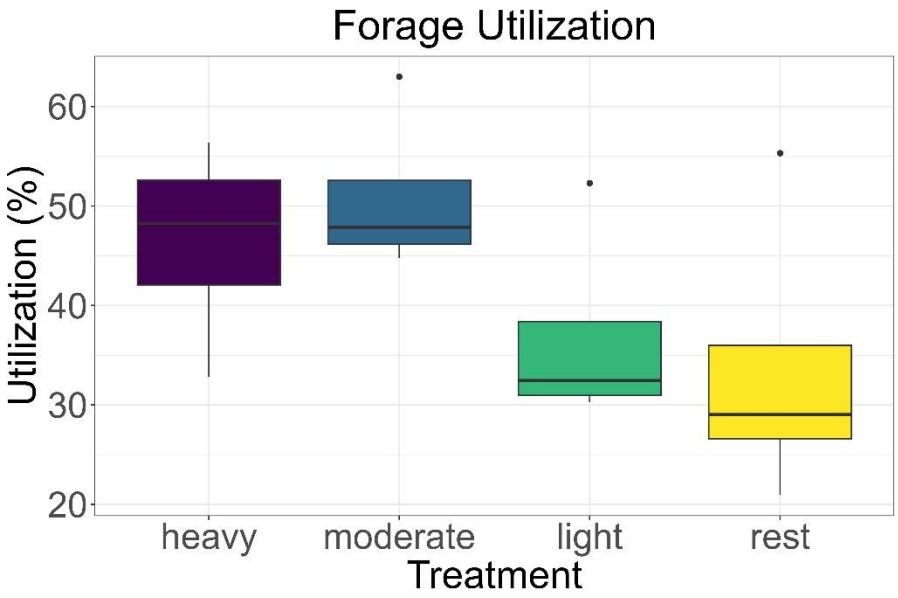

Figure 4. Average forage utilization for 2025. P > 0.05

Average daily gain (ADG) for treatment cows was 0.136 lbs higher than the control cows (P = 0.01). ADG for the calves of treatment cows was 0.1 lbs lower than the calves of control cows (P = 0.58).

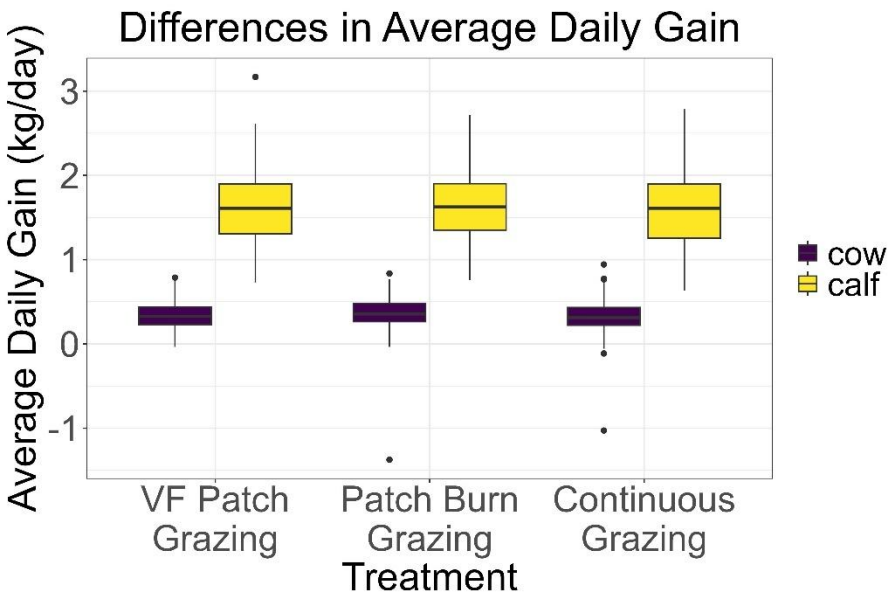

Figure 5. Average daily gain for 2025. P = 0.01 for cows. P > 0.05 for calves.

Discussion

The results of this study add to the growing body of work investigating how virtual fence technology can be used in livestock production, including to improve conservation outcomes and implement more intensive grazing systems remotely. It is unique in that it uses virtual fence technology to apply a patch grazing management strategy to improve vegetation structure in an extensive grazing system. Containment rates were relatively high throughout the data collection period but were not sufficient for herd management without using a physical fence for the outer perimeter. Multiple software updates during the second grazing rotation in 2025 likely contributed to lower containment rates in 2025. The lower containment rate for the second rotation period is likely due to multiple software updates that occurred during this time period as software updates can impact collar efficacy. However, this potential explanation does not provide insight into the containment results observed in 2023 and 2024. Another potential source of decreased containment rates across the entire data collection period may be due to social interactions between cow-calf pairs. Calves were not equipped with virtual fence collars and therefore could graze the entire pasture unrestricted. It is possible that cows followed- and remained with their calves outside of the fence boundary long enough for the virtual fence management cues to cease after the three-minute cue threshold. Further work is needed to investigate this potential explanation for lower containment rates exhibited by some animals. The treatment group did have a statistically significant higher ADG than the control group. Additional data are needed to further investigate the environmental and behavioral sources of variation, as well as to determine if patch grazing managed via virtual fence can significantly impact forage production, utilization, and composition.

Conclusion

In this study, virtual fence technology was shown to successfully contain cattle through a patch grazing management plan on rangeland with 75% efficacy in a grazing season, with pasture, grazing rotation, and individual differences all having significant impacts on virtual fence technology's containment success. Taking this information, this study finds that virtual fence technology is an effective tool for remotely managing cattle in a patch grazing system on rangeland, as it successfully contained cattle in changing virtual fence boundaries. Additional research is needed to better understand its impact on forage production, forage utilization, and livestock production.

Additional replications will be conducted at these sites for the 2026 and 2027 grazing seasons. More research is needed to determine virtual fence technology's capacity to effectively implement patch grazing and other intensive grazing systems in rangeland settings outside of North Dakota and the subsequent impact on rangeland biodiversity.

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Impacts of grazing technologies within intensive strip grazing systems

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Summary

Various novel technologies are available to aid intensive grazing strategies by managing grazing livestock. These technologies include virtual fencing and automated gate openers. Virtual fencing utilizes GPS enabled devices worn on livestock which produce audible and electrical cues to restrict cattle from areas without physical fencing. Automated gate openers allow livestock access to new grazing allotments without manually opening gates and moving livestock. This study aims to determine the efficacy of virtual fencing and automated gate openers on the containment of grazing cattle under strip grazing management; as well as evaluate the impacts to forage utilization and stocking rates by implementing intensive strip grazing management practices compared to continuous grazing. Fields at three locations were seeded with a season long annual forage mix and divided into four grazing treatments including virtual fencing (VF), automated gate openers (AUTO), manual poly-wire (MAN), and continuous graze (CONT). The VF, AUTO, and MAN treatments were subdivided into eight sections to allow intensive strip grazing management. Cattle location was recorded from GPS-enabled virtual fencing collars and used to determine cattle containment within allotted strips. Forage utilization rates were calculated following the removal of cattle. While containment rates differed by year, containment rates did not differ (P = 0.20) by grazing technology. Containment rates were 80% in AUTO, 83% in MAN, and 86% in VF in 2024, and 90% in AUTO, 93% in MAN and 94% in VF in 2025. Utilization rates did not significantly (P = 0.57) differ by grazing treatment. While stocking rates did not statistically differ (P = 0.35) between treatments throughout the study, intensive grazing strategies provided up to an additional 18 grazing days compared to continuous grazing.

Introduction

Grazing management has a major impact on grazing efficiency of grazing livestock. Intensive grazing practices, such as strip grazing, can increase grazing efficiency by increasing forage utilization and stocking rates of pastures (Blount et al., 1991; Davies-Jenkins et al., 2024). These practices subdivide pastures to increase stocking densities, which can increase grazing efficiency by reducing grazing selectivity and trampling waste, creating a more homogeneously grazed pasture (Barnes et al., 2008). Subdivision of pastures and increased movement of cattle within pastures increase labor and fencing infrastructure requirements, which may serve as barriers to implementation of intensive grazing practices. Various grazing technologies are available to producers and can serve as valuable grazing management tools. These technologies include automated gate openers and virtual fencing (VF). Automated gate openers modify electric fencing gates with programmable latches, allowing livestock access to new pastures on set intervals. Virtual fencing removes the need for interior fencing with GPS-enabled devices

worn on cattle. Virtual fencing devices utilize audible and electrical stimuli to alert and deter livestock from remotely set boundaries. These technologies may be able to reduce the in-field labor requirements of intensive grazing, creating more flexible and adaptable grazing management.

Virtual fencing is already being used to implement more intensive grazing practices within rangeland grazing systems. Virtual fencing has demonstrated the ability to make stocking densities dynamic, either increasing or reducing grazing intensity within certain areas of pastures depending on conditions (Campbell et al., 2019; Boyd et al., 2023). Currently there is little research investigating the impacts of grazing technologies within smaller intensive grazing systems. Literature using virtual fencing for smaller scale intensive grazing practices have used either larger allocations or shorter grazing durations (Hamidi et al., 2023; Harland et al., 2025). Effective, alternative uses for VF outside of the rangeland setting could also help make VF more cost effective compared to physical fencing (Hoag et al., 2025).

Grazing technologies could prove to be effective tools to implement intensive grazing practices within smaller scale systems, such as integrated crop livestock systems, grazing stockpiled forages, or bale grazing. Grazing technologies will require more precision to achieve intensive management goals within these smaller systems. The objectives of this on-going study are: 1) determine the efficacy of grazing technologies within small-area strip grazing 2) evaluate the effects of intensive strip grazing on forage utilization and stocking rates compared to continuous grazing practices.

Materials and Methods

Three fields 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 (BCRTC) in Fargo, ND were established with a season long annual forage mix consisting of forage oats (*Avena sativa*), sorghum-sudangrass (*Sorghum × drummondii*), forage pea (*Pisum sativum*), and pasja brassica (*Brassica rapa × napus*). Seeding rates were 20 lbs/ac forage oats, 10 lbs/ac forage pea, 4 lbs/ac sorghum-sudangrass, and 1 lb/ac pasja brassica. 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 automated gate openers (AUTO), strip graze with manual poly-wire gates (MAN), or continuous grazing (CONT). Each strip graze paddock was subdivided into eight sections and managed with the assigned grazing technology to create grazing strips ranging from 0.5-1 acre. Water and mineral supplement were provided for each paddock. Forage utilization rates were determined by clipping eight 0.5 m^2 quadrats within each paddock and comparing remaining forage biomass to a control plot.

All cattle were fitted with VF collars for GPS tracking and trained to audible and electrical cues before being randomly assigned to one of four treatments. Only cattle assigned to VF paddocks were actively managed with VF, and auditory and electrical cues were disabled for cattle in all other treatments. Stocking rates were adjusted at each location to sustain approximately one week of grazing duration in each strip (Table 1). 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 for each grazing technology. Cattle within AUTO and MAN paddocks were considered contained if the GPS location was within the assigned or previous strip during that period. Cattle within VF paddocks were considered contained if the GPS location was within the auditory boundary or assigned strip during that period.

Table 1. Cattle class and grazing head per paddock at Central Grasslands Research Extension Center, the Beef Cattle Research and Teaching Center (BCRTC), and Carrington Research Extension Center (CREC) in 2024 and 2025.

			Head per Paddock[1]			
Location	**Year**	**Cattle Class**	**AUTO**	**MAN**	**VF**	**CONT**
CGREC	2024	Heifer	10	10	10	10
	2025[2]	Heifer	7	7	7	6
BCTRC	2024	Heifer	9	9	9	9
	2025[3]	Heifer	8	9	8	9
CREC	2024	Cow	11	11	11	11
	2025	Cow	10	10	10	10

[1]AUTO = automated gate, MAN = manual polywire, VF = virtual fence, CONT = continuous graze.
[2]Rates differed due to differences in productive area within the CONT paddock.
[3]Rates differed due to heavy weed establishment in the VF and AUTO paddocks.

Cattle performance was measured using pre- and post-graze weights to determine average daily gain. Cattle at the CREC location were not included for performance data due to differences in cattle class. Heifer rate of gain at CGREC and BCTRC were compared across grazing treatments as well as strip versus continuously grazed paddocks.

Results and Discussion

Livestock containment rate did not significantly differ ($P = 0.20$) between grazing technologies both years. In 2024, mean strip containment rate was 80% in AUTO, 83% in MAN, and 86% in VF. In 2025, mean strip containment rate was 90% in AUTO, 93% in MAN, and 94% in VF (Figure 1). While efficacy differed ($P < 0.01$) each year, efficacy rates across technologies indicate virtual fencing and automated gate openers are effective tools for managing grazing livestock. A treatment by strip tendency was observed ($P = 0.08$), with containment rates differing by allotted strip and technology used during the grazing season (Figure 2). The largest reduction in containment rates occurred during the fourth and fifth grazing strips. Cattle gained access to these strips in mid to late October which may be reflective of reduced forage quality increasing preferential grazing behaviors as the forage reaches senescence. This temporary drop in containment efficacy across treatments is likely more reflective of the difficulty of completely

containing livestock with temporary fencing under low forage quality and availability conditions rather than the technology itself.

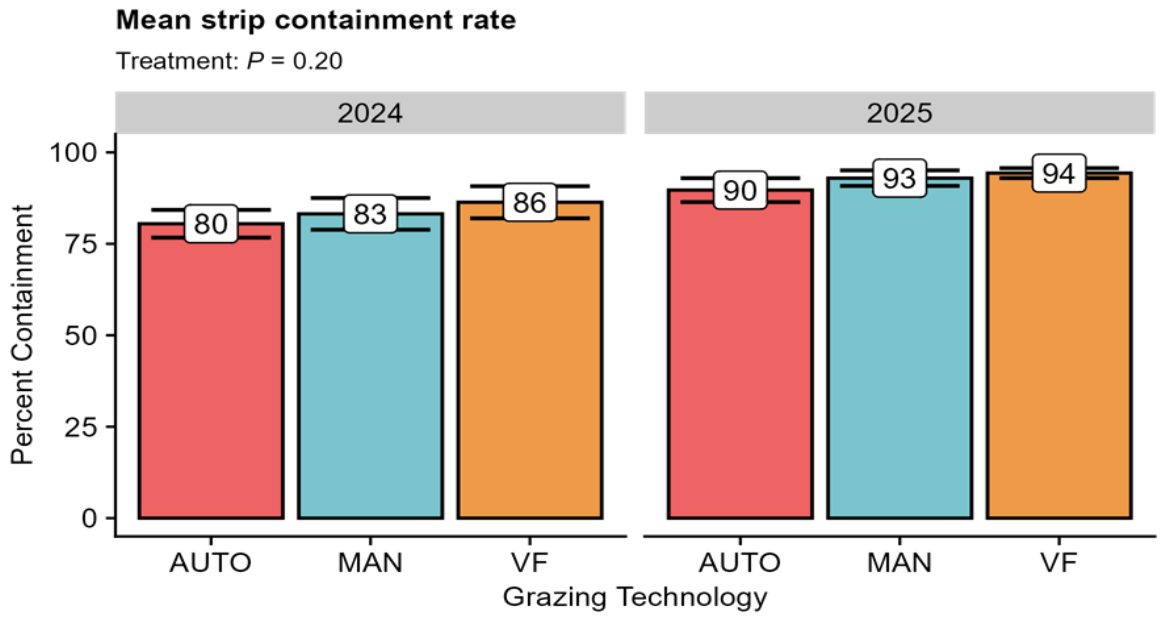

Figure 1. Mean livestock containment rates for each grazing technology by year. Containment rates were averaged within each sequential strip. AUTO = automated gate, MAN = manual polywire, VF = virtual fence.

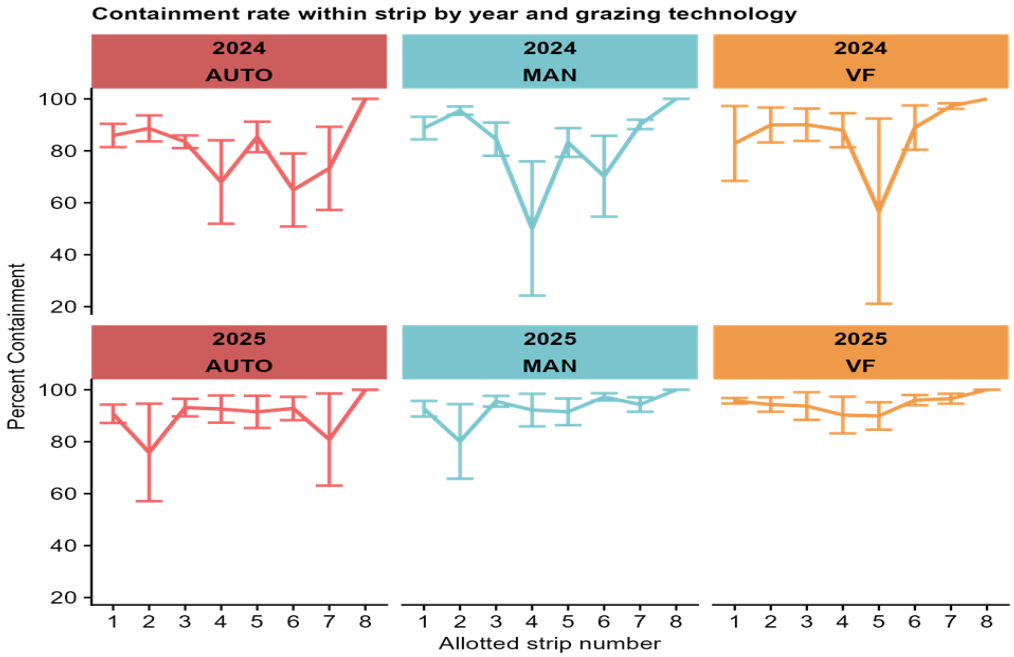

Figure 2. Mean cattle containment efficacy rates by strip number within each grazing technology treatment. Percentage of points contained within the assigned strip was averaged throughout the duration the strip was actively grazed. (P = 0.08). AUTO = automated gates, MAN = manual polywire, VF = virtual fence.

Forage utilization rates varied each year but did not differ (P = 0.48) between grazing treatments (Figure 3). In 2024 utilization rates were lower than the targeted 60% biomass removed with 40% in AUTO, 40% in MAN, 46% in VF and 50% in CONT. Lower utilization rates may be due to delayed turnout at the CREC location, increasing initial forage maturity and reducing palatability. Utilization rates in 2025 reached the target 60% biomass removal with 60% in AUTO, 65% in MAN, 60% in VF and 62% in CONT. The mean stocking rate across years was 2.61 AUM/ac in AUTO, 2.71 AUM/ac in MAN, 2.35 AUM/ac in VF, and 2.15 AUM/ac in CONT. While no difference in stocking rate or grazing duration was found between grazing technologies and continuous grazing, strip grazing regardless of technology used resulted in an average of seven and up to eighteen additional grazing days or approximately 16% to 35% greater grazing duration than continuous grazing (Figure 4).

Livestock performance was variable across years but was not significantly affected by grazing treatment (P = 0.55) or grazing strategy (P = 0.34). In 2024, average gain was 0.86 lbs/day in AUTO, 0.62 lbs/day in MAN, 0.70 lbs/day in VF, and 0.67 lbs/day in CONT. Average daily gain in 2025 was 0.47 lbs/day in AUTO, 0.51 lbs/day in MAN, 0.24 lbs/day in VF, and 0.29 lbs/day in CONT. While previous studies have shown reduced individual livestock gain under intensive grazing management compared to continuous grazing management; our study did not observe this trend (Blount et al., 1991; Davies-Jenkins et al., 2024). As utilization rates were similar between grazing treatments, forage quality in the continuously grazed paddocks was likely reduced compared to ungrazed strips, limiting late season performance in the CONT paddocks.

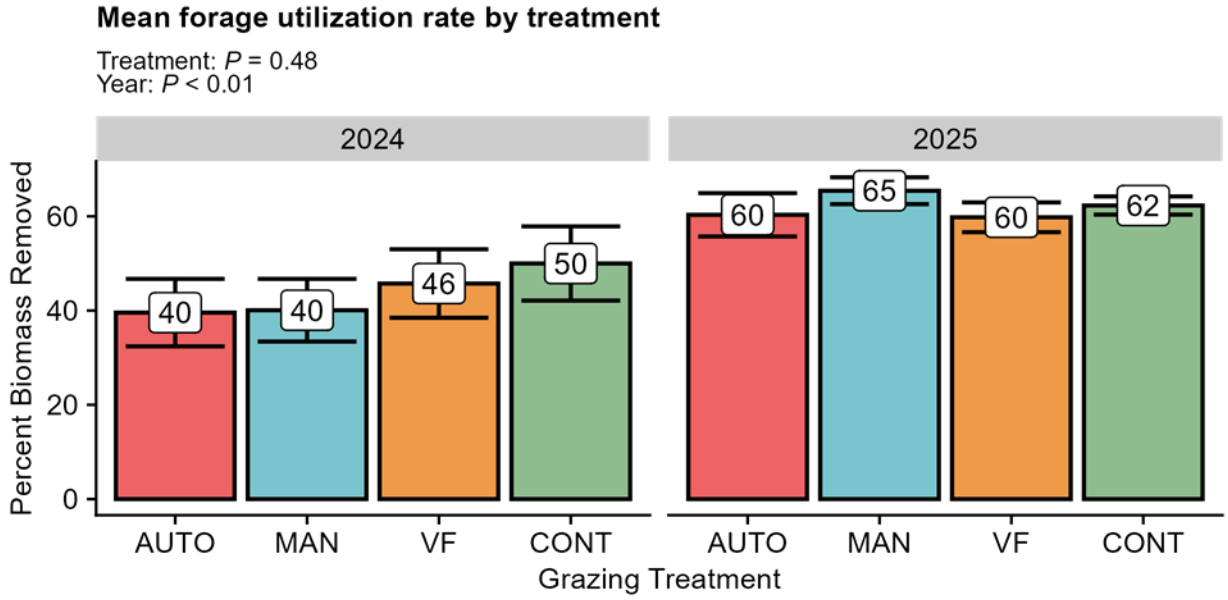

Figure 3. Mean forage utilization rate by year for each treatment. AUTO = automated gate, MAN = manual polywire, VF = virtual fence, CONT = continuous graze.

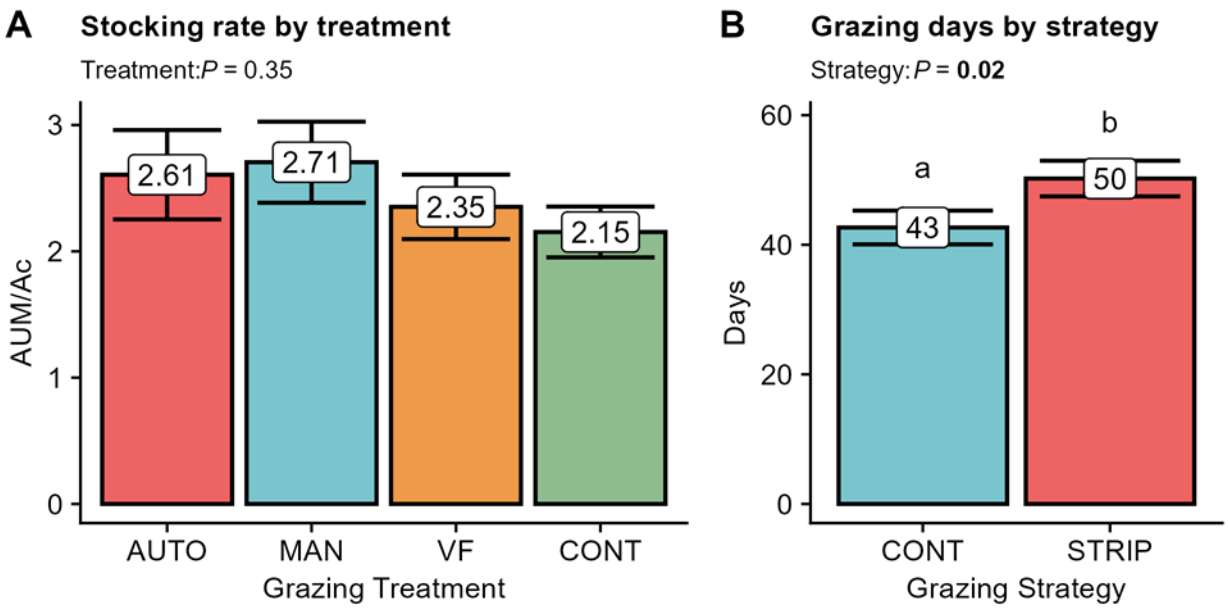

Figure 4. A) Grazing treatment effects on mean stocking rate across years. AUTO = automated gates, MAN = manual polywire, VF = virtual fence, CONT = continuous graze. **B**) Grazing strategy effects on mean grazing duration across years. CONT = continuous graze, STRIP = intensive strip graze. Means not connected by same letter are significantly different ($P < 0.05$).

Conclusion

Virtual fencing and automated gate openers can serve as effective livestock management tools within small pasture settings. These grazing technologies increase flexibiltiy and adaptability of grazing systems by reducing the need for in-field labor to move cattle. Virtual fence in particular also increases opportunities of implementing alternative grazing systems such as residue, cover crop, or winter bale grazing when already used within extensive systems. These increased opportunites, outside of the rangeland setting, could prove to be important methods to increase the return on investment for virtual fencing infrastructure.

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Comparisons of winter cereal cover crops within an integrated crop livestock system

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Summary

In the Northern Great Plains, cover crops (CCs) are becoming widely used for their soil health benefits, but economic returns can take years to be realized and are hard to track. Grazing CCs has the potential to extend the grazing season and offset the costs of CC establishment through short-term returns utilizing an integrated crop-livestock system. The objective of this study was to enhance the profitability of crop production and soil health, through livestock integration, and CC management. This project utilized CC management of winter rye, winter triticale, and winter wheat, under dual season (fall and spring) grazing (DG), spring grazing (SG), no grazing (NG), or no cover crop (NCC) treatments. Winter rye produced the greatest spring biomass. Winter wheat and triticale biomass were low due to winter kill. Winter cereal CCs suppressed weed establishment, and suppression was unaffected by grazing. Grazing had no impact on cash crop yield or soil health indicators. A triticale CC lowered corn grain yield compared to NCC. Soil volumetric water was highest in NG plots throughout the growing season. Grazing of winter cereals provided a return on CC investment through lowering livestock feeding and yardage costs.

Introduction

Cover crops (CCs) have gained popularity as a practice implemented by producers across the United States. In North Dakota alone, CC acreage has increased 107% (838,252 acres) between 2017 and 2022 (USDA NASS, 2024). A recent national survey found agriculture advisors anticipate this trend of increasing CC acreage to continue (CTIC 2025). Producers are incorporating CCs to improve soil health, increase crop yields, reduce soil erosion, manage water, and increase forage options for livestock.

Rye is the most frequently grown CC, with the winter cereals wheat and triticale also being common. Recently, farmers' number one question about cover crops, is what species to select (CTIC 2025). Winter rye is commonly selected due to its winter-hardiness, high biomass production, and low cost; however, winter wheat and triticale varieties produce higher-quality forage. Winter cereals are typically planted in the fall following a cash crop. They initiate growth in the fall, go through the differentiation process (change in growing point from vegetative to spikelet) during vernalization in the winter, and regrow in the spring. Winter cereal CCs enhance soil health by increasing organic matter, enhancing pore development for better water-holding capacity, feeding microbial communities, and reducing erosion and nitrate concentrations in runoff. In addition, some winter cereals have been shown to have an allelopathic effect (suppression) on pigeon grass, kochia, pigweeds and marestail (Dhima et al. 2006).

When a winter cereal CC is used in conjunction with a corn cash crop, a synergistic system is created, which overcomes many challenges of incorporating corn in a cropping system. These benefits include reducing wind and water erosion, suppressing early-season glyphosate-resistant weeds, and providing stability in saline areas. There is a significant body of research on the benefits of grass CCs, but the impacts they have on corn production are variable and results are conflicting. Despite the ecological benefits of incorporating CCs into a system, the economic benefits may not be realized if livestock are not incorporated into the system. The most common reason farms stop using CCs is the lack of a measurable economic return (CTIC 2025).

Due to the short growing season in the Northern Great Plains, it can be difficult to establish a CC as part of a dual crop system. Currently, there is no research evaluating the potential to dual harvest a winter cereal for livestock forage in the Northern Great Plains, and assessing the economic and ecological benefits of integrated crop-livestock systems. The objectives of this study were to determine the effects of grazing winter rye, winter triticale, and winter wheat CCs on crop performance, soil physical and chemical properties, and the profitability of the system.

Methods

A research plot at the Central Grasslands Research Extension Center, near Streeter ND, was selected, where the grazing treatments have been implemented since Fall of 2022. The plot was divided into nine pastures and randomly assigned one of three treatments: dual season (fall and spring) grazing (DG), spring grazing (SG), or no grazing (NG). The NG plots were split in half to include no cover crop (NCC) treatments. October 3rd, 2024, all CC treatment plots were planted with a strip of winter rye, winter triticale, and winter wheat. There was insufficient biomass to support grazing in the fall.

Spring of 2025, DG and SG plots were grazed for 0.56 AUMs, each, from May 13th to May 21st (Figure 1). Two-day weights were collected from heifers pre- and post-grazing. Prior to and following grazing, forage samples of winter cereals were collected to determine production, set stocking rates, and evaluate utilization. Ground cover was estimated pre- and post-grazing for percentage bare ground, weeds, residue, and live CC cover. Soil samples were taken post-grazing for analysis of total nitrogen (TN), nitrate (NO3), phosphorus (P), potassium (K), soil organic matter (OM), soil inorganic carbon (SIC), soil organic carbon (SOC), aggregate stability, and bulk density.

Grain corn was planted on May 24th, and winter cereal CCs were terminated three days later. Sprinkler infiltrometers were used to evaluate infiltration rates in each pasture. Soil moisture sensors were installed in every pasture in mid-June, and removed at the end of September, before freezing. Soil moisture and temperature were recorded every hour at 6” and 12” depths. Population counts and growth staging were completed in July, and yield data was collected at harvest. A partial budget was created to evaluate system economics for the year.

Figure 1. Heifers in a strip of winter rye at grazing turnout, spring 2025.

Results

Spring 2025, DG and SG pastures supported 0.56 AUMs of grazing, each. Rye, triticale, and wheat strips provided 261.5lbs ac-1, 72.4lbs ac-1, and 141.5lb ac-1, of biomass, respectively. Spring grazing was short due to a majority winter kill of winter triticale and wheat. Animal weights were not significantly different between treatments pre- or post-grazing. On average, animals lost 2.5lbs day-1.

Spring 2025, pre- and post-grazing, winter rye provided significantly greater cover (Figure 2) than triticale in all CC treatments. There were no differences in residue cover, between grazing treatments or cereal type, pre- or post-grazing. Bare ground was not different pre-grazing, but post-grazing NCC pastures had 24.6% bare ground, which was significantly less than the NG triticale and wheat plots at 56.7% and 58.3%, respectively. Post-grazing weed cover, was significantly lower in all winter cereal plots, regardless of grazing. Grazed rye had 7.7% weed cover versus NCC pastures at 37.1% weed cover. Residue cover did not vary significantly between treatments.

Following three years of CC and livestock integration there have been no changes in soil health indicators. There were no significant differences between treatments for soil OM, pH, TN, NO3-, P, K, TC, TOC, bulk density, or soil aggregates. There were no differences between treatments for water infiltration rates. Soil volumetric water was highest in NG plots throughout the growing season (Figure 3).

