Central Grasslands Research Extension Center

2022 Annual Report

Grazing – Forage – Wildlife – Livestock

NDSU NORTH DAKOTA AGRICULTURAL EXPERIMENT STATION

NDSU | EXTENSION

Summary of the Year

Welcome to the 2022 CGREC Annual Report

The year 2022 started with a mild winter, however, like much of the state a series of blizzards hit in April. For the most part, we didn't lose many calves to the wet, cool weather and the growing season started with good moisture. Unlike 2021 where we received a 40 percent hay crop, in 2022 we grew a bumper crop with over 3500 round bales put up (compared to less than 1,000 in 2021).

The pastures were very productive in 2022; however, drought hit again starting early July with the grazing treatments dominated by mature, dry grass from August through November. So, livestock performance, in terms of calf performance, was the lowest since I've been the director in 2017. Average calf daily gain was 2.39 lb/day compared to our best year in 2019 at 2.69 lb/day. Winter hit early, with our first snow occurring on November 9 and temperatures not reaching 40 degrees until early April, 2023.

Our grazing program focused on two large scale experiments included 1) testing heterogeneity-based grazing treatments studies and 2) integrated livestock-cropping system trials. 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. The integrated livestock-cropping system trials were design 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. See the research reports for our updated reports on these trials.

Our forage program is designed to assess different annual forage crops for production and quality. We have assessed cereal forages, warm-season forages, and silage production. Again, see the research reports for our updated reports on these trials.

The wildlife and pollinator trials focused on impacts of the grazing treatments that were designed to assess heterogeneity-based grazing on habitat. We studied patch-burn grazing, a modified twice-over rest rotation grazing system, and continuous grazing. See reports for latest updates.

Finally, our livestock trials focus on impacts of limit feed vitamins and minerals, or dietary energy on heifer and fetal development. See reports for latest updates.

I would like to end by providing an update on our capital projects. We received special funding from the 2021-2023 state legislative session for a new livestock working facility and research complex. We are hoping to break ground in 2023 and have the project completed by 2024. We are hoping to go out on bids for the director's residence this spring and have a completed project by spring 2024. We received funding to build new pasture working facilities, with these projects projected to be completed in June 2023.

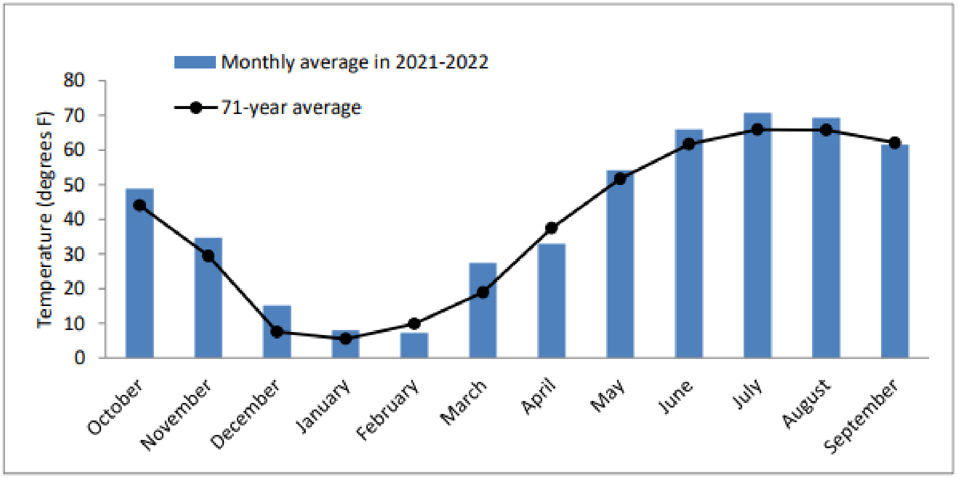
Our 2023 annual field day is scheduled for July 10. We plan to run two tours, one focusing on a new trial that will start in May 2023 looking at a new heterogeneity-based trial using virtual fencing. We think this treatment will allow heterogeneity in structure and plant community composition similar to patch-burn grazing (without fire) without giving up livestock performance that we see with the modified twice-over rest rotation grazing system. Fire does create a flush of flowering plants that grazing alone doesn't achieve, so I don't expect the grazing with virtual fencing treatment to change that impact. We will also tour the new livestock – cropping system study looking at grazing winter rye prior to planting soybeans to assess soil health impacts of this type of integrated system. All are welcome and come enjoy a good meal and southcentral North Dakota hospitality.

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

Table of Contents

Monthly Temperatures for the 2021-2022 Crop Year



Last spring frost: May 3 (31°F)

First fall frost: Oct. 5 (31°F)

155 frost-free days

Average[1] last spring frost: May 13

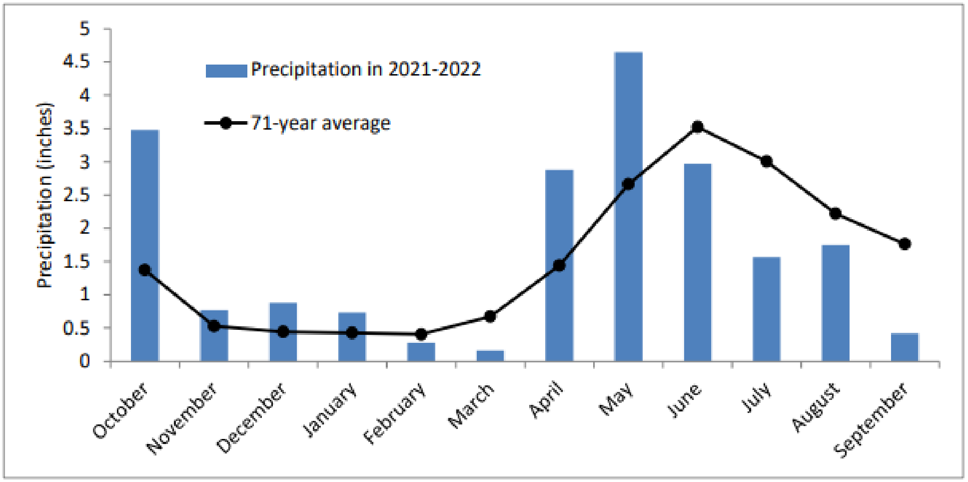
Average first fall frost: Sept. 22

Average: 132 frost-free days

Month	Maximum temperature[2]	Minimum temperature	Average temperature	Long-term[1] average temperature	2021-2022 deviation from long-term average
October	82	21	48.8	44.0	4.8
November	69	0	34.7	29.4	5.2
December	58	-23	15.2	7.6	7.6
January	37	-27	8.0	5.5	2.5
February	41	-20	7.3	9.9	-2.6
March	55	-9	27.5	18.9	8.5
April	60	8	33.0	37.4	-4.5
May	78	28	54.2	51.7	2.5
June	95	40	66.0	61.7	4.3
July	97	50	70.8	65.9	4.9
August	93	50	69.3	65.8	3.5
September	94	34	61.5	62.1	-0.6

[1] 1951-2022; 71 years   [2] Degrees F

Monthly Precipitation for the 2021-2022 Crop Year



Month	Precipitation[1]	Long-term[2] average precipitation	Deviation from long-term average	Percent of long-term average	Accumulated precipitation	Accumulated long-term average	Snow[3]
October	3.48	1.37	2.11	253	3.48	1.37	0
November	0.77	0.53	0.24	146	4.25	1.90	3
December	0.88	0.44	0.44	199	5.13	2.34	21
January	0.73	0.43	0.30	171	5.86	2.77	13
February	0.28	0.40	-0.12	69	6.14	3.18	5.5
March	0.16	0.67	-0.51	24	6.30	3.85	1.5
April	2.88	1.44	1.44	200	9.18	5.29	22
May	4.65	2.66	1.99	175	13.83	7.95	0
June	2.97	3.52	-0.55	84	16.80	11.47	0
July	1.57	3.01	-1.44	52	18.37	14.48	0
August	1.75	2.22	-0.47	79	20.12	16.70	0
September	0.42	1.76	-1.34	24	20.54	18.46	0
Total	**20.54**	**18.48**	**2.06**	**111**	**20.54**	**18.46**	**66**

[1] Rain and melted snow in inches [2] 1951-2022; 71 years [3] Depth in inches

Grazing Management Practices to Enhance Soil Health in the Northern Great Plains

Erin Gaugler[1,2], Katelyn Landeis[2], Miranda Meehan[3], and Kevin Sedivec[1,2]

[1]Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D.
[2]School of Natural Resource Sciences, North Dakota State University, Fargo, N.D.
[3]Department of Animal Sciences, North Dakota State University, Fargo, N.D.

The objective of this project is to identify the impacts of livestock grazing management on the environmental and economic sustainability of an integrated crop and livestock system. Our focus is the influence of forage utilization on: 1) soil physical and chemical properties, 2) crop production, 3) livestock performance, and 4) economics.

Introduction

Cover crops have gained popularity as a practice implemented by producers across the United States. According to Wallander et al. (2021), cover crop acreage increased 50% between 2012 and 2017, with 15.4 million acres in 2017. North Dakota is no exception to this trend; acreage reports for North Dakota show an increase in annual crops planted for forage or grazing of 26,241 acres between 2019 and 2021 (USDA-FSA, 2021). Producers are incorporating cover crops to improve soil health and increase crop production (USDA, 2019; CTIC, 2017). Despite the ecological benefits of incorporating cover crops into a system, the economic benefits may not be realized if livestock are not incorporated into the system (Costa et al., 2014; Franzluebber and Stuedemann, 2015).

The benefits of integrated crop and livestock systems (ICLSs) include enhanced nutrient cycling as well as reduced inputs and livestock feeding costs. Research on the ecological impacts of ICLSs in semi-arid ecosystems, such as the Northern Great Plains, is limited (Faust et al., 2018). Livestock management decisions regarding stocking rate, stock density, and forage utilization have the potential to impact both environmental and economic sustainability of ICLSs.

This producer-led demonstration project will help develop practices for managing grazing livestock on cropping systems to enhance soil health, livestock performance, crop production, and economic sustainability.

Procedures

A three-year ICLS project was initiated in the spring of 2020. NDSU Extension partnered with producers to establish five research sites located in central North Dakota, along with a demonstration site near the main campus of NDSU. Each location was developed to test forage utilization rates in a split-plot design. An annual forage crop representing a cover crop was subjected to two forage utilization treatments: 1) 50% and 2) 75%. A non-grazed treatment served as the control and comparisons were also made to a traditional cropping system. Treatments were imposed for two years, followed by a cash crop of corn.

<u>Forage Establishment</u>

A full-season annual forage crop was planted by mid-June of 2020 and 2021. The mix included Haywire Forage Oats, Sweething MAXX Sorghum Sudangrass, Golden German Millet, Peredovic Sunflower, Buster Forage Radish, Sub Zero Hybrid Kale, Pasja Hybrid Brassica, Brown Flax, and 4010 Forage Pea seeded at a rate of 18, 3, 2, 1.5, 1, 0.75, 0.75, 2, and 10 lbs/ac, respectively. After two years of an annual forage crop, corn was planted during the spring of 2022. Producers and site managers had the option to plant corn for use as silage or grain production.

Livestock and Grazing Management

Beef cattle were randomly assigned to forage utilization treatments, and carrying capacities were determined based on available forage production. Stocking rates were determined by dividing the available forage by anticipated dry matter intake per day per animal unit month, then divided by 30 to calculate animal units per day. Animal units per day was divided by the available animal units to predict the grazing period for each location and plot. The available forage for 50% and 75% utilization treatments was calculated using a 35% and 50% harvest efficiency of the total forage produced, respectively (Meehan et al., 2018). The estimated dry matter intake was based on recommendations in the Beef Cattle Handbook (National Research Council, 2016), but was increased by 20% according to trials previously conducted at NDSU Central Grasslands Research Extension Center (Fraase, 2012).

A visual scoring system was used to describe the relative fatness or body condition of cattle pre- and post-treatment (Wagner et al., 1988). Type and class of cattle varied from site to site and grazing turnout ranged from the late July to early October. Electric poly-wire and temporary posts were utilized as portable cross-fence to limit-graze livestock and maintain grazing efficiency. Each treatment was divided into four sections. Windbreak shelters were available for use and continued access to water was provided.

Soil Sampling

Soil samples were collected to characterize physical, chemical, and biological properties. Soil physical properties included bulk density, infiltration, and aggregate stability collected pre- and post-treatment. Six sub-samples were collected from a similar soil series within each treatment prior to seeding of annual forage crop. Soil chemical properties included soil nutrients, pH, and organic matter collected annually with assessment of nutrient distribution only occurring pre- and post-treatment. Samples for nutrient distribution were collected from each 1-acre sub-plot, whereas once yearly levels were extracted from a similar soil series within each treatment. Above ground residue was gently removed at each sampling site prior to conducting the sampling technique.

A soil core sampler with hammer attachment was used to measure bulk density at a depth of 0-6 inches. In calculating bulk density, the weight of the oven-dried soil was divided by the volume of the ring to determine lb/ft^3. Soil infiltration was determined by utilizing the Cornell Sprinkle Infiltrometer system (van Es and Shindelbeck, 2003). It consists of a portable rainfall simulator that is placed onto a single 9.5-inch inner diameter infiltration ring and allows for application of a simulated rainfall event. Field-saturated infiltrability reflects the steady-state infiltration capacity of the soil after wet-up. It is based on the data collected at the end of the measurement period, or whenever steady-state conditions occur. Since the apparatus has a single ring, conversion factors from Reynolds and Elrick (1990) are needed to account for the three-dimensional flow at the bottom of the ring. Soil aggregate stability samples were collected with a tiling spade at a depth of 0-6 inches. A manual wet sieving method by Six et al. (1998) was used to develop an automated method for assessing aggregate stability. Due to variation in soil across locations, the sand correction procedure by Mikha and Rice (2004) was applied to each sample to remove the sand fraction from the water stable aggregates total. Soil nitrate-nitrogen (NO_3-N), phosphorus (P), potassium (K), pH, organic matter (OM), sulfate-sulfur (SO_4-S), zinc (Zn), and copper (Cu) were determined from samples collected at 0-6 and 6-12 inches with a 0.7-inch diameter soil probe. Soil nitrates (Vendrell and Zupancic, 2008) were measured using the Brinkmann PC910 Colorimeter. This colorimeter was also used to determine levels of P after applying the Olsen Test (Nathan and Gelderman, 2015). Potassium was measured using an atomic absorption spectrophotometer. Zinc and copper were extracted with diethylenetriaminepentaacetic acid and also measured with an atomic absorption spectrophotometer (Nathan and Gelderman, 2015). Recommended chemical soil test procedures for the North Central Region (Nathan and Gelderman, 2015) were used to analyze pH, OM, and SO_4-S.

Forage Production and Utilization

Forage production and utilization of the annual crop was estimated by clipping six frames per experimental treatment within a similar soil series. Samples were oven-dried at 50°C for 48 hours, weighed, and multiplied by the appropriate conversion factor. Clipping for peak biomass production occurred during the week prior to grazing. Clipping to determine forage utilization occurred upon removal of cattle from the grazing treatments.

Crop Production

Forage biomass of corn was estimated at physiological maturity by clipping six plots per experimental treatment within a similar soil series (Meehan and Sedivec, 2017). The size and shape of the plots depended on the type of row spacing established at each site. Clipping length was determined by the following formula: 10.8 ÷ (row spacing in inches ÷ 12) = length in feet. For example, 30-inch row spacing requires a clipping length of 4 feet 3 inches. Samples were oven-dried, weighed, and multiplied by the appropriate conversion factor.

The kernel count method was used to estimate corn grain yield by collecting fifteen cobs per experimental treatment within a similar soil series (Carlson and Reicks, 2019). This method is based on the premise that yield can be estimated from the components that constitute grain yield, including ear number, number of kernel rows, and kernels per row.

Results and Discussion

Spring conditions were dry during 2020 and 2021 (Table 1). In fact, Fargo and Lehr were the only locations that did not start with a major deficit of moisture. Total seasonal rainfall was below normal for most locations during 2020 and 2022. Although spring conditions were dry during 2021, seasonal totals were near- or above-normal for most locations except Fargo and McKenzie. Despite widespread drought conditions during the spring of 2021, most locations received rain during the fall. While the spring of 2022 was near- or above-normal, the rain shut-off by mid-summer for most locations.

It is important to acknowledge that precipitation, field conditions, and cropping history are variable across sites and differences may be reflected in results. For example, seeding depth of annual forages was not consistent across sites during 2020. The crop was seeded to a depth greater than ¾ inch at Fargo and Jamestown resulting in little to no germination of brassicas, which influenced forage production and quality. Fargo and Jamestown produced a limited amount of forage in 2020, averaging 5,200 and 7,700 lb/acre, respectively. The McClusky site had calibration issues and, thus, forage production averaged 6,800 lb/acre. The other sites averaged 7,700 to 14,400 lb/acre (Table 2). Strategies for successful field preparation and drill calibration were discussed with site managers and the problem did not persist.

Drought conditions during the fall of 2020 and an early September frost slowed down or halted plant growth. While the annual forage mix was designed to meet requirements of beef cattle and maintain or improve ecological benefits, less than ideal conditions made it difficult to meet nutrient requirements of cattle late in the season. Supplementation should be considered when grazing annual forages during the late fall or early winter months when forage supply or quality is compromised. Livestock response to forage quality was variable (Table 3).

Despite widespread drought conditions in 2021, most locations received moisture during the fall. The late-season rain boosted growth and/or re-growth of forages in Fargo, Jamestown, Lehr, and Tappen. Even though fall moisture was helpful, the overwhelming lack of subsoil moisture resulted in limited forage production across all sites except Fargo during 2021. Average forage production ranged from 2,300 to 8,300 lb/acre with Fargo having the highest production (Table 2).

Grazing turnout during 2021 ranged from late July to early October. Producers were encouraged to graze the annual forage cover crop earlier, so that livestock could graze quality feed. However, persistent drought conditions caused concern for nitrate toxicity and prussic acid poisoning. Samples were collected and tested to ensure that forages were safe. Livestock response to forage quality continued to be variable (Table 3).

Soil physical characteristics are still being analyzed, but preliminary results suggest that grazing cattle on cropland in the late summer or fall does not cause soil particle separation, soil compaction, or impede water infiltration (Table 4). Bulk density was similar between the cover crop only and grazing treatments. Water infiltration varied between sites due to differences in soils, however, rates seemed similar across treatments at each location. Infiltration appeared to decrease from 2020 to 2022, this is likely due to differences in field conditions between years. Similarly, total soil aggregate stability did not differ between treatments. However, an increase in macroaggregates was observed over the study period, indicating increased soil stability.

Soil chemical and biological characteristics are also still being analyzed, but preliminary results suggest that livestock integration did not lead to an accumulation of soil NO_3-N or P, but K did increase over time (Table 5). In eastern North Dakota, soil nutrient requirements for 180-bushel (bu) corn on non-irrigated cropland is 100, 104, and 60 parts per million (ppm) for NO_3-N, P, and K, respectively (Franzen, 2022). Livestock integration did not meet soil nutrient requirements for NO3-N or P, but did exceed requirements for K.

Nitrate-nitrogen is highly soluble and easily moves with water throughout the soil (Keena et al., 2022). It is likely that differences in weather conditions, soil type, and cropping history impacted soil nutrient responses. Phosphorus consists of both organic and inorganic forms in the soil. It is an “immobile nutrient”, which means that its range of movement in the soil is minimal over time. Effectiveness of P uptake is enhanced by the availability of soil moisture and temperature. Livestock manure is a source of slow-release P that must be broken down by soil microbes into plant-available forms (Berg et al., 2018). Potassium very seldom leaches from the soil. However, dry soil conditions can negatively affect soil K uptake by plant roots (Korb et al. 2005).

Soil organic matter (SOM) is influenced by the amount of carbon in the soil. Soil organic matter directly influences nutrient availability and water holding capacity of a soil. Soil organic matter does not appear to be different between treatments. However, when evaluating changes in

SOM over the study period by grazing treatment, SOM increased by 0.65% and 0.75% on average for the 50% and 75% utilization treatments, respectively. In comparison the no graze cover crop treatment had an average increase in SOM of 0.52%. The traditional crop system had a 0.46% increase in SOM over time.

Despite the low levels of soil NO_3-N and P, corn biomass and yield responded positively to livestock integration (Table 6). This may be a response to change in nutrient availability and soil carbon levels, which may be influenced by the increases in SOM over the study period. The no grazing treatment averaged 7,500 lb/ac of corn biomass across locations. However, production increased to 8,900 and 9,700 lb/ac across locations for the 50% and 75% utilization treatments, respectively. Livestock integration also increased corn yield (Table 6). The no grazing treatment averaged 86 bu/ac across locations, but corn yield increased to 100 and 106 for the 50 and 75% utilization treatments, respectively.