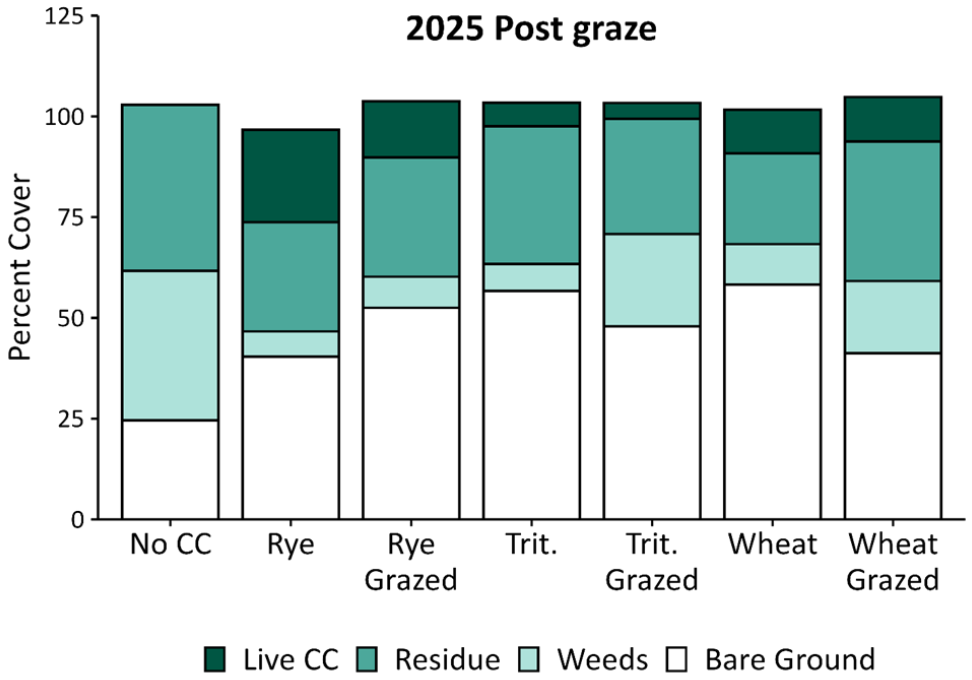

Figure 2. Post-grazing absolute ground cover estimates for spring 2025

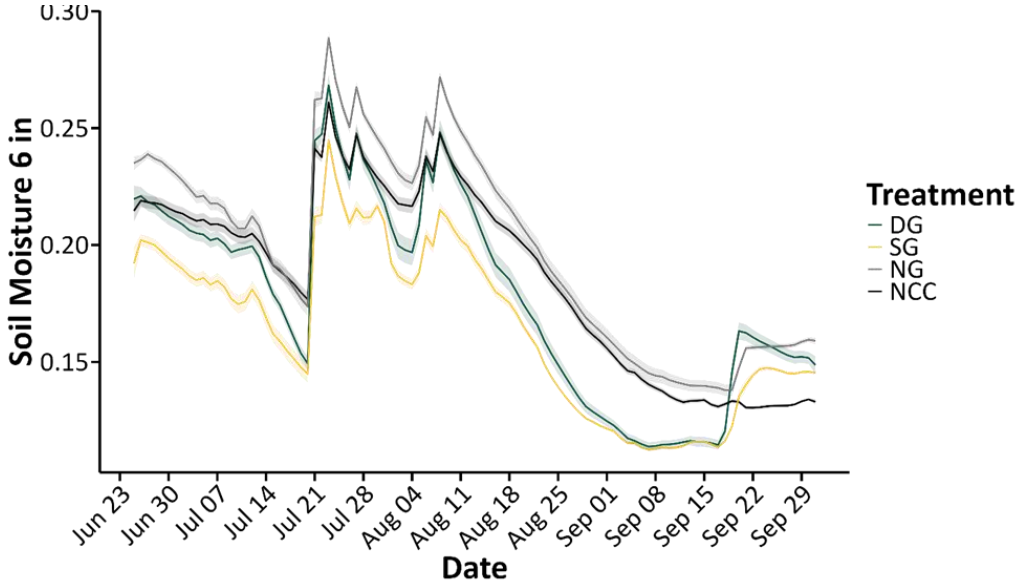

Figure 3. Soil moist at the 6-inch depth throughout the 2025 growing season for the dual graze (DG), spring grazed (SG), no grazed (NG), and no cover crop (NCC) treatments.

Grazing did not impact corn grain yield, but type of winter cereal CC did (Figure 4). Average corn grain yield for triticale, rye, wheat, and NCC plots were 122bu ac-1, 130bu ac-1, 132bu ac-1, and 145bu ac-1, respectively. Grain yield was significantly lower in triticale CC plots than NCC.

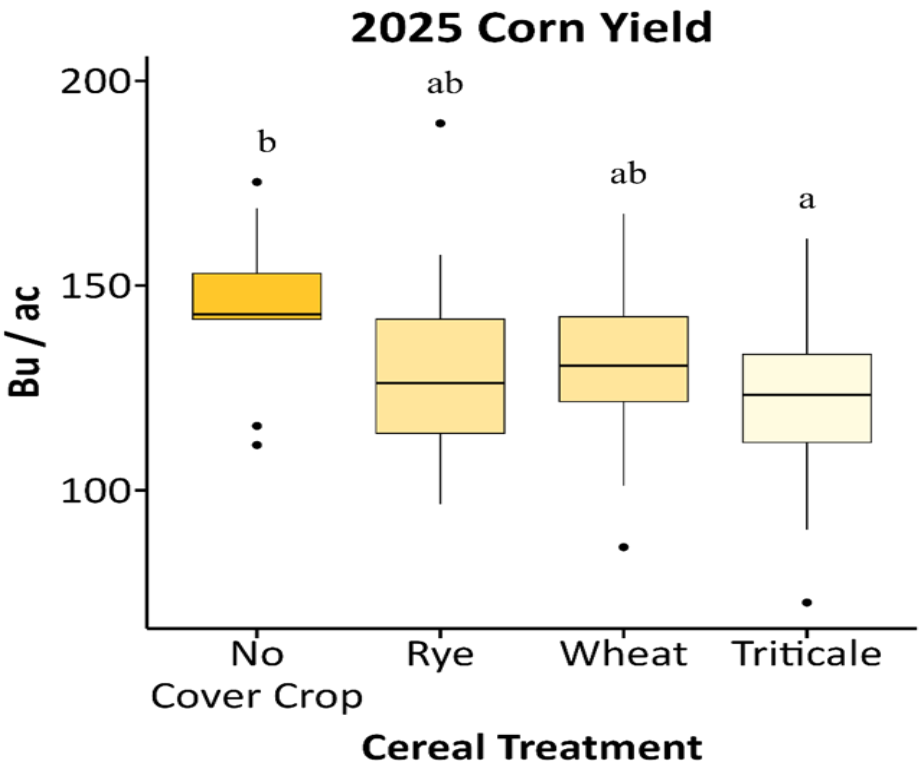

Figure 4. 2025 Corn grain yield estimates by cover crop treatment, means not connected by the same letter are significantly different (P≤0.05)

The cost of CC establishment was $62.13ac-1 for rye, $180.71ac-1 for triticale, and $89.76ac-1 for wheat (Figure 5). Grazing provided a $26.88 ac-1 return for rye, $1.18 ac-1 for triticale, and $12.2 ac-1 for wheat.

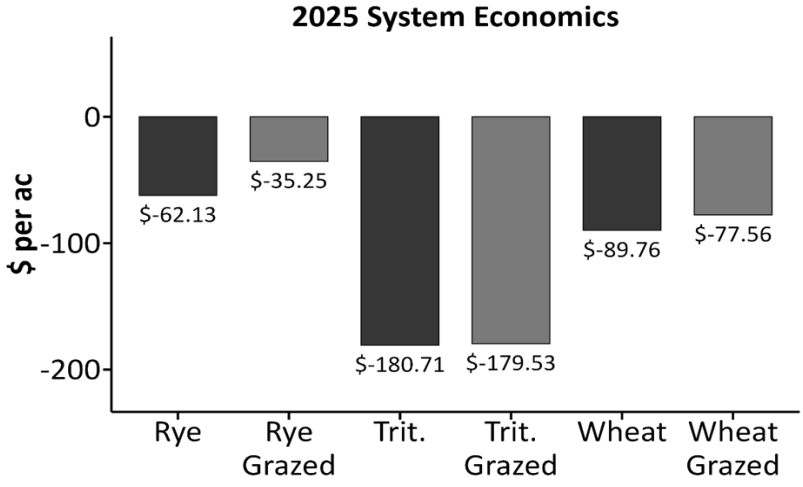

Figure 5. Estimated net economic effect for incorporating winter cereal cover crops with and without grazing for 2025.

Discussion

Late planting of winter cereals, in fall of 2024, led to low fall biomass production that could not support grazing. Spring grazing did occur, but was short due to a majority winter kill of triticale and wheat. The winter kill may have been due to a major thaw and refreeze in the middle of winter. Due to the short grazing period, cattle experienced weight loss, as they did not have adequate time to acclimate to the change in diet. Livestock, in spring 2023, grazed 16 days, which resulted in a rate of gain of 0.61lbs day-1, due to the longer grazing period allowing acclimation to the diet.

All winter cereal CCs significantly lowered weed cover. Winter cereals may suppress weeds, through allelopathic effects (Dhima et al. 2006). The primary weed in the field was kochia, which has become a major problem for many farmers in the Northern Great Plains, as it is glyphosate resistant, making it hard to combat. Rye provided the greatest cover and the highest weed suppression of the three winter cereals. The superior performance of the rye was due to winter kill of triticale and wheat. Notably, ground cover was not significantly affected by grazing.

Chemical and physical soil properties did not vary between treatments. This is consistent with other research in semi-arid regions that has documented no to little change in soil health indicators after three years of CC implementation; it was concluded a longer period of cover cropping is needed to impact soil health in semi-arid environments (Wu et al. 2024). Currently, CC and grazing treatments have been implemented for three years. Long-term studies are needed to better understand responses of soil chemical and physical properties to livestock integration.

Cover crop plots that were not grazed maintained higher soil moisture at six-inch depths throughout the growing season. These plots retained cover from the CC growth and previous crop residue. The increased ground cover may have lowered evapotranspiration rates. Plots with no cover crop had the lowest bare ground estimates but the highest weed cover. The increase in weed density may have lowered soil moisture due to water uptake by the weeds.

Grazing did not impact corn grain yields. Plots that had a triticale CC, prior to planting, had significantly lower yield than NCC plots, but did not vary from rye or wheat CC plots. Corn grain yield in rye and wheat plots was not significantly different from NCC plots. Triticale plots may have seen a decrease in yield due to increased percent bare ground, prior to spring planting. The yield decrease may also have been due to where the triticale strips were located in the field, as all of them were in the middle of a pasture, never along a fence line.

Winter cereal CC costs varied due to differences in seed cost. Grazing provided a return on CC investment, by lowering livestock feeding and yardage costs. Rye provided the greatest return as it produced the greatest biomass, and supported the most grazing. Wheat provided minimal returns from grazing, and triticale returns came entirely from savings in yardage. Integrating livestock is a way to improve profitability when incorporating CC into a system (Kelly et al. 2021). In 2023, about two weeks of spring grazing was achieved, and the cost of

establishing a winter rye CC was completely offset by livestock feed and yardage savings. The short grazing period in 2025 limited returns from incorporating livestock into the system.

Returns from grazing CCs are heavily dependent on cereal type, planting date, temperature, and precipitation. There is potential for grazing to provide a return on CC investment through reducing feeding costs without negatively impacting soil health or crop performance and yield. As farmers continue to combat kochia, the use of a winter rye CC may be considered to suppress the establishment of the weeds in the spring. Grazing CCs can provide a net income or return on CC investment, depending on biomass production.

Acknowledgements

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Hay Quality Across Beef Operations in North Dakota

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Summary

This study evaluated nutrient composition, fiber characteristics, mineral profiles, and microbial loads of hay produced on beef operations in North Dakota. A total of 68 hay samples, which included alfalfa hay, alfalfa-grass hay, grass hay, and a diverse category of "other" hays including small-grain forages and stover, were collected from beef producers across eight counties. Samples were analyzed for chemical composition, mold and yeast counts. Nutrient composition differed among forage types. Alfalfa hay was the most nutrient-dense and exhibited the lowest variability in crude protein (CP), total digestible nutrients (TDN), and mineral concentrations. Alfalfa-grass mixtures showed substantial variability in CP, adjusted CP, fiber fractions, and minerals, reflecting wide differences in species proportion and maturity at harvest. Grass hay was lower in nutrient density but more uniform across samples, while "other" hay types displayed the greatest inconsistency in nutrient supply, fiber digestibility, and mineral balance. Mold and yeast counts were generally higher in alfalfa and alfalfa-grass hays than in grass hay, consistent with slower drying rates and greater leaf retention. Across all forage types, acid-detergent insoluble crude protein (ADICP) was highly variable, showing the effect of harvest moisture and storage conditions on heat damage and protein availability. These results demonstrate that hay type is a major determinant of nutrient composition and microbial load on beef operations in the region.

Introduction

Hay is an essential feed source for beef cattle in North Dakota, particularly during the long winter months. Producing high-quality hay is challenging because it depends heavily on favorable weather. To store safely, hay must be dried to 15 to 20% moisture, a process which can take two to ten days of good drying conditions (Fonnesbeck et al., 1986). In many years, these ideal conditions are difficult to achieve. When hay remains in the field for a long time, leaves become more fragile and break off easily, leading to significant nutrient losses. To avoid these field losses, some producers bale hay at higher moisture levels, this can create a different set of risks. Hay that is baled too wet is far more susceptible to mold growth. As molds proliferate, they consume nutrients and generate heat, which can damage proteins, reduce forage quality, and cause hay to darken or develop a musty odor (Cherney et al., 1987; Collins et al., 1987). Moldy hay also poses health concerns for both livestock and people. Certain fungi have been associated with mycotic abortion and mastitis in cattle, while individuals handling moldy hay may be exposed to respiratory hazards such as farmer's lung (Lacey, 1975; Knudtson and Kirkbride, 1992). In some cases, molds may also produce mycotoxins that negatively affect livestock health and performance.

Although many fungi are capable of colonizing hay, most past research relied on culture-based laboratory methods that detect only a small portion of the microbial community (McAllister et al., 2017). Newer DNA-based tools, including next-generation sequencing (NGS), can identify a much broader range of fungi and bacteria. While NGS has been widely applied in silage research, its use in hay systems remains limited. This study aims to address that gap by providing a comprehensive assessment of hay quality and microbial development on beef farms in south-central North Dakota. This study focuses on three major objectives: evaluating hay quality across the region, identifying the fungal and bacterial communities present in hay, and determining how baling moisture influences heating, nutrient losses, and microbial growth. Based on previous research, we expect that wetter hay will heat more intensely and lose more nutrients because higher moisture creates a more favorable environment for microbial activity. We also anticipate that microbial communities will be more diverse than previously documented, with NGS revealing species that older methods could not detect.

Methods

The study was conducted in two phases. In the first phase, hay samples were collected, with the help of county extension agents, from beef farms across counties in south-central North Dakota. Each sample was analyzed for nutrient composition, microbial communities, and mycotoxin presence. Using next-generation sequencing, fungi and bacteria present in hay will be examined to assess how these communities vary across farms, forage types, and storage conditions. This phase was used to establish a regional baseline for hay quality and mold prevalence. The second phase involved more controlled hay storage studies using alfalfa and grass hay baled at two moisture contents, representing low and high moisture content. Hay samples were collected at baling (day 1) and after 84 days of storage analyzed for nutrient changes, microbial community composition, and mycotoxin concentrations. Internal bale temperatures were recorded on days 1, 7, 14, 21, 28, 35, 42, 49, 56, and 84 to track heating patterns.

Results and Discussion

A total of 68 samples were collected from North Dakota beef producers in eight counties. The majority of the samples were alfalfa-grass hay (37%) followed by alfalfa hay (30%), with grass hay and “other hays contributing 13% and 20%, respectively. “Other” hay included rye hay, rye straw hay, corn stover, ditch hay, barley hay, oat hay, and millet hay.

Nutrient composition differed markedly among hay types. Alfalfa hay showed the highest nutrient density and the most consistent chemical profile (Table 1). Total digestible nutrients (TDN) averaged 58% with a coefficient of variation (CV) of 5.6%, while crude protein (CP) averaged 16.7% and showed similarly low variability (CV 12.2%). Acid-detergent insoluble crude protein (ADICP) showed great variability (CV 28.3%), indicating that the amount of heat-damaged or indigestible protein was variable across samples. Mineral concentrations were generally stable, particularly calcium, which averaged 1.55% with a CV of 15.2%. The relatively low variability in alfalfa hay reflects the more controlled nature of alfalfa production systems, where stands are typically managed for uniform maturity and harvested on predictable schedules.

Alfalfa-grass hay showed more variability across nearly all nutrient categories (Table 2). TDN averaged 56.2% (CV 7.6%), but CP exhibited a wide distribution (mean 12.6%; CV 33.8%), and adjusted CP showed even greater variability (CV 36.9%). ADICP was also highly variable (CV 35.5%). Mineral concentrations were inconsistent, with calcium ranging from 0.28% to 2.33% (CV 49.9%) and similar dispersion observed for phosphorus, magnesium, potassium, and sulfur (CVs 31–44% Table 2). Fiber fractions were moderately variable (NDF CV 11.8%; ADF CV 11.7%), and relative feed value (RFV) averaged 88 with a CV of 18.6%. Compared to alfalfa hay, the high variability in nutrient content observed in alfalfa-grass hay shows the differences in proportions of grass and alfalfa in the hays submitted, with some samples having a greater proportion of either grass or alfalfa.

Grass hay was characterized by lower nutrient concentrations but greater uniformity than alfalfa-grass hay (Table 3). TDN averaged 56.3% with a CV of 4.4%, and CP averaged 8.7% with a CV of 15.9%. Fiber fractions were consistent (NDF CV 7.6%; ADF CV 9.7%), and RFV averaged 88 with a CV of 11.4%. ADICP remained variable (CV 31.2%), although absolute concentrations were lower than in alfalfa-based hays. Mineral concentrations were modest and moderately variable, with calcium averaging 0.65% (CV 31.1%; Table 3). Grass hay, while lower in nutrient density, demonstrates greater uniformity than alfalfa-grass hay. The narrow distributions for TDN and fiber fractions suggest that grass stands were harvested at relatively consistent maturities, likely due to synchronized growth patterns and simpler stand structure. The lower microbial loads compared with alfalfa-based hays align with the faster drying rates of grasses and their lower leaf-to-stem ratios, which reduce moisture retention and limit the substrate available for fungal colonization.

Hays classified as “other” showed the greatest inconsistency in nutrient composition which was not surprising given the different types of hays that were included in this category (Table 4). Many of these forages, such as straw, stover, and ditch hay, are harvested at advanced maturities or under opportunistic conditions, contributing to high fiber concentrations and low digestibility. TDN averaged 55.2% (CV 6.1%), while CP averaged 9.9% with a CV of 21.4%. ADICP was highly variable (CV 39.7%), indicating substantial differences in protein degradability and heat damage among samples (Table 4). Fiber fractions were high and moderately variable (NDF CV 8.3%; ADF CV 10.8%). Mineral concentrations, particularly calcium, showed extreme dispersion (mean 0.43%; CV 48.3%). RFV averaged 82 with a CV of 13.3%.

These results showed differences in both nutrient density and consistency across hay types. Alfalfa hay provides the most uniform and nutrient-rich forage base, grass hay is predictable but lower in quality, while alfalfa-grass hay introduces substantial variability due to species composition and maturity differences. The consistently high variability in ADICP underscores the influence of harvest moisture, baling conditions, and storage environment on forage quality.

Comparison of hay types showed similar ($P = 0.409$) TDN across hay types but CP concentrations was greatest ($P < 0.001$) in alfalfa hay, followed by alfalfa–grass mixtures, with grass hay and other hays containing less than 10% CP (Table 5). Adjusted CP values followed the same pattern, indicating that the relative ranking of protein availability was consistent across

hay types. Acid-detergent insoluble CP (ADICP) comprised a larger proportion of total CP in grass hay (16.8%) compared with alfalfa (9.2%), with intermediate values for alfalfa–grass and other hays ($P = 0.001$), suggesting greater heat-damaged or bound protein in more mature or lower-quality forages. Fiber concentrations also differed among hay types. Alfalfa hay contained less ($P < 0.001$) NDF than alfalfa–grass (61.6%), grass (61.9%), and other hays (65.7%;). ADF did not differ ($P = 0.188$) among hay types. Alfalfa hay contained greater ($P < 0.001$) Ca and Mg than all other hay types (Table 5). P concentrations were greater ($P = 0.037$) in alfalfa and other hays relative to grass hay. Concentrations of K and S did not differ ($P \geq 0.05$) among hays. Relative feed value (RFV) was greatest ($P = 0.001$) in alfalfa hay relative to all hay types. Mold and yeast counts were greater ($P \leq 0.035$) in alfalfa and alfalfa–grass hays compared with grass hays, although all values remained within typical ranges for stored hay.

Conclusions

The nutrient composition of hay produced on beef operations in North Dakota varies substantially across forage types. Alfalfa hay provides the most consistent forage, whereas grass hay offers predictable but lower nutrient concentrations. Alfalfa-grass hay is highly variable due to differences in grass-alfalfa distribution across samples as well as differences in forage maturity. The diverse category of other hays, which included small-grain forages, stover, and ditch hay, showed the highest variability in nutrient supply, fiber digestibility, and mineral balance. These results suggest the need for routine forage testing to ensure that beef cattle receive balanced and predictable diets, particularly when relying on variable forage sources. These results show that hay type is a major determinant of nutrient composition, with alfalfa-based hays providing greater protein, minerals, and forage quality when compared to grass hay or other hay types.

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Table 1. Nutrient composition of alfalfa hay from beef farms in North Dakota.

	Mean	SD[1]	CV[2]	Minimum	Maximum
TDN	58	3.19	5.55	52	62
CP	16.7	2.03	12.19	12.7	20.0
ADICP, %CP	9.2	2.61	28.26	5.4	14.9
Adj. CP	16.7	2.09	12.45	12.9	20.4
NDF	51.7	6.57	12.71	42.9	64.2
ADF	40.6	4.69	11.50	34.6	52.5
Ca	1.55	0.246	15.24	1.08	1.86
P	0.20	0.041	20.34	0.16	0.31
Mg	0.34	0.069	20.18	0.24	0.45
K	1.95	0.365	18.71	1.45	2.75
S	0.19	0.034	17.53	0.13	0.23
RFV	106	17.9	16.8	83	135
Mold, cfu[3]/g hay	576459	1371103	237.9	22752.290	5931271
Yeast, cfu/g hay	1208025	2539024	210.2	1152.350	9376082

[1]Standard deviation

[2]Coefficient of variation

[3]Colony forming units/g of hay

Table 2. Nutrient composition of Alfalfa-grass hay from beef farms in North Dakota.

	Mean	SD[1]	CV[2]	Minimum	Maximum
TDN	56	4.35	7.56	43	65
CP	12.6	4.25	33.82	6.5	23.9
ADICP, %CP	12.5	4.45	35.49	6.4	21.3
Adj. CP	12.4	4.56	36.88	6.0	22.7
NDF	61.2	7.21	11.78	44.5	77.6
ADF	43.9	5.14	11.70	34.1	59.2
Ca	0.94	0.47	49.87	0.28	2.33
P	0.17	0.08	43.76	0.06	0.34
Mg	0.25	0.08	31.19	0.13	0.46
K	1.76	0.71	40.36	0.32	3.05
S	0.17	0.06	38.64	0.07	0.35
RFV	88	16.3	18.58	51	129
Mold, cfu[3]/g hay	622675	897368	144.12	11695	3822976
Yeast, cfu/g hay	1287316	2815818	218.74	23390	12157909

[1]Standard deviation

[2]Coefficient of variation

[3]Colony forming units/g of hay

Table 3. Nutrient composition of grass hay from beef farms in North Dakota.

	Mean	SD[1]	CV[2]	Minimum	Maximum
TDN	56	2.49	4.42	52	59
CP	8.7	1.40	15.86	7.0	11.0
ADICP, %CP	16.8	5.24	31.20	9.9	26.1
Adj. CP	8.3	1.58	19.08	6.6	10.9
NDF	61.9	4.67	7.55	54.2	67.2
ADF	42.7	4.14	9.70	38.6	49.4
Ca	0.65	0.20	31.12	0.42	1.05
P	0.13	0.03	25.43	0.09	0.19
Mg	0.22	0.05	24.30	0.17	0.34
K	1.41	0.31	22.05	0.78	1.70
S	0.18	0.05	26.45	0.11	0.23
RFV	88	9.74	11.35	73	99
Mold, cfu[3]/g hay	77298	67386	87.18	1185	218208
Yeast, cfu/g hay	51250	32889	64.17	11202	109104

[1]Standard deviation

[2]Coefficient of variation

[3]Colony forming units/g of hay

Table 4. Nutrient composition of other[1] hay types from beef farms in North Dakota.

	Mean	SD[1]	CV[2]	Minimum	Maximum
TDN	55	3.34	6.05	51	61
CP	9.9	2.12	21.39	5.4	14.5
ADICP, %CP	12.6	5.01	39.72	5.4	25.0
Adj. CP	9.9	2.54	25.68	4.6	15.2
NDF	65.7	5.47	8.32	54.3	77.0
ADF	43.7	4.72	10.82	35.8	52.9
Ca	0.43	0.21	48.33	0.18	0.84
P	0.20	0.07	34.66	0.08	0.31
Mg	0.21	0.08	37.95	0.12	0.34
K	1.79	0.50	27.68	1.00	2.52
S	0.16	0.05	33.39	0.07	0.28
RFV	82	10.9	13.3	66	105
Mold, cfu[3]/g hay	799835	1293024	161.66	8521	3908693
Yeast, cfu/g hay	936159	947754	101.24	6086	3165130

[1]Rye hay, rye straw hay, corn stover, ditch hay, barley hay, oat hay, and millet hay
[1]Standard deviation
[2]Coefficient of variation
[3]Colony forming units/g of hay

Table 5. Nutrient composition of hay samples collected from beef farms in North Dakota.

	Hay type				SE	P
	Alfalfa	Alfalfa-grass	Grass	Other[1]		
TDN	57	56	56	55	0.4	0.409
CP	16.7[a]	12.6[b]	8.9[c]	9.9[c]	0.53	<0.001
ADICP, %CP	9.2[b]	12.5[ab]	16.8[a]	12.6[ab]	0.61	0.001
Adj. CP	16.4[a]	12.3[b]	8.3[c]	9.9[bc]	0.57	<0.001
NDF	51.7[b]	61.6[a]	61.9[a]	65.7[a]	1.06	<0.001
ADF	40.7	43.9	42.7	43.7	0.63	0.188
Ca	1.55[a]	0.94[b]	0.65[c]	0.43[c]	0.069	<0.001
P	0.20[a]	0.17[ab]	0.13[b]	0.20[a]	0.008	0.0370
Mg	0.34[a]	0.25[b]	0.22[b]	0.21[b]	0.011	<0.001
K	1.95[a]	1.76[ab]	1.41[b]	1.79[a]	0.071	0.144
S	0.19	0.17	0.18	0.16	0.007	0.306
RFV	106[a]	88[b]	86[b]	82[b]	2.3	0.001
Mold, Log[2] cfu/g hay	5.3[a]	5.5[a]	4.6[b]	5.5[a]	0.09	0.017
Yeast, Log cfu/g hay	4.9[ab]	5.5[a]	4.6[b]	5.6[a]	0.12	0.035

[1]Rye hay, rye straw hay, corn stover, ditch hay, barley hay, oat hay, and millet hay

[2]Log_{10} colony forming units/g of hay

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

Managing Annual Forage Crops for Late-Season Grazing: A Preliminary Study

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Summary

This preliminary study examined whether planting date and swath-grazing management could help maintain the nutritive value of annual forage crops for late-season grazing in the Northern Great Plains. A diverse mixture of warm- and cool-season annuals was managed under four strategies, early- and late-planted standing forage, and early- and late-cut swath forage, and evaluated for biomass, forage quality, and beef cow performance. Although all heifers lost weight in all treatments, swath-grazed forages consistently supported greater gains than standing forage, regardless of whether swathing occurred in August or October. These results show that swath grazing may better preserve forage quality or improve utilization during late fall, while delayed planting alone did not extend forage quality enough to affect cattle performance. The results further suggest that there may be a need to supplement heifers grazing annual forage crops in late fall and winter.

Introduction

Late-season forage availability is a persistent challenge in integrated crop-livestock systems across the Northern Great Plains. As forages mature, both biomass and nutritive value decline, leaving producers with limited options for grazing during the fall. Annual forage crops offer a promising solution by providing high-quality biomass when perennial pastures are insufficient (McCartney et al., 2004). Annual forage crops can provide short-term grazing between crop rotations or can be inter-seeded into perennial pastures to increase forage quality and productivity (Dillard et al., 2018). Annual forage crops also provide an opportunity to increase the economic and environmental sustainability of grazing systems. Cool-season annual forage crops provide high-quality, abundant forage biomass when forage availability from perennial forage species is lacking, reducing the need for stored feeds during the winter months (Dillard et al., 2018). Previous research has highlighted the role of annual forages in biomass production and soil health, but relatively little attention has been given to their forage quality and the resulting impacts on livestock performance (Wyffels et al., 2022). Some studies have demonstrated improved cattle performance when grazing cool-season mixtures such as rye, oats, and ryegrass (Kouka et al., 1994) and wheat, and annual ryegrass (Beck et al., 2005), yet the sustainability of these systems remains uncertain due to the lack of comprehensive data on forage quality during late-season grazing.

Maintaining forage quality into late fall is particularly challenging because nutritive value declines as plants mature, underscoring the need for management strategies that preserve quality and extend grazing opportunities. The objective of this study was to evaluate planting and cutting strategies that preserve the nutritional quality of annual forage crops for late-season grazing. By identifying management practices that optimize forage availability and quality during the critical late fall period, this research aimed to provide producers with practical tools to sustain integrated crop-livestock systems. Our hypothesis was that delayed planting will slow

forage maturity, thereby maintaining quality later into the season, and that swath grazing strategies will influence both forage preservation and cattle performance.

Methods

The study was conducted in a field divided into eight paddocks. A diverse mixture of warm- and cool-season annual crops, including oats, sorghum-sudan grass, foxtail millet, sunflower, radish, kale, turnip, flax, and forage peas (Table 1), was planted across the paddocks. Four treatments were evaluated: early-planted standing forage, late-planted standing forage, early-cut swath forage, and late-cut swath forage. Forages in the early-planted, early-cut, and late-cut treatments were seeded into six paddocks in mid-June while the late-planted treatment was seeded in late July into the remaining two paddocks. Forages in the early-cut treatment were swathed in late August, allowing for regrowth that cattle can graze alongside the swath. In contrast, the late-cut treatment was swathed in late October to minimize regrowth and preserve forage for late-season grazing.

Eighty (80) non-lactating pregnant Angus-cross beef cows were divided into eight groups of similar average body weight and randomly assigned to treatments beginning mid-November. Grazing was managed through portable electric fencing to control access to forage and cows were moved to new forage when it was visually estimated that forage availability in present grazing patch was low. Cows had *ad libitum* access to fresh water. Cow performance was assessed from two-day body weights (BW) taken at the start and end of the study. Animal handling and care procedures were approved by the North Dakota State University Animal Care and Use Committee.

Results and Discussion

Initial cow body weight (BW) did not differ among treatments ($P = 0.99$), indicating that cows entered the study with comparable nutritional status (Table 2). Similarly, planting date and swathing strategy did not influence ($P = 0.58$) final BW. Despite similar final BW, clear differences emerged in average daily gain (ADG). Cows grazing swathed forages, whether cut in August (ECSW) or October (LCSW), showed greater ($P < 0.0001$) ADG than cows grazing standing forage, despite still losing weight. Early- and late-planted standing forages (EPST and LPST) supported similar ADG, both of which were negative and significantly lower than gains observed in swath treatments (Table 2). In this study, swathing appeared to maintain nutritive value sufficiently to support higher ADG compared with standing forage, which likely experienced greater declines in digestibility and crude protein as plants matured. The lack of difference between early- and late-swathed treatments suggests that once forage is cut and cured in the swath, the timing of cutting may be less critical than the act of swathing itself for preserving quality during late-season grazing.

Cows grazing standing forage lost BW across both planting dates, indicating that delaying planting did not provide sufficient biomass to sustain cow performance. Also, although late planting was expected to slow maturity and extend the window of high-quality forage, the results suggest that environmental conditions or species composition may have limited the effectiveness of this strategy. Warm-season species such as sorghum-sudan grass and foxtail

millet likely matured rapidly regardless of planting date, while cool-season brassicas and peas may not have compensated sufficiently to maintain overall nutritive value. Overall, the results indicate that swath grazing is a more effective strategy than delayed planting for maintaining forage quality and supporting cow performance during late-season grazing. Swathing preserved forage nutritive value sufficiently to reduce BW loss and improve ADG, while standing forage, regardless of planting date, declined in quality as the season progressed. Since all heifers lost weight, these results suggest that there may be a need to supplement heifers grazing under such conditions.

Conclusion

This preliminary study shows that swath grazing is a more effective strategy than delayed planting for maintaining forage quality and supporting beef cow performance during late-season grazing. While altering planting date did not influence cow BW or ADG, swathing, whether it occurred in late August or late October, consistently improved animal performance relative to standing forage. These results show that swathing helps preserve nutritive value or enhances forage utilization during periods when standing annual forages rapidly decline in quality. Further, the results highlight swath grazing as a practical and effective management tool for extending the grazing season and reducing reliance on harvested feeds in integrated crop-livestock systems. The results suggest that there may be a need to supplement heifers grazing annual forage crops in late fall and winter.

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Table 1. Annual forage crop species mixtures grown for late-season grazing.

Forage	Season	Amount in mix (%)
Oat (*Avena sativa*)	Warm-season	46
Sorghum Sudangrass (*Sorghum* × *drummondii*)	Warm-season	7.7
Foxtail Millet (*Setaria italica*)	Warm-season	5.1
Sunflower (*Helianthus annuus*)	Warm-season	3.9
Radish (*Raphanus sativus*)	Cool-season	2.6
Kale (*Brassica oleracea*)	Cool-season	1.9
Turnip (*Brassica rapa*)	Cool-season	1.9
Flax (*Linum usitatissimum*)	Cool-season	5.1
Forage Pea (*Pisum sativum*)	Cool-season	25.6

Table 2. Cow performance following late-season grazing of early-seeded standing forage, early cut forage plus re-growth, late cut forage and late-seeded standing forage.

	EPST	LPST	ECSW	LCSW	SE	P
Initial BW, kg	506	501	502	503	14.6	0.990
Final BW, kg	476	469	483	488	14.5	0.579
ADG, kg/d	-1.45[b]	-1.72[b]	-0.83[a]	-0.63[a]	0.209	<0.0001

[1]EPST = early-planted standing forage, LPST = late-planted standing forage, ECSW = early cut forage, LCSW = late cut forage.

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

Corn Residue Grazing as a Winter-Feeding System for Pregnant Heifers in the Northern Great Plains

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Summary

Winter feed is the largest annual cost in cow–calf production, and strategies that extend the grazing season may reduce reliance on harvested feeds. This study evaluated the effects of grazing corn residue alone, grazing residue with interseeded cover crops, or dry-lot feeding on the performance of pregnant beef heifers. Forty-eight bred heifers were assigned to one of three treatments for a 33-day grazing period followed by a 22-day dry-lot period. Forage quality differed among feed types, with residue-cover crop providing higher crude protein (10.12%) than residue alone (5.64%). During grazing, heifers grazing residue lost body weight (−0.086 $kg \cdot d^{-1}$), whereas those grazing residue-cover crop gained 0.209 $kg \cdot d^{-1}$; dry-lot heifers gained 0.835 $kg \cdot d^{-1}$ ($P < 0.05$). Body condition score (BCS) declined in both grazing treatments but increased in dry lot. During the subsequent dry-lot phase, compensatory gain was observed, with residue-only heifers gaining 1.00 $kg \cdot d^{-1}$ compared with 0.576 $kg \cdot d^{-1}$ for residue-cover crop and 0.440 $kg \cdot d^{-1}$ for dry-lot heifers ($P = 0.008$). Final BCS did not differ among treatments. These results show that late-season grazing, particularly when cover crops are included, can maintain acceptable heifer condition while reducing reliance on harvested feeds.

Introduction

Winter feed costs account for the largest proportion of annual expenses in cow–calf production systems, particularly in northern climates where extended periods of snow cover limit grazing. Strategies that extend the grazing season and reduce reliance on harvested feeds can improve profitability (Mccutcheon and Samples 2015). Corn residue, a by-product of grain production, is abundant in North Dakota and represents a low-cost forage resource for ND beef producers. However, its low crude protein and mineral concentrations can limit intake and digestibility, resulting in reduced animal performance when fed without supplementation (ARC 1980).

Interseeding cover crops into standing corn has gained interest as a means to improve soil health, increase ground cover, and provide additional forage for livestock (Magdoff and van Es 2009; Wortman et al. 2012). Cool-season annuals such as triticale, rye, oats, peas, and brassicas can enhance forage quality and extend grazing opportunities into late fall. Although cover crops are widely promoted for agronomic benefits, less research has evaluated their role in integrated crop–livestock systems, particularly regarding livestock performance during late-season grazing. This study evaluated the long-term effects of grazing corn residue alone or residue with interseeded cover crops on heifer performance, and compared these systems with traditional dry-lot feeding. We hypothesized that cover crops would improve forage quality and

heifer performance during grazing, and that compensatory gain during subsequent dry-lot feeding would minimize differences in final body condition.

Methods

The study was conducted at the North Dakota State University Central Grasslands Research Extension Center. A 5.2-ha field was divided into four, 1.3-ha paddocks, two of which were interseeded with a cover crop mixture containing oat (23%), forage pea (30%), radish (2%), rape (2%), triticale (19%), winter rye (15%), and forage barley (8%) at a rate of 146.8 $kg \cdot ha^{-1}$. The cover crop was interseeded into standing corn at the V6–V7 corn growth stage. The remaining paddocks contained only corn residue following grain harvest. The cover crop was successfully established and monitored throughout the growing season.

In the fall, 48 pregnant Angus-cross heifers were stratified by initial body weight and assigned to one of three treatments: corn residue grazing, residue plus cover crop grazing, or dry-lot feeding with grass hay. Heifers in the grazing treatments remained on their respective paddocks for 33 days before being moved to dry-lot pens for an additional 22 days. Heifers assigned to the dry-lot treatment remained in confinement for the full 55-day period. Body weight was recorded over two consecutive days at the beginning and end of each phase. Body condition score (BCS) was evaluated independently by two trained technicians using the 1–9 scale described by Rasby et al. (2014). All data were analyzed using mixed-model procedures with treatment included as a fixed effect. Differences among treatment means were considered statistically significant at $P \leq 0.05$.

Results and Discussion

Nutrient composition of corn residue

Nutrient composition differed substantially among corn residue components (Table 1). Grain and leaf fractions contained the highest concentrations of crude protein (CP), with grain at 9.4% and leaves at 7.1%, compared with markedly lower CP in husk, cob, and stalk (2.4–2.8%). Total digestible nutrients (TDN) were also greatest in grain (89%), whereas cob exhibited the lowest TDN value (17%). Leaves, husk, and stalk provided intermediate energy concentrations (55–60% TDN). Fiber content varied widely across components. Grain had minimal neutral detergent fiber (NDF; 8.7%) and acid detergent fiber (ADF; 2.4%). Husk, cob, and stalk contained the greatest NDF concentrations (71.6–83.2%), and ADF values ranged from 40.6% to 46.4% among these structural tissues. Leaves exhibited moderate fiber levels (68.3% NDF; 45.5% ADF). Mineral concentrations also differed among plant parts. Leaves contained the highest Ca (0.9%) and Mg (0.4%) concentrations, whereas grain had the greatest P content (0.3%). Potassium was highest in the stalk (1.7%), exceeding concentrations in all other components. Sulfur levels were low across all fractions (0.03–0.1%). Dry matter (DM) content ranged from 64.9% in stalk to 91.9% in grain, with residue (whole plant minus grain) averaging 67.8% DM. Whole corn residue contained low crude protein (5.64%) and moderate energy (TDN 63.6%; Table 2). This is consistent with previous reports of nutrient limitations in residue-based diets. Interseeding cover crops increased crude protein to 10.12% and improved mineral concentrations, particularly Ca, P, and Mg (Table 2).

Heifer Performance During Grazing

Heifer performance differed markedly among treatments during the 33-day grazing period. Heifers grazing residue alone lost body weight (−0.09 kg·d^{-1}) and 0.41 BCS units Table 3), reflecting the inadequate protein supply of residue. In contrast, residue-cover crop heifers gained 0.21 kg·d^{-1} and lost only 0.22 BCS units. Dry-lot heifers gained 0.83 kg·d^{-1} and increased BCS by 0.19 units ($P < 0.05$; Table 3). These results are consistent with previous findings that showed that cool-season annuals can improve forage quality and support greater gains during late-season grazing (Beck et al. 2005; Kouka et al. 1994). The improved nutrient profile of the cover crop mixture likely enhanced microbial activity and forage digestibility, reducing the performance gap between grazing and dry-lot feeding.

During the 22-day dry-lot phase, heifers previously grazing residue alone exhibited greater compensatory gain (1.01 kg·d^{-1}), followed by residue-cover crop heifers (0.58 kg·d^{-1}; Table 3). Dry-lot heifers gained 0.44 kg·d^{-1} ($P = 0.008$). This response is consistent with compensatory growth, where cattle experiencing moderate nutrient restriction exhibit accelerated gains when transitioned to higher-quality diets. Despite differences in ADG, final body weight and BCS did not differ ($P = 0.165$) among treatments at the end of the dry-lot period. This indicates that short periods of dry-lot feeding can restore condition in heifers grazing lower-quality forages.

Across the full 55-day period, overall ADG was lower $P < 0.001$ for grazing treatments, 0.35 kg d^{-1} for both residue and residue-cover crop, than for dry-lot heifers (0.68 kg·d^{-1}). However, final BCS did not differ among treatments, demonstrating that grazing systems, particularly those incorporating cover crops, can maintain adequate heifer condition entering late gestation. These findings show the potential of integrated crop–livestock systems to reduce winter feed costs while maintaining acceptable animal performance. Cover crops improved grazing-period performance and reduced BCS loss, while compensatory gain minimized differences in final body condition.

Conclusion

Late-season grazing of corn residue, with or without interseeded cover crops, provided a viable overwintering strategy for pregnant beef heifers in the Northern Great Plains. Although heifers grazing residue alone lost body weight and condition, the inclusion of cool-season cover crops improved forage quality and moderated these declines. Compensatory gain during subsequent dry-lot feeding allowed previously grazed heifers to recover body weight and BCS, resulting in similar final condition across treatments. While dry-lot feeding produced the highest gains, grazing systems, especially those incorporating cover crops, offer a cost-effective alternative to traditional winter feeding without compromising heifer development.

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Table 1. Chemical composition (%DM) of corn residue components.

	Grain	Leaf	Husk	Cob	Stalk
DM%	85.3	91.9	85.8	84.8	64.9
CP	9.4	7.1	2.6	2.4	2.8
TDN	89	56	60	17	55
NDF	8.7	68.3	80.3	83.2	71.6
ADF	2.4	45.5	40.6	43.0	46.4
Ca	0.04	0.9	0.1	0.05	0.1
P	0.3	0.09	0.04	0.05	0.07
K	0.3	0.2	0.4	0.4	1.7
Mg	0.1	0.4	0.2	0.09	0.1
S	0.1	0.1	0.04	0.03	0.04

Table 2. Chemical composition (%DM) of corn residue, residue plus cover crop and grass hay offered to cows during grazing and in the dry lot (2023).

	Corn residue	Residue-cover crop	Grass hay
Chemical composition			
CP	5.6	10.1	10.5
TDN	63.6	59.2	56.7
NDF	58.0	61.3	59.5
ADF	34.5	38.1	41.3
Ca	0.25	0.51	0.58
P	0.25	0.31	0.15
Mg	0.18	0.22	0.25
K	1.71	2.01	1.52
S	0.13	0.20	0.11

Table 3. Performance of heifers grazing corn residue or corn residue and cool season cover crop or kept in a dry lot and fed grass hay.

	Corn residue	Residue-cover crop	Dry lot	SE	P
Pasture or Dry-lot Phase					
Days	33	33	33	-	-
Initial BW, kg	479	478	476	9.3	0.949
Final BW, kg	476[b]	484[ab]	503[a]	9.6	0.021
ADG, kg/d	-0.09[b]	0.21[b]	0.83[a]	0.158	<0.001
Initial BCS	5.5	5.5	5.4	0.128	0.759
Final BCS	5.1[b]	5.3[ab]	5.6[a]	0.147	0.003
BCS change	-0.41[b]	-0.22[ab]	0.19[a]	0.179	0.006
Dry-lot Phase[1]					
Days	22	22	22	-	-
Initial BW, kg	476[b]	484[ab]	503[a]	9.6	0.021
Final BW, kg	498	497	513	9.1	0.165
ADG, kg/d	1.01[a]	0.58[ab]	0.44[b]	0.177	0.008
Initial BCS	5.1[b]	5.3[ab]	5.6[a]	0.147	0.003
Final BCS	5.8	5.7	5.6	0.132	0.895
BCS change	0.66[a]	0.41[ab]	0.06[b]	0.175	0.006
Overall (Pasture and Dry lot Phase)					
Days	55	55	55	-	-
Initial BW, kg	479	478	476	9.3	0.949
Final BW, kg	498	497	513	9.1	0.165
ADG, kg/d	0.35[b]	0.35[b]	0.68[a]	0.078	<0.001
Initial BCS	5.5	5.5	5.4	0.128	0.759
Final BCS	5.8	5.7	5.7	0.132	0.895
BCS change	0.25	0.19	0.25	0.136	0.870

[1]All heifers were kept in the dry-lot during this phase.

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

Assessing Grassland Bird Responses to Grazing Strategies to Promote Avian Conservation

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Summary

Grassland bird populations have declined rapidly across North American rangelands, largely due to the loss of grasslands and grazing management that reduces structural heterogeneity in remaining rangelands. Heterogeneity-based strategies such as patch-burn grazing have demonstrated benefits for grassland bird conservation but are not always feasible due to logistical constraints associated with prescribed fire. Virtual fence technology may offer a novel alternative to manage for heterogeneity in rangelands by enabling spatial and temporal control of grazing behavior. We evaluated vegetation structure and grassland bird community responses across three grazing strategies—season-long grazing (SLG), patch-burn grazing (PBG), and patch-grazing with virtual fence (VF)—in a mixed-grass prairie in central North Dakota during 2024 and 2025. We quantified vegetation structure using visual obstruction readings and assessed avian community composition using line-transect surveys, with species categorized into obligate and facultative grassland functional groups. VF generated a clear gradient in vegetation structure across patch-grazing intensities, resulting in greater heterogeneity than traditional season-long grazing. Facultative species abundance did not differ across grazing strategies or patch-grazing intensities. In contrast, obligate grassland bird abundance varied among grazing strategies and across patch-grazing intensities, with patch-burn grazing consistently supporting the greatest abundance and virtual fencing producing comparable outcomes in some years. Within VF grazing strategy, obligate species utilized vegetation structure across the full gradient of grazing intensities. These findings suggest that patch-grazing with virtual fence can generate vegetation heterogeneity sufficient to support diverse grassland bird communities and may function as a flexible management tool that can promote biodiversity in working rangelands.

Introduction

Globally, rangeland ecosystems provide crucial ecosystem services (The Nature Conservancy et al., 2023). This includes providing 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 typically focused on livestock production and grazing at moderate use, which results in homogeneous vegetation structure (Fuhlendorf & Engle, 2001). This management focus has resulted in the simplification of rangeland landscapes, ultimately contributing to broad-scale declines in rangeland biodiversity (McNew et al., 2023). Conversely, a promising alternative for maximizing ecosystem services would be to adhere to the framework of pattern

and process conservation that promotes both conservation and production through the generation of structural heterogeneity (Fuhlendorf et al., 2012). To bridge the gap between producer needs and conservation, alternative heterogeneity-based land management strategies that can promote conservation and production in working lands need to be designed, assessed, and implemented (Keyser et al., 2020). Historically, rangelands within the Great Plains region experienced disturbances including spatially patchy wildfire and vast roaming herds of grazing bison (*Bison bison*) (Fuhlendorf & Engle, 2001). These disturbances created heterogeneous landscapes, diverse in both structure and composition (Fuhlendorf et al., 2006). Such out-of-sequence successional stages (i.e., the coexistence of multiple successional states across a landscape) generate gradients in vegetation structure and composition that have influenced the evolution of species in rangeland ecosystems (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).

Previous research has examined restoring heterogeneity with methods such as patch-burn grazing. Patch-burn grazing utilizes the interacting effects of focal fire and grazing to generate heterogeneity across the landscape (Fuhlendorf & Engle, 2004; Duquette et al., 2022). A portion of pasture is burned annually, and the resulting nutrient-rich regrowth is then preferentially selected by grazers, which maintains low vegetation structure in burned areas. (Archibald et al., 2005; Duquette et al., 2022). Moreover, patch-burn grazing offers neutral to positive effects on cattle production (Fuhlendorf & Engle, 2004; Limb et al. 2011; Allred et al. 2014; Augustine and Derner, 2015), and simultaneously promotes grassland bird diversity and conservation through the resulting structural and compositional variation (Augustine & Derner, 2015; Hovick et al., 2015). However, the application of fire on the landscape is not always feasible given atmospheric or topographic circumstances. Advancements in technology may help overcome this issue by creating new heterogeneity-based management strategies, which can also provide more equitable win-win scenarios for production and conservation.

New advancements in virtual fence technologies may give managers greater flexibility to implement management practices that generate heterogeneity through alteration of grazing patterns in space and time (Goliński et al., 2022; Murray et al., 2025). Virtual fence technology implements computer-programmed boundaries, capable of retaining cattle, much like a

standard wire fence, but with the benefits of instant mobility and reduced labor (de Avila et al., 2025). Boundaries can be altered in real-time, enabling the implementation of complex grazing systems designed to improve rangeland conditions or promote variation in grazing intensity. (Goliński et al., 2022). Cattle are fitted with collars which relay these boundary changes and emit audio cue and electric stimuli to retain cattle within the set boundaries (Boyd et al., 2022; Goliński et al., 2022; Avila et al., 2025). Virtual fencing provides the flexibility for managers to design and implement innovative strategies that influence stocking densities and the spatial and temporal patterns of animal grazing (Goliński et al., 2022).

Our study will assess the grassland bird community across three different grazing strategies in a mixed-grass prairie of central North Dakota. Two of the strategies are focused on creating heterogeneity with fire (patch-burn grazing) and without (patch-grazing with virtual fencing) and one is a more homogeneity focused strategy implemented by many landowners in the region (season-long grazing). The goal of this study is to assess how comparable patch-grazing with virtual fence is to patch-burn grazing, a strategy that has previously been shown to be effective at creating structural heterogeneity and increase avian community diversity. The specific objectives of this study are:

1) Quantify structural variation in the plant community resulting from the three different grazing strategies.

2) Evaluate avian community composition across the three grazing treatments.

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

Methods

Study Site

This study was conducted at North Dakota State University's Central Grassland Research Extension Center (CGREC) located near Streeter, North Dakota, (46°45'N, 99°28'W) in the years 2024 and 2025. Located in the Missouri Coteau ecoregion of the northern mixed-grass prairie, the growing season extends from May to September. The CGREC is dominated by native perennial cool season grasses such as, 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). The forb community is diverse and includes goldenrods (*Solidago spp.*), sages (*Artemisia spp.*), coneflower (*Asteraceae spp.*), thistles (*Cirsium spp*.), and numerous other species. Other important species are the native shrub western snowberry (*Symphoricarpos occidentalis*), and non-native invasive grasses such as, Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) (Patton et al., 2007; Limb et al., 2018).

Treatments

Our study assessed the avian community across three grazing management treatments: season-long grazing (SLG), patch-burn grazing (PBG), and patch-grazing with virtual fencing (VF) (Figure 2). Each treatment has four replicate pastures, approximately 65 hectares(ha) in size.

Each pasture was divided into four equally-sized patches (~16 ha) (Figure 1). Each patch had two randomly placed 100m transects, placed > 75m from pasture and patch boundaries

Figure 1. A map of the Central Grasslands Research Extension Center (CGREC) grazing treatments. Individual pastures divided equally into four patches (~16ha), with two randomly placed 100m transects within each patch. The disconnected white lines represent transects.

All grazing strategies were moderately stocked (2.26-2.31 Animal Unit Months/ha) with cattle from mid-May – October. The SLG strategy utilizes cattle to graze a pasture uniformly to increase livestock production (Fuhlendorf & Engle, 2001). The PBG strategy supplements season-long grazing with a dormant season spring patch-burning (one patch burned late April – early May) at a four-year return interval (Figure 2). Burned patches attract cattle, drawing grazing pressure away from the adjacent unburned patches, creating contrast in vegetation structure and composition and resulting in pasture scale heterogeneity (Archibald et al., 2005). The VF strategy is novel and unique to this study as it uses virtual fence technology to implement a patch-grazing strategy in the absence of physical fencing, promoting heterogeneity across a pasture through variation in grazing intensity over time and space (Figure 2). This is achieved by providing cattle access to pasture, divided into 4/4, at the start of the growing season (May) and restricting them to ¼ for the duration of the 78 days (heavy use). Then we altered the virtual fencing to increase access to ½ of the pasture for the duration of 39 days (moderate use). Then we altered the virtual fencing for the final time to increase access to ¾ of the pasture for the duration of 39 days (light use). The remaining ¼ of pasture is excluded from

grazing. This patch of pasture functions to promote plant recovery (Goosey et al., 2024) and offers refugia from disturbance, increasing resiliency from annual variations in precipitation. Grazing intensities are rotated between patches annually so that each patch receives each grazing intensity over a four-year period (Figure 2).

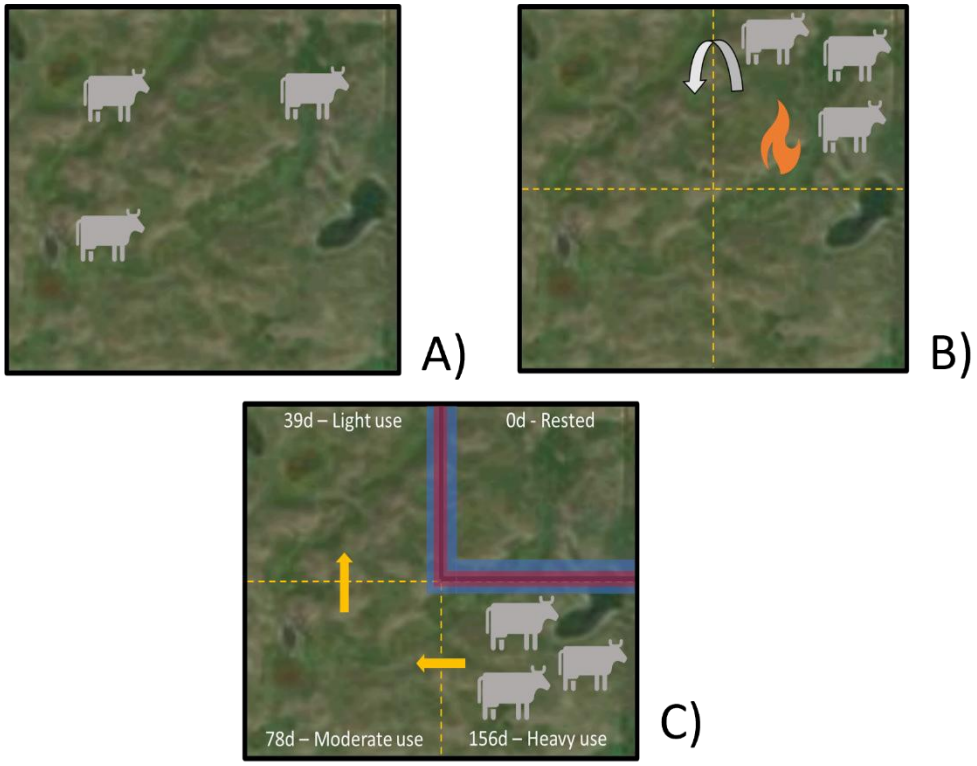

Figure 2. The three grazing strategies utilized within this study: **A**) season-long grazing, **B**) patch-burn grazing, and **C**) patch-grazing with virtual fence. The dashed lines represent conceptual patch boundaries. The blue bars indicate audio stimulus zone. The red bars indicate the electric stimulus zone. The arrows indicate the rotation of treatment specific disturbance regimes over time. (Modified from Duquette et al., 2022).

Data Collection

Bird Surveys

We monitored the grassland bird community composition within each of our pastures from May 27th to July 15th in 2024 and 2025. In each patch, we conducted line transect distance sampling surveys along two, 100m transects 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). Each transect was surveyed three times during the breeding season (288 surveys). Upon detection (visual or auditory) we recorded a bird's species, sex, behavior, and perpendicular distance to the transect (within 50m).

Vegetation Surveys

We conducted vegetation surveys to quantify structure along each 100m transect. On each side of the transect, we used a $0.5m^2$ quadrat to assess the vegetative community every 25 meters (10 quadrats/transect, offset by 15 meters from the transect). Vegetation was categorized into functional groups (i.e., Forb, Grasslike, Woody) with Kentucky bluegrass and Smooth brome grouped separately. Additionally, we measured vegetation structure (Robel, 1970), absolute cover of functional groups (Daubenmire, 1959), and litter depth at each quadrat.

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.

Objective 1

We calculated average vegetation density at the patch level across all grazing strategies. Grazing strategies were grouped into a "Disturbance Regime", which reflected the various types and durations of disturbances across patches within grazing strategies. SLG was not divided into sub-levels and was labeled "SLG", as the entire pasture receives a uniform grazing intensity. PBG was divided into time-since fire (TSF), with "0" being a patch burn that year and "4-5" being a patch that has not experienced a fire in either four or five years. VF was divided into the duration of time each patch was grazed, with "0d" being a patch that received no grazing that year and "150d" being a patch that received 150 days were of grazing. A GLM was used to determine whether patch-grazing intensity or time-since fire affected average vegetation.

Objective 2 & 3

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. A GLM was used to determine whether treatment (SLG, PBG, 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 grazing strategy affected average grassland bird abundance.

Results

Objective 1

PBG

In 2024, vegetation density was significantly lower ($p<0.05$) in the "0" TSF patch than in "2-3" and "4-5" TSF patches (Figure 3). We observed vegetation density to be statistically similar in the "1" TSF patch compared to the remaining patches (i.e., "0", "2-3", "4-5"). In 2025, vegetation density was significantly lower ($p<0.05$) in the "0" TSF patch compared to the remaining patches (i.e., "1", "2-3", "4-5") (Figure 3).

VF

In 2024, vegetation density did not differ ($p>0.05$) across patch-grazing intensities (Figure 3). In 2025, vegetation density was significantly lower ($p<0.05$) in the "150d" patch compared to the "100d" patch (Figure 3). We observed vegetation density to be statistically similar in the "0d" and "50d" compared to "100d" and "150d" patches.

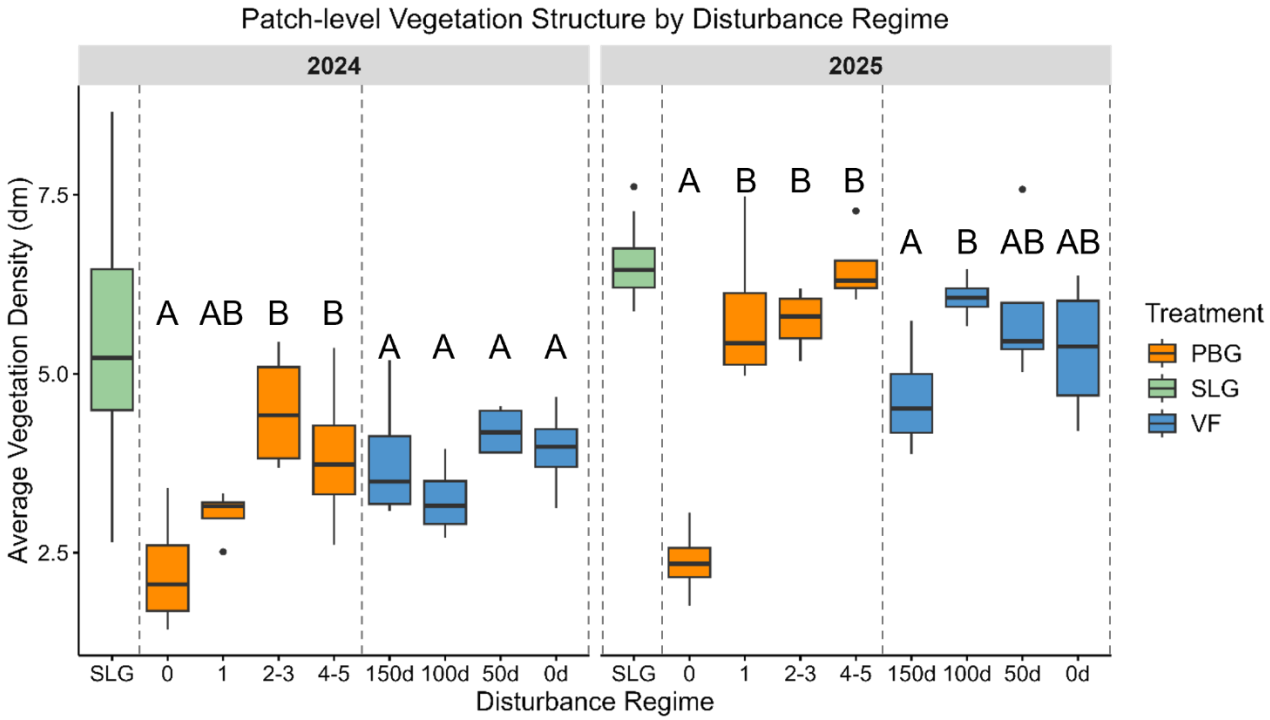

Figure 3. Average vegetation density (dm) based on visual obstruction reading (VOR) during peak growing season in 2024 and 2025 (late June to early July) across all grazing strategies. The X-axis, "Disturbance Regime", describes the various types and durations of disturbances within and across grazing strategies. Patches are labeled according to time-since fire or the grazing intensity they received. The vertical dashed lines separate grazing strategies. Significance ($p<0.05$) was determined within year and within grazing strategy indicated through a difference in letters above each column.

<u>Objective 2</u>

In 2024, we detected 1,271 birds representing 34 species (23 facultative species (FAC) and 11 obligate species (OBL)) from late May to mid-July. We observed no differences ($p>0.05$) in FAC species abundance across grazing strategies (Figure 4). We observed greater ($p<0.05$) OBL species abundance in PBG when compared to SLG. OBL species abundance in PBG was significantly greater ($p<0.05$) than in SLG, but was similar in VF.

In 2025, we detected 1,224 birds representing 41 species (29 facultative species (FAC) and 12 obligate species (OBL)) from late May to mid-July. We observed no differences ($p>0.05$) in FAC species abundance across grazing strategies. OBL species abundance was significantly greater ($p<0.05$) in PBG compared to VF and SLG.