While an economic analysis has not yet been performed, initial calculations indicate that incorporating livestock into cropping systems can provide a cost savings and has no negative affect on soil physical characteristics. With the exception of Tappen and McClusky, where challenges were evident because of inclement weather, limited feed or water quality, body condition of cattle was maintained. Implementing management strategies, such as altering grazing density or forage utilization, should reflect the goals and resources of an operation. Preliminary results suggest that integration of crops and livestock has the potential to influence soil health, crop production, livestock performance, and economics.

Acknowledgements

The authors acknowledge the North Central Region Sustainable Agriculture Research and Education Grant Program for their financial support. A special thanks to our cooperating producers: Jerry Doan, Mike Keily, Alice Labor, Lyndon Murch, Kim Saueressig, and Adam Weigel, and the NDSU Beef Unit and research technicians for their assistance.

Literature Cited

Berg, M., M. Meehan, D. Franzen, and T. Scherer. 2018. Phosphorus behavior in the environment. NM1298. Accessed March 2, 2023. https://www.ndsu.edu/agriculture/ag-hub/publications/phosphorus-behavior-environment

Carlson, G.C. and G. Reicks. 2019. Estimating corn yields. Chapter 38 in iGrow Corn. D. Clay, G. Carlson, S. Clay and E. Byamukama, eds. South Dakota State University, Brookings, SD.

Conservation Technology Information Center (CTIC). 2017. Report of the 2016-17 National Cover Crop Survey. Joint publication of the Conservation Technology Information Center, the North Central Region Sustainable Agriculture Research and Education Program, and the American Seed Trade Association. West Lafayette, IN.

Costa, S.E.V.G.A., E.D. Souza, I. Anghinoni, P.C.F. Carvalho, A.P. Martins, T.R. Kunrath, D. Cecagno, F. Balerini. 2014. Impact of an integrated no-till crop-livestock system on phosphorus distribution, availability and stock. Agr. Ecosyst. Envir. 190:43-51.

Faust, D.R., S. Kumar, D.W. Archer, J.R. Hendrickson, S.L. Kronberg, and M.A. Liebig. 2018. Integrated crop-livestock systems and water quality in the Northern Great Plains: Review of current practices and future research needs. J. Environ. Qual. 47:1-15.

Fraase, A.R. 2012. Utilizing annual forages in a single and dual crop system for late-season grazing in southcentral North Dakota. Master's Thesis. North Dakota State University, Fargo, ND.

Franzen, D.W. 2022. Soil fertility recommendations for corn. Accessed Feb 28, 2023. https://www.ndsu.edu/agriculture/extension/publications/soil-fertility-recommendations-corn

Franzluebbers, A.J. and J.A. Stuedemann. 2015. Does grazing of cover crops impact biologically active soil carbon and nitrogen fractions under inversion or no tillage management? J. Soil Water Conserv. 70:365-373.

Korb, N., C. Jones, and J. Jacobsen. 2005. Potassium cycling, testing and fertilizer recommendations. 4449-5. Accessed March 3, 2023. https://apps.msuextension.org/publications/pub.html?sku=4449-5

Keena, M., M. Meehan, and T. Scherer. 2022. Nitrogen behavior in the environment. NM1299. Accessed March 3, 2023. https://www.ndsu.edu/agriculture/extension/publications/nitrogen-behavior-environment#:~:text=Plants'%20Nitrogen%20Uptake,-Animal%20manures%20and&text=Although%20nitrogen%20can%20be%20added,they%20are%20available%20to%20plants.

Meehan, M., and K.K. Sedivec. 2017. NDSU Extension range and forage production. R1838. Accessed Feb. 11, 2022. https://www.ag.ndsu.edu/publications/environment-natural-resources/ndsu-extension-range-and-forage-production-sample-kits

Meehan, M., K.K. Sedivec, J. Printz, and F. Brummer. 2018. Determining carrying capacity and stocking rates for range and pasture in North Dakota. R1810. Accessed Feb. 9, 2022. https://www.ag.ndsu.edu/publications/livestock/determining-carrying-capacity-and-stocking-rates-for-range-and-pasture-in-north-dakota/r1810.pdf

Mikha, M.M. and C.W. Rice. 2004. Tillage and manure effects on soil and aggregate-associated carbon and nitrogen. Soil Science Society of America Journal. 68(3):809-816.

Nathan M.V. and R. Gelderman. 2015. Recommended chemical soil test procedures for the North Central Region. No. 1001. Missouri Agriculture Experiment Station, University of Missouri, Columbia, MO.

National Research Council. 2016. Nutrient requirements of beef cattle. 8th rev. ed. The National Academies Press, Washington, DC.

National Weather Service. 2023. Accessed March 1, 2023. https://w2.weather.gov/climate

North Dakota Agricultural Weather Network. 2023. North Dakota State University, Fargo, ND. Accessed March 1, 2023. www.ag.ndsu.edu

Reynolds, W.D. and D.E. Elrick. 1990. Ponded infiltration from a single ring: I. Analysis of steady flow. Soil Science Society of America Journal. 54:1233-1241.

Six, J., E.T. Elliott, K. Paustian, and J.W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Science Society of America Journal. 62(5):1367-1377.

USDA. 2019. 2017 Census of Agriculture – United States data. USDA. National Agriculture Statistics Service. Washington, D.C.

USDA-FSA. 2021. Crop acreage data. Accessed December 30, 2021. https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index.

van Es, H.M. and R.R. Schindelbeck. 2003. Field procedures and data analysis for the Cornell sprinkle infiltrometer. Dept. of Crop and Soil Sciences Research Series R03-01, Cornell University, Ithaca, NY.

Vendrell, P.F. and J. Zupancic. 2008. Determination of soil nitrate by transnitration of salicylic acid. Communications in Soil Science and Plant Analysis. 21. 13-16 (1990):1705-1713.

Wagner, J.J., K.S. Lusby, J.W. Oltjen, J. Rakestraw, R.P. Wettermann, and L.E. Walters. 1988. Carcass composition in mature Hereford cows: Estimation and effect on daily metabolizable energy requirement during winter. Anim. Sci. J. 66:603-612.

Wallander, S., D. Smith, M. Bowman, and R. Claassen. 2021. Cover crop trends, programs, and practices in the United States. EIB 222. U.S. Department of Agriculture, Economic Research Service. Washington, D.C.

Table 1. Average monthly precipitation and seasonal totals (inches) by month and year as compared to normal (30-year average) at each project location during 2020-2022.

		Rainfall (inches) by Month						
Location	Year	May	June	July	Aug	Sep	Oct	Seasonal Total
Fargo[1]	2020	1.5	2.6	5.3	4.8	0.9	0.9	16.0
	2021	0.4	3.5	0.7	3	3.3	2.7	13.6
	2022	3.4	2.7	3.8	2.7	0.5	0.3	13.4
	Normal	2.8	3.9	2.8	2.6	2.6	2.2	16.9
Jamestown[2]	2020	2.2	0.4	3.5	2.4	0.2	0.4	9.1
	2021	1.8	2.5	0.2	1.8	2.5	5.1	13.9
	2022	4.0	2.6	1.3	1.1	0.7	0.1	9.8
	Normal	2.7	3.5	3.3	2.1	2.3	1.7	15.6
Lehr[1]	2020	1.7	1.6	3.1	2.9	0.7	0.2	10.2
	2021	3.4	1.5	1.6	6.8	3.5	4.5	21.3
	2022	3.8	3.7	1.7	0.5	0.5	0.2	10.4
	Normal	2.6	3	2.7	2	1.3	1.6	13.2
McClusky[2]	2020	1	2	2.4	3.8	0.2	0.4	9.8
	2021	1.9	2.8	1.2	2.2	1.3	4.2	13.6
	2022	1.8	2.1	2.2	1.5	0.9	0.9	9.4
	Normal	2.4	3.2	2.6	2.1	1.6	1.4	13.3
McKenzie[2]	2020	0.7	0.9	3.5	0.7	0.5	0.5	6.8
	2021	1.3	1.6	1.6	1.1	1.1	3.4	10.1
	2022	2.0	1.2	3.8	1.2	1.0	0.5	9.7
	Normal	2.4	3.2	2.9	2.3	1.6	1.3	13.7
Tappen[1]	2020	1.5	2.4	2.3	4	0.3	0.2	10.7
	2021	2.2	5.1	0.6	3.2	2.5	4.1	17.7
	2022	4.0	2.3	1.7	1.3	1.0	0.6	10.9
	Normal	2.6	3.2	3.2	2.2	2	1.5	14.7

[1] Data obtained from or near specific locations affiliated with the North Dakota Agricultural Weather Network (2023).
[2] Data obtained from or near specific locations affiliated with the National Weather Service (2023).

Table 2. Average forage production (lb/ac), carrying capacity (AUMs/ac) and degree of use (%) by treatment and location during 2020 and 2021.

		2020					2021				
Location	Treatment	Forage Production (lb/ac)	Standard Deviation	Carrying Capacity (AUMs/ac)	Degree of Use (%)	Standard Deviation	Forage Production (lb/ac)	Standard Deviation	Carrying Capacity (AUMs/ac)	Degree of Use (%)	Standard Deviation
	No grazing	3,914	1,781				6,065	1,281			
Fargo	50%	5,916	647	1.7	53	11	7,599	1,390	1.9	57	4
	75%	5,960	1,522	2.4	70	8	8,250	1,138	3.0	75	2
	No grazing	8,049	1,531				3,590	346			
Jamestown	50%	7,181	1,366	2	44[1]	5	8,049	1,531	1.7	54	2
	75%	8,049	1,531	2.7	51[1]	0.6	4,019	712	2.1	69	3
	No grazing	14,437	5,686				4,903	2,266			
Lehr	50%	12,725	3,433	3.7	53	14	5,015	2,038	1.4	50	3
	75%	11,017	2,710	4.5	61	6	4,381	2,364	1.8	49[1]	13
	No grazing	6,375	1,402				4,005	1,905			
McClusky	50%	7,164	1,129	2.1	33	8	5,258	2,342	1.4	58	3
	75%	6,893[2]	1,966	1.0	44[1]	2	6,874	1,723	0.9	63	2
	No grazing	8,079	918				4,361	783			
McKenzie	50%	9,333	3,811	2.7	60	8	2,392	652	0.7	51	5
	75%	7,714	2,374	3.2	71	1	3,17 7	1466	1.3	72	6
	No grazing	6,444	1,202				2,686[3]	721			
Tappen	50%	10,536	2009	3.0	43[1]	4	4,228[3]	506	0.5	49	7
	75%	8,782	2,204	3.6	72[1]	6	3,485[3]	449	0.6	75	10

[1]Livestock pulled early due to inclement weather, limited feed or water.
[2]Forage production consisted of 65% weeds. Stocking rate was adjusted accordingly.
[3]Forage production consisted of 60% weeds. Stocking rate was adjusted accordingly.

Table 3. Type of cattle, average change in body condition score (BCS) and number (#) of grazing days by treatment and location during 2020 and 2021.

		2020			2021		
Location	Treatment	Type of Cattle	Change in BCS	# of Grazing Days	Type of Cattle	Change in BCS	# of Grazing Days
Fargo	50%	Pairs	0.5	20	Pairs	0	22
	75%		0.5	27		-0.5	30
Jamestown	50%	Pairs and heifers	0	33[1]	Pairs	0.5	46
	75%		-0.5	33[1]		0	61
Lehr	50%	Fall calving cows	0.5	64	Heifers	0	45
	75%		0	62		0	54[1]
McClusky	50%	Pairs	0.5	24[2]	Pairs	0.5	20
	75%		0	24[1]		0	25
McKenzie	50%	Heifers	0	36	Heifers	0	13
	75%		0	41		0	17
Tappen	50%	Pairs and heifers	NA	18[1]	Pairs	0	9[3]
	75%		NA	18[1]		0.5	16[3]

[1]Livestock pulled from grazing trial early due to inclement weather, limited feed, or water.
[2]Forage production consisted of 65% weeds. Stocking rate adjusted accordingly.
[3]Forage production consisted of 60% weeds. Stocking rate adjusted accordingly.

Table 4. Soil physical properties of bulk density (Bd), infiltration and aggregate stability (AS) at 0-6" by treatment and location within a similar soil ecological type during 2020 and 2022.

			Soil Nutrient Levels (ppm)					
			2020			2022		
Location	Soil Ecological Type	Treatment	Bd	Infiltration	AS	Bd	Infiltration	AS
Fargo	Clayey subsoil	Traditional	1.02	0.15	66.8	0.85	2.03	64.1
		No grazing	1	1.61	69.4	0.96	1.15	62.7
		50%	1	1.61	69.4	0.94	1.66	67.4
		75%	1	1.61	69.4	0.9	1	69.9
Jamestown	Loam	Traditional	1.13	2.35	41.1	1.12	2.92	32.2
		No grazing	1.21	2.20	38.8	1.25	0.96	35.7
		50%	1.21	2.20	38.8	1.21	0.51	32.3
		75%	1.21	2.20	38.8	1.32	0.9	25.3
Lehr	Loam	Traditional	1.28	1.10	23.8	1.2	3.23	26.5
		No grazing	1.18	4.35	37.5	1	1.9	44.7
		50%	1.18	4.35	37.5	1.25	2.19	29.9
		75%	1.18	4.35	37.5	1.31	0.77	25.3
McClusky	Loam	Traditional	1.07	6.90	49.3	0.99	1.49	51
		No grazing	1.19	2.96	53.5	1.26	0.93	29.7
		50%	1.19	2.96	53.5	1.14	0.88	41.5
		75%	1.19	2.96	53.5	1.04	1.94	41
McKenzie	Loam	Traditional	1.31	1.91	20.6	1.29	0.45	18.8
		No grazing[1]	1.32	2.22	36.7	1.22	4.32	33.6
		50%	1.32	2.22	36.7	1.31	2.62	33.8
		75%	1.32	2.22	36.7	1.3	1.27	30.7
Tappen	Very droughty loam	Traditional	1.23	1.36	33.1	1.2	0.23	29.5
		No grazing	1.21	3.97	30.2	1.22	2.01	29.4
		50%[2]	1.21	3.97	30.2	1.31	0.46	29.5
		75%[2]	1.21	3.97	30.2	1.3	0.88	25.5

Table 5. Soil nitrogen (NO_3-N), phosphorus (P), potassium (K), and soil organic matter (SOM) levels at 0-6" by treatment and location within a similar soil ecological type during 2020 and 2022.

			Soil Nutrient Levels							
			2020				2022			
Location	Soil Ecological Type	Treatment	NO_3-N (ppm)	P (ppm)	K (ppm)	SOM (%)	NO_3-N (ppm)	P (ppm)	K (ppm)	SOM (%)
Fargo	Clayey subsoil	Traditional	31	25	384	5.5	8.8	19	582	7.2
		No grazing	4.0	6.7	377	4.9	4.5	5.7	450	6
		50%	3.5	7.5	295	5.7	3.6	12	467	7.2
		75%	3.4	9.8	328	4.9	3.2	11	481	6.4
Jamestown	Loam	Traditional	6	24	290	4.0	3.3	34	329	3.9
		No grazing	2.3	17	224	3.9	4.7	19	345	4.3
		50%	3.8	20.4	244	3.4	4.3	22	401	3.7
		75%	2.6	20.6	263	3.5	3.9	25	377	3.6
Lehr	Loam	Traditional	6.9	4	203	3.1	3.5	3.7	176	3.2
		No grazing	3.9	4.4	298	4.5	4.3	4.6	309	4.9
		50%	10	8	248	4.1	4.8	6.3	376	4.1
		75%	3.0	4.3	236	4.5	3.5	3.3	214	4.4
McClusky	Loam	Traditional	11	11	328	3.9	5.3	18	511	4.7
		No grazing	12	12	593	3.9	5.8	12	490	5.9
		50%	17	10	496	4.2	5	10	666	4.6
		75%	17	8.7	360	4.1	3.5	12	481	4.8
McKenzie	Loam	Traditional	7.7	2.8	124	2.4	3.2	3.8	108	2.6
		No grazing[1]	3.1	5.3	272	3.1	3.4	5.0	319	3.7
		50%	11	5.6	220	2.6	2.3	3.4	236	2.4
		75%	6.1	4.4	189	2.6	2.4	2.7	209	2.5
Tappen	Very droughty loam	Traditional	5.8	15	348	3.1	7.4	34	566	2.9
		No grazing	7.9	16	295	4.7	6.9	14	475	4.3
		50%[2]	13	17	242	5.2	9.8	76	598	4.9
		75%[2]	11	3.4	228	3.6	6.8	5.2	457	3.8

[1]Cattle broke into control during final week of grazing in 2020.
[2]Grazing activity was limited due to issues with water toxicity in 2020 and forage production/quality in 2021.

Table 6. Average corn biomass (lb/ac) and corn yield (bu/ac) by treatment and location during 2022.

Location[1]	Treatment	Corn Biomass (lb/ac)	Standard Deviation	Corn Yield (bu/ac)	Standard Deviation
	No grazing	6,790	2,299	91	25
Fargo	50%	10,145	1,325	129	22
	75%	11,045	1,709	131	25
	No grazing	6,820	345	71	17
Jamestown	50%	6,402	1,309	63	23
	75%	10,045	2,299	130	26
	No grazing	7,515	1,770		
Lehr	50%	11,829	4,578	NA	NA
	75%	11,010	1,155		
	No grazing	8,818	950	94	18
McClusky	50%	8,192	1,893	111	21
	75%	7,396	1,414	88	18
	No grazing[2]	10,274	3,120		
McKenzie	50%	10,660	1,685	NA	NA
	75%	11,815	1,586		
	No grazing	7,902	3,173	88	26
Tappen	50%[3]	6,302	503	100	18
	75%[3]	6,699	70	75	16

[1]Fargo, Jamestown, and McClusky were planted to a grain variety corn; Lehr and McKenzie were planted to a silage variety corn; and Tappen was planted to a dual-purpose corn.
[2]Cattle broke into control during final week of grazing in 2020.
[3]Grazing activity was limited due to issues with water toxicity in 2020 and forage production/quality in 2021.

Enhancing Profitability of Soybean Production and Soil Health through Livestock Integration

Joshua Wianecki[1], Miranda Meehan[2], Kevin Sedivec[1,3], Erin Gaugler[3], Zachary Carlson[2], Colin Tobin[4], Michael Ostlie[4]

[1]Department of Natural Resource Management, North Dakota State University, Fargo, N.D.
[2]Department of Animal Sciences, North Dakota State University, Fargo, N.D.
[3]Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D.
[4]Carrington Research Extension Center, North Dakota State University, Carrington, N.D.

Summary

This ongoing study aims to enhance the profitability of soybean production and soil health through integrated crop livestock systems. The focus of this study is to evaluate the impacts of winter rye management using grazing livestock on crop production, soil health (physical, chemical and biological properties), livestock production and economic sustainability of soybean production. Specifically, the influence of dual grazing (fall and spring), spring grazing and no grazing of winter rye on: 1) soil physical, chemical and biological properties, 2) soil erosion risk, 3) soybean production, 4) livestock production and 5) economic outcome.

Introduction

North Dakota adoption of cover crops has greatly increased in recent years. From 2012 to 2017, North Dakota increased cover crop acreage by 89%, up 190,457 acres to 404,267 acres; while the national acreage had a 49.7% increase, up 5,109,881 acres to 15,390,674 acres (USDA-NASS, 2019). While producers are utilizing cover crops for soil health, integrated crop livestock systems (ICLS) offer additional methods for diversification and enhancement of cover crop benefits.

The grazing component of an ICLS can increase nutrient cycling, suppress weed populations, and offer reduced inputs and feed costs for livestock. Fall season cover crops provide advantages in increased forage quality (Coblentz et al., 2020), increased nutrient cycling of nitrogen (N), soil organic carbon (SOC) (Liebig et al., 2012), and potassium (K) (Assmann et al., 2014). The increase in organic matter and SOC can also stabilize soil structures by promoting macro-aggregate formation (Bronick & Lal, 2005). Some potential disadvantages of an ICLS include near-surface soil compaction; however, in regions that undergo an annual freeze-thaw cycle, this risk is reduced, if not eliminated (Liebig et al., 2012). Although dual season grazing is utilized in other regions, the variability of harvest timing and fall planting, as well as less predictable fall weather makes dual season cover crop grazing questionably feasible in North Dakota. This trial aims to determine management techniques that can add to the production and profitability of integrated crop livestock systems.