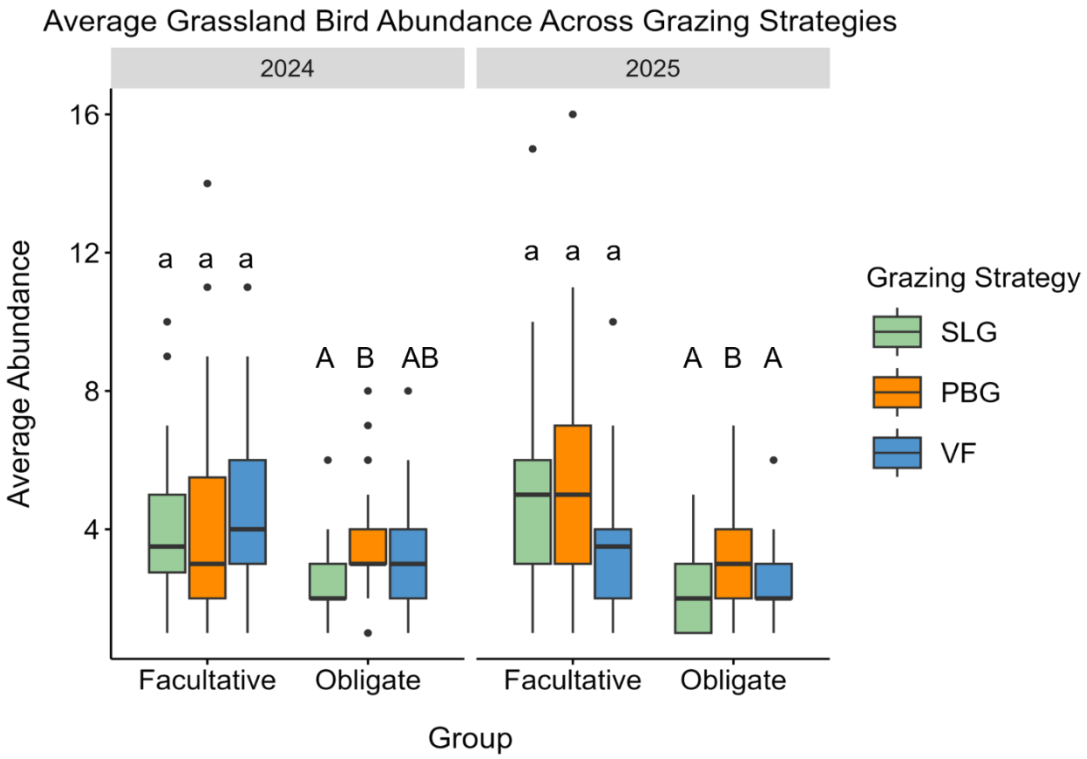

Figure 4. Average abundance of facultative (FAC) and obligate (OBL) avian species within each grazing strategy from late May through mid-July of 2024 and 2025. Significance ($p<0.05$) was determined within year and is indicated by the letters above each column with capital and lowercase letters assigned to differing groups.

Objective 3:

In 2024, within the VF grazing strategy we detected 421 birds representing 25 species (17 facultative species (FAC) and 8 obligate species (OBL)) from late May to mid-July. Moreover, in 2025 we detected 341 birds representing 24 species (14 facultative species (FAC) and 10 obligate (OBL)). Across years we observed no differences in FAC species abundance across patch-grazing intensities. OBL species abundance varied in both magnitude and direction across years and patch-grazing intensities. In 2024, OBL species abundance was significantly greater ($p<0.05$) in the Rested patch compared to the Heavy patch, while this relationship was reversed in 2025 (Figure 5). In contrast, OBL species abundance did not differ between the Light and Moderate patches and were statistically similar to the Rested and Heavy patches in both years.

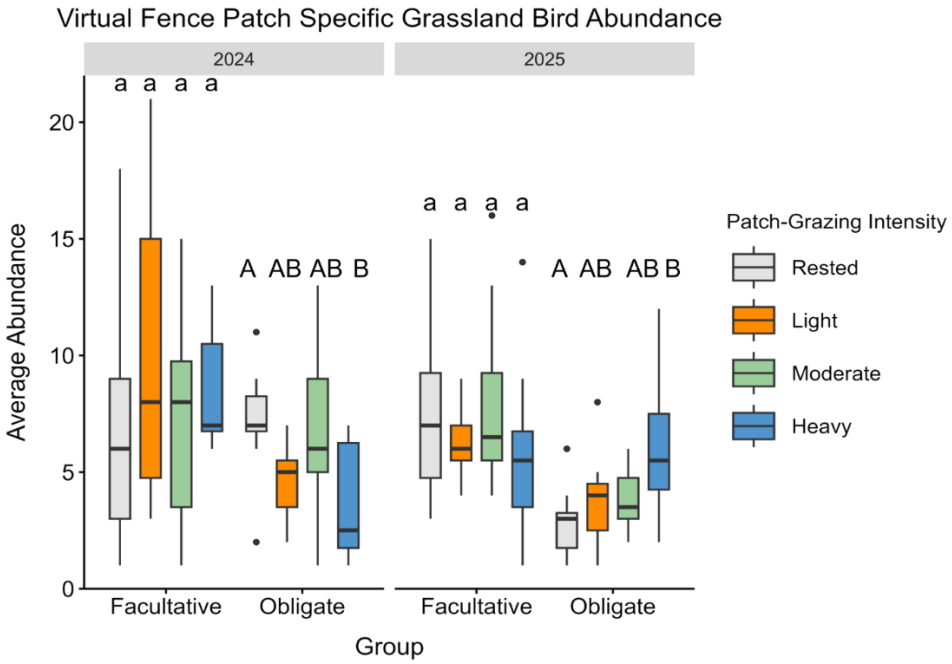

Figure 5. Average abundance of facultative (FAC) and obligate (OBL) avian species from late May through mid-July of 2024, observed within a patch-grazing with virtual fence grazing strategy. Patches are labeled according to the grazing intensity they received. Significance ($p<0.05$) was determined within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

Discussion

Collectively, our results demonstrate that heterogeneity-based management strategies (e.g., patch-burn grazing, patch-grazing using virtual fence) and the variable structure they create positively affects the obligate grassland bird community.

Visual obstruction readings (VOR) provided measures of vegetation height and density that were used to characterize vegetation structure within the VF grazing strategy. While VF patch-grazing intensities did not differ in 2024, a clear structural gradient emerged in 2025, indicating increased variability among patch-grazing intensities through time. The patterns observed in 2025 aligned with expectations that heavily grazed patches (Heavy) would result in low vegetation density while ungrazed patches (Rested) would support higher levels of vegetation density. Such patterns are commonly associated with grazing systems that incorporate rotation and periods of rest (Hagen et al., 2004; Derner et al., 2009; Toombs et al., 2010). Patch-burn grazing (PBG) produced a comparable gradient, where recently burned patches consistently supported lower vegetation density and patches with longer time since fire exhibited greater structure. These results indicate that VF and PBG can generate similar structural outcomes via different disturbance pathways, though heterogeneity may develop at different rates.

The development of structural heterogeneity can increase the availability and/or quality of breeding habitat for grassland birds (Fuhlendorf et al., 2006; Gregory et al., 2010; Holcomb et

al., 2014), potentially enhancing avian biodiversity, particularly for obligate species with specific structural affinities (Cody, 1985; Knopf, 1996; Fuhlendorf & Engle, 2001). The ability of VF to generate heterogeneity comparable to PBG suggests that it may serve as a viable alternative in systems where the use of fire is constrained.

We observed no differences ($p>0.05$) in facultative species abundance across examined grazing strategies, indicating suitable structure was equally available. This said, we observed that obligate species abundance was consistently the greatest ($p<0.05$) in PBG with it being statistically similar to the VF grazing strategy one year. PBG is known to effectively restore structural heterogeneity and promote grassland bird diversity (Fuhlendorf and Engle, 2001; Fuhlendorf et al., 2006), making the similar species responses observed under VF particularly encouraging.

We measured obligate grassland bird abundance in each patch grazing intensity (i.e., Rested, Light, Moderate, Heavy) within the VF grazing strategy. Across years we observed no differences ($p>0.05$) in facultative species abundance across patch-grazing intensities. Alternatively, obligate species abundance varied in both magnitude and direction across years and patch-grazing intensities. In 2024, we observed greater ($p<0.05$) average species abundance in the Rested patch when compared to the Heavy patch while the inverse in direction of significance was observed in 2025. When assessed alongside average vegetation density within the VF grazing strategy (Figure 3), we determined that obligate grassland birds utilized the full vegetation structure gradient (short and sparse – tall and dense) (Knopf 1996). Consistent with previous works, specialist species tended to select structural extremes, while generalist species selected intermediate conditions (Fuhlendorf et al., 2006, Augustine and Baker, 2013, Hovick et al., 2015). While further analysis is required, we speculate that the significantly lower average abundance of obligate species in the Heavy patch in 2024 and the Rested patch in 2025 is a result of yearly environmental variation (e.g., precipitation) and topo-edaphic characteristics of the landscape. These responses reflect short-term patterns and longer-term population responses may differ as vegetation structure and surrounding bird community change. This said, these findings suggest that virtual fence patch-grazing can function as a flexible grazing strategy capable of generating the structural diversity required by both specialist and generalist obligate grassland birds, offering a promising alternative or complement to traditional heterogeneity-based grazing systems.

Conclusion

Our findings demonstrate that patch-grazing using virtual fence technology can generate meaningful structural heterogeneity and support diverse grassland bird communities, particularly obligate grassland species of conservation concern. Although, patch-burn grazing consistently supported the highest obligate bird abundance, virtual fencing produced comparable responses in some years and facilitated use of the full vegetation structure gradient within pastures. Accordingly, virtual fencing may be especially valuable where prescribed fire is impractical due to infrastructure, topography, or regulatory constraints. Continued evaluation over longer time frames will be necessary to assess longer term grassland bird responses.

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Assessment of Pollinator Communities Across Three Grazing Strategies

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Summary

Rangelands and their associated pollinators are threatened by land-use change and management practices that promote homogeneity, such as season-long grazing. These threats lead to loss of rangeland ecosystems and degradation of remaining rangelands. This limits floral resources that are crucial for supporting native and managed pollinators and can negatively influence declining butterfly and bee populations. To address these challenges, we investigated the responses of butterfly populations, bee populations, and floral resources to grazing strategies that aim to restore structural heterogeneity to rangelands. Our study focused on two treatments designed to restore heterogeneity, patch grazing with virtual fence technology (PGVF) and patch-burn grazing with early-season fire (late April-early May) (PBG), and compared these approaches to season-long grazing (SLG), which acted as a control. Our first year of data shows that community composition of butterflies, bees, and floral resources varied among grazing strategies, but strategies that focused on increasing heterogeneity (PGVF, PBG) promoted the highest species richness and abundance. For butterflies, richness was greater for both PGVF and PBG ($p<0.001$) compared to SLG, and abundance was greater in PGVF ($p<0.001$) compared to PBG and SLG. For bees, bumble bee species richness was greater for both PGVF and PBG compared to SLG ($p=0.021$) and total spp. abundance was similar across all strategies ($p>0.05$). For floral resources, both species richness ($p<0.001$) and floral abundance ($p<0.01$) were greater for both PGVF and PBG compared to SLG. These preliminary results suggest that restoring heterogeneity to rangelands through novel grazing management strategies can promote pollinator populations and floral resources.

Introduction

Native pollinators play a critical role in both natural and agricultural ecosystems, contributing approximately $201 billion to global agriculture per year (Gallai et al., 2009). Despite this critical role, pollinator populations are in decline (Edwards et al., 2025; Goulson et al., 2015; Hanberry et al., 2021; Swengel et al., 2011). Declines are occurring in both butterflies (Edwards et al., 2025; Leuenberger et al., 2025) and bees (Burkle et al., 2013; Cameron et al., 2011), along with drastic range contractions across taxa (Cornelisse et al., 2025; Richardson et al., 2023). Anthropogenic drivers such as land-use change, habitat fragmentation, and degradation all contribute to these declines (Cornelisse et al., 2025; Otto et al., 2016; Potts et al., 2010). Each driver has the potential to affect pollinator populations individually, but effects are increased when multiple drivers impact populations. These drivers can be especially

prevalent in the northern Great Plains, which has one of the largest remaining grasslands but also one of the highest rates of land conversion (WWF et al., 2023). These rangelands provide important food for pollinators (Black et al., 2011) and are considered critical areas for pollinator conservation (Society for Range Management, 2023). Despite rangelands' importance to pollinators, traditional grazing management promotes uniform grazing and reduces natural variation that is critical for supporting diverse floral communities (Alkemade et al., 2013). Grazing is the primary land use in rangelands and (Alkemade et al., 2013) plays a major role in influencing pollinator populations (Bendel et al., 2018; Bruninga-Socolar et al., 2022; Cutter et al., 2022; Moranz et al., 2012). Understanding the influence of grazing strategies on pollinators is thus essential to pollinator conservation, along with the continued development of novel strategies to provide improved conservation tools.

Although traditional grazing strategies prioritize uniform utilization of forage to maximize sustainable livestock production and decrease bare ground (Fuhlendorf et al., 2006; Fuhlendorf and Engle, 2001), this focus can lead to homogenous landscapes that lack the environment needed for many species. This is because disturbances, such as large herbivore grazing and fire, have historically occurred in rangelands (Axelrod, 1985). These disturbances and their interaction promoted a heterogenous landscape due to temporal and spatial variability creating a shifting mosaic of vegetation structure and composition (Fuhlendorf and Engle, 2001). The loss of the interactions between large herbivores and fire in current grazing strategies can lead to decreases in abundance and diversity of floral resources (Duquette et al., 2022) and reductions in native plants, plant diversity, and structural heterogeneity (Tscharntke et al., 2005). Season-long grazing is an example of a grazing strategy that promotes homogeneity and may experience consequences due to its lack of disturbance.

Alternative grazing strategies that focus on creating both temporal and spatial variability across a landscape to restore heterogeneity may be the most beneficial to pollinator communities. Restoring heterogeneity has the potential to benefit pollinator communities through increasing niche diversity, plant species richness, and floral abundance, along with increasing native plants (Fuhlendorf et al., 2009; Fuhlendorf and Engle, 2004; Hackett et al., 2024). Alternative management approaches are continuously being explored. Patch-burn grazing mimics the historical disturbances present and has shown benefits to plants and pollinators alike (Duquette et al., 2022; Geest et al., 2023; Leone et al., 2022) but may not always be feasible. We propose patch grazing with virtual fence technology as a novel alternative grazing strategy. In this grazing strategy we use computer-programmed boundaries to alter cattle behavior in order to establish variation in grazing intensity throughout the pasture with the goal of promoting heterogeneity.

Due to the critical role pollinators play in rangelands, it is essential to understand the influence that both traditional and novel grazing strategies exert on pollinator populations. In order to further understand this influence, we investigate three grazing strategies in mixed grass prairie rangelands in the Northern Great Plains: patch grazing with virtual fence technology, patch-burn grazing, and season-long grazing. The objectives of this study are to 1) evaluate floral resources across grazing strategies and 2) quantify pollinator communities across grazing strategies.

Methods

Study Area

We conducted research at the Central Grasslands Research Extension Center (CGREC) which is located in central ND, within Kidder and Stutsman Counties (46°71'N, -99°44'W). The site is a mixed-grass prairie within the prairie pothole region of the Missouri Coteau ecoregion. It is dominated by perennial cool season grasses (e.g., western wheatgrass, green needle grass, needle-and-thread grass) and introduced grasses (e.g., Kentucky bluegrass, smooth brome) (Duquette et al., 2020; Limb et al., 2018; Patton et al., 2007). Common forbs include western ragweed, prairie coneflower, common yarrow, yellow sweet clover, goldenrod species., milkvetch species, milkweed species, and thistle species, with a generally high forb diversity (Duquette et al., 2022, 2020; Limb et al., 2018). Western snowberry is the most common woody species. This site is characterized by an average growing season (May 1- Sept. 1) temperature of 17.3°C and precipitation of 28.6 cm (North Dakota Agricultural Weather Network).

Treatment Structure

Three grazing treatments were used, season-long grazing (SLG), patch-burn grazing (PBG), and patch grazing with virtual fence (PGVF) (Figure 1). Each treatment consisted of four replicates of equal pasture size (65 ha) across approximately 260 ha. SLG was utilized as a control that reflects traditional grazing strategies in the northern Great Plains. SLG allows cows to graze freely throughout the pasture throughout May-October.

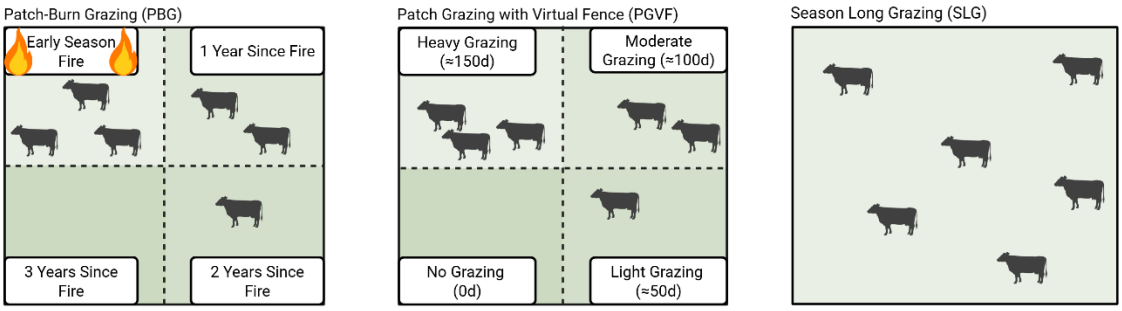

Figure 1. Grazing strategy setup and the expected grazing response. Dashed lines delineate time since fire or grazing intensity and are not actual fences. (https://BioRender.com/ze5fdmw)

PBG is defined by a single dormant season (spring) fire. A quarter of the pasture is burned on a 4-year rotational burning cycle. Cattle are stocked May-October and allowed to graze freely throughout the pasture.

PGVF uses virtual fence to patch graze through excluding three quarters of the pasture at the start of the season and sequentially allowing cattle to graze more quarters as the season goes on. One quarter remains ungrazed each season. Cattle are stocked May-October. Throughout the course of our season, cattle in PGVF spent approximately 150 days in the first quarter, 100 days in the second quarter, 50 days in the third quarter, and 0 days in the fourth quarter.

Pollinator Surveys

We randomly placed two 100-m transects in each patch to quantify pollinator species richness and total detections for both butterfly and bee populations. For butterfly populations, detection rates were also calculated. We conducted butterfly surveys and bee surveys individually, and transects for both were walked at a rate of approximately 10 min/100 m, minus the time spent interacting with pollinators (Kral-O'Brien et al., 2021; Moranz et al., 2012; Royer et al., 1998). Weather variables for all pollinator surveys were collected from the North Dakota Agricultural Weather Network (NDAWN) weather station in Streeter, ND. Three rounds of pollinator surveys occurred from June – mid-August.

During surveys, we recorded detected butterflies ahead and to either side of the transect (Buckland et al., 2001; Kral-O'Brien et al., 2021). For each observation, we recorded the perpendicular distance from the individual to the transect, along with observation time, behavior, and plant visited. Butterflies were identified to the species level. Butterfly surveys were conducted between 09:00 and 18:00 and if it was 1) >20.5° C and <35.5° C if cloud cover <50%, wind <28.96 km/hr, or 2) >30° C and <35.5° C if cloud cover >50%, wind <28.96 km/hr (Riva et al., 2020; Royer et al., 1998).

During bee surveys, all bees observed interacting with floral resources within 1 m of the transect were recorded. The observation time, bee behavior, and plant visited was recorded for each observation. All bees, except European honey bees, were netted and jarred. Bumble bee species were photographed for identification and then released. All other bees were humanely killed and collected. Bees will be identified to the species level. Bee surveys were conducted between 08:30 and 17:30 and if it was >15.5°C and <35°C, <24.14 km/hr average wind and < 32.19 km/hr gusts, and not overcast or really smoky.

Floral Resource Surveys

Floral resource surveys used the same transects as the pollinator surveys (two randomly placed 100-m transects) in each patch to quantify floral resources in each treatment. Three rounds of floral surveys were conducted in association (<3 days between) with pollinator surveys. Ramets of all species within 2.5 m of the transect were counted if classified as either flowering or budding. A ramet was considered flowering if at least one flower had anthers visible (Duquette et al., 2022; Fründ et al., 2010). A ramet was considered budding if at least

one bud was there. If a ramet had both buds and flowers, it was classified as flowering, as it was still a nectar resource.

Statistical Analysis

All statistical analysis was done in R v4.5.1 (R Core Team, 2025). We analyzed floral and bumble bee abundance and species richness using generalized additive mixed-effect models (GAMMs). Butterfly abundance was analyzed using unmarked and then visualized based using a GAMM. Butterfly species richness was analyzed using a GAMM. Significance was determined at $p \leq 0.05$.

Results

In 2025 we completed 3 rounds of pollinator and floral surveys and observed 201 bumble bees, 3,063 butterflies, and 270,215 flowering plants (Figure 2). We had the most observations in patch grazing with virtual fence (PGVF) (108 bumble bees, 1,233 butterflies, 120,926 flowering plants), followed by patch burn grazing (PBG) (59 bumble bees, 939 butterflies, 79,898 flowering plants). Season-long grazing (SLG) had the least observations (34 bumble bees, 891 butterflies, 69,391 flowering plants). Throughout the 2025 summer, the PGVF strategy had a containment of 74.7%.

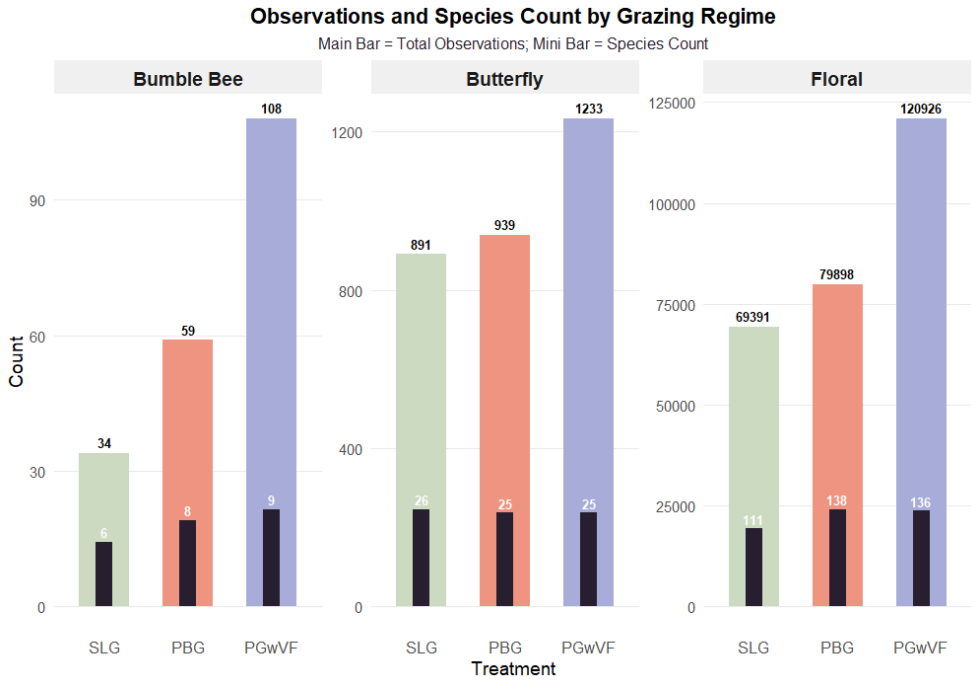

Figure 2. Total observations per grazing strategy are represented by the colored bars, with patch-grazing with virtual fencing (PGwVF) showing the highest observations of bumble bees, butterflies, and floral resources, patch-burn grazing (PBG) showing the second most, and season-long grazing (SLG) showing the least. Species richness per treatment is represented by the small bars.

Across the growing season, we saw that flower abundance was similar between PBG and PGVF ($p=0.190$), with both grazing strategies promoting increased floral resources compared to

SLG ($p<0.001$) (Figure 3a). We observed a similar trend in species richness, as PBG and PGVF had higher species richness compared to SLG ($p<0.001$) (Figure 3b). However, PGVF showed greater species richness over PBG ($p<0.001$). For both floral resource abundance and floral resource species richness, we saw a significant change throughout the growing season ($p<0.001$), as different plants bloomed and senesced, and a significant difference between individual transects ($p<0.001$).

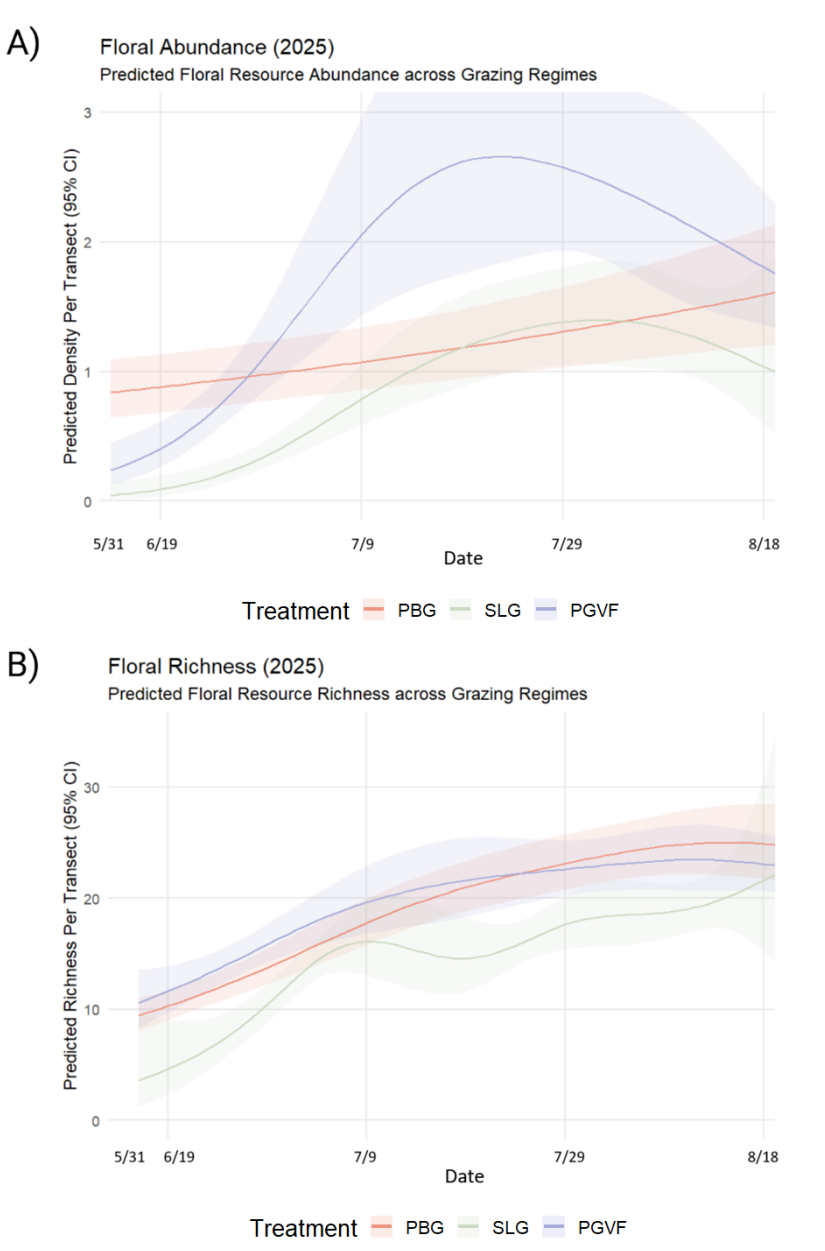

Figure 3. A) Floral abundance across treatments throughout the growing season, represented by the predicted density of flowering resources per transect. **B)** Floral species richness across treatments throughout the growing season, represented by the predicted number of species per transect.

We observed higher pollinator species richness for both PGVF and PBG compared to SLG (butterflies; $p<0.001$, bumble bees; $p=0.021$) (Figure 4b). PGVF showed greater butterfly species richness compared to PBG (butterflies; $p<0.001$), but showed no changes in bumble bees ($p=0.723$). Pollinator abundance showed different responses for each taxa (Figure 4a). For butterflies, abundance was greater in PGVF ($p<0.001$) compared to PBG and SLG, which were similar ($p=0.826$). For bees, abundance was similar across all strategies ($p>0.05$). However, for all pollinator metrics, we saw significant changes throughout the growing season (bee abundance, bumble bee richness, butterfly abundance, butterfly richness; $p<0.001$). We accounted for random variables in our models, and saw some transect level differences (bee abundance; $p=0.001$), some decreases in detection due to wind speed (bee abundance; $p=0.002$, butterfly abundance; $p<0.001$, butterfly richness; $p=0.015$) and changes due to surveyor (bee abundance/bumble bee richness; $p<0.01$; butterfly richness; $p=0.002$). Bumble bee richness was not impacted by transect ($p=0.225$) or wind speed ($p=0.426$) and butterfly richness was not impacted by transect ($p=0.912$). Pollinator abundances and richness were not significantly impacted by changes in time of day (bee abundance; $p=0.203$, butterfly abundance; $p=0.550$, bumble bee richness; $p=0.697$, butterfly richness; $p=0.550$), temperature (bee abundance; $p=0.558$; bumble bee richness; $p=0.662$, butterfly richness; $p=0.506$), humidity (bee abundance; $p=0.842$, bumble bee richness; $p=0.249$, butterfly richness; $p=0.988$), or cloud cover (bee abundance; $p=0.656$, bumble bee richness; $p=0.227$, butterfly richness; $p=0.227$), within our survey conditions.

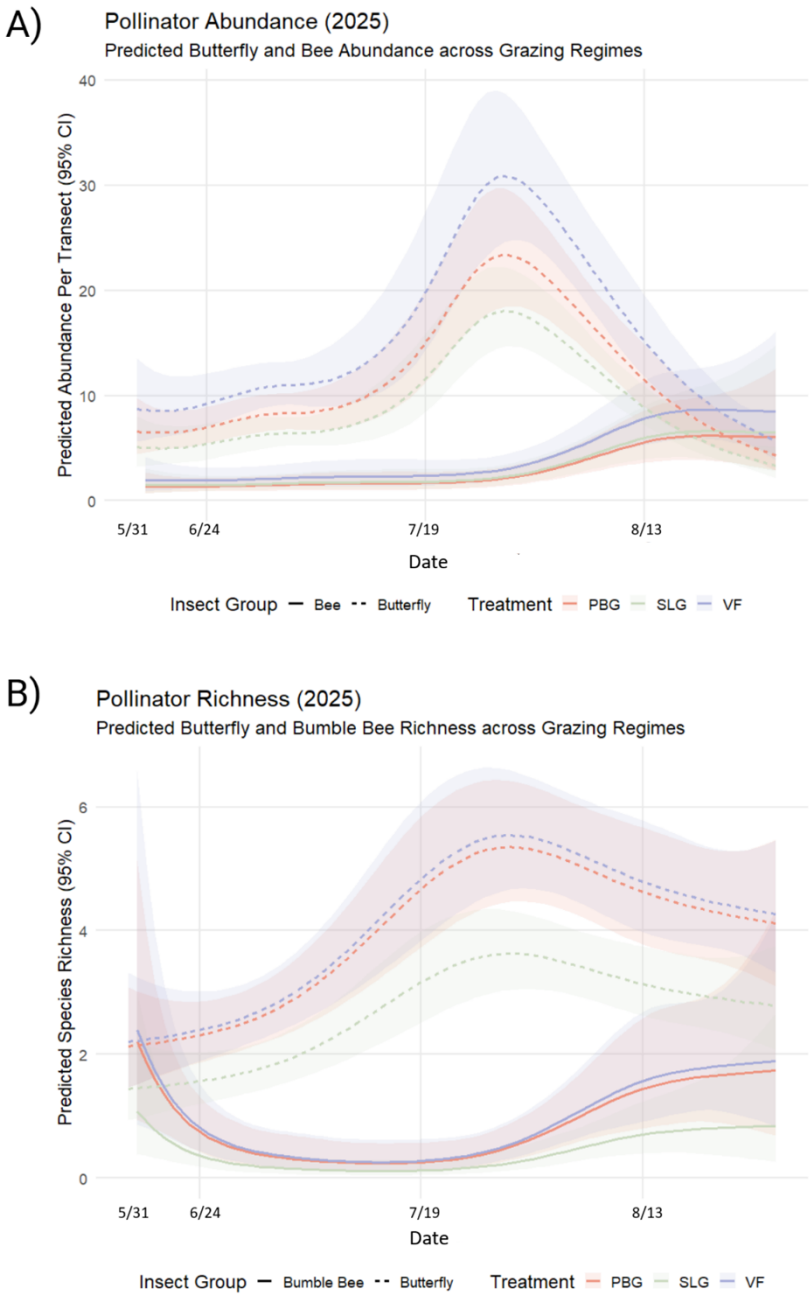

Figure 4. A) Pollinator abundance across treatments throughout the growing season, represented by the predicted number of pollinators per transect. Bees are represented with a solid line and butterflies are represented with a dashed line. **B)** Pollinator species richness across treatments throughout the growing season, represented by the predicted number of species per transect. Bumble bees are represented with a solid line and butterflies are represented with a dashed line.