Procedure

In the fall of 2022, a two-year project was established. Two locations were selected in central North Dakota, at the NDSU Central Grasslands Research Extension Center (CGREC) located 7 miles northwest of Streeter, N. D. and the NDSU Carrington Research Extension Center

(CREC), located four miles north of Carrington, N. D. At each location, a winter rye (*Secale cereale*) crop was established and subjected to three treatments: 1) fall and spring (dual) grazing, spring grazing, no grazing. Additionally, a no rye or grazing treatment was evaluated. Each location consisted of nine main plots, with three plots of each treatment (dual graze, spring graze, and no graze) randomly selected. The no graze plots were split to create no graze rye and no rye; for a total of 12 plots.

Following the 2022 summer small grain crop [German millet (*Setaria italica*) at CGREC and wheat (*Triticum aestivum*) at CREC], winter rye 'ND Gardner' was no-till drilled at a rate of 60 lbs/acre on 9/8/2022 at both locations. Seeding depth was set to 1.25 inches and row spacing at 7.5 inches. Prior to applying fall grazing treatments, high tension electric fencing was constructed around each plot. Water troughs were provided for each grazing treatment. Cattle were turned out for the fall grazing treatments on 10/19/2022 CGREC and 11/1/2022 at CREC.

Soybeans will be planted following the grazing treatments and termination of the winter rye cover crop in the spring of 2023. Soybean production will be measured by stand counts and yield data after harvest. Weed species and density will also be evaluated along with other physiological responses within each plot. To simulate a cash crop rotation, corn (*Zea mays*) will be planted in 2024 following a 2023 winter cereal cover crop planting.

Pre-grazing soil samples were collected after small grain harvest and preemergence of winter rye for baseline data. Soil samples will also be collected each spring prior to establishment of the cash crop. In-field sampling locations were stratified within the same soil series as according to the USDA-NRCS Soil Web Survey (2022) to reduce sample variability.

Soil nutrient analysis samples were collected at depths of 0-15 centimeters and 15-30 centimeters using a 15-inch AMS soil probe for each replicated plot. Each replicate was sampled a total of four times and composited, with a subsample for each depth collected. Samples were placed on ice and delivered to AgVise laboratories (Northwood, ND). Analyses of organic matter (OM), nitrogen (N), nitrate (NO_3), potassium (K), phosphorous (P) and pH were conducted using recommended chemical soil testing procedures for the North Central Region (Nathan and Gelderman, 2015). Soil total carbon (TC), organic carbon (SOC) and inorganic carbon (SIC) were determined by gas chromatography (Nelson and Sommers, 1996). Soil carbonates (CCE) was analyzed by pressure calcimeter (Sherrod et al., 2002).

Soil biological samples of arbuscular mycorrhizal fungi (AMF) hyphae length, and soil microbial biomass carbon (MBC) were collected at a depth of 15 centimeters using a 15-inch AMS soil probe for each replicate. Each replicate was sampled four times and composited with a subsample collected. Soil biological samples were placed on ice and frozen before analysis via soil fumigation and microscopy.

Bulk density was collected and measured using soil core sampler with slide hammer attachment at depths of 0-3 cm and 5-8 cm. Bulk density was calculated by dividing the weight of oven-dried soil by a standard volume. Soil aggregate stability was collected at a depth of 0-15 centimeters with a tiling spade. Complete soil slices were placed on ice and sent to AgVise Laboratories (Northwood, ND) for analysis. Aggregate stability was determined with an automated slake wet sieving method derived from Six et. al (1998) and utilized sand correction as outlined by Mikah and Rice (2004). Water infiltration was determined with a Cornell sprinkle infiltrometer (van Es & Schindelbeck, 2003). This system simulates a natural rainfall event within a 9.5-inch ring, and the time required for soil to reach field saturation and run-off is measured to determine field-saturated infiltrability.

Forage samples were collected before turn-out. Three 0.25 m^2 frames were randomly placed throughout each plot and all rye was clipped to ground level. Each sample was oven dried for 48 hours and dry weights were subtracted from wet weights to determine dry matter content. Forage production was calculated from forage dry weights and clipping area. Forage quality samples were taken pre-grazing and sent to the NDSU Nutrition lab for analysis of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and *in vitro* dry matter digestibility (IVDMD).

Animal performance was measured by two-day weights pre and post grazing. Visual body condition scoring (BCS) is conducted pre- and post-spring-grazing; BCS was omitted for fall grazing due to the short grazing period. Cattle used for fall grazing were groups of bred heifers that were weighed before being assigned to a grazing treatment. Grazing durations were based on predetermined carrying capacity and visual monitoring during the grazing period. Post grazing utilization rates were determined by clipping after cattle were removed from the plots and compared to the forage quantity within the no graze plots.

Project Update

Weather at CGREC and CREC was abnormally dry in 2022 and extended into a moderate drought during establishment of the winter rye cover crop (Table 1). This moisture deficit delayed germination and lead to low biomass of the winter rye stand. Stands between locations varied, with CREC experiencing inconsistent, but higher yields (Table 2). Variation in soils, field management and history could lead to these variations, as well as differences in weather conditions throughout the establishment period.

Table 1. Mean monthly temperature and rainfall at CGREC and CREC in 2022.

		Temperature		Rainfall	
		Monthly Mean[1] (°F)	30-Year Average[2] (°F)	Monthly Total[1] (inches)	30-Year Average[2] (inches)
CGREC	July	71	69	1.28	3.35
	Aug	69	67	1.41	2.38
	Sept	61	58	0.96	2.09
	Oct	46	44	0.16	1.6
	Nov	23	29	--	0.59
CREC	July	70	69	1.46	3.60
	Aug	68	67	1.23	2.33
	Sept	60	58	0.62	1.97
	Oct	46	43	0.15	1.9
	Nov	22	27	--	0.67

[1] Obtained from North Dakota Agricultural Weather Network (2022).
[2] 30-year average is based off North Dakota Agricultural Weather Network data from 1992 to 2022.

All baseline soil samples were collected prior to electric fence construction and cattle turn-out. Aggregate stability, chemical analysis, and microbial organic carbon analyses have been completed, with bulk density, water infiltration and arbuscular mycorrhizal fungi hyphal length pending results. Baseline data was not included in this report, as the results are not influenced by the treatments.

Forage production and carrying capacity was determined before turning cattle out for the fall grazing period. While carrying capacities were calculated, visual monitoring was also used to determine forage utilization as crop residues were not included in estimations. Forage utilization differed greatly between locations. Plots at CGREC averaged 0% utilization and CREC averaged 46.7% utilization (Table 2). Both locations suffered from inconsistency in plot biomass both pre- and post-grazing, which will require a larger number of samples taken in the future to account for possible variation. CGREC also retained a higher amount of crop residue from the prior crop, which supplemented the winter rye and may have deterred cattle from consuming a shorter growing forage within the plot. Visual inspection of grazed plots saw increased manure deposits near remnants of harvested hay swaths at CGREC. While rye stands at CREC tended to be higher, the grazing period was shorter due to cattle escaping the dual graze plots. Forage nutritive value was determined from pre-grazing samples. Clipped rye samples were sent to the NDSU Animal Nutrition Lab for analysis of NDF, ADF, CP, and IVDMD.

Table 2. Forage yield of winter rye and cattle performance by treatment at CGREC and CREC in 2022.

	Treatment	Average Dry Matter (Pre-graze)	Estimated Forage Yield (lb/ac)	Average Estimated Utilization	Days Grazed	Average Animal Gain (lb)
CGREC	Dual Graze	58.7	156.1	0%	5	-13.75
	Spring Graze	52.9	119	--	0	--
	No Graze	51.1	100.8	--	0	--
CREC	Dual Graze	46	197.9	47%	3[1]	-14.12
	Spring Graze	47.9	259.5	--	0	--
	No Graze	35.3	208.47	--	0	--

[1]Cattle escaped plot, ending grazing period.

Due to the shortened grazing period, BCS was not measured on grazing cattle. Cattle weights were taken two consecutive days prior to turnout, and again after being taken off pasture. While weights are across two days, weights can still fluctuate based on gut-fill and other factors. At CGREC each plot contained four head of bred heifers for a total of twelve heifers grazing the fall season. The average weight of the heifers was 987 pounds before turnout and 973 pounds post-grazing, averaging a loss of 13.75 pounds. At CREC each plot contained five head of bred heifers for a total of fifteen heifers grazing the fall season. The average weight of the heifers was

1,195 pounds before turnout and 1,181 pounds post-grazing resulting in an average loss of 14.12 pounds.

Future Work

Before grazing in spring 2023, field cover will be estimated with twelve $0.25m^2$ quadrants per plot as a measure of soil erosion prevention. Forage samples will also be clipped to determine forage yield and carrying capacity of each plot. Dual graze and spring grazing plots will have forage samples analyzed at the NDSU Animal Nutrition Lab to determine forage quality. Post-grazing, livestock performance will be evaluated by weight gain and visual body condition score. Soil samples will be taken post-grazing for chemical, physical, and biological soil properties.

Following sampling, soybeans will be seeded into each plot. Soybean performance will be evaluated through stand counts and harvest yield data. Other plant physiological responses such as height, maturity, seed quality, and normalized difference vegetation index (NDVI) will be evaluated. Weed species and density will be determined for anti-weed effects of both cover crop and grazing.

Economic analyses will be used to determine cost/revenue change throughout each cover crop management practice. Practices will be evaluated against baseline practices, no grazing and no rye treatments, for potential financial benefits and pay-off of ICLS within livestock and soybean production.

Literature Cited

Assmann, T. S., de Bortolli, M. A., Assmann, A. L., Soares, A. B., Pitta, C. S. R., Franzluebbers, A. J., Glienke, C. L., & Assmann, J. M. (2014). Does cattle grazing of dual-purpose wheat accelerate the rate of stubble decomposition and nutrients released? *Agriculture, Ecosystems & Environment*, *190*, 37–42. https://doi.org/10.1016/j.agee.2014.01.011

Bronick, C. J., & Lal, R. (2005). Soil structure and management: a review. *Geoderma*, *124*(1–2), 3–22. https://doi.org/10.1016/J.GEODERMA.2004.03.005

Coblentz, W. K., Akins, M. S., & Cavadini, J. S. (2020). Fall dry matter yield and nutritive value of winter rye, wheat, and triticale cultivars in Wisconsin. *Crop, Forage & Turfgrass Management*, *6*(1), e20075. https://doi.org/10.1002/cft2.20075

Liebig, M. A., Tanaka, D. L., Kronberg, S. L., Scholljegerdes, E. J., & Karn, J. F. (2012). Integrated crops and livestock in central North Dakota, USA: Agroecosystem management to buffer soil change. *Renewable Agriculture and Food Systems*, *27*(2), 115–124. https://doi.org/10.1017/S1742170511000172

Mikha, M. M. and C. W. Rice. (2004). Tillage and manure effects on soil and aggregate associated carbon and nitrogen. *Soil Science Society of America Journal. 68*(3):809-816.

Nathan, M. V. and R. Gelderman. (2015). Recommended chemical soil test procedures for the North Central Region. No. 1001. Missouri Agriculture Experiment Station, University of Missouri, Columbia, MO.

Nelson, D. W., and L. E. Sommers. (1996) Chapter 34: Total Carbon, Organic Carbon, and Organic Matter. In Sparks D. L., Page A. L., Helmke P. A., Loeppert R. H., Soltanpour P. N., Tabatabai M. A., Johnston C. T., Summer M. E. (eds.) Methods of Soil Analysis Part 3: Chemical Analysis. American Society of Agronomy and Soil Science Society of America. Madison, WI. p. 961-1010

North Dakota Agricultural Weather Network. (2021). North Dakota State University, Fargo, ND. Accessed February 17, 2022. https://ndawn.ndsu.nodak.edu

Sherrod, L. A., Dunn, G., Peterson, G. A., & Kolberg, R. L. (2002). Inorganic carbon analysis by modified pressure-calcimeter method. *Soil Science Society of America Journal*, *66*(1), 299–305. https://doi.org/10.2136/SSSAJ2002.2990

Six, J., Elliott, E. T., Paustian, K., & Doran, J. W. (1998). Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Science Society of America Journal*, *62*(5), 1367–1377. https://doi.org/10.2136/SSSAJ1998.03615995006200050032X

USDA - Natural Resources Conservation Service, United States Department of Agriculture. (2022). Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed 12/20/2022.

USDA. (2019). 2017 Census of Agriculture – United States data. USDA. National Agriculture Statistics Service. Washington, D.C.

van Es, H. M. and R. R. Schindelbeck. (2003). Field procedures and data analysis for the Cornell sprinkle infiltrometer. Dept. of Crop and Soil Sciences Research Series R03-01, Cornell University, Ithaca, NY.

Reducing Kentucky Bluegrass Thatch and Litter Promotes Native Plant Biodiversity

Esben L. Kjaer[1], Torre J. Hovick[1], Kevin K. Sedivec[1,2]

[1]School of Natural Resource Sciences, North Dakota State University, Fargo, ND, USA
[2]Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND, USA

Summary

Invasive cool-season grasses reduce rangeland diversity and homogenize ecosystems, creating novel ecosystems. In the northern Great Plains, Kentucky bluegrass (hereafter: bluegrass) creates novel agro-ecosystems through the development of a pseudo-O horizon, or thatch, on top of existing mineral soil. Bluegrass thatch is not historically present in the northern Great Plains and alters water and nutrient cycling, soil microbiota, soil-surface microclimate, and reduces native forb and grass abundance. Conventional management of invasive cool-season grasses is often broad (i.e. fire, targeted grazing, or herbicide), focusing on reducing grass abundance, not the mechanisms that make bluegrass invasive. However, the effects of these all-purpose management strategies are often lost after a few years, demonstrating a need for new management that aims to reduce or eliminate the mechanisms that allow for the expansion of invasive cool-season grasses. One such strategy may be to target the mechanisms that promote bluegrass invasion, such as litter and thatch.

To better understand the mechanisms behind bluegrass invasion, we monitored the effect of targeted litter and thatch removal on bluegrass abundance and native plant abundance and diversity in south-central North Dakota. We established 18 plots and removed litter and thatch from nine using a rotary brush attached to a skid-steer and measured species composition, litter and thatch depth in each plot.

Over three years, Simpson's diversity was consistently higher and bluegrass abundance lower in removal plots than in non-removal plots. Additionally, native species abundance was higher in removal plots than non-removal plots; suggesting that reducing bluegrass thatch and litter initially reduces bluegrass abundance, allowing for native species to increase in abundance over several years. These results also demonstrate that management practices aimed at controlling the mechanisms promoting invasive cool-season grasses, such as bluegrass, in rangelands are effective over several years.

Introduction

Invasive species cause significant ecological and economic impacts worldwide, affecting both managed and native ecosystems (Pimentel et al., 2001). Invaders modify their ecosystem, altering ecosystem function and integrity (Gasch et al., 2020; McKinney and Lockwood, 1999). Once started, these changes are often irreversible through positive feedback cycles (Link et al., 2017; Palit et al., 2021). The rapid spread of invasive plants in North America has caused many native rangelands ecosystems to be dominated by invasive species (Toledo et al.,2014), reducing biodiversity (Limb et al. 2018), and ecosystem services (Estes et al., 2011; Nouwakpo et al., 2019). For example, Kentucky bluegrass (*Poa pratensis* L.; hereafter "bluegrass") increased in abundance from 1984 to 2007, accounting for up to 60% of all vegetative cover in North and South Dakota (DeKeyser et al., 2015), resulting in a decline in native plant diversity while altering community structure and function (Hendrickson et al., 2019; Toledo et al., 2014).

In North America, bluegrass occurs in every Canadian province and territory, and every state in the United States (USDA - NRCS, 2021). It is one of the most aggressive non-native grasses spreading across the Great Plains (Printz and Hendrickson, 2015; Samson and Knopf, 1994; Toledo et al., 2014). The success of bluegrass is owed primarily to the build-up of a novel thatch layer and accumulation of low lignin litter, but other mechanisms have been described (Hendrickson et al., 2021; Nouwakpo et al., 2019; Palit et al., 2021; Printz and Hendrickson, 2015). Both the thatch and litter layer created by bluegrass alter water and nutrient cycling, shade-out competing species, and suppress native seed recruitment and germination (Hendrickson et al., 2021; Nouwakpo et al., 2019; Printz & Hendrickson, 2015; Sanderson et al., 2017)

Over time, abundant litter accumulation compresses older litter into a novel thatch layer that is similar to an O-horizon in a soil profile, with unique biological and chemical properties (Gaussoin et al., 2013; Millar et al., 1966). O-horizons are not historically present in the prairies of the northern Great Plains (DeKeyser et al., 2015; Millar et al., 1966). Both the bluegrass thatch and litter layer alter water and nutrient cycling (primarily total N and soil organic C), shade out competing species, alter soil microbial communities, and suppress native seed recruitment and germination (Dornbusch et al., 2018; Hamilton III and Frank, 2001; Hendrickson et al., 2021; Nouwakpo et al., 2019; Printz and Hendrickson, 2015; Sanderson et al., 2017).

Bluegrass management in the northern Great Plains takes a top-down approach to management. Meaning that management of bluegrass is focused on controlling or reducing the aboveground biomass of bluegrass (Dornbusch et al., 2020; Ereth et al., 2017; Gasch et al., 2020). Typically, these broad management practices (fire, targeted grazing, herbicide, etc.) focus on treating the symptoms of bluegrass invasion (loss of diversity and community structure). While this works in the short term, changes from broad management practices are either quickly lost (Ereth et al., 2017) or slow to occur (Dornbusch et al., 2020). This loss of positive effects from management or slow changes from management may be the result of management efforts that do not target the main mechanism promoting bluegrass invasion: litter and thatch production. If management practices were targeted at the mechanisms that facilitate bluegrass invasion (such as litter and thatch accumulation), positive effects from management might occur more quickly and be more long-lasting.

Current management aimed at controlling or reducing the invasive species abundance is not optimal due to increases in both cost and time to properly implement. Additionally, current management efforts are either slow to implement (Dornbusch et al., 2020) or their effects are lost after a few years (Ereth et al. 2017). Conservation and restoration of native rangelands are extremely important to protect biodiversity, ecosystem multifunctionality and services, and economic interests. Thus, we manually removed live bluegrass, bluegrass thatch, and litter from nine plots in south-central North Dakota. We hypothesize that reductions in bluegrass and its thatch and litter will allow native plants to increase in abundance, replacing the bluegrass that is removed.

Methods

Site Description

This study took place at the North Dakota State University Central Grasslands Research Extension Center (CGREC) for three growing seasons (2020 - 2022). Our sites are located in the Missouri Coteau ecoregion, an area composed of rolling hills interspersed with small glacial lakes (USDA Soil Conservation Service, 1982). This area experiences a continental climate with average temperatures ranging from -0.4 ^{o} C to 11.5 ^{o} C during this study (NDAWN, 2023). Sites received a total of 233.55 mm of precipitation in 2020 (170.1 mm below 30-year average), 332.56 mm in 2021 (71.1 mm below 30-year average), and 342.77 mm in 2022 (60.9 mm below 30-year average: **Table 1**) (NDAWN, 2021).

Historically, the sites were comprised of northern mixed-grass prairies, which primarily consisted of cool-season grasses such as western wheatgrass (*Pascopyrum smithii*, [Rydb.] À. Löve.), and green needlegrass (*Nasella viridula*, [Trin] Barkworth), but also contained a mix of warm-season grasses (such as *Schizachyrium scoparium*, [Michx.] Nash), sedges (mostly *Carex* spp., rarely *Cyperus* spp.), and various forbs (such as *Artemisia* spp. and *Solidago* spp.) (Limb et al., 2018). However, deviations from historic grazing and fire regimes have allowed a native shrub, western snowberry (*Symphoricarpos occidentalis* Hook.), and bluegrass to dominate these sites.

Table 1: A table of environmental conditions at the Central Grasslands Research Extension Center (CGREC) from 2020 to 2022 as well as grazing intensity and duration.