Discussion

Our preliminary results from the 2025 season suggest that grazing strategy impacts the floral resources available to pollinators. Grazing strategies that were designed to increase heterogeneity across the pasture, such as patch-burn grazing (PBG) and patch-grazing with virtual fence (PGVF), had larger amounts of flowering plants and more species compared to a traditional grazing strategy, season-long grazing (SLG). This increase in individuals and species will lead to a greater amount of nectar available for pollinators across these pastures and also across the summer. Notably, while PBG and PGVF had similar amounts of floral resources, PGVF was able to support higher floral species richness. This could potentially be due to the fire in PBG creating a non-selective disturbance, while PGVF allowed for us to precisely move cattle, creating selective disturbances, which may have allowed for a more complex gradient of disturbance across the pastures and preserved fire-sensitive plants. However, this is more likely to be driven by the accessibility afforded to cattle in PBG- while they spend more time grazing the burned patch, they are free to go eat highly nutritious forbs at any point, while in PGVF, most cattle don't have that flexibility, as heifers had to stay inside the virtual fences, giving nutritious forbs the ability to grow before being grazed, which will increase their persistence.

These changes in floral resources likely mediated differences in the pollinator populations. Butterfly abundances were higher in PGVF, potentially due to the increased variety of floral species that were present in PGVF compared to SLG and PBG (which had similar butterfly abundances). Many butterflies have specific environmental requirements or respond quickly to environmental changes (Dennis et al., 2003; Fleishman and Murphy, 2009; Nadeau et al., 2017). The higher species richness in PGVF may have provided increased resources that butterflies quickly responded to. For bees, abundance was similar across strategies, potentially due to adequate floral resources across strategies and greater bee species adaptability to different levels of resources. Bumble bees are typically more generalist foragers than butterflies (Fontaine et al., 2008), and most bees are capable of traveling quite large distances to find resources (Osborne et al., 2008). Bee abundance typically responds to resources at a landscape level rather than a local level (Griffin et al., 2021).

Pollinator species richness was higher across taxa in both grazing strategies that aimed to promote heterogeneity, PBG and PGVF, compared to SLG. This is likely due to the increased number of floral resources and the creation of more niche spaces (Fuhlendorf et al., 2009; Fuhlendorf and Engle, 2004; Hackett et al., 2024). Increasing floral resources richness has been found to lead to native pollinator population increases (Bendel et al., 2019; Pei et al., 2023) and increasing abundance of certain native floral resources has been found to lead to native pollinator increases as well (Antonsen et al., 2021; Leone et al., 2023). Further, creation of more niche spaces is well documented to lead to higher species richness (Hackett et al., 2024). This also shows that strategies with varying degrees of disturbance across the landscape are important to supporting less common or more specialized pollinator species that may be absent in pastures managed with traditional grazing.

Due to its ability to mimic historical disturbance strategies (Fuhlendorf and Engle, 2004, 2001), PBG has been shown to simultaneously support livestock production and biodiversity

conservation (Fuhlendorf and Engle, 2004), . Despite this, PBG may be un-feasible (Clark et al., 2022), or land managers may have perceived risks and doubts about its potential benefits (Bendel et al., 2020). Our preliminary data suggests that PGVF can promote floral resources and pollinator populations, and may provide additional benefits. Utilizing virtual fence to patch graze would offer a flexible management strategy to support pollinator communities in working rangelands.

Conclusion

Our preliminary results show that utilizing management strategies that promote structural heterogeneity, such as patch-burn grazing and patch-grazing with virtual fencing, can have conservation benefits compared to traditional grazing management (season-long grazing). Patch-burn grazing and patch-grazing with virtual fencing can support larger and more diverse flowering plant and pollinator populations in northern Great Plains grasslands. Notably, patch-grazing with virtual fence increased both floral species richness and butterfly abundance more than patch-burn grazing. This suggests that patch-grazing with virtual fence may be a good option for modern grazing management, as it offers a more flexible and accessible alternative to promote pasture heterogeneity and pollinator populations.

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Heterogenous grazing strategies support native bee floral selection

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Summary

Grazed rangelands have the potential to be productive areas for native bee communities. To better understand how rangeland grazing management may support native bees, we examined bee and flower abundance, diversity, and network structure (mapping what pollinators are visiting which floral species) across three management strategies (modified twice-over rest rotational grazing- MTORG, patch-burn grazing- PBG, and season-long grazing- SLG) for four summers (2021-2024). We detected 291 native female bees visiting flowers and counted 357,446 individual flowering plants across three rounds of surveys each summer. Our network structure analyses examining bee visitations to flowers found that PBG supported more community specialization in which taxonomic groups of bees were visiting fewer floral species compared to the other grazing regimes. In other words, bees in PBG seemed to be able to preferentially select flowers due to the high floral diversity present in PBG. As for the MTORG regime, bees appeared to also show preference when selecting flowers, but to a lesser extent and with lower network specialization (i.e. bee groups were visiting more flower species). MTORG may therefore also be important for bees because of its implications for supporting high bee abundance and exhibiting some floral preference. Finally, we found the SLG strategy to potentially give bees fewer floral choices and put constraints on bee-floral interactions. Our findings are important because we have detected differing network structure for native bees and floral resources in grazing strategies despite our treatments having no significant difference in bee diversity, floral abundance, or relative network size (number of bee groups interacting with floral species). These conclusions support that heterogenous grazing strategies (PBG and MTORG), can provide resources that allow bees to be more selective in their food choices which can further support native bee populations in grazed rangelands.

Introduction

Native 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). These services include efficient pollen transfer between flowers, promotion of diverse floral communities, long-term crop yield, and landowner profit (Winfree et al. 2008, Garibaldi et al. 2014, Wahengbam et al. 2019). While native bees are vital, their populations have undergone global declines due to habitat loss, agricultural intensification, and climate change (Brown and Paxton 2009, Potts et al. 2010). Rangelands can aid bee populations by providing pollinator food

resources and nesting sites (Black et al. 2011), making these areas critical for pollinator conservation (Cole et al. 2017). However, if we are to effectively use these lands to support bee communities, we must explore which grazing management strategies can create sustainable habitat and support diverse bee and floral assemblages.

We can assess the impact of management techniques on bees and flowers through community metrics like abundance and diversity, but also through network analyses, which quantify interactions between pollinators and the floral species they visit (Bosch et al. 2009). Network analyses studying pollinator-plant visitations have been applied in many regions (Weiner et al. 2014, Carvalho et al. 2014, Biella et al. 2017), but there is a need to study them more extensively within grazed rangelands (Bendel et al. 2019). This is mainly because management techniques involving grazing and/or fire can potentially impact bee visitation to flowers through the alteration of floral abundance and diversity (Lázaro et al. 2016, Mola and Williams 2018). As a result, bees searching for flowers may change their foraging strategies based on the present floral community. For example, when presented with several floral species in an area, bees may be more selective in choosing what flower to visit (Gomez-Martinez et al. 2022), indicating preference when given the option. Allowing bees to visit preferred flowers is essential so that bees can fill their nutritional needs to thrive and reproduce (Goulson et al. 2007, Nicolson 2011, Vaudo et al. 2020).

In this report, we focus specifically on bee and floral abundance, diversity, and network structure within each of three grazing strategies at the Central Grasslands Research Extension Center. Our goal is to identify any strategies that may better support native bee communities by providing diverse floral communities and allowing bees to have more preferences in selecting flowers to visit. Our two objectives are to therefore examine 1) native bee and floral abundance and diversity and 2) bee-floral network structure among grazing strategies.

Methods

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 Strategy Structure

We used three grazing strategies covering approximately 260 hectares each (Figure 1): modified twice-over rest rotational grazing (MTORG), patch-burn grazing (PBG), and season-long grazing (SLG). All treatments were stocked with Angus-cross cow-calf pairs to achieve an average of 40-50% degree of disappearance across the entire treatment. The MTORG and PBG

treatments were designed to create heterogeneity of use, so pastures within the MTORG and areas within the PBG would be grazed light or rested and other pastures or areas grazed heavy.

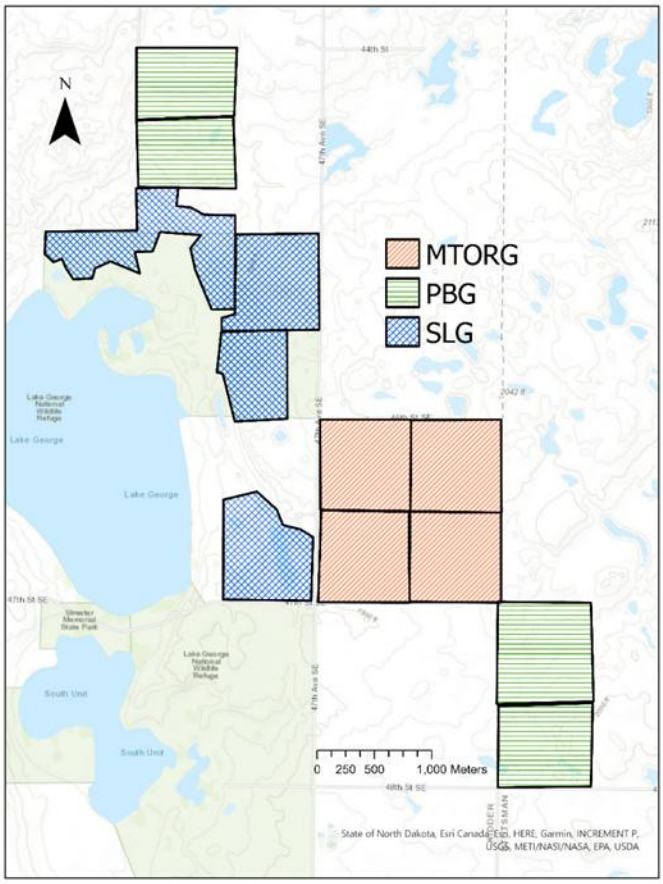


Figure 1. The three grazing strategies used at the CGREC: modified twice-over rest rotational grazing (MTORG, red), patch-burn grazing (PBG, green), and season-long grazing (SLG, blue).

Each treatment has four replicates of equal pasture size (65 ha). Within the MTORG, fences are used to create sixteen, 16-ha paddocks. A single replication includes four of these paddocks with each paddock assigned to a different grazing intensity: heavy (60%+ utilization), full (40-60% utilization), moderate (20-40% utilization), and rested (0% utilization). These grazing intensities are rotated through the paddocks each year. 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.

Bee Transect Surveys

For our surveys, we divided each pasture replicate 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 visiting flowers within reach using a sweep net (approximately 1 meter on each side of the transect to keep the surveyor from straying too far from the transect). All captured bees were euthanized for identification except for bumble bees (which were photographed and released live). For each bee, we recorded the flowering species that the bee was visiting.

For our analyses, we included native, female bees that were observed visiting flowers which included behaviors such as perching, crawling, or appearing to feed off the flowers. We only used female bees because we wanted to focus on the portion of bee community that is contributing to the next generation. Females actively collect pollen to bring back to their offspring while males do not (Thorp 2000). Additionally, females and males within the same species have been found to visit different floral communities (Roswell et al. 2019), and we did not want to have any skews in our networks caused by these selection differences. Bees that did not have a verified sex or genus identification (such as bees that were on a flower but flew away before the surveyor got a good view of them) were not included. However, bumble bees that did not have a verified sex because they were flying away from a flower were included if they were observed before July 15 of each year because they are an easily identifiable genus in the field and are more than likely female before the middle of the summer. Bees that were caught while flying through the transect, hovering around plants, perched on leaves or stems, or nesting were not included. Each bee was identified to genus from a collected specimen, photograph, or trained technician field sighting. All bees from specimens and photographs were identified by B. Roberton and Dr. C.K. Pei (Williams et al. 2014, Arduser 2020, Ascher et al. 2025).

Floral Transect Surveys

We conducted floral surveys to quantify the flower resources available for bees during the growing season. We surveyed along the same 100-m transect used for bee surveys immediately following each bee survey. We counted and identified individual flowering plants (one individual was counted as stems originating from the same point in the soil) within 2.5 meters on each side of the transect. We counted plants at a larger distance from the transect compared to the bee surveys to cover a wider sampling area that better represents the floral community and to keep consistent with previous floral surveys at CGREC. We surveyed in three rounds each summer for a total of 192 surveys each year except for the third round in 2024 (36 completed out of 64 for this final round to give 164 total surveys for this year).

Data Analysis

All analyses were performed in R 4.4.2 (R Core Team 2024). Figures were created using the function ggplot in the ggplot2 package (Wickham 2016). Results were considered significant if $p \leq 0.05$.

Objective 1: Native bee and floral abundance and diversity

We compared bee and floral abundances and diversity between grazing strategies using separate generalized linear mixed models (GLMMs). We utilized the glmmTMB package (Brooks et al. 2017) and checked residuals with the DHARMa package (Hartig 2024). We used the "emmeans" argument in the emmeans package (Lenth 2025) to perform pairwise comparisons following all GLMMs. For the abundance models, we used a negative binomial family along with counts of bees and flowering individuals as the response variables with grazing treatment as the fixed effect, and year, pasture replicate, and survey round as random effects. To plot abundance following the models, we extracted the estimated marginal means and plotted the predicted means with 95% confidence intervals.

For diversity, we calculated Shannon's indices for bees and flowers using the "diversity" function in the vegan package (Oksanen et al. 2025) For both bees and flowers, we grouped counts per bee genus and floral species by treatment, pasture replicate, and survey round. We then ran a generalized linear mixed model with a Tweedie distribution to account for having multiple zero values and continuous data in our models. We used Shannon's index as the response variable, treatment as the fixed effect, and pasture replicate and survey round as random effects. We reported the z-ratios for abundance and diversity, which tests if the fixed effects in the model are significantly different from zero (higher z-ratio values indicate significance).

Objective 2: Bee-floral network structure

We analyzed patterns of interactions between bees and visited floral species through pollinator network analyses with the bipartite package (Dormann et al. 2008, Dormann et al. 2009). At the community level, we extracted network specialization (H_2') indices using the "networklevel" argument for each regime replicate (four pastures per treatment) to describe our interactions. This pooled together all interactions across years (four survey years) and rounds (three survey rounds per summer) to get a single value per replicate. The H_2' index (scale 0 to 1, with 0 being most generalized and 1 being most specialized) is an analysis that quantifies specialization across interaction webs and is robust to network size (Bluthgen et al. 2006). We compared each grazing strategy's H_2' index values to each other with an ANOVA model using the "aov" function in the stats package (R Core Team 2024). Posthoc analyses were done with the "TukeyHSD" function. We also used ANOVA to compare the number of surveyed bee genera and links per species between treatments after checking for normality (Shapiro-Wilk normality test $p > 0.05$). To compare number of visited floral species, we used a Kruskal-Wallis nonparametric test (Shapiro test $p = 0.04$) and performed posthoc analysis with the "dunn.test" function in the dunn.test package (Dinno 2024).

Results

Objective 1: Native bee and floral abundance and diversity

Over the four years of transect surveys, we caught a total of 291 female bees within 17 genera: MTORG = 134 individuals; PBG = 87; SLG = 70. The MTORG had greater abundance than both PBG (z-ratio = 2.534, p = 0.03) and SLG (z-ratio = 3.205, p = 0.003), but the Shannon's

diversity index, which shows biodiversity in an ecosystem, did not differ between strategies (Figure 2).

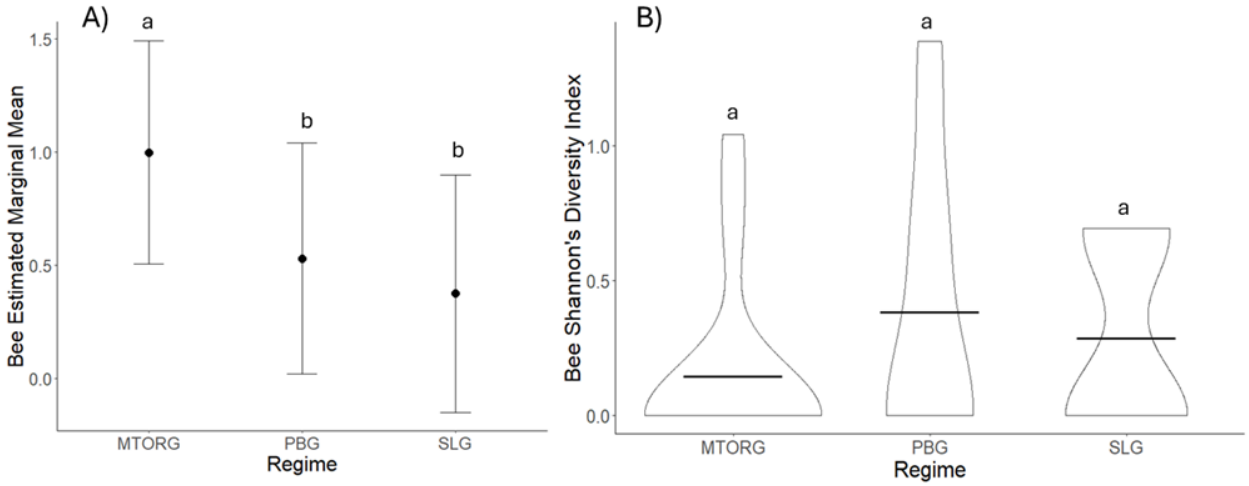


Figure 2. A) The estimated marginal means and 95% confidence intervals of native bee abundance between strategies pooled over years with year, pasture replicate, and survey round removed as random effects in our generalized linear mixed model. **B**) The Shannon's diversity index values for the native bee community between strategies combined across years with pasture replicate and survey round removed as random effects. The horizontal black bars show the mean index value. The letters show significance ($p < 0.05$).

We counted 357,446 individual flowering plants within 155 species across the four years of floral surveys: MTORG = 126,501 individuals; PBG = 137,402; SLG = 93,543. Floral abundance did not differ between strategies after accounting for year, survey round, and pasture replicate in our model (Figure 3). Shannon's diversity indices were significantly different wherein patch-burn grazing had higher floral diversity than both the MTORG (z-ratio = 3.041, p = 0.006) and SLG (z-ratio = 3.450, p = 0.0016) (Figure 3).

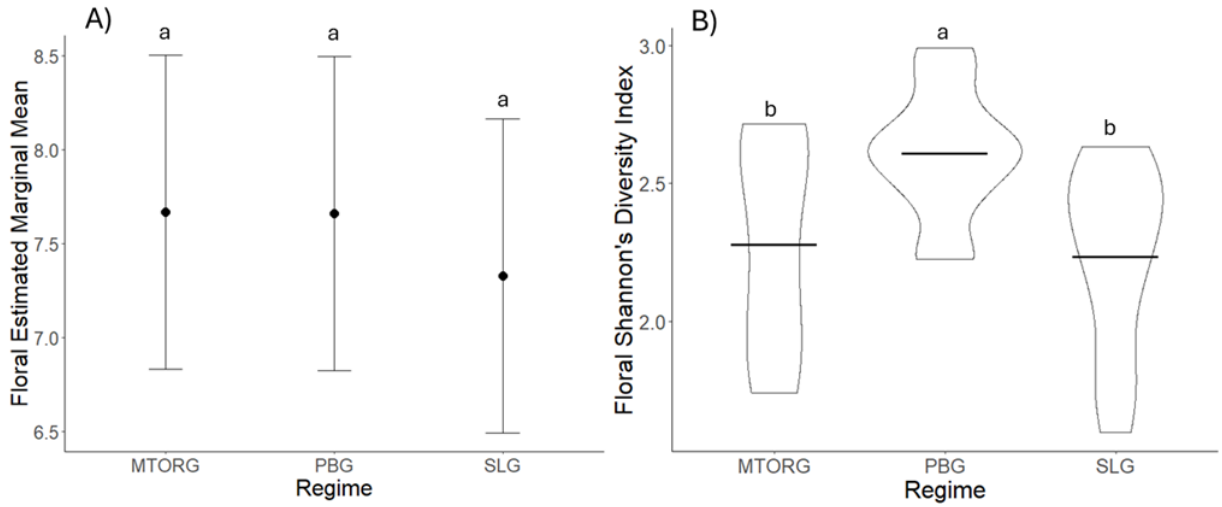
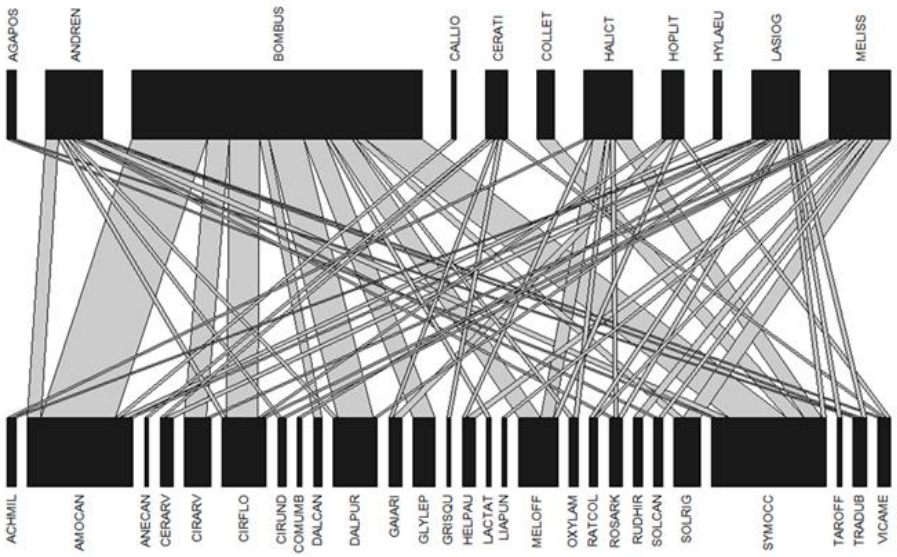


Figure 3. A) The estimated marginal means and 95% confidence intervals of flowering abundance between strategies pooled over years with year, pasture replicate, and survey round removed as random effects in our generalized linear mixed model. **B**) The Shannon's diversity index values for the flowering plant community between strategies combined across years with pasture replicate and survey round removed as random effects. The horizontal black bars show the mean index value. The letters show significance ($p < 0.05$).

Objective 2: Bee-floral network structure

In our networks of bees visiting flower species, MTORG had 11 bee genera visiting a total of 27 floral species, PBG had 12 bee genera visiting 24 floral species, and SLG had 13 bee genera visiting 23 floral species (Figure 4). For each network in Figure 4, the bee genus is on the top row while the plant species is on the bottom row. The lines connecting the rows "link" bees to flowers, showing which floral species the bees are visiting. The widths of the connecting lines represent the number of visits that bee genus had to the connected floral species.

A) MTORG


AGAPOS
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CALLIO
CERATI
COLLET
HALICT
HOPLIT
HYLAEU
LASIOG
MELISS
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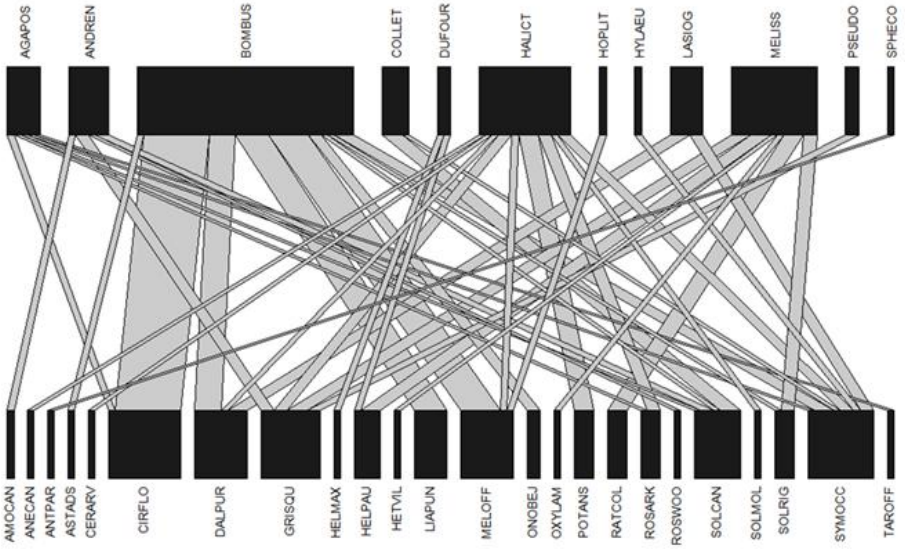
AMIOCAN
ANECAN
CERARV
CIRARV
CIRFLO
CIRUND
COMUMB
DALCAN
DALPUR
GAVARI
GLYLEP
GRISQU
HELPAU
LACTAT
LIAPUN
MELOFF
OXYLAM
RATCOL
ROSARK
RUDHIR
SOLCAN
SOLRIG
SYMOCC
TAROFF
TRADUB
VICAME

B) PBG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ANECAN
ANTPAR
ASTADS
CERARV
CIRFLO
DALPUR
GRISQU
HELMAX
HELPAU
HETVIL
LIAPUN
MELOFF
ONOBEJ
OXYLAM
POTANS
RATCOL
ROSARK
ROSWOO
SOLCAN
SOLMOL
SOLRIG
SYMOCC
TAROFF

C) SLG

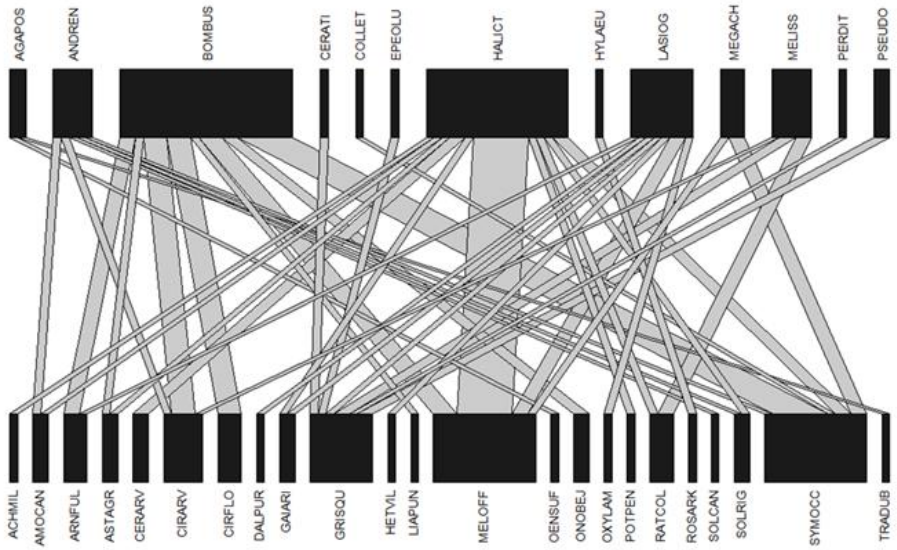

Figure 4. The networks for **A**) MTORG, **B**) PBG, and **C**) SLG. For each network, bee genera are on the top row and floral species are on the bottom row. The lines connecting the rows "link" bees to flowers, showing which floral species the bees are visiting. The widths of the connecting lines represent the number of visits that bee genus had to the connected floral species.

Bee genera: AGAPOS = Agapostomen, ANDREN = Andrena, BOMBUS = Bombus, COLLET = Colletes, HALICT = Halictus, HYLAEU = Hylaeus, LASIOG = Lasioglossum, MELISS = Melissodes

Floral species: ACHMIL = Achillea millefolium, AMOCAN = Amorpha canescens, ANECAN = Anemone canadensis, ANTPAR = Antennaria parlinii, ASTADS = Astragalus adsurgens, ARNFUL = Arnica fulgens , CERARV = Cerastium arvense, CIRARV = Cirsium arvense, CIRFLO = Cirsium flodmanii, CIRUND = Cirsium undulatum, COMUMB = Comandra umbellata, DALCAN = Dalea candida, DALPUR = Dalea purpurea, GAIARI = Gaillardia aristata, GLYLEP = Glycyrrhiza lepidota, GRISQU = Grindelia squarrosa, HELMAX = Halianthus maximiliani, HELPAU = Helianthus pauciflorus, HETVIL = Heterotheca villosa, LACTAT = Lactuca tatarica, LIAPUN = Liatris punctata, MELOFF = Melilotus officinalis, OENSUF = Oenothera suffrutescens, ONOBEJ = Onosmodium bejariense, OXYLAM = Oxytropis lambertii, POTANS = Potentilla anserina, POTPEN = Potentilla pensylvanica, RATCOL = Ratibida columnifera, ROSARK = Rosa arkansana, ROSWOO = Rosa woodsii, RUDHIR = Rudbeckia hirta, SOLCAN = Solidago canadensis, SOLMOL = Solidago mollis, SOLRIG = Solidago rigida, SYMOCC = Symphoricarpos

Within our indices for network analysis, we found that PBG had a higher H_2' index value than SLG but lower links per species than MTORG (Table 1). The H_2' index quantifies community specialization, or the selective interactions of bees to choose specific floral species. Links are the actual number of visits between bees and floral species. There was no difference in number of bee genera or floral species in each strategy network which shows that the network size was similar between grazing strategies (Table 1).

Table 1. The p-values comparing each network's number of floral species, number of bee genera, links per species, and H_2' indices. Bolded values are significant ($p \leq 0.05$).

Comparison	No. Floral Species*	No. Bee Genera	Links per Species	H_2' Index
MTORG-PBG	0.123	1.000	**0.026**	0.113
MTORG-SLG	0.070	0.464	0.250	0.766
PBG- SLG	1.000	0.464	0.340	**0.037**

*Distribution not normal so used Kruskal-Wallis test.

Discussion

We found differing native bee-floral network structures across the three grazing strategies from four summers of surveys. Patch-burn grazing had the highest floral diversity of all three regimes and potentially allows bees to be more selective in what floral species they choose to visit. A clear example of this is shown in Figure 4. When looking at the commonly found bee genera LASIOG (genus *Lasioglossum*) on the top row of PBG's network, we can see fewer lines connecting LASIOG to the flowers on the bottom row compared to LASIOG in MTORG and SLG. This means that LASIOG bees were generally visiting fewer floral species in PBG than in the other two treatments. When this result is combined with the higher community specialization index along with the significantly higher floral diversity, our finding supports that PBG had the most selective interactions in its network. The network analysis for MTORG had more "links" or visits between bee genera and plant species (once again seen in Figure 4), but the lower network specialization index from our network analysis indicates that this regime may not support as much selectivity as PBG. Finally, the SLG strategy appears to have the most generalized network with the potential for forcing bees to use what flower species are available rather than exhibiting preference or given options to choose flowers to visit.

The PBG strategy stands out as being supportive for native bee communities because of its diverse floral community. Grasslands with greater plant diversity and floral availability have a positive impact on network structure by providing more flowers for bees to visit (Bendel et al. 2015, Larkin and Stanley). In our network analysis, we found PBG to have significantly higher network specialization than SLG which is supported by previous research that has also reported increased network specialization in heterogenous landscapes (Gomez-Martinez et al. 2022). Furthermore, when floral diversity is high, bee communities tend to segregate themselves into visiting different floral species and decreasing overlap in their floral diets (Carvalho et al. 2014, Gomez-Martinez et al. 2022). Our findings fit into this because we detected lower numbers of species links, or visits, between bees and flowers in PBG, indicating some segregation in floral visitation between taxonomic groups of bees. Partitioning flowers and having less overlap between bee diets can limit resource competition and disease transmission, providing a benefit for bee communities and potentially allowing more bees to coexist in the same space (Carvalho et al. 2014, Doublet et al. 2022).

Although PBG seems to give bees opportunities to visit their preferred floral species, the MTORG strategy should also be recognized as potentially important for bee communities. MTORG had significantly higher bee abundance than both PBG and SLG. MTORG had bees visiting more floral species than PBG and had less (but statistically similar) network specialization compared to PBG. Together, these metrics indicate that MTORG may also allow bees to visit preferred species, but to a lesser extent and with more diet overlap between taxonomic bee groups. MTORG, like PBG, is utilized as a management technique that promotes heterogeneity (Fuhlendorf and Engle 2001). MTORG may therefore provide some type of habitat structure or resource variation outside of floral diversity that supports higher abundances of bees. This is an idea that should be further explored because it indicates that floral diversity is not the only component necessary to support bee communities in grazed rangelands. Nesting resources, for example, could be one of these components. Native bees depend on nesting resources for reproduction and exhibit different nesting needs within habitats, even at the species level (like between bumble bee species, Svensson et al. 2000). We assume that heterogenous landscapes can provide different nesting materials and structures for bees to use for reproduction, but bee nesting needs are relatively understudied (Harmon-Threatt 2026). Further studies examining bee nesting requirements and the nesting resources available in grazing strategies would give more insight into how heterogenous landscapes can support bee and floral communities.

Moving forward, we plan to examine our network analyses at a finer temporal scale, specifically between years and survey rounds due to intra- and inter-annual variation effects on networks (Burkle and Alarcón 2011). Even within a single bee genus, selectivity can change throughout the growing season due to differences in the plant community (Bendel et al. 2019, Lanterman Novotny et al. 2023). Analyses at differing scales would help us better understand variation of interaction structure within each strategy over time, variable weather conditions, and varying plant community structure. We are also going to incorporate another index, nestedness, which will better quantify diet overlap and bolster our current findings.

Conclusion

Across three different grazing strategies, our network analyses support that PBG has the highest floral diversity and may best support bee preference for floral resources. MTORG may also support bee communities by promoting high bee abundance and allowing some preference in bee visits to flowers. Finally, SLG exhibits the most generalized network of the three strategies with potential constraints on bee selection of flowers to visit. Both PBG and MTORG support heterogenous landscapes that can provide diverse vegetation and floral communities for bees, and research should further explore bee-floral networks in these grazing strategies.

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Protein and Energy Supplementation to Beef Heifers Grazing Native Range During Mid-Gestation

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Summary

The objectives of this study were to evaluate the effects of providing a protein and energy supplement to beef heifers during mid-gestation grazing fall native range pasture on body weight performance, supplement intake, and metabolic status of the heifer. Our investigation continued to determine the potential impacts on birth and pasture turnout weights of the calves born to females exposed to protein and energy supplementation (or the lack thereof). We observed greater body weights in heifers receiving supplementation compared with non-supplemented heifers, but did not observe an impact on calf birth or pasture turn out body weights. Metabolic status appeared to be improved in supplemented heifers, as circulating concentrations of blood urea nitrogen and non-esterified fatty acids reflected a more positive energy balance and nitrogen recycling state compared with control-fed heifers. Future investigations on additional markers of metabolic status and diet digestibility in response to protein and energy supplementation during pregnancy are certainly warranted areas of investigation, in addition to the potential fetal programming outcomes on the calf later in postnatal life.

Introduction

Grazing lands in the Northern Great Plains provide forages of exceptional nutritional value throughout the growing season. However, forage quality declines drastically in the late summer and fall as plants reach vegetative maturity (Llewellyn et al., 2006). This period of low-quality forage intake aligns with mid-gestation in cows and heifers, which is a typical production scenario for spring-calving cow herds in North Dakota. Insufficient protein and energy intake on pasture, such as in fall and winter grazing practices, may have the opportunity to influence both the forage utilization, digestibility, and performance in the cow, but also outcomes on the calf *in utero*, which is a concept understood as *developmental programming*. Supplementing protein and energy on extensive range scenarios may therefore elicit both positive outcomes on the cow, her gestating calf, and the length of the fall grazing season; however, supplement delivery systems vary in efficacy, consistency, and ease of application.

Thus, the goals of this study were to evaluate the impacts of utilizing a precision supplement delivery system to provide a protein and energy supplement to beef heifers grazing native range pastures during mid-gestation on circulating blood metabolic markers, and performance in the dam and early life performance in the calf exposed to treatments *in utero*. We hypothesized that providing protein and energy supplementation to beef heifers during this

critical window of pregnancy would improve body weight gain and metabolic status in the dam and long-term influence the growth performance of her calf.

Methods

Angus-based heifers (*n* = 30; initial body weight [BW] = 960 ± 79.3 lbs) were bred by live cover bulls, then ranked by BW and randomly assigned to one of two treatments at approximately day 90 of pregnancy (start of second trimester). Heifers were either assigned to graze native range pasture (CON; *n* = 15) or graze the same native range pasture plus have access to a protein and energy supplement (SUPP; *n* = 15) delivered at a rate of 0.6% of BW on a dry-matter basis using SmartFeed Pro units from C-Lock, Inc. that were housed in two enclosed trailers placed on the pasture (Figure 1). The protein and energy supplement was a corn and dried distillers grains-based supplement with 18% crude protein. Treatments were applied for 62 days beginning in late September and concluding in late November. Following the end point collection at the end of the 62-d period, heifers were managed on a common diet in a single pen until pasture turn out in the spring.

Figure 1. Images show one of the SmartFeed Pro units (C-Lock, Inc.) in use on a single native range pasture. Both SUPP and CON heifers were placed together in a single pasture, and RFID tags fitted to each animal either allowed or denied access to the feeding units (Right). Supplement allowances were programmed on the C-Lock online interface and were reset automatically on a daily basis. Once a heifer reached her daily feed allowance, she was no longer able to access the supplement for the remainder of the day.

Intake was controlled for all animals in the pasture with the use of a radio frequency identification (RFID) tag. The RFID tag associated with each individual animal either allowed access to the supplement by a gate activated to open with a maximum intake level assigned daily (SUPP) or did not allow access into the feeders (CON). This system allowed individualized management and feed intake records of each animal on a daily basis.

Consecutive-day body weights, blood serum, and pasture clippings were collected at the beginning (September), mid-point (October), and end (December) of the 62-d supplementation period. Consecutive-day body weights were used to assign the heifers to their individual feed allotments at 0.6% of body weight on a dry-matter basis. Weights were also collected from the dam prior to calving (late January) and at pasture turnout (May), and from the calves born in

the spring at birth (April) and again at pasture turnout to evaluate the potential long-term outcomes on maternal supplementation during the second trimester of gestation.

Blood samples were analyzed for concentrations of glucose, non-esterified fatty acids (NEFA), and blood urea nitrogen (BUN) to assess metabolic status of the dams throughout the supplementation period. A chemical analysis was performed on pasture clippings collected throughout the supplementation period to assess the expected decline in forage quality as the grazing season advanced.

Results

As expected, crude protein levels in the native range pasture decreased from 8.6% in September to 5.8% in November. Neutral detergent (NDF) and acid detergent fiber (ADF) increased, however, throughout the 62-d period, with NDF increasing from 61.1% to 67.6% and ADF increasing from 34.1% to 38.1% from September to November. Supplement intake recorded from the SmartFeed Pro system indicated that despite average daily feed allowances set for SUPP heifers across the 62-d feeding period at 6.63 lbs per day, as-fed the average supplement consumption was only 5.15 lbs per day, which reflects a daily intake of 0.45% of body weight on a dry-matter basis (DMB) – slightly below the 0.6% of body weight on a DMB target.

Heifer body weights (Figure 2) were not affected ($P = 0.44$) by the interaction of treatment and day, but tended to be affected by treatment ($P = 0.08$) and the effect of day ($P < 0.01$), increasing for both treatments from the start to the end of the supplementation period, then decreasing as calving and pasture turnout approached (Figure 2). Interestingly, SUPP heifers appeared to lose less weight into late gestation and early lactation compared with CON, being 71 pounds heavier than CON heifers prior to calving in January and 33 pounds heavier than CON at pasture turnout in May. Average daily gain during the 62-d treatment period on pasture tended ($P = 0.08$) to be greater for SUPP compared with CON heifers (2.4 lbs/d and 2.1 lbs/d, respectively).

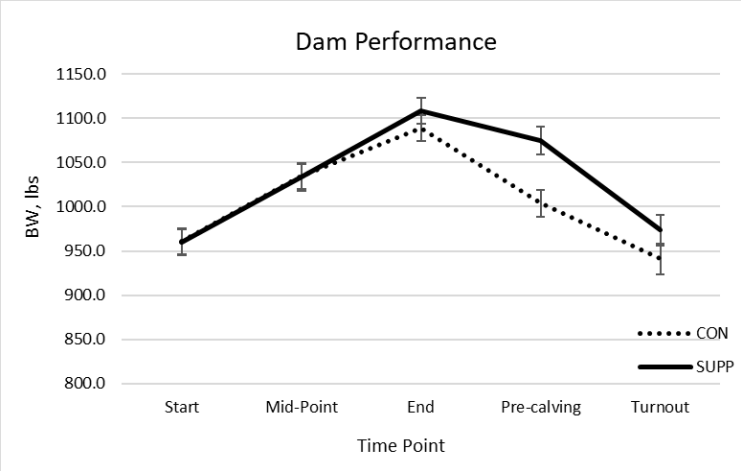

Figure 2. Performance of the pregnant heifer during the 62-d feeding trial (start to end) followed by pre-calving and pasture turnout time points. Heifers were either assigned to graze native range pasture

(CON; n = 15) or graze the same native range pasture plus have access to a protein and energy supplement (SUPP; n = 15) delivered at a rate of 0.6% of BW on a dry-matter basis. Treatments were applied in late September (start) through late November (end). After the end point collection, heifers were managed on a common diet until pasture turnout.

Circulating blood metabolites for heifers during the 62-d fall grazing period indicated that SUPP heifers had improved metabolic status during this window, which was especially reflected with concentrations of blood urea nitrogen (BUN) and non-esterified fatty acids (NEFA). Concentrations of BUN (Figure 3) were greater in SUPP heifers compared with CON at the mid-point and end of the 62-d feeding period, but similar at the start of the trial, as identified with an interaction of treatment and day (P = 0.02). Similarly, concentrations of NEFA (Figure 4) were also greater in SUPP heifers compared with CON at the end-point blood collection but were similar to the beginning and midpoint of the feeding trial, as observed as an interaction between treatment and day (P = 0.01). No differences were observed between SUPP and CON for concentrations of blood glucose (Figure 5) throughout the feeding period ($P \geq$ 0.11); however, a day effect was observed (P = 0.03) in which glucose concentrations increased throughout the feeding period for both CON and SUPP heifers.

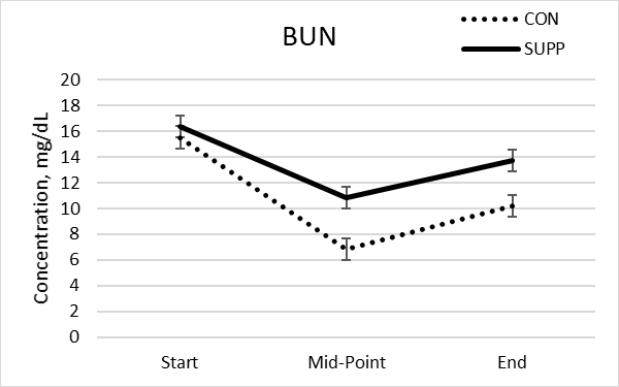

Figure 3. Blood concentrations of blood urea nitrogen (BUN) at the start, mid-point, and end of the 62-d feeding trial on fall native range pasture. Heifers were either assigned to graze native range pasture (CON; n = 15) or graze the same native range pasture plus have access to a protein and energy supplement (SUPP; n = 15) delivered at a rate of 0.6% of BW on a dry-matter basis. Treatments were applied in late September (start) through late November (end). P-values ≤ 0.05 denoted by *.

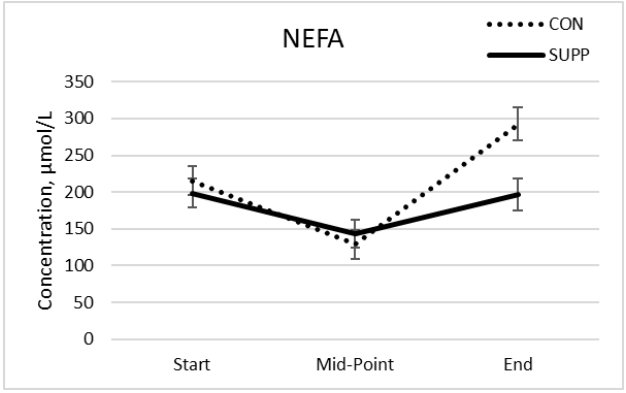

Figure 4. Blood concentrations of non-esterified fatty acids (NEFA) at the start, mid-point, and end of the 62-d feeding trial on fall native range pasture. Heifers were either assigned to graze native range pasture (CON; n = 15) or graze the same native range pasture plus have access to a protein and energy supplement (SUPP; n = 15) delivered at a rate of 0.6% of BW on a dry-matter basis. Treatments were applied in late September (start) through late November (end). P-values ≤ 0.05 denoted by *.

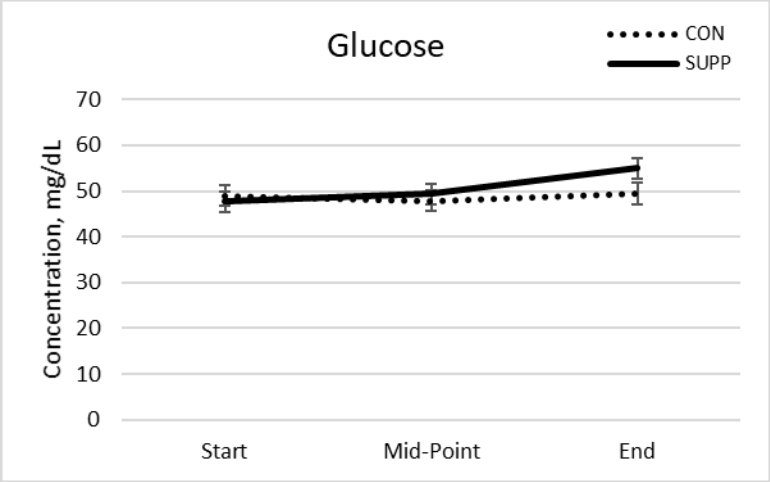

Figure 5. Blood concentrations of glucose at the start, mid-point, and end of the 62-d feeding trial on fall native range pasture. Heifers were either assigned to graze native range pasture (CON; n = 15) or graze the same native range pasture plus have access to a protein and energy supplement (SUPP; n = 15) delivered at a rate of 0.6% of BW on a dry-matter basis. Treatments were applied in late September (start) through late November (end). P-values ≤ 0.05 denoted by *.

Interestingly, despite body weight differences in the SUPP and CON heifers at pre-calving and pasture turnout, we did not observe body weight differences at birth and at pasture turnout in calves born to these dams ($P \geq 0.27$). Average birth weights for calves were 71.4 lbs and 79.4 lbs for CON and SUPP, respectively, and average pasture turn out weights for calves were 148.4 and 159.2 lbs, respectively.

Discussion

While supplement intakes for SUPP assigned heifers was lower than anticipated (0.15% of BW on a DMB lower), the metabolic status and long-term performance of SUPP heifers appeared to benefit from mid-gestational protein and energy supplementation. The elevated BUN in SUPP heifers suggests that as the feeding period advanced, SUPP heifers received more adequate protein in the diet to be used to maintenance and growth, with perhaps increased nitrogen recycling back to the rumen, reflected by greater urea in the blood (NASEM, 2016). The CON heifers, on the other hand having decreased concentrations of BUN, suggests perhaps poorer efficiency of rumen microbes and less nitrogen entering the urea cycle, which is indicative of inadequate nitrogen supply in the diet (NASEM, 2016). Similarly, increased NEFA toward the end of the feeding period in CON heifers suggests perhaps a mobilization of body fat reserves to be used as an energy source for maintenance and growth of the pregnancy, since energy was likely deficient in the control diet (pasture grazing only).

Interestingly though, the altered metabolic status we observed in SUPP and CON heifers wasn't immediately reflected in maternal body weights during the feeding period, but appear to have had sustained impacts on the body weight gain into late gestation and early lactation. Certainly, we'd expect some body weight loss into parturition as the calf is expelled, uterine involution begins, and females potentially enter a negative energy balance in the first several weeks of early lactation as energy demands increase dramatically. While not investigated in this

study, the body condition and metabolic status of a beef female entering her second breeding season is one of the most critical windows of her productive life. We suspect that the sustained body weights of the SUPP dams we observed in this study through pasture turn out may have positive outcomes on pregnancy success in the subsequent breeding season.

Conclusion

Protein and energy supplementation to pregnant heifers grazing low-quality fall pasture enhanced their energy and protein status, and supplemented heifers exhibited a tendency for improved ADG. We have further interests in evaluating feed utilization and digestibility on fall pasture in response to protein and energy supplementation, given our observations with cow performance and metabolic status. The improved metabolic status of the dam during pregnancy may have other subsequent effects on the calf gestated at the time of supplementation and requires further investigation.

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Protein and Energy Supplementation to Beef Heifers During Mid-Gestation and the Impacts on Growth Performance and Blood Metabolic Profiles of the Dam and Intact Male Offspring

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Summary

Forage quality for beef cattle often declines in late summer/fall and winter, with protein levels falling below what pregnant cows and heifers need to support both themselves and their developing calves. During mid-gestation, when fetal growth increases, dams may struggle to meet nutrient demands on forage alone. Strategic protein and energy supplementation during this period may help support cow condition and early calf growth.

This study evaluated whether providing a protein and energy supplement to pregnant beef heifers during mid-gestation could improve growth performance and blood indicators of nutritional status in the dam and her calf through weaning. Angus-based heifers pregnant with bull calves were fed either a forage-only diet (CON) or a forage diet plus a protein and energy supplement (SUPP) from day 90 to 186 of gestation. After mid-gestation, all dams were managed the same through calving and grazing.

Heifers receiving the supplement gained more weight during pregnancy and had enhanced body condition by the end of mid-gestation. Blood measurements showed that supplemented heifers relied less on body fat reserves and had improved protein status, indicating that the supplement helped meet pregnancy nutrient demands through the diet rather than body reserves. Calves born to supplemented cows were heavier at birth and at pasture turnout but not at weaning. These calves also showed differences in blood markers related to energy use early in life. Overall, protein and energy supplementation during mid-gestation improved cow condition and supported greater early calf growth. Further evaluation of post-weaning performance will help determine the long-term production value of this management strategy.

Introduction

Nutritive value of grazed forages for beef cattle often declines in the late summer/fall and winter months, with crude protein levels dropping below 6% in some regions (Schauer et al., 2005). During this period, pregnant heifers in the Northern Great Plains, often in their second trimester of gestation for spring-calving cow herds, may struggle to meet the protein and energy demands of gestation with grazed forages alone. Strategic supplementation during mid-gestation therefore has the potential to not only improve forage utilization and digestibility in the dam, but also elicit positive outcomes on calf growth before birth and subsequently throughout postnatal life (Llewellyn et al., 2006; Cappellozza et al., 2014).

The objectives were to evaluate the impacts of providing a protein and energy supplement to beef heifers during mid-gestation on dam performance, calving outcomes, circulating blood metabolites in the dam and calf, and growth performance of the male offspring through weaning. We hypothesized that protein/energy supplementation would increase dam and calf body weights, enhance circulating blood metabolites, and positively influence placental and colostrum characteristics at calving.

Methods

Angus-based beef heifers (*n* = 44; initial body weight [BW] = 940.9 ± 68 lbs) were bred via artificial insemination (AI) using male sexed semen at the Central Grasslands Research Extension Center (CGREC). Pregnancies were confirmed on day 35 after breeding and fetal sex was determined at day 65 after breeding. Shortly after, heifers pregnant with male fetuses were transported to the NDSU Beef Cattle Research Complex (BCRC) in Fargo, ND, ranked by body weight, and randomly assigned to receive a protein/energy supplement with a basal forage diet (SUPP; n = 22) or a basal forage diet with no supplementation (CON; n = 22) from day 90 to day 186 of gestation. The diet for SUPP heifers consisted of 30% corn silage, 45% grass hay, and 25% Accuration (Land O' Lakes Purina) on a dry-matter basis, while the diet for CON heifers consisted of 40% corn silage and 60% grass hay on a dry-matter basis. All heifers received a pelleted mineral product at the company directed rate of 1 lb per day.

Daily feed intakes were managed strategically with the Insentec feeding system to target daily gains of 0.62 lbs/day for heifers assigned to CON and 1.74 lbs/day for heifers assigned to SUPP. Body weights were collected on the pregnant heifers every two weeks and body condition scores were recorded at the start (d 90), mid-point (d 138), and end (d 186) of the second trimester feeding trial. Following the treatment period, all heifers were transported back to the CGREC and managed on a common forage-based diet through parturition and pasture turnout. Heifers were also weighed shortly before calving (d 257), at calving (average d 279), and at pasture turnout (average 68 d postpartum). Blood collections were also performed on the dams at these six major timepoints throughout the experiment and from their calves at birth, pasture turnout, and at weaning. Blood serum samples were analyzed for concentrations of glucose, non-esterified fatty acids (NEFA), and blood urea nitrogen (BUN).

At calving and prior to suckling, BW of the dam and neonatal calf (*n* = 21 CON; *n* = 21 SUPP) were recorded and calving date was recorded to calculate gestation length. Dams were assigned a calving ease score from 1 to 5 (1: unassisted birth to 5: cesarean). Additionally, a single quarter of the udder was completely milked to estimate colostrum volume and mass. The placenta was collected upon expulsion and rinsed, weighed, and total number of cotyledons counted. In the period shortly after birth, calves were assigned a vigor score of 1 to 5 (1: nursed independently to 5: stillborn). At 24 h after colostrum consumption, calf BW was recorded and morphometric characteristics were evaluated, including chest and abdominal circumference, crown-rump length, shoulder-to-hip length, hip width, and hip height. Calves continued to be weighed through pasture turnout and at weaning.

Results

The actual gains recorded during the mid-gestation supplementation period were 0.55 lbs/day and 1.66 lbs/day for CON and SUPP heifers, respectively. Body weights of the pregnant heifers were impacted by protein/energy supplementation, as expected, from the supplementation period in mid-gestation through pasture turnout, which was observed as an interaction of treatment and day ($P = 0.02$; Figure 1), day ($P < 0.01$), and treatment ($P < 0.01$). While heifers were similar in BW at the start of the trial (d 90 in pregnancy) by design, by day 138 of gestation we observed a 40 lb difference between CON and SUPP heifers, and by day 186 we observed a 108 lb difference between treatments ($P < 0.05$). Interestingly, this weight difference was sustained through late pregnancy (78 lbs; $P < 0.05$) and pasture turnout (47 lbs; $P > 0.10$). The body condition scores recorded during this period complement the weight differences we observed here, with body condition scores being greater in SUPP heifers at the end of the supplementation period (5.8 vs. 4.7 BCS) compared with CON heifers ($P = 0.01$).

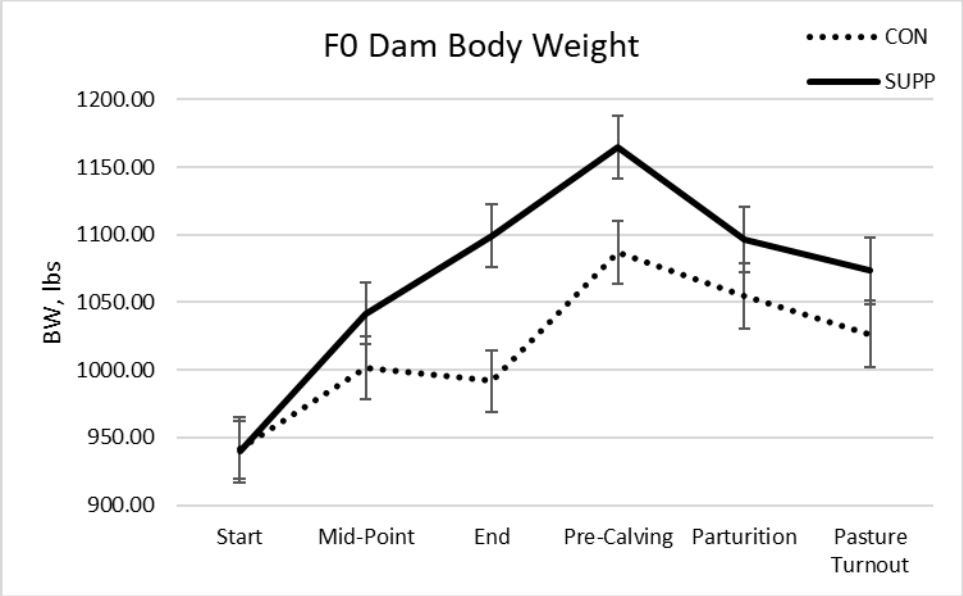

Figure 1. Body weights of pregnant (F0) beef heifers from the start of the second trimester of gestation (treatment start) to the conclusion of the second trimester (treatment end) and into late gestation and early lactation. Treatments were: F0 dams were provided with either a basal forage diet (CON) or a basal forage diet plus a protein and energy supplement (SUPP) from d 90 to 186 of gestation. Dams were managed as a single group from the end of the second trimester through weaning the next fall. Sampling timepoints were: start (d 90 of gestation); mid-point (d 138 of gestation); end (d 186 of gestation); pre-calving (d 257 of gestation), parturition (average d 279 of gestation); and pasture turnout (average 68 d postpartum). P-values < 0.05 indicate significance and P-values < 0.10 but > 0.05 indicate a tendency.

We observed no impact ($P \geq 0.18$) of the interaction of treatment and day on circulating blood metabolites in the dam for glucose, NEFA, or BUN. However, we observed that both NEFA and BUN were impacted ($P \leq 0.05$) by protein/energy supplementation (or the lack thereof) during mid-gestation (Table 1), in which concentrations of NEFA were lower ($P = 0.04$) for SUPP heifers compared with CON and concentrations of BUN were greater ($P = 0.05$) in SUPP

compared with CON heifers. However, we observed no impact (P = 0.34) of treatment during mid-gestation on circulating concentrations of glucose in the dam. The effect of day was also observed ($P \leq 0.01$) for glucose, NEFA, and BUN in SUPP and CON dams.

Table 1. Blood metabolites in beef heifers provided with a basal diet (CON) or to heifers provided with a basal diet plus a protein/energy supplement (SUPP) from d 90 to 186 of gestation. Blood evaluation time points began at the time treatments were initiated and concluded at pasture turnout.

	Treatment[1]			*P*-Values		
Item	CON	SUPP	SEM	TRT	Day	TRT×Day
Glucose, mg/dL				0.34	<0.01	0.79
Start[2]	66.0	69.3	3.10			
Mid-Point	60.0	64.0	3.07			
End	63.7	63.1	3.10			
Pre-Calving	68.5	71.2	3.18			
Parturition	96.1	95.8	4.73			
Pasture Turnout	59.9	58.7	3.31			
NEFA[3], µmol/L				0.04	<0.01	0.18
Start	258.4	225.0	70.97			
Mid-Point	280.4	264.5	70.97			
End	620.2	453.0	72.73			
Pre-Calving	983.7	799.8	76.48			
Parturition	668.1	634.2	74.53			
Pasture Turnout	366.7	418.9	76.48			
BUN[4], mg/dL						
Start	7.6	7.7	0.56	0.05	<0.01	0.77
Mid-Point	10.8	11.5	0.56			
End	11.1	11.8	0.57			
Pre-Calving	9.6	9.4	0.57			
Parturition	6.7	7.5	0.59			
Pasture Turnout	8.9	9.7	0.61			

[1]Treatments were: F0 dams were provided with either a basal forage diet (CON) or a basal forage diet plus a protein and energy supplement (SUPP) from d 90 to 186 of gestation. Dams were managed as a single group from the end of the second trimester through weaning the next fall.

[2]Sampling timepoints were: start (d 90 of gestation); mid-point (d 138 of gestation); end (d 186 of gestation); pre-calving (d 257 of gestation), parturition (average d 279 of gestation); and pasture turnout (average 68 d postpartum).

[3]NEFA: non-esterified fatty acids.

[4]BUN: blood urea nitrogen.

At calving, we observed no differences ($P \geq 0.13$) in calving ease, gestation length, colostrum production, or placental characteristics (Table 2) for CON and SUPP dams. However, calves born to SUPP dams were approximately 5.2 lbs heavier at birth than ($P = 0.04$) calves

from CON. Furthermore, measurements of chest circumference were greater ($P = 0.05$) and abdominal circumference and hip height tended ($P \leq 0.10$) to be greater in SUPP calves compared with CON. No differences were observed ($P \geq 0.18$) for measurements including crown-rump length, shoulder-to-hip length, hip width, or vigor score between SUPP and CON calves.

Table 2. Calving characteristics and morphometric measurements of the newborn calf at birth (pre-suckling) and at 24 h of age.

	Treatment			
Item	**CON**	**SUPP**	**SEM**	***P*-Value**
Dam				
Gestation Length, d	280.7	278.8	1.24	0.13
Calving Ease Score	1.0	1.1	0.14	0.32
Colostrum				
Volume, mL	475.7	579.2	71.97	0.16
Mass, g	516.7	614.0	72.93	0.19
Placenta				
Total Weight, g	4097	4196	288.5	0.73
Cotyledon Weight, g	39.7	42.3	3.74	0.50
Total Cotyledon Count	85.5	83.0	6.84	0.72
Calf				
Calf BW (0 h), kg	66.3	71.5	2.40	0.04
Calf BW (24 h), kg	68.1	73.8	2.47	0.03
Calf Vigor Score	1.10	1.05	0.11	0.68
Chest Circumference, cm	71.5	73.2	0.83	0.05
Abdombinal Circumference, cm	68.6	70.7	1.22	0.10
Crown-Rump Length, cm	75.2	76.9	1.23	0.18
Shoulder-Hip Length, cm	30.1	30.1	0.66	0.99
Hip Width, cm	11.8	11.8	0.33	0.88
Hip Height, cm	72.3	74.4	1.18	0.08

Despite a difference in birth weights of SUPP and CON calves, the long-term growth performance of the F1 bull calves was not impacted by the interaction of treatment and day ($P = 0.36$; Figure 2). However, postnatal bull calf growth performance tended ($P = 0.10$) to be greater in SUPP calves compared with CON, which was driven by a 17.5 lb weight advantage in SUPP calves at pasture turnout but only a 1-pound advantage in SUPP calves at weaning. Calf body weight was also impacted by the effect of day ($P < 0.01$), which is expected as calf weights increased from birth to weaning.

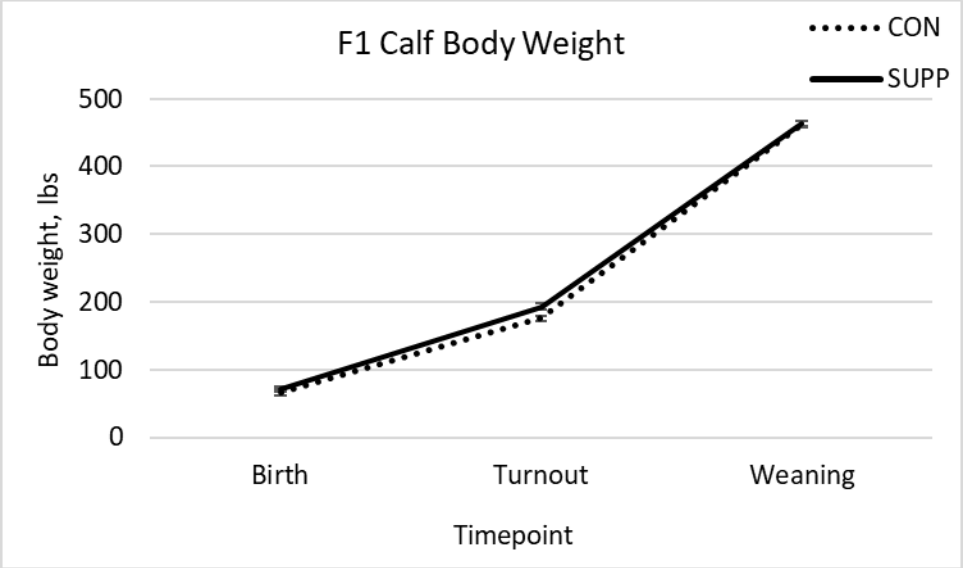

Figure 2. Body weights for the F1 bull calves from birth to weaning. Treatments of the F0 dams during mid-gestation were: F0 dams were provided with either a basal forage diet (CON) or a basal forage diet plus a protein and energy supplement (SUPP) from d 90 to 186 of gestation. Dams were managed as a single group from the end of the second trimester through weaning the next fall. Sampling timepoints were birth (average 279 d gestation length); pasture turnout (average 68 d of age), and weaning (average 174 d of age). P-values < 0.05 indicate significance and P-values < 0.10 but > 0.05 indicate a tendency.