Year	**Yearly High Temperature (^{o} C)**	**Yearly Low Temperature (^{o} C)**	**Rainfall (mm)**	**Grazing Days**	**Approximate Degree of Disappearance**
2020	34.01	-33.1	233.55	26	30.2%
2021	37.24	-35.65	332.56	48	54.2%
2022	35.28	-32.09	342.77	73	>60%

Experimental Design

In April 2020, we created 10- x 20-meter (m) plots using a split-plot design replicated nine times with two treatments (thatch/litter removal and control) in four 16-hectare (ha) paddocks (approx. 40 acres) that were invaded by bluegrass (**Figure 1**). The paddocks are a part of a larger modified twice-over rest-rotation grazing system that uses fencing and variable grazing duration to create landscape-level heterogeneity (see Duquette et al., 2022). Each year, the grazing duration that a paddock receives is rotated to create a shifting mosaic of vegetation structure. For this study, all plots were placed into paddocks that would receive the same grazing intensity within a given year. Plots were initially placed in paddocks that had been rested the previous year to not only reduce any effects from previous grazing events but to also maximize thatch and litter accumulation. Every year pastures were stocked with calf-cow pairs aimed at achieving a different level of utilization. The degree of disappearance was 30.2 percent in 2020, 54.2 percent in 2021, and >60 percent in 2022 (**Table 1).**

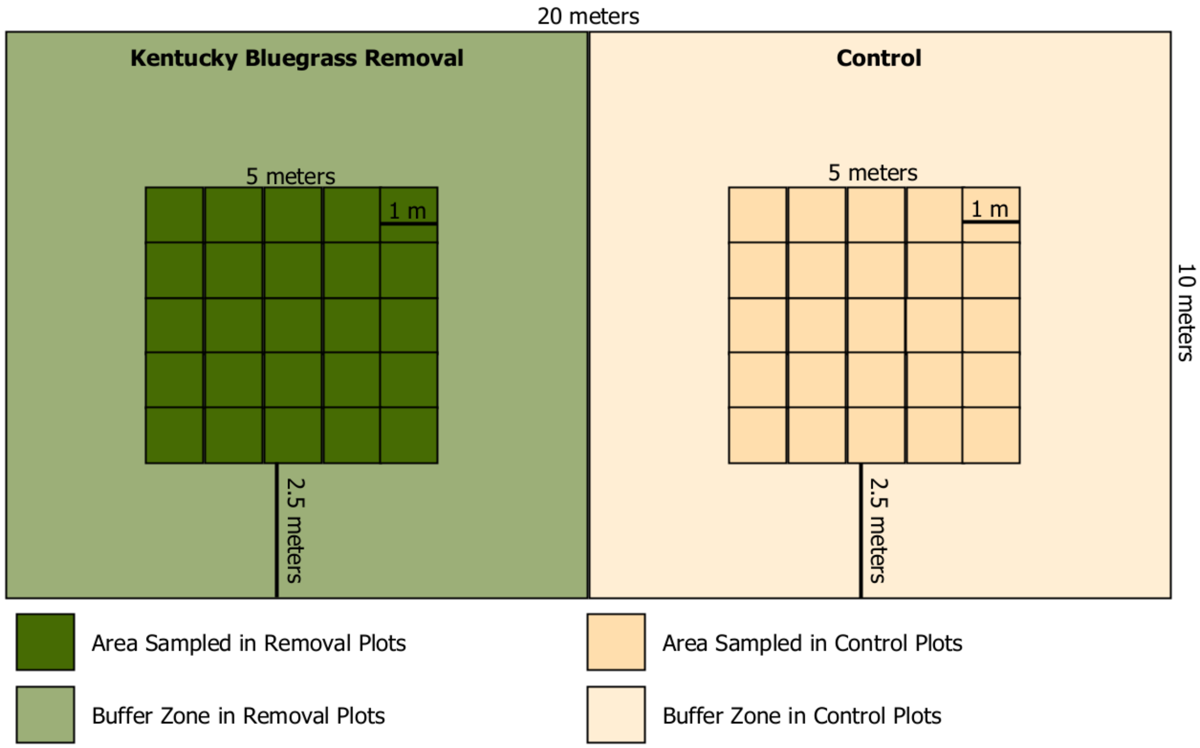


Figure 1: A hypothetical 10- x 20-m split plot. Each half is randomly assigned to either be a control (yellow) or removal plot (green). For vegetation sampling, a 5- x 5-m sub-plot divided into 25 one-meter squares is nested within each half.

We removed thatch and litter from one randomly selected side of each paired plot in May of 2020 using an 82-inch Titan Implement X-treme Skid-Steer Angle Broom Attachment connected to an SSV75 Kubota Skid-Steer (**Figure 2a**). Each plot was brushed until the root mat and mineral soil matrix was visible (**Figure 2b**). To minimize edge effects, both sides of each split-plot had a 5- x 5-m sub-plot placed in the center of them. Each sub-plot was then further divided into 25 one-meter squares. These sub-divisions would be used for vegetation sampling.

Figure 2a: An 82-inch Titan Implement X-treme Skid-Steer Angle Broom Attachment connected to an SSV75 Kubota Skid-Steer used to remove bluegrass thatch and litter from plots. Photo by Hayley Hilfer

Figure 2b: A split plot following litter and thatch removal. Litter and thatch removal plots (left) were brushed until the root-soil matrix was visible. Control plots (right) were unmanipulated. Photo by Hayley Hilfer

Data Collection

Every year during the first week of July, we recorded plant community composition in each sub-division by identifying every plant to species and then recording species abundance using modified Daubenmire cover classes (**Table 2**) (Daubenmire, 1959). All cover classes were converted to the mid-point for their respective ranges (**Table 2**). This meant that we collected data approximately one month, 12 months, and 24 months after litter and thatch removal. We also sampled litter depth and thatch depth at five randomly-chosen locations within the buffer zone between each 5- x 5-m sub-plot. We sampled thatch depth using a sod hole cutter with a 4.25-inch diameter to extract a thatch and soil profile sample 'puck'. Each 'puck' was removed from the sampler, placed on the ground and then the thatch present in each sample was measured as the distance from the aboveground standing dead and litter to the belowground root mass. (**Figure 3**). After data collection and midpoint calculation, species average abundance was calculated for each sub-plot by summing the abundance for a given species and dividing by 25.

Data analysis

We used R 4.2.2 to test for treatment effects on litter depth, thatch depth, bluegrass abundance, species richness, Simpson's diversity, and native forb, grass, and legume abundance using a generalized linear mixed-effect model (GLMM) (Bates and Davies, 2018; Fox, and Weisberg, 2019; R Core Team, 2022). GLMM was used because it allowed us to test both random (unintended) and fixed (intended) effects, while also controlling for non-normal data distributions. We used a Poisson distribution with an identity link to assess the interactive effects of treatment nested within time since removal on species richness. For all other GLMMs we analyzed the interactive effects of treatment nested within time since removal using a Gamma distribution with an inverse link function. The GLMM was then used to run Analysis of

Deviance – Wald Chi-square Test using the 'Anova' function from the *car* package (Fox, and Weisberg, 2019). We also used the 'emmeans' function from the *emmeans* package to further investigate how each response variable varied within time since removal (Lenth, 2020). Indicator Species Analyses (ISA) were used as a posthoc test to identify which species were driving differences between our treatments and increasing in both abundance and frequency in response to litter and thatch removal.

Table 2: Modified Daubenmire cover classes, their ranges and midpoints.

Cover Class	Cover Range	Midpoint
1	Trace - 1%	0.5
2	1% - 2%	1.5
3	2% - 5%	3.5
4	5% - 10%	7.5
5	10% - 20%	15
6	20% - 30%	25
7	30% - 40%	35
8	40% - 50%	45
9	50% - 60%	55
10	60% - 70%	65
11	70% - 80%	75
12	80% - 90%	85
13	90% - 95%	92.5
14	95% - 98%	96.5
15	98% - 99%	98.5
16	99% - 100%	99.5

Figure 3: A typical thatch depth sample. The area in between the blue and green line is considered thatch. Anything above the green line is aboveground plant material, below the blue line is the root mass and mineral soil.

Results

Species Richness and Simpson's Diversity

In all three years, plant species richness was consistently higher in removal plots than control plots, however, this difference was only significant 24 months after removal with control plots having average of 34.9 +/- 2.8 species and removal plots having an average of 48 +/- 3.4 species ($p < 0.001$; **Table 3)**. Richness also varied by time since removal, with average richness being highest 24 months post-removal and lowest 12 months post-removal (**Table 3**; **Figure 4a**). Similarly, removal plots were significantly more diverse than control plots in all years ($p_{2020} < 0.001$, $p_{2021} = 0.003$, $p_{2022} < 0.001$; **Table 3**; **Figure 4b**). Simpson's diversity one-month post-removal was 2.07 +/- 0.4 in control plots and 3.5 +/- 0.7 in removal plots. 12 months post-removal Simpson's diversity was 1.39 +/- 0.1 in control plots and 1.76 +/- 0.1 in removal plots.

Diversity 24 months after removal was 2.52 +/- 0.4 in control plots and 3.40 +/- 0.7 in removal plots.

Table 3: A table reporting, species richness, Simpson's Diversity, litter and thatch depth, Kentucky bluegrass, native forb, native grass, and native legume abundance in each treatment in each year of the study.

Months Since Removal	Treatment	Richness	Simpson's Diversity	Kentucky Bluegrass Abundance	Litter Depth (cm)	Thatch Depth (cm)	Native Forb Abund-ance	Native Grass Abund-ance	Native Legume Abund-ance
1	Control	30.4	2.07	59.3	11.19	3.12	11.33	5.48	2.25
1	Removal	33.7	3.49	42.9	3.07	2.49	16.47	10.28	4.05
12	Control	25.2	1.39	73.4	6.09	2.49	5.78	4.64	1.02
12	Removal	29.2	1.76	68.4	0.72	2.06	11.11	7.15	2.09
24	Control	34.9	2.52	56.2	1.36	2.5	12.27	5.83	3.67
24	Removal	48	3.4	45.3	0.32	1.28	15.48	10.37	4.27

Kentucky Bluegrass Abundance, Litter, and Thatch

Bluegrass abundance was consistently lower in removal plots than control plots (16.4%, 5%, and 10.9% lower one, 12, and 24 months post-removal, respectively; **Table 3**; **Figure 5a**); however, this difference was only significant one-month post-removal ($p = 0.005$) and marginally significant 24 months post-removal ($p = 0.060$). Litter and thatch depth were also consistently and significantly thinner in removal plots than control plots across all three years ($p_{LitterOneMonth} < 0.001$, $p_{ThatchOneMonth} = 0.007$, $p_{Litter12Months} < 0.001$, $p_{Thatch12Months} = 0.035$, $p_{Litter24Months} = 0.013$, $p_{Thatch24Months} < 0.001$; **Table 3**; **Figure 5b** and **5c**).

Native Plant Abundance

At all-time points, native forb, grass, and legume abundance were higher in removal plots than control plots (**Table 3**; **Figure 5d, 5e, and 5f**). Native forb abundance was 5.14 percent higher in removal plots than control plots one month after removal (a marginal difference, $p = 0.064$), 5.33 percent higher 12 months post-removal ($p = 0.017$), and 3.21 percent higher 24 months post-removal (though this difference was not significant, $p > 0.05$; **Table 3**; **Figure 5d**). Native grass abundance was 4.8 percent, 2.51 percent, and 4.54 percent higher one, 12, and 24 months post-removal, respectively ($p_1 = 0.002$, $p_{12} = 0.095$, $p_{24} = 0.025$; **Table 3**; **Figure 5e**). Similarly, native legume abundance was slightly higher in removal plots than control plots (**Table 3**; **Figure 5f**). Native legume abundance was 1.80, 1.08, and 0.60 percent higher in removal plots one, 12, and 24 months post-removal, respectively; however, this difference was only marginally significant in one- and 12-months post removal ($p_{2020} = 0.066$, $p_{2021} = 0.067$, $p_{2022} > 0.05$; **Table 3**; **Figure 5f**).

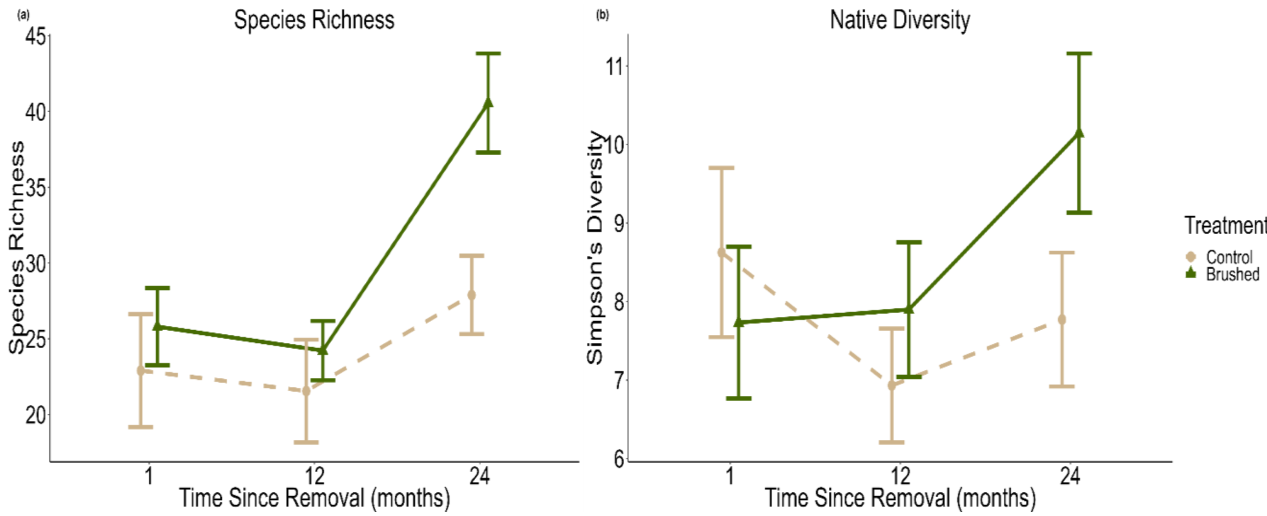


Figure 4: Average (a) species richness in each treatment across time, and (b) average Simpson's diversity over the course of the study. Plots that receive bluegrass litter and thatch removal are in green, while control plots are in tan. Error bars represent standard error.

Indicator Species Analysis

We used Indicator Species Analysis to determine which species were showing up most often and in greatest abundance in our different treatments during our different sampling periods. Control plots had eleven, five, and eight indicator species, one, 12, and 24 months post-removal (Table S1). On the other hand, removal plots had 23, 18, 34 indicator species at the same time periods (Table S1). There were a few species that repeatedly showed up as indicator species. For example, *Schizachyrium scoparium* was an indicator species for control plots at all time points, while *Pascopyrum smithii*, *Solidago missouriensis*, and *Symphyotrichum ericoides* were indicators for removal plots at all time points (Table S1). Ultimately, while the number of indicator species and their identities varied across time, removal plots consistently had more indicators species than control plots (Table S1).

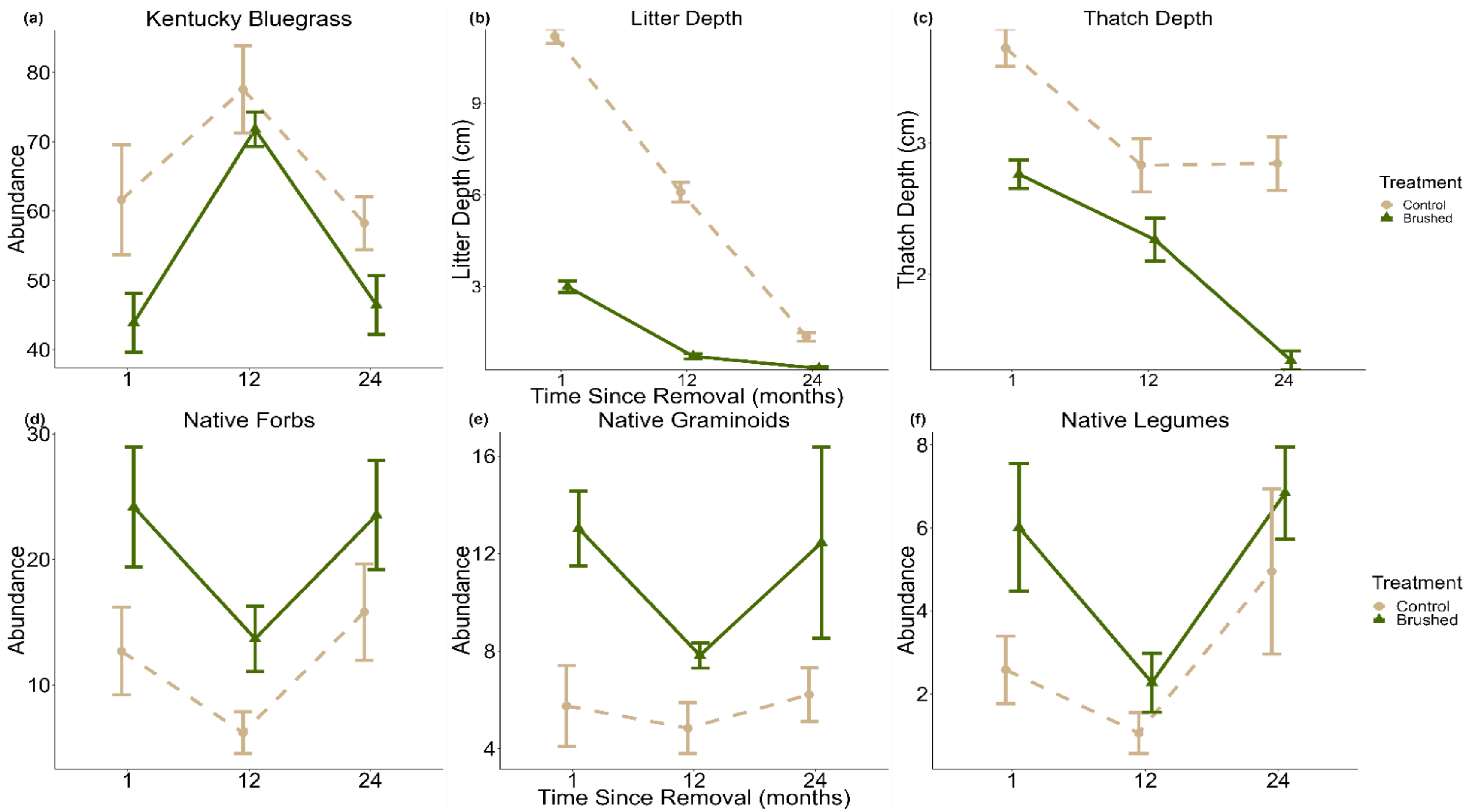


Figure 5: Average (a) Kentucky bluegrass abundance, (b) litter depth (cm), (c) thatch depth (cm), (d) native forb abundance, (e) native grass and grass-like abundance, (f) native legume abundance in control plots (tan) and removal/brushed plots (green). Error bars represent standard error

Discussion

Management efforts aimed at controlling bluegrass only treat the symptoms of invasion (loss of biodiversity and physical space occupied by bluegrass) and not the mechanisms behind invasion (litter and thatch accumulation), causing their benefits to be lost after a couple of years. This creates a need for management practices that target the mechanisms underlying bluegrass invasion. In a working landscape, we removed bluegrass thatch and litter from nine plots and monitored plant community composition and bluegrass thatch and litter abundance for three years. We found that targeting the mechanisms thought to be key to bluegrass invasion reduced bluegrass abundance for at least three years and promoted native plant growth.

Our findings are similar to other studies that have found that one-time control/mitigation efforts can promote biodiversity across multiple years (Adkins and Barnes, 2013; Bahm et al., 2011; Ereth et al., 2017). Specifically, in our study, bluegrass removal that reduced thatch and litter (thought to be the main drivers of bluegrass invasion, see Printz and Hendrickson, 2015) promoted native forb and legume abundance for 12 months and native grass abundance for at least 24 months following removal. This differs slightly from other studies that suggest that the effects of one-time bluegrass management are lost relatively quickly following management (Dornbusch et al., 2020), while meaningful differences in native plant and bluegrass abundance still exist between our treatments. This suggests that when the mechanisms underlying bluegrass are impaired, native plants increase in abundance to fill in the gaps created by bluegrass decline.

Our Indicator Species Analysis (ISA) also suggests that native plants are increasing in abundance to fill in those gaps created by litter and thatch removal. Removal plots consistently had more indicator species than control plots at all time points. These indicator species were primarily native plants and consisted of a variety of forbs, legumes, and graminoids (Table S1). In addition, the indicator species for removal plots are comprised of a mix of warm and cool-season plants (such as, *Bouteloua gracilis* and *Pascopyrum smithii*, respectively). This indicates that not only does removing bluegrass litter and thatch open spaces in the community for native species to return, but that all types of native species (warm- and cool season, and forbs, graminoids, and legumes), can benefit from litter and thatch removal.

The consequences of bluegrass invasion can be severe, reducing local biodiversity, and altering ecosystem services such as pollinator populations, water cycling, and livestock forage production (Nouwakpo et al., 2019; Toledo et al., 2014). While bluegrass may potentially be beneficial for forage early in the growing season, any benefits are lost as bluegrass quickly goes dormant when temperatures begin rising and precipitation is scarce (the transition from growth to dormancy is particularly quick during droughts) (Hockensmith et al., 1997; Toledo et al., 2014). Increased species richness and diversity following bluegrass control produces higher quality forage that is also more resistant to environmental stressors (Spiess et al., 2020).

Implications

Our use of a novel method to control bluegrass thatch and litter reduced bluegrass abundance and promoted native plant biodiversity that persists over several years. We recognize that brushing away bluegrass thatch and litter is unconventional and highly impractical, especially at large scale. As such, we do not recommend that land managers go out and start brushing their rangelands. Instead, management efforts should focus on using methodology that focuses on reducing bluegrass thatch and litter. For example, the combination of fire and grazing has been shown to reduce bluegrass thatch (Dornbusch et al., 2020). While monitoring these brushed plots for additional years will let us know just how long the effects of one-time targeted management last, we know that reducing bluegrass thatch and litter benefits native plant diversity, and as such, future conservation efforts should favor management practices that reduce bluegrass litter and thatch while promoting native species.

References

Adkins, J.K., Barnes, T.G., 2013. Herbicide Treatment and Timing for Controlling Kentucky Bluegrass (Poa pratensis) and Tall Fescue (Festuca arundinacea) in Cool Season Grasslands of Central Kentucky, USA. Nat. Areas J. 33, 31–38. https://doi.org/10.3375/043.033.0104

Bahm, M.A., Barnes, T.G., Jensen, K.C., 2011. Herbicide and Fire Effects on Smooth Brome (Bromus inermis) and Kentucky Bluegrass (Poa pratensis) in Invaded Prairie Remnants. Invasive Plant Sci. Manag. 4, 189–197. https://doi.org/10.1614/IPSM-D-10-00046.1

Bates, J.D., Davies, K.W., 2018. Quaking aspen woodland after conifer control: Herbaceous dynamics. Forest Ecology and Management 409, 307–316. https://doi.org/10.1016/j.foreco.2017.11.032

Daubenmire, R., 1959. Canopy coverage method of vegetation analysis. Northwest Sci 33, 39–64.

DeKeyser, E.S., Dennhardt, L.A., Hendrickson, J., 2015. Kentucky bluegrass (Poa pratensis) Invasion in the Northern Great Plains: A Story of Rapid Dominance in an Endangered Ecosystem. Invasive Plant Science and Management 8, 255–261. https://doi.org/10.1614/IPSM-D-14-00069.1

Dornbusch, M.J., Limb, R., Sedivec, K.K., 2020. Alternative Grazing Management Strategies Combat Invasive Grass Dominance. Nat. Areas J. 40, 86–95. https://doi.org/10.3375/043.040.0110

Dornbusch, M.J., Limb, R.F., Gasch, C.K., 2018. Facilitation of an Exotic Grass Through Nitrogen Enrichment by an Exotic Legume. Rangel. Ecol. Manag. 71, 691–694. https://doi.org/10.1016/j.rama.2018.06.009

Duquette, C., McGranahan, D.A., Wanchuk, M., Hovick, T., Limb, R., Sedivec, K., 2022. Heterogeneity-Based Management Restores Diversity and Alters Vegetation Structure without Decreasing Invasive Grasses in Working Mixed-Grass Prairie. Land 11, 1135. https://doi.org/10.3390/land11081135

Ellis-Felege, S.N., Dixon, C.S., Wilson, S.D., 2013. Impacts and management of invasive cool-season grasses in the Northern Great Plains: Challenges and opportunities for wildlife. Wildlife Society Bulletin 37, 510–516. https://doi.org/10.1002/wsb.321

Ereth, C.B., Hendrickson, J.R., Kirby, D., DeKeyser, E.S., Sedivec, K.K., West, M.S., 2017. Controlling Kentucky Bluegrass with Herbicide and Burning Is Influenced by Invasion Level. Invasive Plant Science and Management 10, 80–89. https://doi.org/10.1017/inp.2017.2

Estes, J.A., Terborgh, J., Brashares, J.S., Power, M.E., Berger, J., Bond, W.J., Carpenter, S.R., Essington, T.E., Holt, R.D., Jackson, J.B.C., Marquis, R.J., Oksanen, L., Oksanen, T., Paine, R.T., Pikitch, E.K., Ripple, W.J., Sandin, S.A., Scheffer, M., Schoener, T.W., Shurin, J.B., Sinclair, A.R.E., Soulé, M.E., Virtanen, R., Wardle, D.A., 2011. Trophic Downgrading of Planet Earth. Science 333, 301–306. https://doi.org/10.1126/science.1205106

Fox, J., Weisberg, S., 2019. An {R} Companion to Applied Regression.
Gasch, C.K., Toledo, D., Kral-O'Brien, K., Baldwin, C., Bendel, C., Fick, W., Gerhard, L., Harmon, J., Hendrickson, J., Hovick, T., Lakey, M., McGranahan, D., Kossi Nouwakpo, S., Sedivec, K., 2020. Kentucky bluegrass invaded rangeland: Ecosystem implications and adaptive management approaches. Rangelands 42, 106–116. https://doi.org/10.1016/j.rala.2020.05.001
Gaussoin, R.E., Berndt, W.L., Dockrell, C.A., Drijber, R.A., 2013. Characterization, Development, and Management of Organic Matter in Turfgrass Systems, in: Turfgrass: Biology, Use, and Management. John Wiley & Sons, Ltd, pp. 425–456. https://doi.org/10.2134/agronmonogr56.c12
Hall, C.R., Hodges, A.W., Haydu, J.J., 2006. The Economic Impact of the Green Industry in the United States. HortTechnology 16, 345–353. https://doi.org/10.21273/HORTTECH.16.2.0345
Hamilton III, E.W., Frank, D.A., 2001. Can plants stimulate soil microbes and their own nutrient supply? Evidence from a grazing tolerant grass. Ecology 82, 2397–2402. https://doi.org/10.1890/0012-9658(2001)082[2397:CPSSMA]2.0.CO;2
Hendrickson, J.R., Liebig, M.A., Printz, J., Toledo, D., Halvorson, J.J., Christensen, R.G., Kronberg, S.L., 2021. Kentucky Bluegrass Impacts Diversity and Carbon and Nitrogen Dynamics in a Northern Great Plains Rangeland. Rangeland Ecology and Management 79, 36–42. https://doi.org/10.1016/j.rama.2021.07.005
Hendrickson, J.R., Sedivec, K.K., Toledo, D., Printz, J., 2019. Challenges Facing Grasslands inthe Northern Great Plains and North Central Region. Rangelands 41, 23–29. https://doi.org/10.1016/j.rala.2018.11.002
Hockensmith, R.L., Sheaffer, C.C., Marten, G.C., Halgerson, J.L., 1997. Maturation effects on forage quality of Kentucky bluegrass. Canadian Journal of Plant Science 77, 75–80. https://doi.org/10.4141/P95-200
Lenth, R.V., 2020. emmeans: Estimated Marginal Means, aka Least-Squares Means.
Limb, R.F., Hovick, T.J., Norland, J.E., Volk, J.M., 2018. Grassland plant community spatial patterns driven by herbivory intensity. Agriculture, Ecosystems & Environment 257, 113–119. https://doi.org/10.1016/j.agee.2018.01.030
Link, A., Kobiela, B., DeKeyser, S., Huffington, M., 2017. Effectiveness of Burning, Herbicide, and Seeding Toward Restoring Rangelands in Southeastern North Dakota. Rangeland Ecology & Management 70, 599–603. https://doi.org/10.1016/j.rama.2017.03.001
McKinney, M.L., Lockwood, J.L., 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. Trends in Ecology & Evolution 14, 450–453. https://doi.org/10.1016/S0169-5347(99)01679-1
Millar, C.E., Turk, L.M., Foth, H.D., 1966. Origin and Classification of Soils, in: Fundamentals of Soil Science. John Wiley & Sons, Ltd, pp. 222–261.
NDAWN, 2021. North Dakota Agricultural Weather Network (NDAWN).
Nouwakpo, S.K., Toledo, D., Sanderson, M., Weltz, M., 2019. Understanding the effects of grazing and prescribed fire on hydrology of Kentucky bluegrass-dominated rangelands in the northern Great Plains. J. Soil Water Conserv. 74, 360–371. https://doi.org/10.2489/jswc.74.4.360
Palit, R., Gramig, G., Dekeyser, E.S., 2021. Kentucky bluegrass invasion in the northern great plains and prospective management approaches to mitigate its spread. Plants 10. https://doi.org/10.3390/plants10040817

Pimentel, D., McNair, S., Janecka, J., Wightman, J., Simmonds, C., O'Connell, C., Wong, E., Russel, L., Zern, J., Aquino, T., Tsomondo, T., 2001. Economic and environmental threats of alien plant, animal, and microbe invasions. Agriculture, Ecosystems & Environment 84, 1–20. https://doi.org/10.1016/S0167-8809(00)00178-X

Printz, J.L., Hendrickson, J.R., 2015. Impacts of Kentucky bluegrass Invasion (Poa pratensis L.) on Ecological Processes in the Northern Great Plains. Rangelands 37, 226–232. https://doi.org/10.1016/j.rala.2015.10.006

R Core Team, 2022. R: A Language and Environment for Statistical Computing.

Samson, F., Knopf, F., 1994. Prairie conservation in North America. BioScience 44, 418–421. https://doi.org/10.2307/1312365

Sanderson, M.A., Johnson, H., Liebig, M.A., Hendrickson, J.R., Duke, S.E., 2017. Kentucky Bluegrass Invasion Alters Soil Carbon and Vegetation Structure on Northern Mixed-Grass Prairie of the United States. Invasive Plant Sci. Manag. 10, 9–16. https://doi.org/10.1017/inp.2016.2

Spiess, J.W., McGranahan, D.A., Geaumont, B., Sedivec, K., Lakey, M., Berti, M., Hovick, T.J., Limb, R.F., 2020. Patch-Burning Buffers Forage Resources and Livestock Performance to Mitigate Drought in the Northern Great Plains. Rangeland Ecology & Management 73, 473–481. https://doi.org/10.1016/j.rama.2020.03.003

Toledo, D., Sanderson, M., Spaeth, K., Hendrickson, J., Printz, J., 2014. Extent of Kentucky Bluegrass and Its Effect on Native Plant Species Diversity and Ecosystem Services in the Northern Great Plains of the United States. Invasive Plant Science and Management 7, 543–552. https://doi.org/10.1614/IPSM-D-14-00029.1

USDA - NRCS, 2021. USDA Plants Database [WWW Document]. Kentucky Bluegrass (Poa Pratensis). URL https://plants.usda.gov/home/plantProfile?symbol=POPR (accessed 11.10.21).

USDA Soil Conservation Service, 1982. Land resource regions and major land resource areas of the United States. -- iii, 156 p. maps (some col.); 28 cm.--.

Supplemental Material

Table S1:

(a) 1 Month Post-Removal						
Treatment	Species	Origin	Functional Group	Indicator Value	p-value	Sig. Indicator
Control	Elymus repens	Introduced	Graminoid	0.449	<0.001	***
Control	Poa pratensis	Introduced	Graminoid	0.756	<0.001	***
Control	Gallium borale	Native	Forb	0.24	0.018	*
Control	Helianthus pauciflorus	Native	Forb	0.234	0.003	**
Control	Heterotheca villosa	Native	Forb	0.218	0.016	*
Control	Ratibida columnifera	Native	Forb	0.247	0.042	*
Control	Viola adunca	Native	Forb	0.163	0.027	*
Control	Viola pedantifida	Native	Forb	0.284	0.026	*
Control	Koeleria macrantha	Native	Graminoid	0.189	0.010	**
Control	Schizachyrium scoparium	Native	Graminoid	0.263	0.002	**
Control	Astragalus flexuosus	Native	Legume	0.231	0.007	**
Removal	Cirsium arvensis	Introduced	Forb	0.356	<0.001	***
Removal	Taraxacum officinale	Introduced	Forb	0.385	<0.001	***
Removal	Ambrosia psilostachya	Native	Forb	0.709	<0.001	***
Removal	Artemisia ludoviciana	Native	Forb	0.645	0.002	**
Removal	Asclepias speciosa	Native	Forb	0.164	0.019	*
Removal	Cirsium flodmanii	Native	Forb	0.581	<0.001	***
Removal	Commandra umbellata	Native	Forb	0.439	0.002	**
Removal	Elymus canadesis	Native	Forb	0.459	0.003	**
Removal	Lactuca tartarica	Native	Forb	0.48	0.010	**
Removal	Lygodesmia juncacea	Native	Forb	0.287	<0.001	***
Removal	Oenothera suffretescens	Native	Forb	0.361	0.005	**
Removal	Solidago canadensis	Native	Forb	0.231	<0.001	***
Removal	Symphyotrichum ericoides	Native	Forb	0.683	0.026	*
Removal	Carex filifolia	Native	Graminoid	0.164	0.015	*
Removal	Dichanthelium wilcoxanum	Native	Graminoid	0.316	<0.001	***
Removal	Hesperostip commata	Native	Graminoid	0.246	0.031	*
Removal	Pascopyrum smithii	Native	Graminoid	0.735	<0.001	***
Removal	Acmispon americanus	Native	Legume	0.222	<0.001	***
Removal	Astragalus agrestis	Native	Legume	0.469	0.003	**
Removal	Lotus corniculatus	Native	Legume	0.149	0.030	*
Removal	Medicago lupulina	Native	Legume	0.213	0.004	**
Removal	Pediomelum agrophyllum	Native	Legume	0.675	<0.001	***
Removal	Vicia americana	Native	Legume	0.482	<0.001	***

Table S1 (continued):

(b) 12 Months Post-Removal						
Treatment	Species	Origin	Functional Group	Indicator Value	p-value	Sig. Indicator
Control	Bromus inermis	Introduced	Graminoid	0.54	<0.001	***
Control	Gallium borale	Native	Forb	0.225	0.011	*
Control	Elymus trachycaulus	Native	Graminoid	0.284	<0.001	***
Control	Hesperostipa spartea	Native	Graminoid	0.165	0.021	*
Control	Schizachyrium scoparium	Native	Graminoid	0.22	0.016	*
Removal	Artemisia absinthimum	Introduced	Forb	0.192	0.017	*
Removal	Cirsium arvense	Introduced	Forb	0.303	<0.001	***
Removal	Ambrosia psilostachya	Native	Forb	0.467	0.004	**
Removal	Artemisia dranunculus	Native	Forb	0.296	0.034	*
Removal	Artemisia ludoviciana	Native	Forb	0.617	0.005	**
Removal	Cirsium flodmanii	Native	Forb	0.555	<0.001	***
Removal	Commandra umbellata	Native	Forb	0.389	0.019	*
Removal	Grindellia squarrosa	Native	Forb	0.19	0.047	*
Removal	Solidago canadensis	Native	Forb	0.231	<0.001	***
Removal	Symphyotrichum ericoides	Native	Forb	0.741	<0.001	***
Removal	Zigadenus elegans	Native	Forb	0.177	0.027	*
Removal	*Carex* spp.	Native	Graminoid	0.577	<0.001	***
Removal	Dichanthelium wilcoxicanum	Native	Graminoid	0.173	0.027	*
Removal	Muhlenbergia asperifolia	Native	Graminoid	0.345	<0.001	***
Removal	Pascopyrum smithii	Native	Graminoid	0.689	<0.001	***
Removal	Astragalus agrestis	Native	Legume	0.264	0.046	*
Removal	Astragalus gracilis	Native	Legume	0.324	0.009	**
Removal	Pediomelum argophyllum	Native	Legume	0.58	<0.001	***

Table S1 (continued):

(c) 24 Months Post-Removal						
Treatment	Species	Origin	Functional Group	Indicator Value	p-value	Sig. Indicator
Control	Tragopogon dubius	Introduced	Forb	0.261	0.005	**
Control	Elymus repens	Introduced	Graminoid	0.223	0.006	**
Control	Poa compressa	Introduced	Graminoid	0.333	0.005	**
Control	Poa pratensis	Introduced	Graminoid	0.746	<0.001	***
Control	Medicago sativa	Introduced	Legume	0.18	0.044	*
Control	Muhlenbergia asperifolia	Native	Graminoid	0.187	0.009	**
Control	Schizachyrium scoparium	Native	Graminoid	0.237	<0.001	***
Control	Symphoricarpos occidentalis	Native	Shrub	0.581	<0.001	***
Removal	Artemisia absinthimum	Introduced	Forb	0.381	0.004	**
Removal	Cirsium arvensis	Introduced	Forb	0.296	0.004	**
Removal	Taraxacum erythrospermum	Introduced	Forb	0.548	<0.001	***
Removal	Medicago lupulina	Introduced	Legume	0.284	0.025	*
Removal	Ambrosia psilostachya	Native	Forb	0.552	<0.001	***
Removal	Androsace occidentalis	Native	Forb	0.299	<0.001	***
Removal	Androsace septentrionalis	Native	Forb	0.412	<0.001	***
Removal	Anemone canadensis	Native	Forb	0.25	0.002	**
Removal	Anemone cylindrica	Native	Forb	0.193	0.023	*
Removal	Artemisia dranunculus	Native	Forb	0.399	<0.001	***
Removal	Castilleja sessiliflorus	Native	Forb	0.189	0.006	**
Removal	Chamaerhodos erecta	Native	Forb	0.394	<0.001	***
Removal	Cirsium flodmanii	Native	Forb	0.447	0.004	**
Removal	Cirsium undulatum	Native	Forb	0.407	0.012	*
Removal	Conyza canadensis	Native	Forb	0.42	<0.001	***
Removal	Gallium borale	Native	Forb	0.278	0.038	*
Removal	Grindelia squarrosa	Native	Forb	0.442	<0.001	***
Removal	Linum sulcatum	Native	Forb	0.33	<0.001	***
Removal	Oxalis striata	Native	Forb	0.246	<0.001	***
Removal	Polygala alba	Native	Forb	0.365	<0.001	***
Removal	Ratibida columnifera	Native	Forb	0.586	<0.001	***
Removal	Solidago missouriensis	Native	Forb	0.414	0.004	**
Removal	Solidago rigida	Native	Forb	0.526	0.002	**
Removal	Bouteloua gracilis	Native	Graminoid	0.221	<0.001	***
Removal	Carex brevior	Native	Graminoid	0.173	0.034	*
Removal	Carex filifolia	Native	Graminoid	0.249	<0.001	***
Removal	Carex inops	Native	Graminoid	0.463	<0.001	***
Removal	Dichanthelium leibergii	Native	Graminoid	0.2	0.003	**
Removal	Dichanthelium wilcoxanum	Native	Graminoid	0.389	<0.001	***
Removal	Panicum capitatum	Native	Graminoid	0.249	<0.001	***
Removal	Pascopyrum smithii	Native	Graminoid	0.729	<0.001	***
Removal	Acmispon americanus	Native	Legume	0.632	<0.001	***
Removal	Astragalus agrestis	Native	Legume	0.434	0.004	**
Removal	Pediomelum argophyllum	Native	Legume	0.629	<0.001	***

Heavy Cattle Grazing of a Smooth Brome-Dominated Rangeland in the Early Spring and Fall

Zach Johnson[1], Edward DeKeyser[1], Cami Dixon[2], John Hendrickson[3], and Kevin Sedivec[1,4]

[1]School of Natural Resources, North Dakota State University, Fargo, ND, USA
[2]U.S. Fish and Wildlife Service, Chase Lake National Wildlife Refuge, Woodworth, ND, USA
[3]Northern Great Plains Research Laboratory, USDA-ARS, Mandan, ND, USA
[4]Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND, USA

Summary

Smooth brome is a perennial grass that has invaded much of the Northern Great Plains and led to drastic declines of biodiversity within the region. Since increasing evidence suggests that diverse plant communities benefit ecosystems and livestock producers, restoration of diverse plant communities could be a desirable investment. Considering this, we started a grazing study to evaluate the potential of heavy cattle grazing during the early spring, fall, or both in improving plant diversity in a smooth brome-dominated rangeland. To monitor changes in plant community composition, we started measuring the abundance of plant species within areas grazed during the spring, fall, both spring and fall, and non-grazed controls. Additionally, we started studying the effects of grazing on the smooth brome population and the species vegetative reproduction. Definite effects from grazing have yet to be seen, but measurable changes are not expected until later in the study. We believe our study could provide insight into the nature of smooth brome-dominated ecosystems, and we hope to see diversity improve within this rangeland. We expect heavy grazing during both the early spring and fall to be most effective at improving diversity, while we are unsure what effects grazing treatments will have on smooth brome's reproduction. If this management plan successfully improves plant diversity, this strategy might help land managers struggling with smooth brome-dominated rangelands.

Introduction

Restored biodiversity may not only benefit ecosystems of the Northern Great Plains, but also livestock producers within the region. After 11 long-term studies of a Minnesota grassland, Tilman et al. (2012) found that increasing plant diversity from 1 to 16 species increased aboveground community production more than all other tested treatments, including fertilization at 95 kg N ha $^{-1}$. Link et al. (2017) had related findings on grasslands in North Dakota, showing production increased due to increased biodiversity. Similarly, aboveground production is more stable in drought and recovers more quickly in diverse plant communities than in less diverse communities (Tilman 1996).