Finally, blood metabolite profiles in the F1 bull calves from birth to weaning were not affected by the interaction of treatment and day ($P \geq 0.14$; Table 3). However, concentrations of NEFA were greater ($P = 0.01$) in SUPP calves postnatally, but concentrations of glucose and BUN were not affected ($P \geq 0.11$) by maternal treatment. However, glucose, NEFA, and BUN were all impacted by the effect of day ($P \leq 0.03$).

Table 3. Blood metabolites in male offspring born to dams provided with a basal diet (CON) or to dams provided with a basal diet plus a protein/energy supplement (SUPP).

	Treatment[1]			*P*-Values		
Item	CON	SUPP	SEM	TRT	Day	TRT×Day
Glucose, mg/dL				0.11	<0.01	0.61
Birth	70.4	63.3	4.01			
Turnout[2]	97.8	89.8	4.23			
Weaning[3]	81.5	80.8	4.12			
NEFA[4], µmol/L				0.01	0.03	0.14
Birth	172.2	252.6	27.51			
Turnout	92.5	194.2	29.29			
Weaning	209.4	208.8	26.74			
BUN[5], mg/dL				0.56	<0.01	0.19
Birth	9.1	10.3	0.48			
Turnout	8.9	8.9	0.52			
Weaning	16.4	15.9	0.50			

[1]Treatments were: F0 dams were provided with either a basal forage diet (CON) or a basal forage diet plus a protein and energy supplement (SUPP) from d 90 to 186 of gestation. Dams were managed as a single group from the end of the second trimester through weaning the next fall.
[2]Average calf age at pasture turnout to a single native range pasture was 68 days of age.
[3]Average calf age at weaning was 174 days of age.
[4]NEFA: non-esterified fatty acids.
[5]BUN: blood urea nitrogen.

Discussion

Most fetal growth and increases in nutrient demand for the pregnant cow occur between mid- and late gestation (Reynolds et al., 2019). Because of this, the level of protein and energy provided to cows during mid-gestation can influence both cow condition and early calf performance. In the current study, protein and energy supplementation increased cow body weight, body condition score, and improved metabolic indicators of energy and protein status during pregnancy. Supplemented cows had lower circulating NEFA, indicating less reliance on body fat mobilization, and slightly greater BUN, reflecting improved protein intake and nitrogen availability (NASEM, 2016; Silva et al., 2019). These results suggest that strategic supplementation helped cows meet pregnancy demands using dietary nutrients rather than body reserves.

Calves born to supplemented cows were 5 lb heavier at birth and 17.5 lb heavier at pasture turnout (approximately 70 d of age), demonstrating a short-term growth advantage. However, body weight differences did not persist through weaning, likely due to similar postnatal grazing conditions across treatment groups and catch-up growth exhibited by CON

calves. Although long-term weight differences were not observed, calves from supplemented cows showed greater circulating NEFA early in life, suggesting differences in energy use or fat metabolism during the pre-weaning period. Because mid-gestation coincides with critical periods of muscle and fat tissue development (Zhu et al., 2006; Du, 2023), improved maternal nutrition during this window may influence early tissue growth and metabolic function in the calf.

Similar responses have been observed in related work from our laboratory, where protein and energy supplementation during early gestation in beef heifers resulted in sustained improvements in cow body weight and modest, short-term increases in calf birth weight, observed as a 2 lb birth weight advantage in calves born to supplemented dams (Baumgaertner et al., 2024). In that study, body weight differences in female offspring were negligible at weaning, but re-emerged after puberty, suggesting that gestational nutrition may have longer-term impacts on animal performance that are not immediately evident at weaning.

Overall, these findings indicate that strategic protein and energy supplementation during mid-gestation can improve cow condition, reduce reliance on body reserves, and enhance early calf growth. While post-weaning management may minimize visible weight differences, improved maternal nutrition during pregnancy may still provide long-term benefits for offspring performance and productivity. Additional evaluation of post-weaning growth and carcass traits will help determine the full production value of mid-gestation supplementation programs for offspring developed for terminal or breeding markets.

Conclusion

These data show that providing supplemental protein and energy and greater rates of gain during the second trimester of pregnancy supported increased birth weight and body measurements in the neonatal calf, but did not impact maternal BW at calving, colostrum production, or placental characteristics. Further evaluation of growth performance and metabolic phenotype in the F1 male offspring at later postnatal timepoints will help determine whether maternal nutritional management during gestation induces long-term programming outcomes that could enhance offspring productivity and contribute to global food security.

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Effects of maternal nutritional supplementation during mid gestation on placental vascular development in beef heifers.

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Summary

This study evaluated the effects of providing protein/energy supplement during mid gestation on placental vascular development in pregnant beef heifers. Heifers pregnant with male calves were assigned to either a forage-based control diet fed to gain a target of 0.62 lb/body weight (BW)/d (CON); or to receive the forage-based diet with the addition of a protein/energy supplement to target 1.74 lb/BW/d (SUP) from day 90 to day 186 of gestation. After the feeding period all heifers were managed as a single group until calving. Immediately upon expulsion of the placenta, samples of cotyledon were collected and preserved in neutral buffered formalin (NBF). Tissues were subsequently analyzed using immunohistochemistry for key indicators of vascularization (using CD 31/34 stain) and cell proliferation (using Ki-67 stain) with data used to calculate capillary area density (CAD), capillary number density (CND), Ki-67 positivity ratio (PR) and spatial cell density (SCD). Data was analyzed using the General Linear Model (GLM) procedure of SAS with individual animal as the experimental unit.

Results showed that CAD tended to be greater (P = 0.07) in SUP compared with CON, indicating enhanced placental vascular development and potential for improved nutrient transfer to the fetus. Conversely, CND was reduced (P = 0.02) in the SUP group, suggesting a more efficient vascular structure with fewer but possibly larger or more functional capillaries. No differences were present between treatments for PR or SCD (P = 0.27; P = 0.33), indicating that overall cellular proliferation and tissue cellularity were not markedly affected by maternal supplementation. These findings suggest that mid gestation protein/energy supplementation can enhance placental vascular features critical for fetal development, particularly by promoting vascular efficiency rather than increasing cellular proliferation.

Introduction

In many beef production systems, nutrient demands of developing heifers are not fully met during mid gestation due to environmental constraints or management practices that often exclude targeted supplementation. During this critical period, heifers are particularly vulnerable to nutrient deficits, which can negatively impact not only their own development but also that of the fetus and associated gestational tissues (Vonnahme et al., 2018). The placenta plays a vital role in mediating nutrient, gas and waste exchange between the dam and fetus, and its proper development is crucial for fetal growth and survival (Reynolds et al., 2023). Placental efficiency is largely influenced by factors such as vascularization, surface area and nutrient transporter activity - processes that are sensitive to maternal nutrient status (Davenport et al.,

2023). Indeed, maternal nutrition has been shown to impact placental morphology and angiogenesis, which may have lasting consequences for offspring outcomes as indicated in Vonnahme et al. (2018) and Davila Ruiz et al. (2024).

Despite growing evidence linking maternal nutrition and placental development, the specific impacts of mid gestation supplementation, particularly regarding protein/energy, remain incompletely understood. Few studies have directly examined how nutritional intervention during this window affects the establishment and growth of the placenta in beef heifers (Davila Ruiz et al., 2024). To address this gap, the current study evaluated the effects of mid gestation supplementation on placental development in beef heifers. We hypothesized that providing a targeted supplement during this stage would enhance placental growth and vascularization compared to unsupplemented heifers, potentially supporting improved fetal development and long-term productivity.

Methods

Crossbred Angus heifers (n=119; initial body weight (BW) 748.9 ± 72.8 lb.), approximately 13 months of age, each pregnant with a male calf from a single artificial insemination (AI) breeding, were randomly assigned to receive one of two diets from day 90 to day 186 of pregnancy. Heifers were assigned to one of two dietary treatments: 1) a forage-based control diet designed to achieve approximately 0.62 pounds of body weight gain per day, or 2) the same forage-based diet with the addition of a corn-based protein and energy supplement designed to achieve approximately 1.74 pounds of body weight gain per day.

At calving, placentas were collected, and the largest cotyledon closest to the umbilical cord was sampled for analysis. Tissue samples were preserved and processed for microscopic evaluation of blood vessel development and cell activity.

Placental blood vessels were identified using established immunohistochemical markers for endothelial cells (CD31/34), and cell nuclei were stained to allow measurement of tissue structure. A separate stain (Ki-67) was used to identify actively dividing cells. Images were captured using a fluorescence microscope and analyzed using specialized imaging software. The images were analyzed to measure placental blood vessel area (CAD), blood vessel number (CND), cell growth activity (PR), and overall tissue cell density (SCD).

Data were analyzed using the General Linear Model (GLM) procedure of SAS 9.4, with individual heifers considered the experimental unit. Treatment means are reported as least squares means ± standard error, with differences considered significant at $P \leq 0.05$ and trends noted at $0.05 \leq P \leq 0.10$.

Results and Discussion

Heifers that received supplementation tended to have greater CAD values (3.72 ± 0.41) compared to control heifers (2.62 ± 0.42; $P = 0.07$; Figure 1). These results suggest that maternal nutritional intervention enhances placental vascular development, potentially improving nutrient delivery to the developing fetus. In contrast, CND was also influenced by maternal supplementation but in the opposite direction. Heifers in the control group had greater (*P* =

0.02) CND values (5.95 ± 0.61) compared to those in the supplemented group (3.92 ± 0.60; Figure 1). This suggests that supplementation during mid gestation may promote the development of fewer but more efficient blood vessels in the placenta.

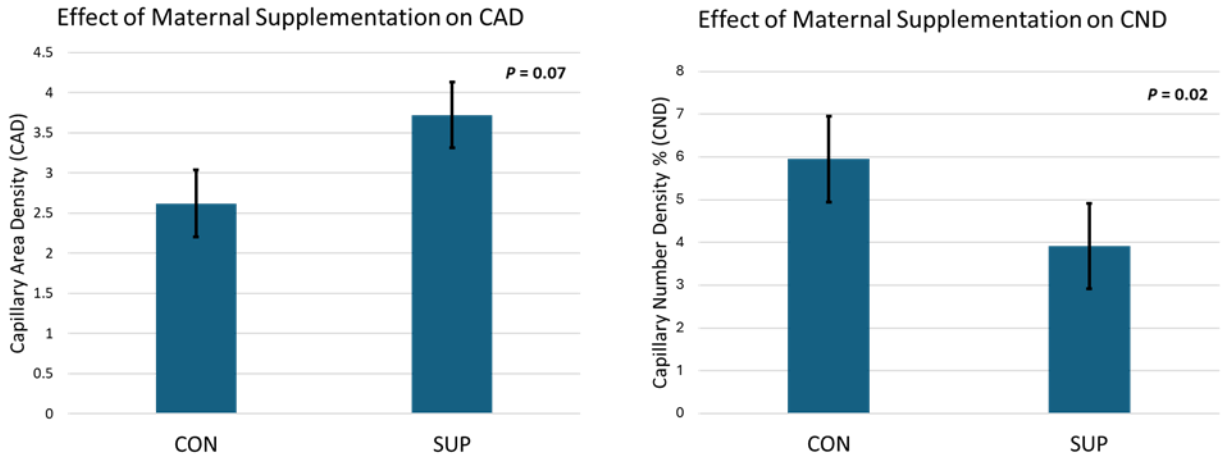

Figure 1. Capillary development in the placental cotyledon from beef heifers fed a protein/energy supplement from day 90 to day 180 of gestation. The graphs show the effect of maternal supplementation on (left) capillary area density and (right) capillary number density. This measurement was obtained through immunohistochemistry, utilizing CD-31 and CD-34 as markers for endothelial cells within blood vessels, followed by image analysis. Data are presented as mean ± SEM.
CON = Control group (no supplementation);
SUP = Supplemented group (received protein/energy supplement during mid-gestation);
CAD = Capillary Area Density; the proportion of placental tissue area occupied by capillaries, expressed as a percentage;
CND = Capillary Number Density; the number of capillaries per unit tissue area, expressed as a percentage.

There was no difference (*P* = 0.27) observed in Ki-67 PR between treatment groups. Control heifers exhibited a PR of 11.87 ± 0.86, while supplemented heifers showed a PR of 10.49 ± 0.86 (Figure 2). These findings suggest that maternal supplementation did not markedly influence cellular proliferation rates in placental tissue (Vonnahme et al., 2018; Davila Ruiz et al., 2024). Similarly, there was no difference in SCD between the control and supplemented groups. The CON group had an average SCD of 1.39 ± 0.14, while the SUP group averaged 1.23 ± 0.13 (*P* = 0.33; Figure 2). Vonnahme et al. (2018) also reported that alterations in maternal diet influenced placental vascular characteristics without uniformly affecting placental morphology.

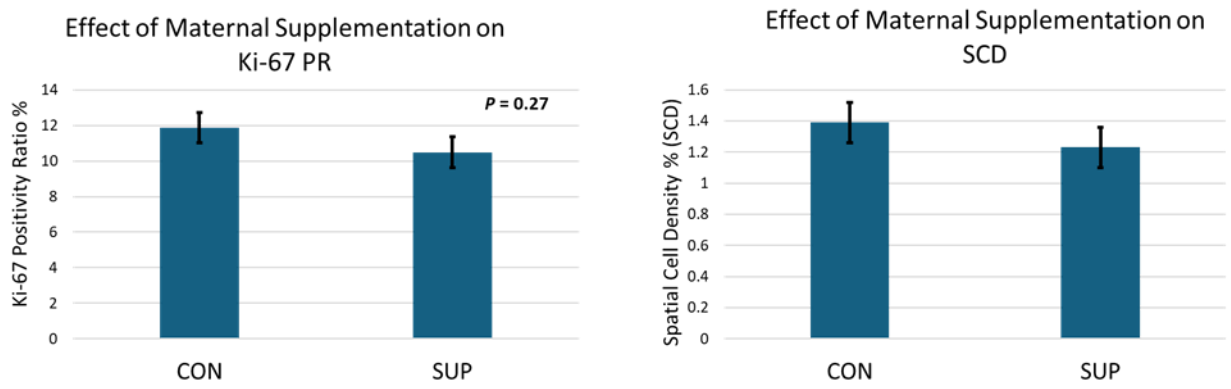

Figure 2. Cellular proliferation and density in the placental cotyledon from beef heifers fed a protein/energy supplement from day 90 to day 180 of gestation. The graphs show the effect of maternal supplementation on (left) Ki-67 Positivity Ratio and (right) Spatial Cell Density. Data are presented as mean ± SEM.
CON = Control group (no supplementation);
SUP = Supplemented group (received protein/energy supplement during mid-gestation;
Ki-67 PR = Ki-67 Positivity Ratio; percentage of nuclei positive for Ki-67 staining, indicating proliferating cells;
SCD = Spatial Cell Density; the number of nuclei per unit tissue area, expressed as a percentage.

Conclusion

The present findings highlight that maternal protein and energy supplementation during gestation can influence specific aspects of placental vascular development in beef heifers. Notably, supplemented heifers had greater CAD, suggesting an enhancement in placental vascular expansion. A greater CAD may indicate increased vascular surface area for maternal-fetal exchange, potentially leading to greater efficiency in nutrient and oxygen transfer to the developing fetus. This aligns with prior work by Reynolds et al. (2023), who reported that nutritional interventions during pregnancy can modulate placental angiogenesis, supporting fetal growth trajectories and developmental programming. Future research should focus on evaluating the functional consequences of these vascular changes, such as blood flow capacity, nutrient transport efficiency and fetal metabolic outcomes, to better understand how maternal supplementation translates to long-term offspring performance and health.

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Factsheets

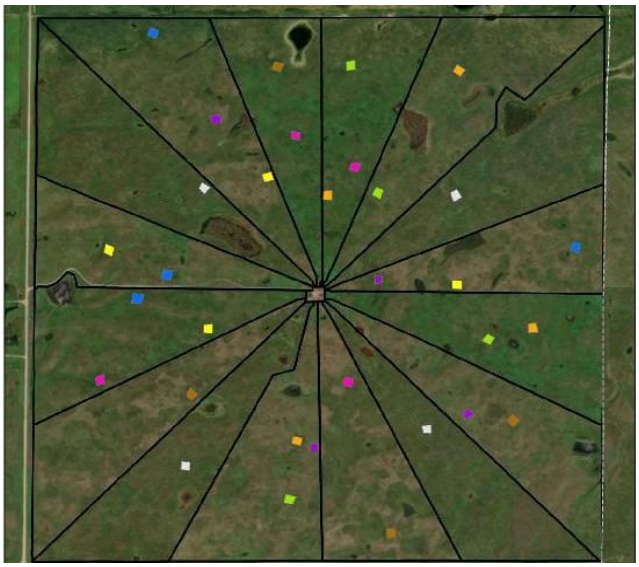
Tackling Buckbrush: Enhancing Production and Conservation Outcomes in North Dakota's Grasslands

Daniel Asplin, Joslin Forness, Dillon Fogarty, Vinicius Marcilio da Silva, Torre Hovick, and Kevin Sedivec

BACKGROUND

Buckbrush (also known as western snowberry) is the most common encroaching woody plant in North Dakota rangelands. Over time, a lack of disturbance has allowed this native shrub to increase in density at the expense of native plant diversity and forage production for livestock. Reducing buckbrush density is oftentimes a common goal among rangeland producers and wildlife managers. However, research on buckbrush management is limited, and best management practices for reducing this aggressive re-sprouter are lacking.

Buckbrush encroachment (dark brown areas) in a pasture.

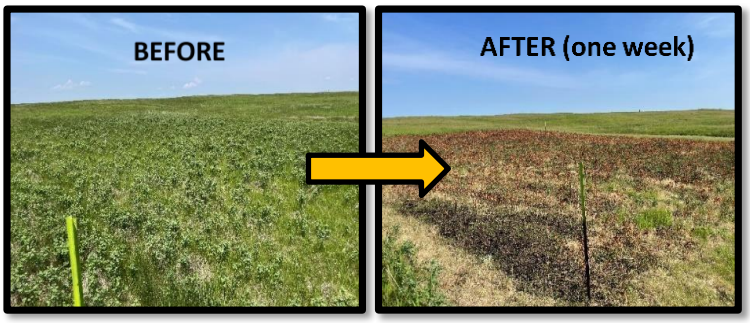


PROJECT OBJECTIVES

1. Determine thresholds at which buckbrush encroachment reduces forage production.
2. Track the effectiveness of various management treatments for reducing buckbrush.
3. Assess treatment effects on plant diversity, floral expression, and pollinator communities.
4. Develop a remote-sensing algorithm to map buckbrush encroachment and monitor plant health.

Management Treatments Evaluated:

Green = Spring Prescribed Fire
Orange = Fall Prescribed Fire
Yellow = Spring Mowing
Blue = Spring + Fall Mowing
Gray = High Intensity, Low Frequency Grazing
Brown = Herbicide (2,4-D Amine)
Pink = Buckbrush Control
Purple = No Buckbrush Control



Prescribed Fire: A buckbrush patch before and after a spring burn.

EXPECTED BENEFITS TO NORTH DAKOTA PRODUCERS

1. **<u>WHEN to reduce buckbrush encroachment.</u>**
   *Knowledge of forage production thresholds will allow rangeland managers to **act early to prevent and reduce yield loss** in rangelands due to buckbrush encroachment.*

Buckbrush burning during a prescribed burn.

2. **<u>HOW to reduce buckbrush encroachment.</u>**
   *This research will **inform best management practices** for reducing buckbrush while also considering plant diversity and pollinator resources.*

Mowing: A shredded buckbrush stem from the hay treatment.

3. **<u>WHERE to reduce buckbrush encroachment.</u>**
   *Buckbrush encroachment maps will allow rangeland managers to **strategically identify and treat problem areas** and maintain rangeland diversity and productivity.*

OVERALL EXPECTED OUTCOME

This research will allow ranchers and land managers to identify **WHEN**, **HOW**, and **WHERE** to tackle buckbrush encroachment and maintain rangeland diversity and forage productivity.

Disturbance and Vegetation: Different Fire-Return Intervals, Fire Seasons, and Grazing Determine Plant Community Attributes

Joslin Forness, Daniel Asplin, Dillon Fogarty, Torre Hovick, Kevin Sedivec

BACKGROUND & OBJECTIVES

Fire and grazing are central to the evolution of Northern Great Plains (NGP) grasslands and are crucial to maintaining native plant diversity, productivity, and functioning. Suppression of these disturbances ir mixed-grass prairies has resulted in reduced diversity, altered vegetation structure, woody plant encroachment, and allowed invasive grasses, like Kentucky bluegrass and smooth brome, to dominate. This study investigates the effect of fire-return interval (FRI), season of fire, and grazing on the plant community.

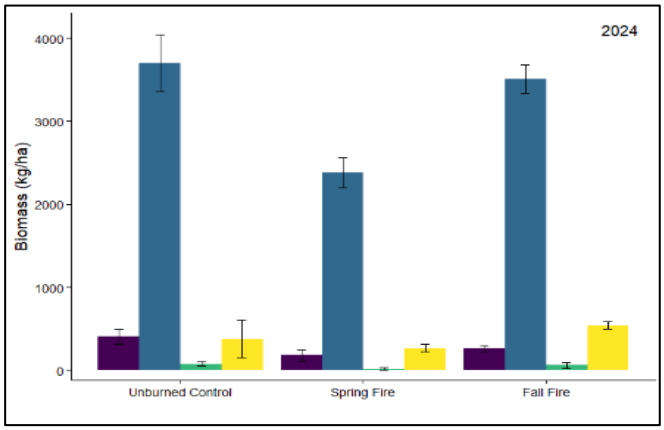
STUDY DESIGN

Design: This study uses a split-plot factorial design with 96 plots. Half the plots are grazed, half are ungrazed. Each plot was randomly assigned a season of fire (spring or fall) and a FRI (1 thru 5 years or unburned control).

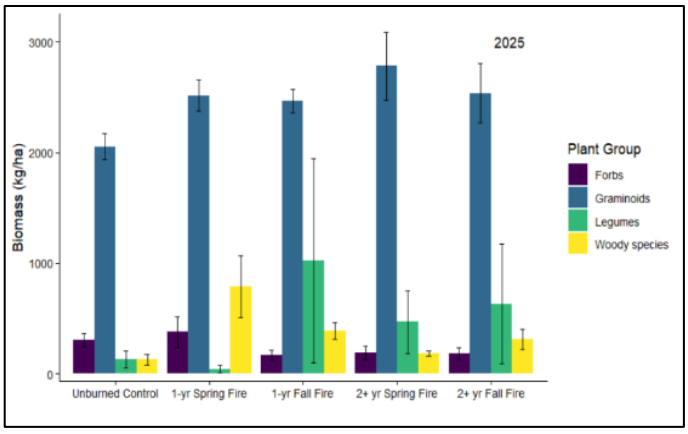
Data collected: Plant canopy cover, litter and thatch depth, visual obstruction, plant biomass, and floral resources

RESULTS

Plant Biomass



2024: Spring burn plots produced less plant biomass than fall burn plots or the unburned controls.

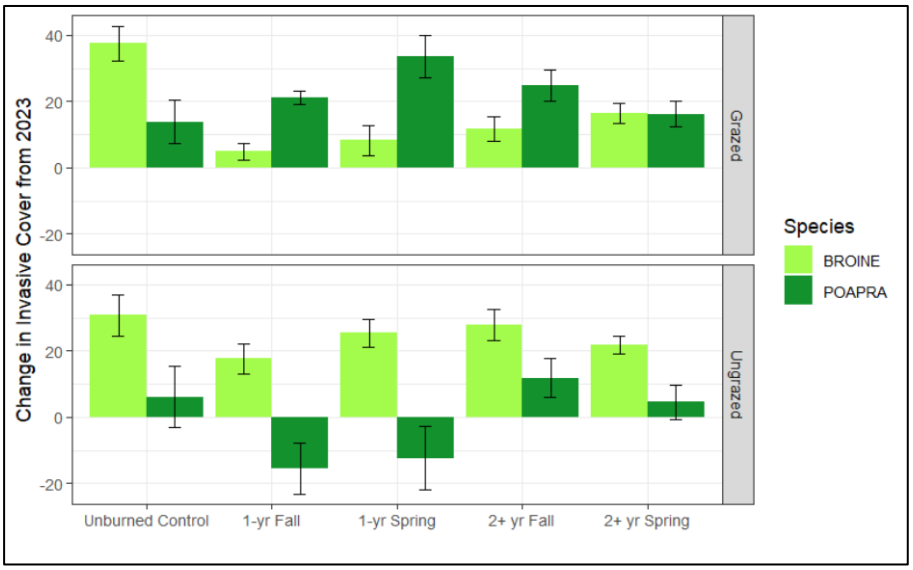


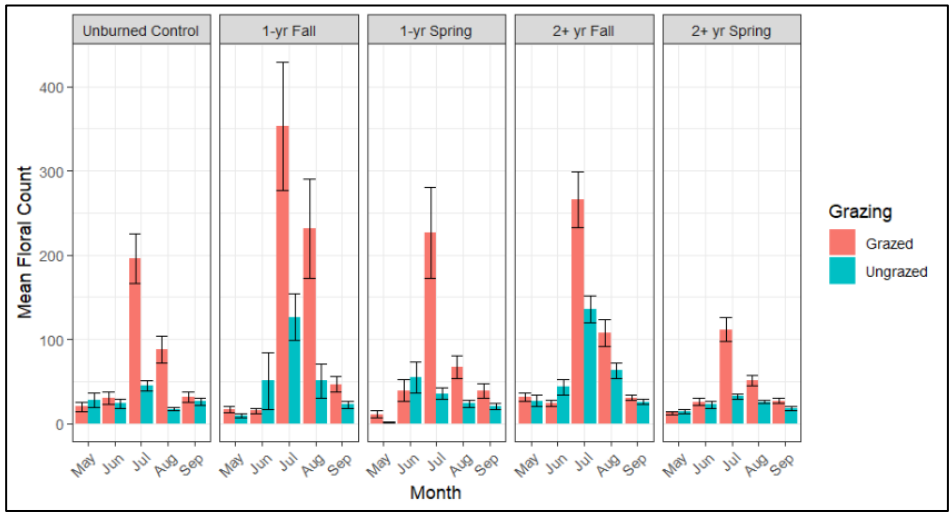
2025: All burn treatments, regardless of FRI, produced higher plant biomass than the unburned control.

Invasive Species Cover

- Kentucky bluegrass (POAPRA) cover increased in every treatment besides the ungrazed 1-year FRI.

- Smooth brome (BROINE) cover increased across all treatments since study onset in 2023. The combination of fire and grazing showed the lowest increases in brome.





Floral Resources

There was no difference in native and non-native floral resource availability across all treatments in 2025. Fall burn plots showed higher floral expression than spring burn or unburned plots, regardless of FRI.

SIGNIFICANCE

- Fire and grazing interact in complex ways to alter plant composition, diversity, structure, and productivity.

- 2 years of data collection reveals short-term effects of recently established disturbances on plant community attributes.

- More years of data are needed to describe long-term effects.

- By investigating combinations of season of fire, FRI, and grazing, this study will provide information on fire and grazing in the NGP that can be used to meet land management goals.

Efficacy of Virtual Fence in Extensive Grazing Systems

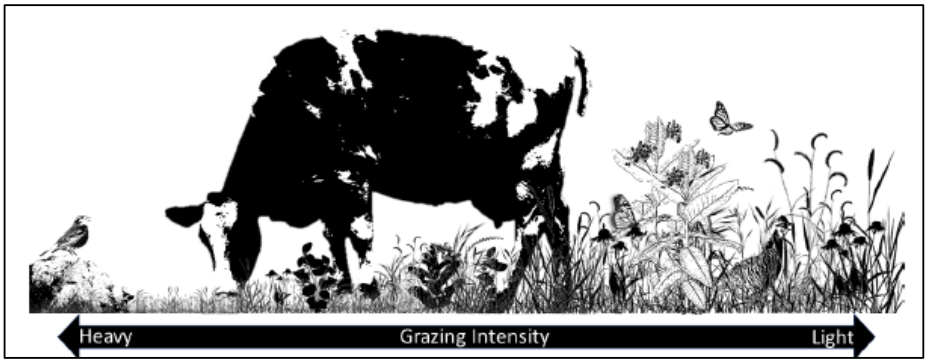
Sallie Sherman, Miranda Meehan, Christopher Byrd, Travis Seaborn, Kevin Sedivec, Torre Hovick, Dillon Fogarty, Joshua Wianecki, Jason Harmon

Using Virtual Fencing

Virtual fencing is a wireless technology that manages grazing livestock without physical fencing. Livestock managers can track animal location, modify pasture boundaries, and move animals from their computer or mobile device.

Heterogeneity-based grazing patterns such as patch grazing can help combat biodiversity loss on working landscapes. Virtual fencing has the potential to be a useful tool for ranchers to more intensely manage their herds' grazing patterns to both improve forage utilization and environmental health.

Right: Heterogeneity in grazing intensity impacts the type and concentration of plant and animal species that can be found in a pasture.



Graphics from work by Ellysa Johnson

Implementation Benefits in Extensive Grazing Systems

- Ranchers can increase grazing efficiency with less labor
- Pasture boundaries can be adapted to current conditions (forage availability, water access, sensitive plants, bird breeding areas, etc)
- Eliminates concern of interior fence damage from wildlife
- Can improve overall pasture health and productivity

Study Design:

In 2023, 2024, and 2025, VF collars were deployed at the Central Grasslands Research Center (CGREC) near Streeter, North Dakota. Cattle with VF collars and their calves grazed on average 150 days between June and October. Four pastures were divided into quadrants using VF and cattle were permitted to graze ¼, then ½, then ¾ of the pastures, excluding ¼.

Efficacy of Virtual Fence in Extensive Grazing Systems

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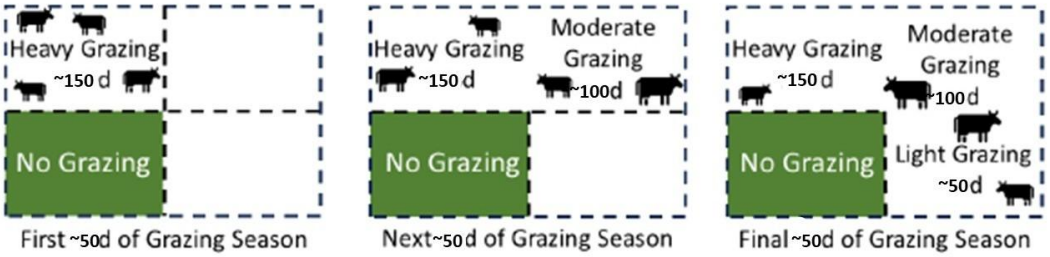
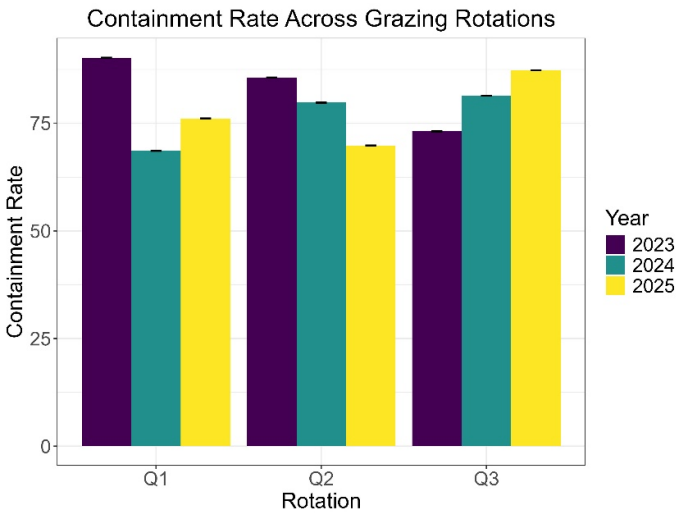


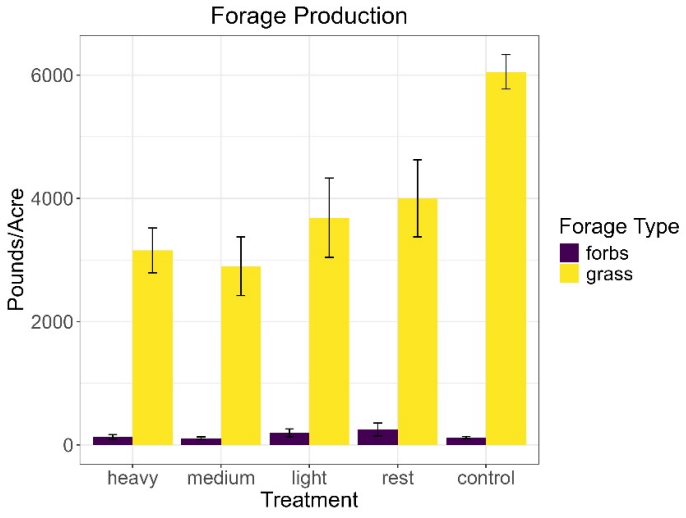
Left. Cattle patch grazed ¼, then ½, then ¾ of the pasture. Cattle were considered contained if they were within the approved quadrants and escaped if they crossed out of the virtual boundary.

Results

The virtual fence containment rate was 74.7% for all cattle (n = 98), ranging from 69.9% to 87.3% between rotations and 57.0% to 86.3% between replications. Pasture, rotation, and individual differences in containment rate were all highly significant (P < 0.001), with rotation having the largest impact. There were not statistically significant differences in forage production. ADG for treatment cows was 0.136 lbs higher than the control cows (P = 0.01). ADG for the calves of treatment cows was 0.100 lbs lower than the calves of control cows (P = 0.58).



Above: Average containment rate for each grazing rotation for each year. P < 0.001.



Above: Average forage production for 2025. P > 0.5.

Impacts of grazing technologies within intensive strip grazing systems

Joshua Wianecki, Miranda Meehan, Christopher Byrd, Kevin Sedivec, Sallie Sherman

Intensive grazing practices can increase forage utilization by grazing livestock resulting in increased stocking rates. Under intensive strip grazing management, pastures are subdivided into smaller grazing allotments or strips and grazed sequentially. These strips increase stocking densities which reduces trampling waste and increases forage utilization.

How can grazing technologies enhance intensive strip grazing:

Implementation of intensive grazing practices requires additional labor and infrastructure compared to continuous grazing. Technologies such as virtual fencing or automated gate openers may reduce labor and enhance intensive grazing practices.

Photo by Jessie Syring

Objectives:

1) Determine the efficacy of virtual fencing and automated gate openers within small-area strip grazing
2) Evaluate the effects of intensive strip grazing on forage utilization and stocking rates compared to continuous grazing

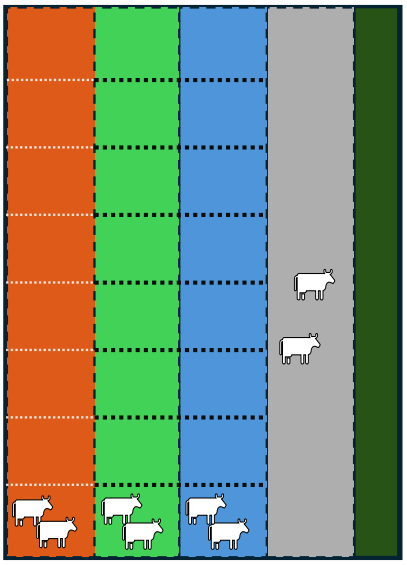
What is Virtual Fencing?

Virtual fencing is a wireless technology that manages grazing livestock without physical fencing. Livestock managers can track animal location, update pasture boundaries, and restrict areas from their computer or mobile device. Livestock wear a GPS enabled device (Above) that administers auditory and electrical cues that warn cattle as they approach assigned boundaries.

Methods:

Three fields were seeded with a season-long annual forage mix and divided into four grazing treatments: automated gate openers (AUTO), manual poly-wire (MAN), virtual fence (VF) and continuous graze (CONT). Cattle in AUTO, MAN, and VF treatments strip grazed paddocks sequentially while CONT had full access of the paddock (right). Following grazing we analyzed:

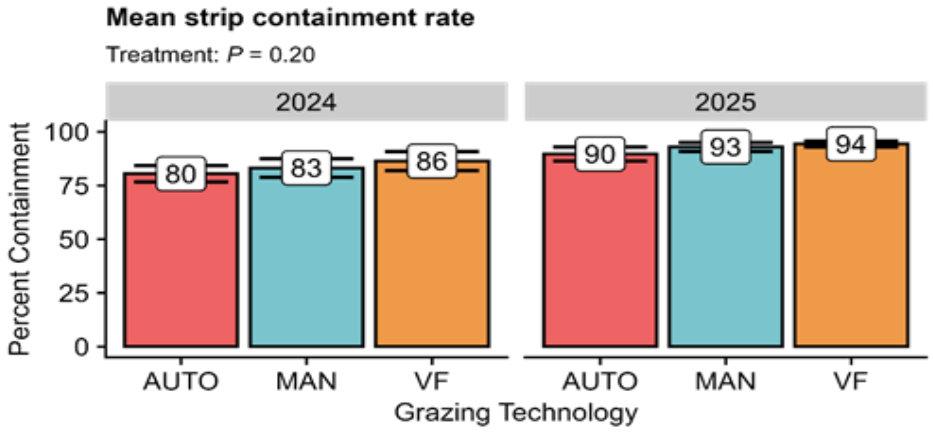
- Containment rates for each grazing technology using GPS location
- Forage utilization rates within each grazing treatment and strategy
- Grazing duration and stocking rates for each grazing treatment and strategy

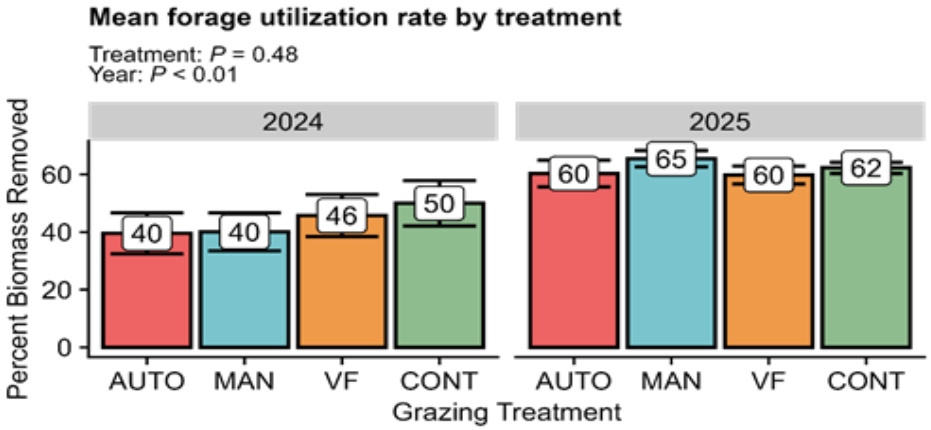


Results

Grazing technology containment rates:

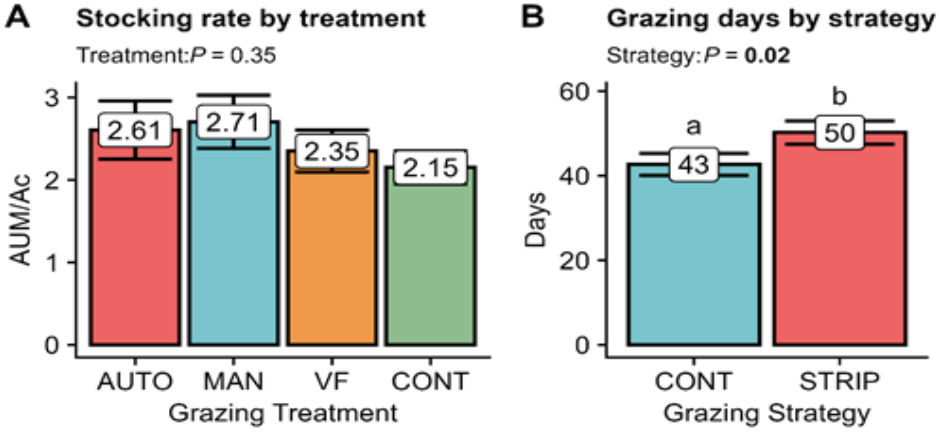
Containment rates were variable by year but did not differ by technology used in 2024 or 2025. Both virtual fencing and automated gate openers are effective livestock management devices.





Forage Utilization:

Forage utilization varied by year but did not differ by treatment. In 2024, forage utilization did not reach the target rate of 60% in any treatment. Forage utilization was greater in 2025.



Stocking rates and grazing duration:

While no effect to utilization or stocking rates was observed by grazing technology (A), across years intensive strip grazing increased grazing duration, providing up to 18 additional grazing days (B).

Implications

- Virtual fencing and automated gate openers can serve as effective livestock management tools within small-area intensive grazing systems.
- Implenting intensive grazing practices increased the total grazing duration by up to18 days compared to continuous grazing

Central Grasslands Research Extension Center

Comparisons of winter cereal cover crops within an integrated crop livestock system

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

Introduction

In North Dakota and nation wide, there is continuing to be a trend of increasing cover crop acreage to conserve and improve soil health. Winter rye is the most frequently grown cover crop, with winter cereals wheat and triticale also being common. One of the biggest challenges of the practice is that economic returns are slow and hard to track. Integrating livestock into the system is a strategy to off set costs in the short-term.

Corn Grain Yield

Grazing did not impact corn grain yields, but a triticale cover crop did. Plots with a triticale cover crop had significantly lower grain yields than no cover crop plots. This decrease may be due to increased percent bare ground prior to planting.

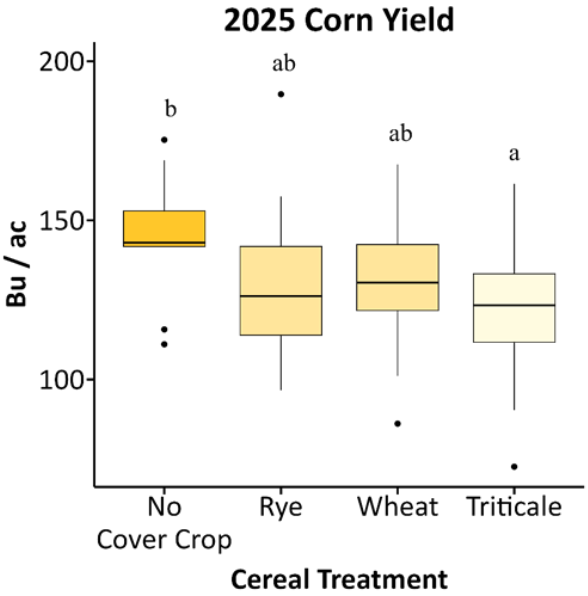


Figure 2. 2025 Corn grain yield estimates, means not connected by the same letter are significantly different (P≤0.05)

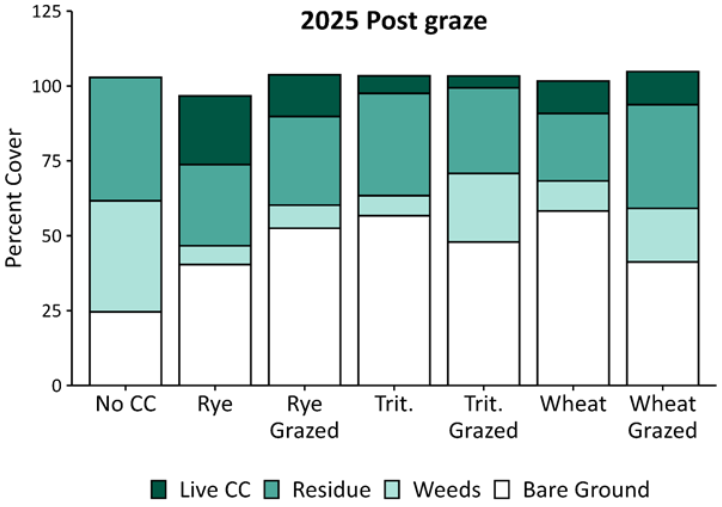


Figure 1. Post-grazing ground cover estimates for spring 2025

Ground Cover

All winter cereal cover crops lowered weed cover, and their suppression was unaffected by grazing. The primary weed in the field was kochia, which has become a major problem for many farmers in the Northern Great Plains as it is glyphosate resistant. Rye provided the greatest cover and the highest weed suppression of the three winter cereals. Ryes' superior performance was due to winter kill of triticale and wheat. This winter kill may have been due to a major thaw and refreeze in the middle of winter.

Integrating Livestock

Winter cereal cover crops can be an excellent source of forage for livestock. Late planting of winter cereals led to low fall biomass production that could not support grazing. In the spring winter rye, triticale, and wheat provided 261.5lbs, 72.4lbs, and 141.5lbs per acre of dry matter, respectively, prior to termination. This supported 0.56 AUMs of grazing in the spring.

Figure 3. Heifers in a strip of winter rye at grazing turnout, spring 2025

2025 Economic Analysis

In 2025, it costed $62.13/ac to have a rye cover crop, $180.71/ac for triticale, and $89.76/ac for wheat. Winter cereals varied largely in seed cost. Grazing provided a return by lowering livestock feeding and yardage costs. Grazing returns for rye, triticale, and wheat were $26.88/ac, $1.18/ac, and $12.2/ac, respectively. Rye provided the largest return as it produced the greatest biomass and supported the most grazing. Wheat provided minimal returns from grazing and triticale returns came entirely from savings in yardage. Grazing cover crops is heavily dependent on cereal type, planting date, temperature, and precipitation. There is potential for grazing to provide a return on cover crop investment through reducing feeding costs without negatively impacting soil health or crop performance.

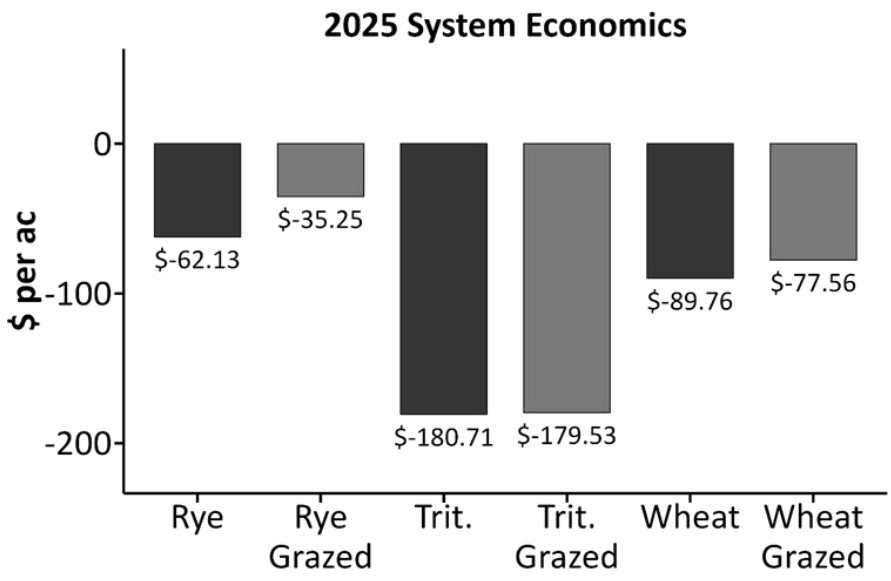


Figure 4. Estimated net economic effect for incorporating winter cereal cover crops with and without grazing for 2025

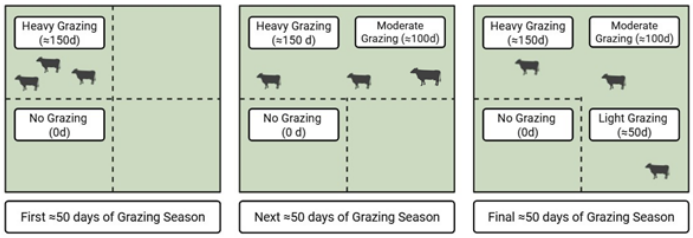
Using Virtual Fence to Achieve Conservation Goals for Birds and Pollinators

Taleigh Adrian, Michael Warne, Dillon Fogarty, Kevin Sedivec, and Torre Hovick

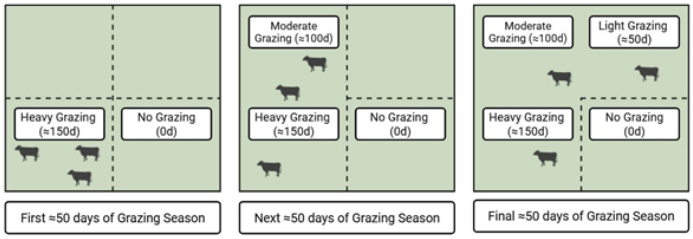
Background

Rangelands are important systems for both wildlife and production, but are threatened by land use changes and landscape simplification. These threats can be mitigated by innovative grazing strategies that increase diversity, like patch-grazing with virtual fence. Across three tested grazing strategies, patch-grazing with virtual fence shows promising results to support native species, making it a feasible way for working lands to benefit conservation.

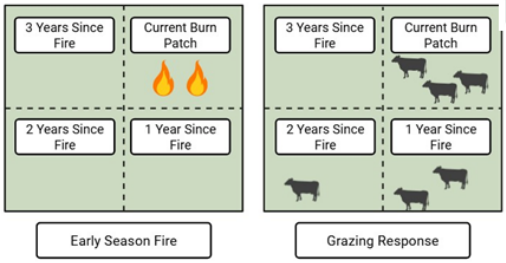
Year 1 Patch-grazing with virtual fence:



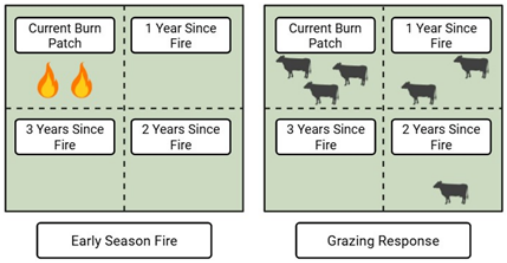
Year 2



Year 1 Patch-burn grazing:



Year 2



Project Objectives

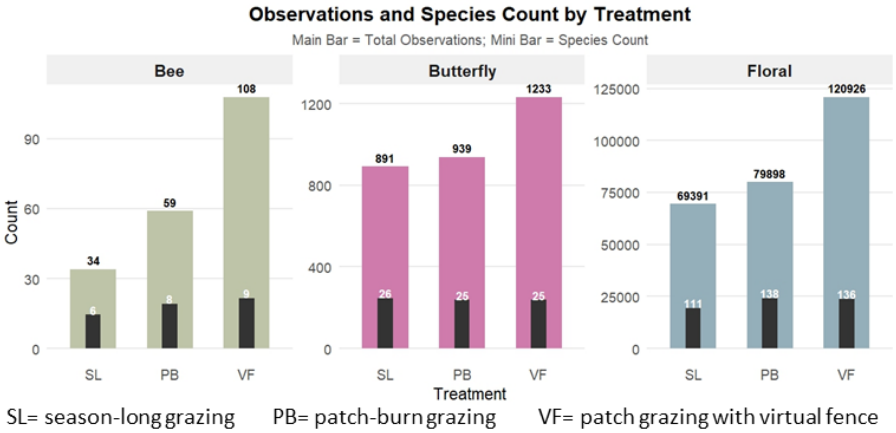
Investigate how patch-grazing with virtual fence performs compared to patch-burn grazing, which has proven benefits to conserving rangelands, and to a traditional season-long grazing strategy through:

1) Evaluating floral resources and plant community structure and composition across grazing strategies

2) Quantifying pollinator communities across grazing strategies

3) Quantifying bird communities across grazing strategies

Pollinator and Plant Responses



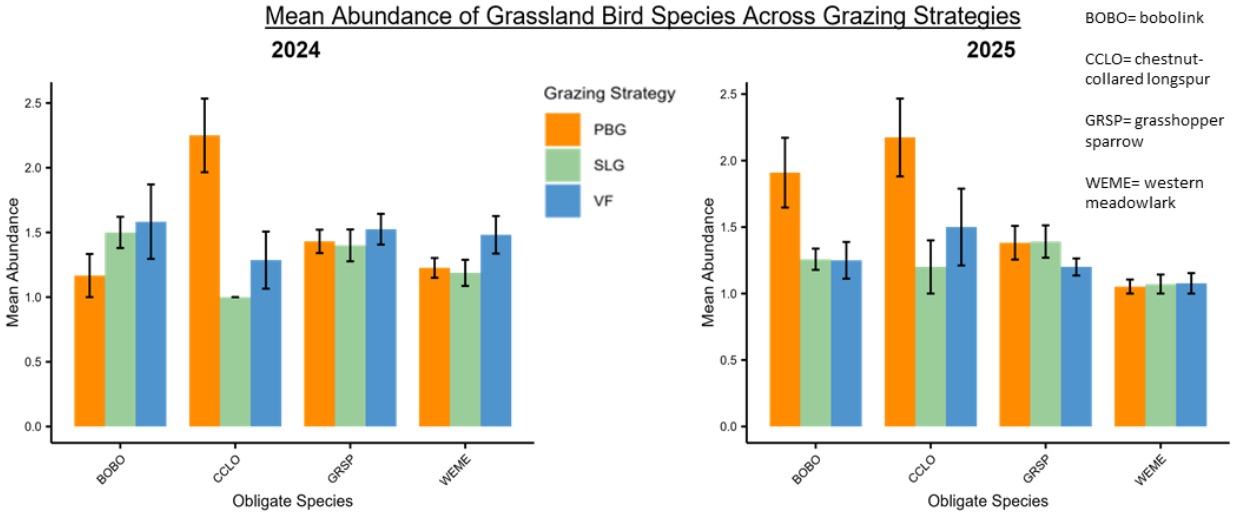
SL= season-long grazing PB= patch-burn grazing VF= patch grazing with virtual fence

- 10 bumblebee species across 201 total observations (June-mid-August)
- 35 butterfly species across 3,063 observations (June-mid August)
- 160 flowering plant species across 270,215 observations (June-mid August)

Grazing Strategy	Bumblebee Species	Butterfly Species	Floral Species
All strategies	Northern Amber Bumblebee	Common Wood Nymph, Clouded Sulfur, Common Ringlet, Meadow Fritillary	Yellow sweet clover, common yarrow, black medick, white milkwort, prairie coneflower, western snowberry, silver-leaf scurf pea, western ragweed, field chickweed, *Canada anemone*
Patch-burn grazing (PB)	Brown-belted Bumblebee, *Yellow Bumblebee*	Aphrodite Fritillary, **Regal Fritillary**, Long-dash Skipper, Pearl Crescent, **Monarch**, Peck's Skipper	Prairie milkvetch, daisy fleabane, blue-eyed grass, American vetch, bastard toadflax
Patch grazing with virtual fence (VF)	Brown-belted Bumblebee, Orange-belted Bumblebee, **American Bumblebee,** *Yellow Bumblebee*	Aphrodite Fritillary, **Regal Fritillary**, Melissa Blue, Northern Crescent, **Monarch**, Pearl Crescent, Eastern Tailed Blue, Peck's Skipper	Purple prairie clover, field milkvetch, prairie milkvetch, daisy fleabane, curly-cup gumweed, dotted blazing star, yellow owl clover, purple locoweed, blue-eyed grass, white clover, wormwood, Canada thistle, northern bedstraw
Season-long grazing (SL)	Orange-belted Bumblebee	Delaware skipper	Canada thistle, northern bedstraw

Table 1: Common bumblebee, butterfly, and floral species across each grazing strategy. "Common" = species that played a significant role in the community based on abundance or species indicative of habitat quality. **Bold = ESA species**, *Italicized*= Vulnerable species.

Bird Responses



Key Takeaways

- Mean abundance generally consistent across years
- Heterogeneity strategies (i.e., PBG and VF) maximize grassland bird abundance
- Mean abundance VF ≥ SLG for most species
- Bobolink abundance dramatically shifts across years
- Chestnut-collared longspur select for habitat provided by PBG

	2024	2025
Total Observations	1373	1369 ↓
PBG Observations	491 (36%)	513 (37%) ↑
SLG Observations	420 (30%)	457 (33%) ↑
VF Observations	462 (34%)	399 (30%) ↓
Species Richness	39	55 ↑

Table 2. *Overall grassland bird abundance and richness across 2024 and 2025. Arrows indicate either an increase (green) or a decrease (red) from the previous year.*

Shaping Conservation

Simplification of rangelands due to losses in plant community heterogeneity is a critical threat in the Great Plains. Patch grazing with virtual fence seems to be a feasible and promising management solution based on preliminary results. We see increased plant community heterogeneity which has so far led to increased pollinator abundance, more robust communities, and benefits to grassland bird habitat use.

Heterogenous grazing strategies support native bee floral selection

Bethany Roberton[1], Dillon Fogarty[1], Jason Harmon[2], Torre Hovick[1], Kevin Sedivec[1,3], and Ben Geaumont[4]

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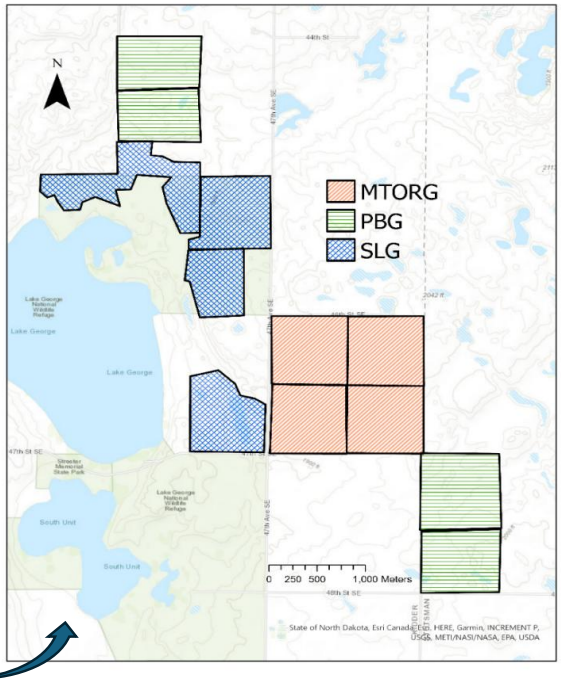
[2]*Department of Natural Resource Ecology & Management, Oklahoma State University, Stillwater, OK*
[3]*Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND*
[4]*Hettinger Research Extension Center, North Dakota State University, Hettinger, ND*

Research Objective: Examine native bee and floral abundance, diversity, and network structure between three grazing strategies.

Rangelands are potential critical areas for pollinator conservation.[1] These landscapes can provide pollinator food resources and nesting sites.[2]
If we are to effectively use these lands to support bee communities, we must explore how grazed rangeland management techniques can create sustainable habitat and support diverse bee and floral assemblages.



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

Methods

Four summers of data collection 2021-2024

Three rounds of surveys each summer in June, July, and August

Bees caught visiting flowers within 1-meter on each side of 100-meter transect

Flowering plants counted and identified within 2.5-meters on each side of 100-meter transect

Definitions[3, 4, 5, 6]

Network: Map of interactions between pollinators and flowers

Links: Visits between pollinators and flowering plant species

Selection: Process in which a pollinator chooses a floral species to visit

Preference: When a pollinator chooses a floral species over others when given a diverse array of species to select from

Sources: [1]Cole et al. 2017, [2]Black et al. 2011, [3]Bosch et al. 2009, [4]Manly et al. 2002, [5]Johnson 1980, [6]Bluthgen et al. 2006

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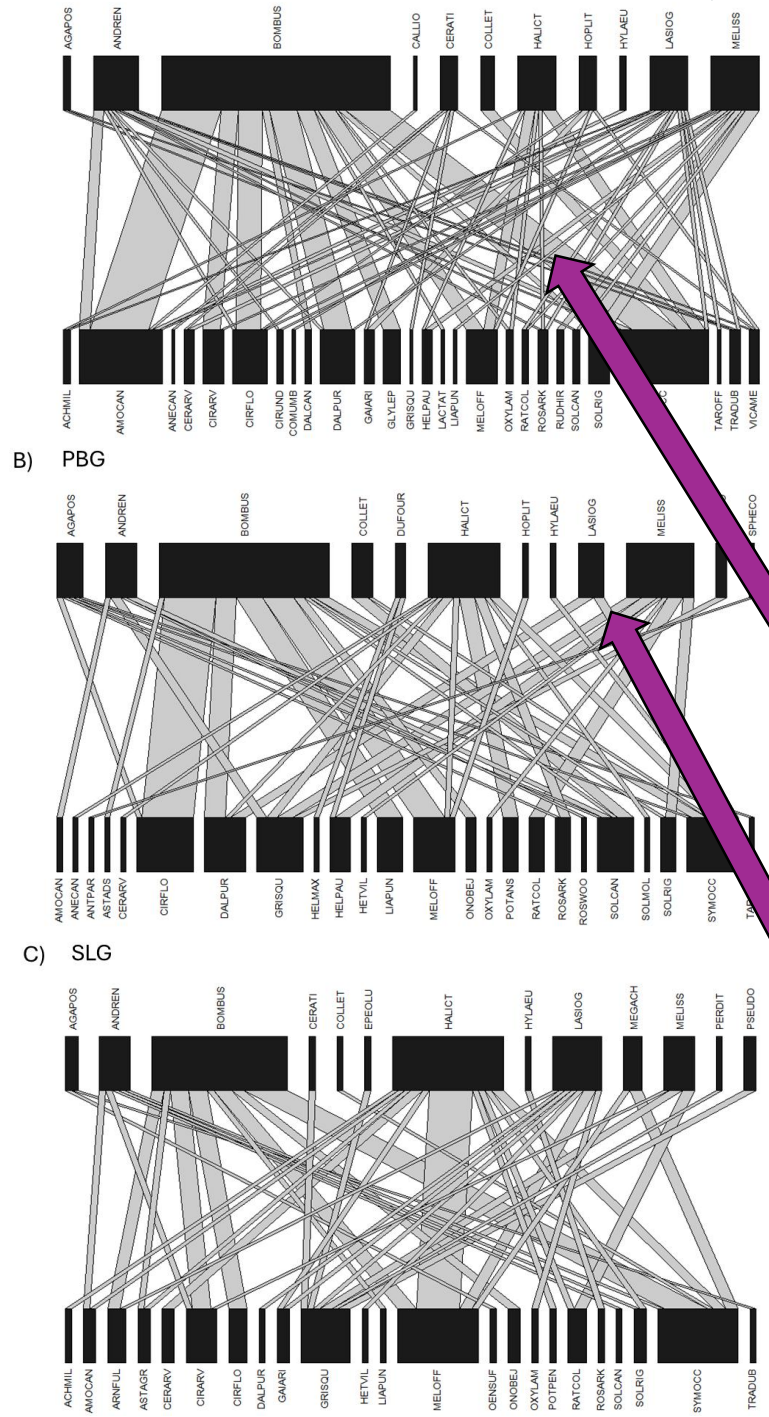
Results



Network Structure

The networks for A) MTORG, B) PBG, and C) SLG. For each network, bee genera are on the top row and floral species are on the bottom row. The lines connecting the rows "link" bees to flowers, showing which floral species the bees are visiting. The widths of the connecting lines represent the number of visits that bee genus had to the connected floral species.

Bees in MTORG visited lots of flower species. This grazing strategy may support a high abundance of bees.

Some bees visited fewer flowers in PBG than MTORG and SLG (like LASIOG). This indicates bees showing preference when given a diversity of flower species to choose from.

Abundance and Diversity

- MTORG had highest bee abundance
- PBG had highest floral diversity
- Bee diversity and floral abundance were similar across all three regimes

Conclusions

- PBG: Highest floral diversity and best supports bee preferences for flowers.
- MTORG: Less floral diversity but still allows bees to visit many flower species.
- SLG: Most general network with constraints on what bees select to visit.

CGREC Staff and Advisory Board

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Cody Wieland	Manager of Operations, Livestock Technician
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The CGREC annual field day will be held on July 7, 2026 and open to the public

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