The benefits of more diverse plant communities also extend to higher trophic levels. Allred et al. (2014) showed that diverse plant communities can stabilize livestock production as well. These results suggest that any reductions to livestock production from improving plant diversity are likely marginal, if present, and the benefits of increased stability may make diversification of plant communities a desirable investment for livestock producers. Additionally, some research argues that ecosystems of greater biodiversity experience less frequent and less severe outbreaks of infectious disease in plants and animals, including humans (Keesing et al.

2010). The benefits of diverse plant communities also extend to wildlife populations, including wild game. Diverse plant communities are an important characteristic of wildlife habitat, not only because they stabilize wildlife populations, but also because less diverse communities support fewer species of wildlife (Ellis-Felege et al. 2013; Sliwinski et al. 2018). Even though maintenance of biodiversity is a goal of many land managers, plant diversity has decreased throughout much of the Northern Great Plains (Ellis-Felege 2013).

Several factors have contributed to loss of biodiversity across the Northern Great Plains (hereafter NGP), including land conversion, fragmentation, and spread of invasive species. Samson et al. (2004) explained that 70% of mixed-grass prairies in the Great Plains have been converted to other uses such as crop production and urbanization. This conversion leads to loss of habitat, which makes it difficult for many populations to survive and recover from disturbances. Conversion also fragments the landscape which, similar to loss of habitat, increases the likeliness of extinctions (e.g. through genetic drift). Additionally, invasive plants often outcompete native plants. Plant communities with a well-established invasive species population are less diverse and therefore support fewer animal species (Ellis-Felege 2013). The loss of plant diversity and the spread of invasive species are occurring in many parts of the NGP (DeKeyser et al. 2013; Toledo et al. 2014; Grant et al. 2020).

Smooth brome (*Bromus inermis* Leyss.) is a perennial, cool-season (C3), rhizomatous grass that tends to invade grasslands, including those of North Dakota (DeKeyser et al. 2013; Grant et al. 2020; Kobiela et al. 2017). Smooth brome was originally introduced to California from Eurasia in the 1880s, where it escaped from cultivation and has now invaded many regions (Otfinowski et al. 2007). Successful invasions of smooth brome are often due to its rapid spread through rhizomes (Otfinowski et al. 2007; Palit and DeKeyser 2022). Smooth brome also grows rapidly and early in the growing season (Lamp 1952; Otfinowski et al. 2007). This rapid and early growth allows smooth brome to establish the canopy much earlier in the spring than most native plants, exploiting sunlight. Both rapid early growth and prolific spread through rhizomes contribute to smooth brome's competitive advantage over many native plants.

Grazing may help promote native plant biodiversity in smooth brome-dominated grasslands in two ways. First, grazing may directly promote native species populations by creating a more suitable light environment. Grazing removes smooth brome tissue from the canopy, which increases the amount of light that passes through the canopy and shines on shorter and less developed plants. Native species often grow later than smooth brome so if more light is available for photosynthesis, they are able to grow and therefore compete with smooth brome (Palit and DeKeyser 2022). However, native plants are not the only species that could benefit from increased sunlight passing through the canopy, as this can also benefit exotic plants. Second, grazing may indirectly promote native species by decreasing smooth brome's competitiveness. Grazing places stress on plants, as plants must use energy to defend themselves from and compensate for herbivory that they could have otherwise used for growth or reproduction (Endara and Coley 2011; Strauss and Agrawal 1999). However, researchers are still learning how smooth brome responds to herbivory. Otfinowski et al. (2007) suggest that more intense and frequent defoliation during the spring and fall could be promising, but some of this evidence was from management methods other than grazing.

The crown is vital for the success of many species of perennial grasses in the NGP (Russell et al. 2015). Tillers are the individual stems of grass you see above ground, and the crown is the part of a tiller that is located underground, excluding the roots (Figure 1). The crown plays a role in energy storage, growth, reproduction, and recovery following disturbance (Ott and Hartnett 2012; Russell et al. 2015). Due to the crown's role in the success of many perennial grasses, bud bank demographics has been increasingly studied. The bud bank is part of the crown and is a collection of meristems (i.e. axillary buds) from which new tillers, stolons, and rhizomes can develop (Hendrickson and Briske 1997; Ott and Hartnett 2012). The development of tillers and rhizomes from axillary buds is the primary form of reproduction for many perennial grasses (Ott et al. 2017; Ott and Hartnett 2012; Russell et al. 2015). Since vegetative reproduction via the bud bank is the primary form of reproduction of smooth brome, quantifying the bud bank can estimate the effectiveness of management treatments on smooth brome's reproduction and success.

Figure 1. Tillers and the crown portion of smooth brome, in which the bud bank is located. Both samples have their roots removed. A partially dissected sample of smooth brome containing one tiller and several new daughter tillers emerging from the bud bank (left). The crown potion of a smooth brome tiller with a collection of axillary buds, tillers, or rhizomes called the bud bank (right).

We hypothesize that heavy cattle grazing during the early spring and fall will decrease smooth brome abundance and shift plant community composition when smooth brome is the dominant plant, because plants must reallocate energy to regrowth following herbivory, rather than growth and reproduction (E.S. DeKeyser, Pers. Comm.; K.K. Sedivec, Pers. Comm.). By testing our hypothesis, we will determine if heavy cattle grazing during the early spring, fall, or both is feasible management for improving native species diversity in a smooth brome-dominated rangeland. To test our hypothesis, we will measure plant community composition and monitor changes to the overall plant community for each grazing treatment, while focusing on native species. The second part of our study utilizes the same study site and same grazing treatments. To learn more about smooth brome's biological and ecological nature in the NGP, we will examine effects of our grazing treatments on smooth brome tiller survivorship, population growth rate, and bud bank demographics.

Methods

Study Site

The study takes place at NDSU's Central Grasslands Research Extension Center (CGREC), located near Streeter, ND. CGREC lies within the Missouri Coteau ecoregion and consists of mixed-grass prairie (Limb et al. 2018). The study is being conducted, specifically, within the Long Pasture (46.7552° N 99.4511° W), which is dominated by smooth brome. The pasture was managed by non-use from the 1980s to early 2000s, which played a part in allowing smooth brome to invade the pasture (DeKeyser et al. 2013; Grant et al. 2020). The pasture has been grazed in recent years, however never above a moderate rate.

Experimental Design

Long Pasture is approximately 150 acres and has been divided into four replicates of similar size (Figure 2A). The pasture will be grazed each spring and again in the fall for the duration of the study. Each replicate will be stocked with heifers and/or cows to achieve heavy grazing rates, 60-80% utilization (Sedivec and Printz 2014). Within each replicate, we randomly placed a plot on upland loamy soils (Figure 2A). Each plot has four treatments, spring only, fall only, both spring+fall, and a control. Treatment areas are approximately 9.75 m x 9.75 m (32 ft x 32 ft). During the spring, control and fall only treatments are excluded from cattle grazing using panels, whereas spring+fall and spring only treatments are open to grazing (Figure 2B). During the fall, control and spring only treatments are excluded, while spring+fall and fall only treatments are open (Figure 2C). The study will last three field seasons.

Plant Community, Native Species, and Diversity

To evaluate our hypothesis, we started measuring relative species cover composition. Relative species cover composition monitors changes in plant community composition and diversity among treatments. We used 1-m^2 quadrats to estimate aerial cover (i.e. abundance) of each plant species present. We did this by randomly placing four quadrats within each treatment area. Cover was measured during peak production, around the beginning of July. Measuring cover during peak production provides a more accurate representation of the overall plant community (i.e. seasonality of the community). Using cover data, we will determine species richness and evenness for each treatment. Species richness and evenness will then be used to evaluate biodiversity differences among treatments.

Smooth Brome Population

We will use censuses of smooth brome tillers to calculate survivorship and relative population growth rate. Due to the challenge of identifying genets and ramets in rhizomatous grasses, tillers are the individual in the censuses. Tiller censuses are completed during the spring and fall. Permanent quadrats were established at the beginning of the study. Each treatment area has four quadrats (16 per replicate, 64 total). Each quadrat is 15 cm x 15 cm. Two nail and whiskers were used to mark opposing corners of each quadrat (Figure 3A). This establishes the permanent location of the quadrat, while allowing us to place and remove quadrat frames. From census data, we will compare survivorship and relative population growth rate among spring only, fall only, spring+fall, and control treatments.

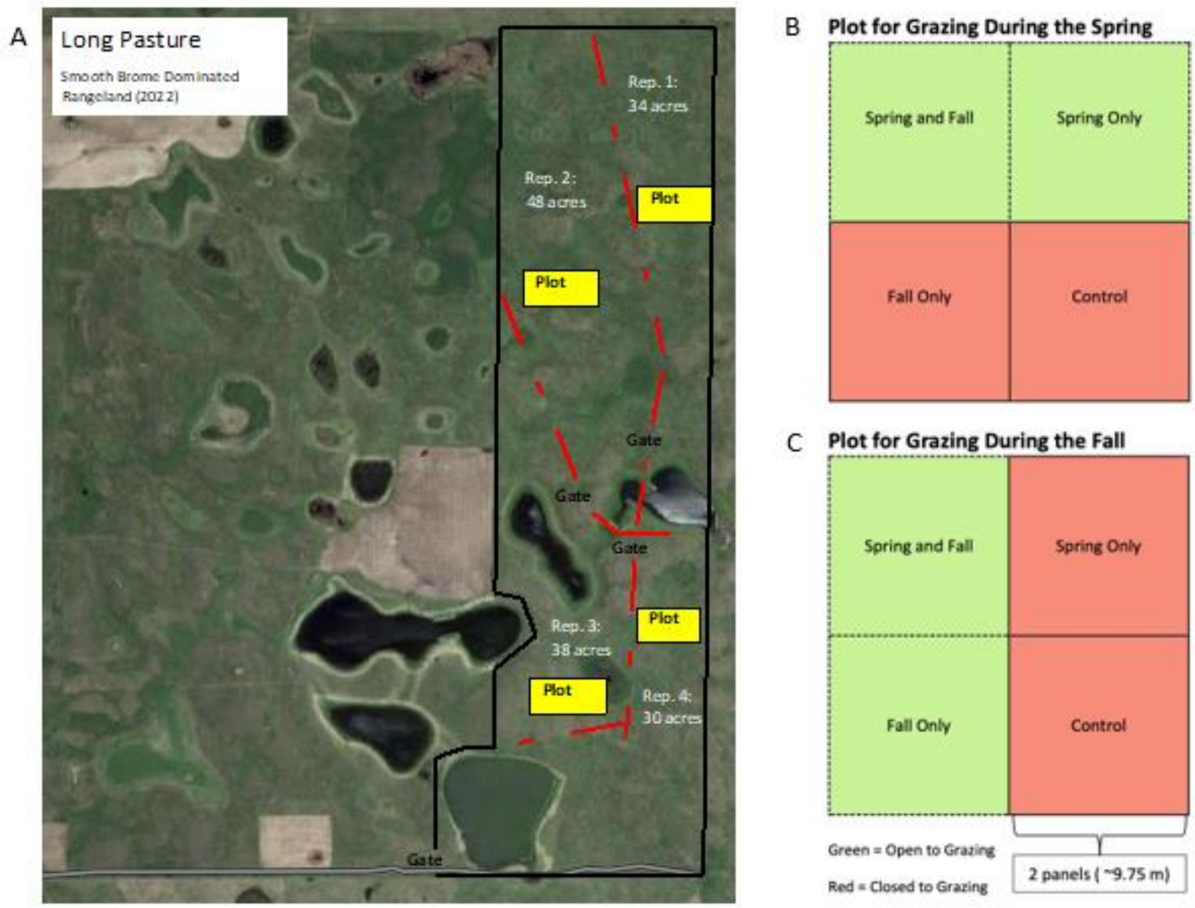


Figure 2. Study design of Long Pasture at Central Grasslands Research Extension Center, Streeter, ND. (A) Boundary of pasture is outlined in black, and red lines show interior fencing creating four replicates. Approximate plot location of each replicate is shown by yellow plot boxes. (B and C) Example of plot design with the four experimental treatments during spring (B) and fall (C). Open treatment areas are free of panels and t-posts. Closed treatment areas are enclosed by panels and t-posts which encloses the area from grazing.

During the initial census, every smooth brome tiller emerging from the surface inside of quadrats were marked, counted, and recorded. Tillers were marked with a small ring made from wire (Figure 3B and C). The number of tillers within each quadrat was recorded. Then the number of those tillers in each morphological stage was recorded. The three morphological stages were: vegetative, elongated, and reproductive. Vegetative tillers are aboveground tillers with no palpable node or inflorescence. Elongated tillers have a palpable node, but no inflorescence. Whereas, reproductive tillers have a palpable node and an inflorescence.

Figure 3. Tiller census quadrats and rings. (A) Quadrat frame and two nail and whiskers marking opposite corners, allowing frame removal. (B) Tiller rings placed around the base of tillers, blue and orange rings placed during different censuses. (C) A tiller ring made from a piece of small wire (~7 cm piece of wire twisted into a ring).

The following censuses recorded the number of new tillers and those that survived from previous censuses. During these censuses, we first counted and recorded the number of tillers that were alive, dead, or missing from the previous census. Live tillers are those that have any visible green tissue. Dead tillers are those that have no green or are not present, but still have a ring. There are two situations in which a ring is recorded as a dead tiller: (1) A ring is found around a tiller that is dead (i.e., no visible green tissue). (2) A ring is found within or immediately next to the quadrat but not with a tiller because some event, like grazing, removed that tiller. Missing tillers are those that were marked during the previous census, but no ring was found in or near the quadrat during the current census. For example, if 12 tillers were alive and marked during the previous census, but now there are only 10 rings from that previous census, then there are two tillers that are missing. We then censused new emerging tillers. New emerging tillers were marked, counted, and recorded the same as the initial census, however a new color ring was used. Different colored rings distinguish tillers marked during difference censuses. The new emerging tillers were also categorized by morphological stage, just like the initial census.

Vegetative Reproduction and Bud Bank Analysis

Samples of tillers were collected after each census for bud bank analysis. First, the proportion of morphological stages of smooth brome was calculated from the census data. Then, four tillers were collected from each treatment area in the proportion closest to that of the census. For example, if the census recorded 48% vegetative tillers and 52% elongated tillers, then two vegetative and two elongated tillers were collected. Sample tillers were located at least three decimeters (one foot) away from census quadrats because sampling is destructive, this prevents skewed data by avoiding clonal tillers of tillers within census quadrats. Nail polish was used to differentiate between the sample tiller and any tillers connected to it. We collected the entire crown of each sample tiller. Samples were then placed with a damp paper towel in Ziplock bags. Samples were kept cool until analysis.

Next, a dissection scope aided in the dissections of samples. Dissections delicately removed all roots from the crown. We then removed the leaves exposing the entire bud bank. Treatment and the number of axillary buds, daughter tillers, and rhizomes were recorded for each sample. Samples were dyed to determine axillary bud, daughter tiller, and rhizome viability following the procedures of Busso et al. (1989), Hendrickson and Briske (1997), and Russell et al. (2015). An overview of the procedure follows. Samples were dyed with a 2,3,5 tetrazolium red (TTC) solution (0.1% W/V). TTC dyes living tissue red or pink when it reacts with metabolic processes. Next, we observed and recorded the number of live axillary buds, tillers, and rhizomes, which dyed from TTC. Samples with remaining axillary buds, tillers, or rhizomes that were not dyed by TTC were dyed with a solution of Evan's Blue (0.25% W/V). Evan's Blue enters cells through degraded cell membrane, so it dyes dead tissue a dark blue color. Whereas, dormant buds do not dye from TTC or Evan's Blue and remain unchanged in color. Therefore, axillary buds that dyed red or pink were alive, dyed blue were dead, and those that didn't change color were dormant. Tillers and rhizomes were only considered live or dead, not dormant. Live tillers were those that dyed red or pink, were visibly green, or did not completely dye blue. Whereas dead tillers and rhizomes dyed completely blue or were obviously dead. From this procedure, we determined how many buds, tillers, and rhizomes were alive, dead, or dormant for each sample. We will test for differences in bud bank demographics among grazing treatments and controls.

Preliminary Results

Plant Community, Native Species, and Diversity

Statistical analysis has not been completed yet, and it is too early to see definite changes in the plant community among treatments. Smooth brome continued to dominate the vegetation of Long Pasture the first year. On average, smooth brome made up ~44% of the canopy. Kentucky bluegrass (*Poa pratensis*), another invasive grass, comprised ~18%. While analysis still needs to be completed, plants that also contributed abundant cover included wild licorice (*Glycyrrhiza lepidota*), quackgrass (*Elymus repens*), poison ivy (*Toxicodendron rydbergii*), Canada thistle (*Cirsium arvense*), and western snowberry (*Symphoricarpos occidentalis*). Other commonly seen plants that did not contribute much to relative cover included western yarrow (*Achillea millefolium*), white sage (*Artemisia ludoviciana*), common milkweed (*Asclepias syriaca*), prairie rose (*Rosa arkansana*), Canada goldenrod (*Solidago canadensis*), stiff goldenrod (*Solidago rigida*), silverleaf scurfpea (*Pediomelum argophyllum*), heath aster (*Symphotrichum ericoides*), and northern bedstraw (*Galium boreale*). Diversity changes among treatments will be evaluated after another season of data collection. We will also focus on changes in native species composition then.

Smooth Brome Population

We have completed the initial census and the fall 2022 census. The initial census took place prior to any grazing. We had a late start to our grazing this spring and the census was late as well since it was completed the day prior to grazing, but we will start grazing sooner next year. The fall census of 2022 took place during mid-September.

The average number of live tillers per quadrat (0.0225 m^2; 15 cm x 15 cm) decreased from 17.9 during the spring to 12.4 in the fall when averages for all treatments and controls were combined (Figure 4). A similar decrease in population existed across all treatments and controls (Figure 5). The declining populations were likely due to season more so than grazing because declines were consistent between grazing treatments and controls (Table 1). We expect to see a trend overtime where populations are larger during the spring and smaller during the fall. By the end of the study, we expect the smooth brome population to generally decline. We also expect any potential declines to correlate with increasing biodiversity of the plant community.

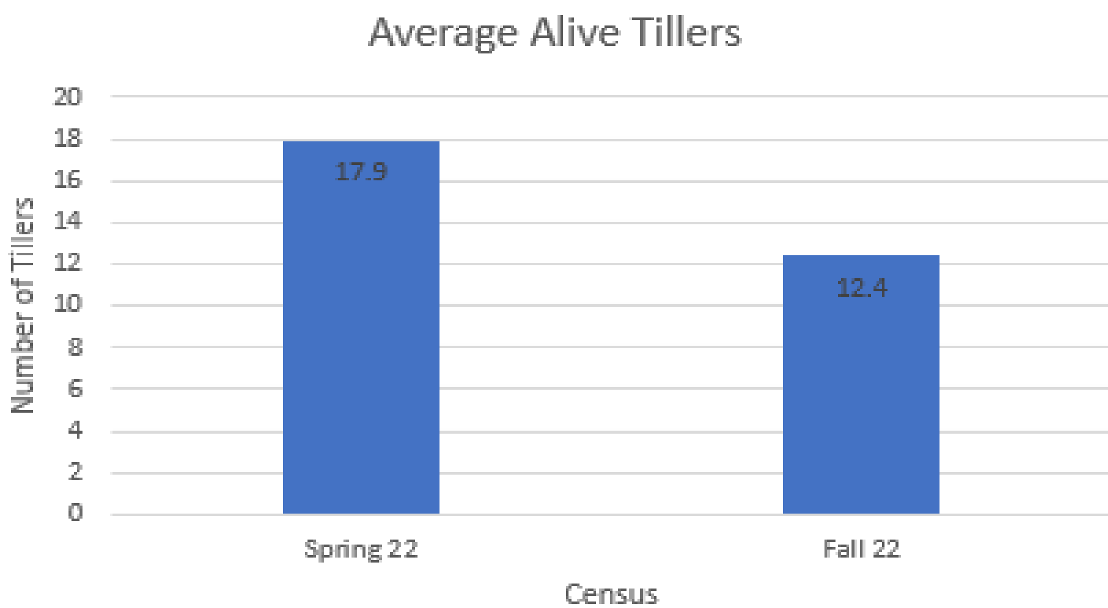


Figure 4 – Preliminary results from censuses of smooth brome tillers. Average is for combined treatments. Number is average live tillers per 0.0225 m^2 (15 cm x 15 cm). Statistical analysis has not been completed yet.

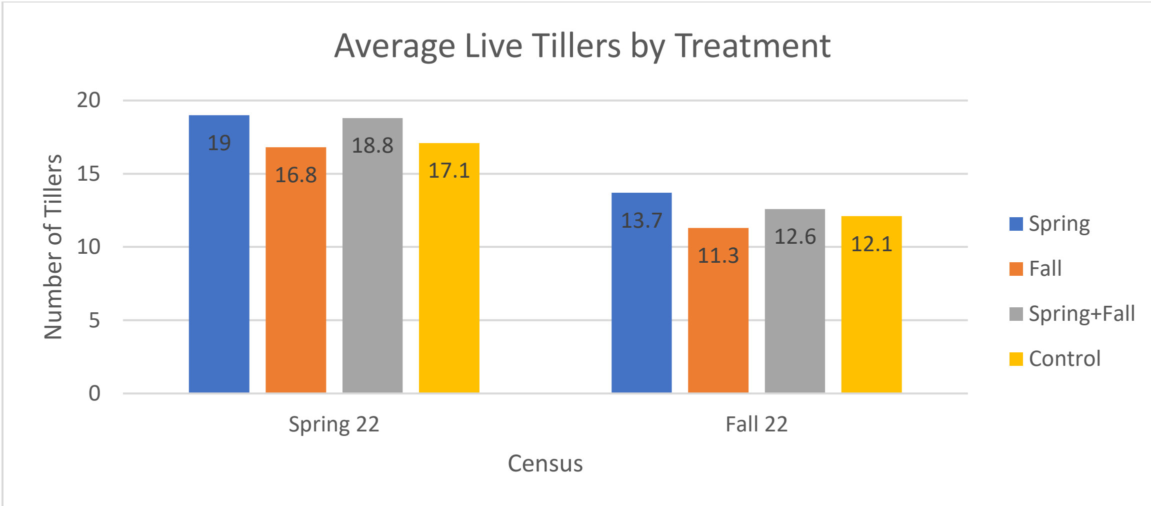


Figure 5. Preliminary results. Average live smooth brome tillers per 0.0225 m^2 (15 cm x 15 cm). By treatment. Statistical analysis has not been completed yet.

Table 1. Preliminary results. Relative population growth rate (λ) from Spring 2022 to Fall 2022 census by treatment. Values > 1 estimate the population is growing. Values = 1 estimate the population is stable. Values < 1 estimate the population is declining.

	Spring	Fall	Spring+Fall	Control
Relative Population Growth Rate (λ)	0.72	0.67	0.67	0.71

Vegetative Reproduction and Bud Bank Analysis

No major trends have been identified yet for bud bank demographics. We are uncertain what effects may be observed in the bud banks among treatments. As this research progresses, there may be an initial increase in bud bank activity in treated areas (i.e. greater amount of active axillary buds, daughter tillers, and rhizomes per tiller). A time-lag from management may exist, where bud bank activity wouldn't differ among treatments until late in the study. Additionally, it is possible that a decrease in bud bank activity or alteration to bud bank structure may not occur from grazing at all. Potential correlations between bud bank activity or structure and smooth brome populations may be measurable. Such correlations, might suggest how grazing treatments affect the bud banks of tillers and consequently smooth brome populations as a whole. This could provide additional insight into how smooth brome bud banks drive vegetative reproduction and tiller recruitment of the species. We hope to see some difference in bud bank demographics between treatments and controls.

Discussion

Our results are preliminary and are not conclusive at this time; however, we believe that heavy grazing in the spring, fall, or both will increase plant diversity, especially of native plants. Heavy grazing during the spring and fall will probably be most effective, if grazing increases the amount of light reaching native plants and the stress of heavy grazing is enough to affect vegetative reproduction of smooth brome. Changes to smooth brome survivorship and relative population growth rate between the spring of 2022 and fall of 2022 are likely due more to season than grazing because smooth brome grows primarily during the spring (Otfinowski et al. 2007). We do not expect measurable effects from grazing until the next field season, or later.

Researchers and managers are learning more about bud bank demographics in perennial grasses, but the link between bud banks and aboveground phenology could inform management in the future (Ott and Hartnett 2012). It should be noted, that data from Ott et al. (2017) suggests bud bank demographics of smooth brome can vary due to temperature and seasonality of precipitation, however these differences were not significant. This proposes that evaluating bud bank demographics of smooth brome among treatments, rather than across years, is likely more informative to our research questions.

Ideas for management could be generated from the results of this study. Cover measurements of the plant community may determine if grazing treatments are effective for smooth brome-dominated rangelands. Therefore, if any of the grazing treatments lead to desirable changes in plant community composition, that treatment may be useful to land managers struggling with smooth brome-dominated rangelands. Additionally, it seems plausible that our grazing treatments could shift the plant community composition to other undesirable plants (e.g. Kentucky bluegrass). We wonder if different management strategies, such as fire or other grazing practices, could then be used in subsequent years to promote native plant communities. Such ideas relate to the philosophy of adaptive management (Ellis-Felege et al 2013), and contribute to the larger idea of succession management (Bahm et al. 2011; Krueger-Mangold et al. 2006).

Through the duration of this study, we will evaluate if our management strategy is successful in promoting biodiversity in a smooth brome-invaded rangeland. We also hope to contribute to the understanding of smooth brome's biology and ecological nature within the NGP. The purpose of our research is to contribute to the understanding of rangelands dominated by invasive species so that native plant diversity can promoted through ecological processes. Through considering biodiversity, future management might restore the benefits of higher biodiversity in ecosystems, further benefitting those that utilize their services.

References

Allred, B. W., Scasta, J. D., Hovick, T. J., Fuhlendorf, S. D., & Hamilton, R. G. (2014). Spatial heterogeneity stabilizes livestock productivity in a changing climate. *Agriculture Ecosystems & Environment*, *193*, 37-41. https://doi.org/10.1016/j.agee.2014.04.020

Bahm, M. A., Barnes, T. G., & Jensen, K. C. (2011). Restoring native plant communities in smooth brome (*Bromus inermis*)-dominated grasslands. *Invasive Plant Science and Management*, *4*(2), 239-250. https://doi.org/10.1614/ipsm-d-10-00047.1

Busso, C. A., Mueller, R. J., & Richards, J. H. (1989). Effects of drought and defoliation on bud viability in two caespitose grasses. *Annals of Botany*, *63*(4), 477-485. https://doi.org/10.1093/oxfordjournals.aob.a087768

DeKeyser, E., Meehan, M., Clambey, G., & Krabbenhoft, K. (2013). Cool season invasive grasses in Northern Great Plains Natural Areas. *Natural Areas Journal*, *33*(1), 81-90.

Ellis-Felege, S. N., Dixon, C. S., & Wilson, S. D. (2013). Impacts and management of invasive cool-season grasses in the Northern Great Plains: Challenges and opportunities for wildlife. *Wildlife Society Bulletin*, *37*(3), 510-516. https://doi.org/10.1002/wsb.321

Endara, M. J., & Coley, P. D. (2011). The resource availability hypothesis revisited: a meta-analysis. *Functional Ecology*, *25*(2), 389-398. https://doi.org/10.1111/j.1365-2435.2010.01803.x

Grant, T. A., Shaffer, T. L., & Flanders, B. (2020). Patterns of smooth brome, Kentucky bluegrass, and shrub invasion in the Northern Great Plains vary with temperature and precipitation. *Natural Areas Journal*, *40*(1), 11-22. https://doi.org/10.3375/043.040.0103

Hendrickson, J. R., & Briske, D. D. (1997). Axillary bud banks of two semiarid perennial grasses: Occurrence, longevity, and contribution to population persistance. *Oecologia*, *110*(4), 584-591. https://doi.org/10.1007/s004420050199

Keesing, F., Belden, L. K., Daszak, P., Dobson, A., Harvell, C. D., Holt, R. D., . . . Ostfeld, R. S. (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. *Nature*, *468*(7324), 647-652. https://doi.org/10.1038/nature09575

Kobiela, B., Quast, J., Dixon, C., & DeKeyser, E. S. (2017). Targeting introduced species to improve plant community composition on USFWS-managed prairie remnants. *Natural Areas Journal*, *37*(2), 150-160. https://doi.org/10.3375/043.037.0204

Krueger-Mangold, J. M., Sheley, R. L., & Svejcar, T. J. (2006). Toward ecologically-based invasive plant management on rangeland. *Weed Science*, *54*(3), 597-605. https://doi.org/10.1614/ws-05-049r3.1

Lamp, H. F. (1952). Reproductive activity in *Bromus inermis* in relation to phases of tiller development. *Botanical Gazette*, *113*(4), 413-438. https://doi.org/10.1086/335731

Limb, R. F., Hovick, T. J., Norland, J. E., & Volk, J. M. (2018). Grassland plant community spatial patterns driven by herbivory intensity. *Agriculture Ecosystems & Environment*, *257*, 113-119. https://doi.org/10.1016/j.agee.2018.01.030

Link, A., Kobiela, B., DeKeyser, S., & Huffington, M. (2017). Effectiveness of burning, herbicide, and seeding toward restoring rangelands in southeastern North Dakota. *Rangeland Ecology & Management*, *70*(5), 599-603.

Otfinowski, R., Kenkel, N. C., & Catling, P. M. (2007). The biology of Canadian weeds. 134. *Bromus inermis* Leyss. *Canadian Journal of Plant Science*, *87*(1), 183-198. https://doi.org/10.4141/p06-071

Ott, J. P., Butler, J. L., Rong, Y., & Xu, L. (2017). Greater bud outgrowth of *Bromus inermis* than *Pascopyrum smithii* under multiple environmental conditions. *Journal of Plant Ecology*, *10*(3), 518-527. https://doi.org/10.1093/jpe/rtw045

Ott, J. P., & Hartnett, D. C. (2012). Contrasting bud bank dynamics of two co-occurring grasses in tallgrass prairie: implications for grassland dynamics. *Plant Ecology*, *213*(9), 1437-1448. https://doi.org/10.1007/s11258-012-0102-9

Palit, R., & DeKeyser, E. S. (2022). Impacts and drivers of smooth brome (*Bromus inermis* Leyss.) invasion in native ecosystems. *Plants-Basel*, *11*(10), 1340. https://doi.org/10.3390/plants11101340

Russell, M. L., Vermeire, L. T., Ganguli, A. C., & Hendrickson, J. R. (2015). Season of fire manipulates bud bank dynamics in northern mixed-grass prairie. *Plant Ecology*, *216*(6), 835-846. https://doi.org/10.1007/s11258-015-0471-y

Samson, F. B., Knopf, F. L., & Ostlie, W. R. (2004). Great Plains ecosystems: past, present, and future. *Wildlife Society Bulletin*, *32*(1), 6-15. https://doi.org/10.2193/0091-7648(2004)32[6:gpeppa]2.0.co;2

Sedivec, K. K., & Printz, J. L. (2014). *Ranchers guide to grassland management* (IV [edition] ed.). NDSU Extension Service.

Sliwinski, M., Burbach, M., Powell, L., & Schacht, W. (2018). Ranchers' perceptions of vegetation heterogeneity in the Northern Great Plains. *Great Plains Research*, *28*(2), 185-197.

Strauss, S. Y., & Agrawal, A. A. (1999). The ecology and evolution of plant tolerance to herbivory. *Trends in Ecology & Evolution*, *14*(5), 179-185. https://doi.org/10.1016/s0169-5347(98)01576-6

Tilman, D. (1996). Biodiversity: Population versus ecosystem stability. *Ecology*, *77*(2), 350-363. https://doi.org/10.2307/2265614

Tilman, D., Reich, P. B., & Isbell, F. (2012). Biodiversity impacts ecosystem productivity as much as resources, disturbance, or herbivory. *Proceedings of the National Academy of Sciences of the United States of America*, *109*(26), 10394-10397. https://doi.org/10.1073/pnas.1208240109

Toledo, D., Sanderson, M., Spaeth, K., Hendrickson, J., & Printz, J. (2014). Extent of Kentucky bluegrass and its effect on native plant species diversity and ecosystem services in the Northern Great Plains of the United States. *Invasive Plant Science and Management*, *7*(4), 543-552.

Winter-Feeding Systems and Supplementation of Beef Cows in Mid-Gestation: Effects on Cow/Calf Performance and Subsequent Steer Feedlot Performance

Michael Undi[1], Colin Tobin[2], Tim Long[1] and Kevin Sedivec[1]

[1]Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND
[2]Carrington Research Extension Center, North Dakota State University, Carrington, ND

This study examined the impact of winter-feeding systems (bale grazing versus dry lot pen feeding) and DDGS supplementation on beef cow performance and pre- and post-weaning calf performance. Cow performance was not influenced by winter-feeding systems or DDGS supplementation. In the feedlot, steer final weights, ADG, and feed-to-gain ratios were not influenced by winter-feeding systems or DDGS supplementation during the backgrounding phase. There was, however, a tendency during the finishing phase towards greater final BW and ADG and lower feed-to-gain ratio in steers from supplemented cows. Carcass characteristics, namely, hot carcass weight, marbling, backfat thickness, ribeye area, and yield grade were not influenced by winter-feeding system or supplementation. Results show that winter-feeding systems such as bale grazing do not negatively impact cow performance and subsequent steer feedlot performance. DDGS supplementation may not be necessary when good-quality grass hay is offered to cows in mid-gestation.

Summary

The impact of winter-feeding systems (bale grazing versus dry lot pen feeding) and distillers' dry grains with solubles (DDGS) supplementation on cow/calf performance and steer feedlot performance was evaluated. The study was divided into a bale grazing/dry lot phase and a feedlot phase. During the bale grazing/dry lot phase, 100 cows in mid-gestation were allocated to four replicated treatments as follows: a) bale-grazing grass hay, b) bale-grazing grass hay plus corn DDGS, c) dry lot pen feeding grass hay, and d) dry lot pen feeding grass hay plus DDGS. After weaning, 40 steers (five from each replicate) were shipped to Carrington Research Extension Center for finishing. Cow performance was not influenced ($P \geq 0.05$) by winter-feeding system or supplementation. As well, winter-feeding system or supplementation did not influence ($P \geq 0.05$) calf birth weights, weaning weights, weaning age, or average daily gain (ADG). In the feedlot, final weights, ADG, and feed-to-gain ratios were not influenced ($P \geq 0.05$) by winter-feeding system or supplementation during the backgrounding phase. There was, however, a tendency during the finishing phase towards greater final body weight (BW) ($P = 0.12$) and ADG ($P = 0.11$) and lower ($P = 0.14$) feed-to-gain ratio in steers from supplemented cows. Carcass characteristics, namely, hot carcass weight, marbling, backfat thickness, ribeye area, and yield grade were not influenced ($P \geq 0.05$) by feeding system and supplementation. Results show that winter feeding systems such as bale grazing do not negatively impact cow performance and subsequent steer feedlot performance. DDGS supplementation may not be necessary when good-quality grass hay is offered to cows in mid-gestation.

Introduction

Spring calving season in North Dakota traditionally extends between January to May on respective farms and ranches. In this system, fall to early winter represents a period when cows are in mid to late gestation. Maternal nutrition during gestation plays an essential role in proper fetal development as well as long-term growth, health, and reproductive performance of offspring (Funston et al., 2010). Therefore, nutritional management during mid and late gestation is critical and diets should contain adequate energy, protein and minerals to meet nutrient requirements of the pregnant cow. Meeting nutrient requirements is easily accomplished in wintering pens where animals can be fed balanced diets as total mixed rations. Meeting nutrient requirements of animals kept in extended grazing systems can be a challenge because their diets are forage-based. In such situations, nutrient requirements can be met through provision of good quality forages and appropriate feed supplements. Corn DDGS is commonly fed as a supplement in extended grazing systems. As a supplement, corn DDGS compares favorably with supplements such as soybean meal and canola meal since corn DDGS is a good source of protein, fat, phosphorus, and readily digestible fiber (Klopfenstein et al., 2008).

Studies examining the effect of supplementing cows in mid to late gestation on steer performance have reported variable results probably due to differences in stage of pregnancy, type of supplement offered, level of supplementation, as well as environmental conditions. Pre-partum supplementation of cows during late gestation with cottonseed meal did not impact calf performance and subsequent carcass characteristics (Mulliniks et al., 2012). Similarly, late gestation cow supplementation with corn DDGS did not influence steer feedlot performance and carcass characteristics (Marshall et al., 2013; Wilson et al., 2015). Other studies Larson et al., 2009; Underwood et al., 2010), however, have reported improvements in calf weaning weights and steer carcass characteristics following late gestation cow supplementation. A long-term study (Larson et al., 2009) reported a trend towards greater final weights and ADG in steers and changes in carcass characteristics following cow supplementation during late gestation. Our study was conducted with cows in mid gestation to examine the impact of winter-feeding systems and supplementation on beef cow performance, calf performance, and steer feedlot performance and carcass characteristics.

Procedures

Animal handling and care procedures were approved by the North Dakota State University Animal Care and Use Committee.

This study was conducted with non-lactating pregnant Angus cows that had been bred by artificial insemination with semen from five bulls. The study was set up in two phases, a bale grazing/dry lot phase and a feedlot phase. During the bale grazing/dry lot phase, 100 non-lactating pregnant Angus-cross beef cows were divided into 8 groups of similar average body weight to evaluate four systems: a) bale grazing grass hay only, and b) bale grazing grass hay with corn DDGS supplementation, c) pen feeding grass hay only and, d) pen feeding grass hay with corn DDGS supplementation. Bale grazing was conducted in 1.3-ha paddocks that were separated by three-strand, high-tensile wire electric fencing. Pen-fed cows were kept in 0.1-ha dry lot pens which were surrounded by 2.5-m high wooden windbreaks on 3 sides of the pen. All cows were fed grass hay round bales [8.6% crude protein (CP), 57.2% total digestible nutrients

(TDN); Table 1]. For supplemented cows, corn DDGS (31.2% CP, 75.3% TDN; Table 1) was delivered twice weekly and fed in bunks.

Table 1. Chemical composition (mean ± SD; % dry matter) of grass hay and corn DDGS fed to cows.

Item	Grass hay	Corn DDGS[1]
Crude protein	8.6 ± 0.62	31.2 ± 1.21
Total digestible nutrients	57.2 ± 0.84	75.3 ± 1.46
Neutral detergent fiber	62.0 ± 0.70	31.0 ± 2.02
Acid detergent fiber	40.8 ± 1.08	14.5 ± 2.60
Calcium	0.63 ± 0.08	0.06 ± 0.01
Phosphorus	0.20 ± 0.04	1.04 ± 0.04
Magnesium	0.21 ± 0.01	0.41 ± 0.01
Potassium	1.94 ± 0.08	1.30 ± 0.09
Sulfur	0.19 ± 0.03	0.71 ± 0.06

After weaning in late October, 40 steers (five from each replicate) were shipped to a feedlot for finishing. To eliminate pen effects and maintain in-utero treatment effects, steers were managed as one group. Upon arrival at the feedlot, steers were implanted with Synovex Choice (100 mg trenbolone acetate; 14 mg estradiol benzoate; Zoetis, NJ). Steers were fed a backgrounding diet (14.4% CP and 69.7% TDN; Table 2) for approximately 60 days before receiving a finishing diet (13.3% CP and 81.3% TDN; Table 2) which was fed for 126 days. Steer weights were taken at 28-day intervals. Steers remained in the feedlot for 186 days (60-day backgrounding and 126-day finishing phase) before shipping to a commercial abattoir for harvest and carcass quality data collection.

Feeding steers was accomplished using a “clean bunk” feeding management. The goal of clean bunk management is for all feed delivered to a pen to be consumed daily, with bunks being empty for a certain period of time prior to next feeding, without restricting feed intake (Erickson et al., 2003). The steers were fed once daily at approximately 09:00 each day and feed bunks were targeted to be empty of feed by the following morning. Amount of feed delivered to bunks each week was based on bunk clearance from the previous week. Steers had *ad libitum* access to fresh water, mineral supplement, and salt blocks.

Table 2. Ingredient and chemical composition of diets fed to steers.

Ingredient, %	Backgrounding ration	Finishing ration
Corn grain	20.5	68.3
Modified distillers	19.8	13.4
Corn silage	32.3	9.4
Straw	23.5	6.8
Supplement[1]	3.0	1.3
Limestone	0.9	0.8
Dry matter, %	56.4	69.8
Chemical composition, % DM		
Crude protein	14.4	13.3
Total digestible nutrients	69.7	81.3
Neutral detergent fiber	32.7	17.7
Acid detergent fiber	22.2	8.9
Ether extract	3.9	4.3
Ash	8.2	3.5
Calcium	0.6	0.4
Phosphorus	0.5	0.4
Magnesium	0.3	0.2
Potassium	1.0	0.8
Sulfur	0.3	0.3

[1]Trace mineral premix, vitamin ADE premix, and monensin.

Results and Discussion

Initial cow BW were similar (P = 0.92) among treatments. Winter-feeding system and supplementation not influence ($P \geq 0.05$) final cow BW and ADG (Table 3). Initial cow BCS were similar (P = 0.97) among treatments (Table 3). Final BCS and change in BCS were not influenced ($P \geq 0.05$) by winter feeding system or supplementation (Table 3). These findings are consistent with results from other studies (Stalker et al., 2006; Mulliniks et al., 2012) in which pre-partum cow supplementation did not influence cow BW or body condition score (BCS). Other studies (Larson et al., 2009; Marshall et al., 2013; Wilson et al., 2015; Lardner et al., 2018) have reported beneficial effects of DDGS supplementation. Differences in response among studies could be due to differences in forage used when evaluating prepartum supplementation of cows. Cows fed higher quality forage may be in a more positive nutrient balance, and their progeny may be less susceptible to nutrient restriction during prenatal development (Wilson et al., 2015). In this study, grass hay (8.6% CP and 57.2% TDN) fed met the energy and CP requirements of dry cows in the middle one-third of pregnancy.

Table 3. Performance of cows kept in two winter-feeding systems and fed grass hay or grass hay supplemented with corn DDGS.

	Diet[1] (D)			Feeding System[2] (S)			*P*-value		
	Hay	H-DDG	SE	BG	DL	SE	D	S	D x S
Initial weight, kg	637	636	13.2	637	636	13.2	0.92	0.93	0.92
Final weight, kg	707	712	13.3	710	708	13.3	0.70	0.89	0.57
ADG, kg/d	0.86	0.92	0.04	0.87	0.90	0.04	0.18	0.53	0.20
Initial BCS	5.8	5.8	0.07	5.8	5.8	0.07	0.71	0.83	0.61
Final BCS	6.2	6.1	0.08	6.2	6.1	0.08	0.77	0.41	0.46
BCS change	0.40	0.35	0.05	0.41	0.35	0.05	0.34	0.12	0.07

[1]Hay = grass hay; H-DDG = Hay plus corn DDGS
[2]BG = bale grazing; DL = dry lot pen feeding

Calf performance is shown in Table 4. There was no difference ($P \geq 0.05$) in calf birth weights, weaning weights, weaning age, and ADG among treatments (Table 4). Studies that have reported greater calf weaning weights following pre-partum cow supplementation have attributed this effect to alterations in fetal growth (Marshall et al., 2013). Supplemented cows consume more nutrients and readily surpass nutrient requirements necessary for fetal growth and gain during later stages of pregnancy (Marshall et al., 2013).

In the feedlot, final weights, ADG, and feed-to-gain ratios were not influenced ($P \geq 0.05$) by treatment during the backgrounding phase. There was a tendency during the finishing phase towards greater final weight ($P = 0.12$) and ADG ($P = 0.11$) and lower ($P = 0.14$) feed-to-gain ratio in steers from supplemented cows (Table 4). This finding is similar to Larson et al. (2009) who reported a trend for greater final weight and ADG in steers from supplemented cows.

Carcass characteristics are shown in Table 4. There was no difference ($P \geq 0.05$) in hot carcass weight, marbling, backfat thickness, ribeye area, and yield grade among treatments (Table 4). These findings are consistent with studies (Marshall et al., 2013; Wilson et al., 2015) that have reported that cow supplementation in late gestation does not influence carcass characteristics. Other studies (Stalker et al., 2006; Larson et al. 2009; Underwood et al., 2010) have reported changes in carcass characteristics following cow supplementation in late gestation. Differences among studies could be due to differences in stage of pregnancy as well adequacy of nutrients supplied to cows. The greater ($P \leq 0.05$) ribeye area in steers from cows overwintered in the dry lot relative to bale-grazed pasture (Table 4) is difficult to explain as all other carcass characteristics between the winter-feeding systems were similar. Changes in carcass characteristics are more like to occur as a result of differences in nutrient supply rather than feeding systems.

Results show that winter feeding systems such as bale grazing do not negatively impact cow performance and subsequent steer feedlot performance. DDGS supplementation may not be necessary when good-quality grass hay is offered to cows in mid-gestation.

Table 4. Performance of steers from cows kept in two winter-feeding systems and fed grass hay or grass hay supplemented with corn DDGS.

	Diet[1] (D)			Feeding System[2] (S)			*P*-value		
	Hay	H-DDG	SE	BG	DL	SE	D	S	D x S
Birth to weaning									
Birth weight, kg	41	41	1.7	40	41	1.7	0.96	0.37	0.58
Weaning weight, kg	275	283	8.4	278	279	8.4	0.40	0.92	0.15
Weaning age, d	189	190	1.4	189	190	1.4	0.21	0.49	0.61
ADG, kg/d	1.24	1.27	0.04	1.27	1.25	0.04	0.56	0.67	0.17
Backgrounding phase									
Initial weight, kg	304	313	8.2	306	311	8.2	0.24	0.59	0.09
Final weight, kg	393	400	9.9	393	399	9.9	0.49	0.55	0.21
ADG, kg/d	1.49	1.44	0.06	1.45	1.48	0.06	0.46	0.67	0.66
Feed:gain	7.12	7.45	0.32	7.35	7.22	0.32	0.31	0.69	0.69
Finishing phase									
Initial weight, kg	393	400	9.9	393	399	9.9	0.49	0.55	0.21
Final weight, kg	614	635	13.6	617	632	13.6	0.12	0.27	0.17
ADG, kg/d	1.75	1.86	0.07	1.77	1.84	0.07	0.11	0.28	0.43
Feed:gain	7.30	6.89	0.27	7.26	6.94	0.27	0.14	0.24	0.42
Overall									
Initial weight, kg	304	313	8.2	306	311	8.2	0.24	0.59	0.09
Final weight, kg	614	635	13.6	617	632	13.6	0.14	0.27	0.17
ADG, kg/d	1.67	1.73	0.05	1.67	1.74	0.05	0.27	0.28	0.61
Feed:gain	7.22	6.98	0.22	7.23	6.97	0.22	0.31	0.25	0.60
Carcass characteristics									
HCW, kg	372	371	10.5	372	372	10.5	0.97	0.99	0.54
Marbling	536	540	28.7	530	546	28.7	0.88	0.57	0.98
Yield grade	3.4	3.4	0.2	3.5	3.3	0.2	0.76	0.12	0.63
Backfat, mm	0.64	0.68	0.04	0.67	0.64	0.04	0.29	0.59	0.85
Ribeye area, cm^2	86.1	86.5	2.42	83.8[b]	88.8[a]	2.42	0.88	0.05	0.13

[1]Hay = grass hay; H-DDG = Hay plus corn DDGS
[2]BG = bale grazing; DL = dry lot pen feeding
[a-b]Means with a different letter within row for diet and feeding system differ ($P \leq 0.05$).

Acknowledgements

We thank Cody Wieland, Tim Schroeder, Jesse Nelson, Kalie Anderson, and Rick Bohn for technical assistance.

Literature Cited

Erickson, G. E., Milton C. T., Fanning K. C., Cooper R. J., Swingle R. S., Parrott J. C., Vogel G., and Klopfenstein T. J. 2003. Interaction between bunk management and monensin concentration on finishing performance, feeding behavior, and ruminal metabolism during an acidosis challenge with feedlot cattle. J. Anim. Sci. 81:2869- 2879.

Funston, R. N., Larson, D. M. and Vonnahme, K. A. 2010. Effects of maternal nutrition on conceptus growth and offspring performance: Implications for beef cattle production. J. Anim. Sci. 2010. 88 (E. Suppl.): E205 - E215. https://doi.org/10.2527/jas.2009-2351

Klopfenstein, T. J., Ericson, G. E. and Bremer, V. R. 2008. Board invited review: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86:1223-1231. https://doi.org/doi:10.2527/jas.2007-0550

Lardner, H. B., Larson, K., Christensen, D. A., McKinnon, J. J., Añez-Osuna, F., Damiran, D., da Silva, M. S., and Clark, L. P. 2018. Performance of stocker cattle grazing bales in winter and supplemented with wheat-based DDGS or barley grain in western Canada. Prof. Anim. Sci. 34:460-468. https://doi.org/10.15232/pas.2018-01723

Larson, D. M., Martin, J. L., Adams, D. C. and Funston, R. N. 2009. Winter grazing system and supplementation during late gestation influence performance of beef cows and steer progeny. J. Anim. Sci. 87(3):1147-55. https://doi.org/doi:10.2527/jas.2008-1323

Marshall, C. L., Fensterseifer, S. R., Arias, R. P., Funston, R. N. and Lake, S. L. 2013. The effect of winter protein supplementation during the third trimester on cow and subsequent calf performance. Proc. West. Soc. Am. Soc. Anim. Sci. 64:103-105.

Mulliniks, J. T., Sawyer, J. E., Mathis, C. P., Cox, S. H. and Petersen, M. K. 2012. Winter protein management during late gestation alters range cow and steer progeny performance. J. Anim. Sci. 90:5099-106. https://doi.org/10.2527/jas.2012-5535

Underwood, K. R., Tong, J. F., Price, P. L., Roberts, A. J., Grings, E. E., Hess, B. W., Means, W. J. and Du, M. 2010. Nutrition during mid to late gestation affects growth, adipose tissue deposition, and tenderness in cross-bred beef steers. Meat Sci. 86: 588–593.

Wilson, T. B., Schroeder, A. R., Ireland, F. A., Faulkner, D. B. and Shike, D. W. 2015. Effects of late gestation distillers' grains supplementation on fall-calving beef cow performance and steer calf growth and carcass characteristics. J. Anim. Sci. 93:4843-4851. https://doi.org/10.2527/jas.2015-9228

Forage Production for Selected Varieties of Corn Silage

Justin Leier[1], Kevin Sedivec[1], and Michael Undi[1]

[1]Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND

Summary

Corn silage is an important feedstuff for North Dakota cattle producers economically and nutritionally. However, deciding which variety to grow can be difficult without local data. The 14 corn silage varieties in this trial ranged in dry matter yield from 2.1 to 6.1 ton/acre. The highest producing variety was Croplan 4100S.

Introduction

Cattle production is a very important part of the North Dakota economy. Production has been stable at around 1.8 million cattle including calves (USDA National Agriculture Statistics Service (USDA NASS, 2020). The largest expense for most cattle producers in North Dakota and across the Northern Great Plains is winter feed. Producers not only need to provide enough dry matter, but also need to provide forage of adequate quality. Many producers in North Dakota choose to produce high quality feed for their livestock in the form of silage. In 2020, approximately 145,000 acres of silage were harvested producing 2.25 million tons of feed (USDA NASS, 2020) at a value of $122.9 million dollars.

Just as a farmer selects wheat, grain corn or soybean varieties based on yield data, a good cattle producer should be selecting their silage varieties based on field trial studies. The issue with this concept is that most of the published corn silage data has not been performed in North Dakota, creating decisions based on findings that may not fit your region. The intent of this trial was to provide producers with accurate, local silage data gathered in North Dakota.

Study Area

This corn silage trial was conducted on the NDSU Central Grasslands Research Extension Center near Streeter, ND. Experimental plots were grown on Williams-Zahl soils which are classified as a loam soil on 3-6% slopes (USDA, Natural Resource Conservation Service, 2023). Growing conditions were not ideal in 2022. Although moisture was above normal in May and June, a severe drought occurred in July through September, reducing forage production.

Methods

- The trial was planted on May 24, 2022 using a John Deere 1700 MaxEmerge Plus (8 rows, 30-inch spacing). Seeds were planted two inches deep at a population of 26,000.
- Nutrients were supplied based on soil testing and required started fertilizer (40lbs of Phosphorus and 20lbs of Potassium per acre) and an application of 100lbs/acre of urea and 100lbs/acre of AMS.

- Plots consisted of two rows, 100ft in length which is equal to 0.011acres. There were 14 varieties replicated three times (Table 2).
- Weed control was accomplished through herbicides. Pre-plant burn down was accomplished by applying 1 quart of glyphosate with one ounce of Sharpen® (BASF Corporation). In season weed control consisted of one quart of glyphosate with fifteen ounces of Armezon® PRO (BASF Corporation).
- Plots were harvested on September 8, 2022. Plots were harvested with a two row Gehl corn chopper that shot the silage directly into a Knight mixer/feed wagon equipped with a digital scale. The silage was mixed with the reel as the plot was harvested. After chopping the whole plot into the wagon, the tractor was stopped and weight record. A composite sample of each plot was taken as the wagon was unloaded and used to determine forage quality.
- Data was analyzed as a randomized complete block design using the general linear model in SAS 9.4 (SAS Institute, Cary, NC). Significant differences of least square means at the $P \leq 0.05$ level were separated using t-tests.

Table 2. List of varieties with company and relative maturity (RM).

Company	Variety	RM
Croplan	CP 4100S	101
Croplan	CP 3200S	93
Croplan	CP 3899	98
Integra	STP4810	98
Integra	STP5191	101
Integra	STP5209	102
Innvictis Seed Solutions	A9938VT2PRIB	99
Innvictis Seed Solutions	A9436VT2PRIB	94
Innvictis Seed Solutions	B8548-3120ez	85
AgVenture	AV4104Q	104
Stine	9543-G	103
Stine	9212-10	89
Stine	9202-G	86
Stine	9319-10	93

Results

Corn varieties were analyzed for harvest weight, yield, and dry matter. There were significant differences among varieties for production.

Table 3 presents all of the harvest and yield data. The top ten varieties ranged in yield from 3.27 – 6.10 tons/acre at 65% dry matter. Variety 4100S was the highest yielding variety, but not significantly different from A9938VT2PRIB, A9436VT2PRIB, 3200S and AV4104Q.

Table 3. LS means at 65% dry matter (DM) yield at Central Grasslands Research Extension Center in 2022.

Variety	65% DM[1]
	Tons/acre
CP 4100S	6.10[a]
A9938VT2PRIB	5.58[ab]
A9436VT2PRIB	5.34[ab]
CP 3200S	5.05[abc]
AV4104Q	4.98[abc]
STP5209	4.51[bcd]
STP5191	4.21[cde]
CP 3899	4.20[cde]
STP4810	4.12[cde]
B8548-3120ez	3.27[def]
9543-G	3.09[ef]
9212-10	2.66[f]
9202-G	2.36[f]
9319-10	2.10[f]
LSD	1.34

[1] Values in the same column followed by the same letter are not significantly different by the t-test at the 95% level of confidence.

Literature Cited

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. 2023. Web Soil Survey. Available online at the following link: http://websoilsurvey.sc.egov.usda.gov/. Accessed [3/28/2023].

United States Department of Agriculture National Agriculture Statistics Service [USDA/NASS]. 2021. 2020 State Agriculture Overview – North Dakota. Retrieved from https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=NORTH%20DAKOTA

Yield of Five Clovers Spring Inter-Seeded with Forage Oats at Two Seeding Rates

Justin Leier, NDSU - Central Grasslands Research Extension Center, Streeter N.D.

In 2021, we planted an annual forage legume trial. The purpose of this trial was to see annual legumes that we had not seen in the field and to compare forage production and nitrogen fixation. However, due to weed control issues, the trial was mowed off in July prior to field day. Subsequently, it was observed that several of the clovers grew back exceptionally well. This observation and knowledge of clover inter-seeding done with spring wheat in Wisconsin gave birth to the idea of inter-seeding these clovers with annual forages.

In 2022, we chose forage oats (Goliath), as it is a good annual forages model crop and inter-seeded five clovers: Berseem, Crimson, Mammoth Red, Medium Red, and Subterranean. In all plots, the oats were seeded at full rate because it would be unrealistic to sacrifice the main crop yield to grow a cover crop. Clovers were seeded at recommended full rate and 75% rate. Due to the nature of our plot seeder, the oats and clover were mixed and planted together along with inoculant for the clovers that was applied on the day of planting.

We intended to measure yield data of the forage oats, however the forage harvester had a faulty scale and the data was unreliable. We harvested the oats on July 15 and clipped cumulative clover growth on September 15, prior to any damaging frost.

Seeding the clovers at a full seeding rate proved beneficial as every species yielded more dry matter at 100% seeding rate than at 75% seeding rate. The only clover that did not perform well was the Berseem clover, which was not the expectation. Our hypothesis is that because the Berseem clover had grown taller than the others, we cut more of the plant material off when we harvested the oats. This cutting may have been enough to kill the plants.

This is only the first year of experimentation, but the results are promising (Table 1). These clovers show promise as a ground-protecting cover crop. The dry matter yield also would provide excellent quality forage for livestock, which would be the most cost-effective way to utilize these inter-seeded clovers (Table 2). By planting these clovers at the same time as the oats, we eliminate the extra field pass which is required to plant most cover crops. No herbicide can be applied to this inter-seeded mix, but we also noted that the plots with clovers had fewer weeds growing in them than the oats plots without clover.

Table 1. Cumulative growth of five clovers inter-seeded with forage oats at two seeding rates at CGREC in 2022.

Variety	Seeding Rate	Forage Yield[1]
	(%)	----lbs./acre----
Crimson	100	4027.5[a]
Subterranean	100	3715.8[a]
Mammoth	100	2899.7[ab]
Medium	100	3603.2[ab]
Berseem	100	0[c]
Crimson	75	2895[ab]
Subterranean	75	3401.1[ab]
Mammoth	75	2374.1[b]
Medium	75	2829.8[ab]
Berseem	75	0[c]
LSD		*1309*

[1] Values followed by the same letter in the column are not significantly different.

Table 2. Cost comparison of five clovers inter-seeded with forage oats at two seeding rates at CGREC in 2022.

Variety	Seeding Rate	Seeding Rate	Seed Cost		Forage Cost
	(%)	lbs./acre	$/lb.	Price/acre	$/lb. of Dry Matter
Berseem	100	12	2.95	35.40	na
Crimson	100	25	2.15	53.75	0.01
Mammoth	100	12	3.05	36.60	0.01
Medium	100	12	3.15	37.80	0.01
Subterranean	100	25	4.25	106.25	0.03
Berseem	75	9	2.95	26.55	na
Crimson	75	18.75	2.15	40.31	0.01
Mammoth	75	9	3.05	27.45	0.01
Medium	75	9	3.15	28.35	0.01
Subterranean	75	18.75	4.25	79.69	0.02

Figure 1. Clover variety Subterranean on the day of clipping, Sept. 15, 2022.

Figure 2. Clover variety Subterranean on the day of clipping, Sept. 15, 2022.

Yield and Quality of Oats Grown for Forage

Justin Leier, NDSU - Central Grasslands Research Extension Center, Streeter N.D.

Introduction

Many producers in North Dakota depend on annual forages such as oats as a source of cattle nutrition. Not all of these producers are growing forage oats specifically, but may be planting grain oats and harvesting them for forage. There are differences between oat varieties in grain yield, grain quality, and also forage quality. Gill et al. (2013) found forage oat varieties to exhibit significant differences in plant height, dry matter, detergent fibers, certain mineral contents (calcium, magnesium, sodium and sulfur), forms of energy including total digestible nutrients, and relative feed value.

Variety trials are an effective way to inform producers which oat varieties will produce the highest quality or the highest yield. This two-year trial is collaboration between the NDSU oat breeding program and the NDSU Central Grasslands Research Extension Center. It was designed to include oat varieties commonly grown in the state, along with forage quality and yield check varieties. This trial is intended to provide producers with forage data on oat varieties and help them to make an educated decision on which variety is right for their operation.

Table 1. List of varieties included in the oats for forage trial at CGREC in 2022.

Variety	Type
Beach	Grain
Goliath (SD)	Dual Purpose
Newburg	Grain
Paul	Grain
ND000461	Grain
Souris	Grain
Jerry	Grain
Everleaf 126	Forage
Everleaf 114	Forage

Methods

- Trial consisted of nine varieties (Table 1).
- Plots were planted on May 3, 2021 and May 10, 2022 using a custom-built small plot drill. Plots were 5- ft x 20-ft and planted at a depth of 1.25 inches at a rate of 85 lb/acre.
- Plots were fertilized with 100 lb/acre of urea and 100 lb/acre of AMS on May 12th.
- Weeds were controlled by a single application of Glyphosate and Sharpen according to product labels on May 4, 2021 and May 8th, 2022.
- Height measurement was taken at the time of harvest, which was executed when each plot reached soft dough.
- A 0.25-m^2 biomass cutting was used to calculate the forage yield. This sample was also used for nutrient analysis.
- Trial was designed and analyzed as a randomized complete block with three replicates. Analysis was performed using the general linear model procedure in SAS 9.4 (SAS Institute, Cary, NC). Significant differences of least square means at the $P \leq 0.05$ level were separated using t-tests.

Results

Over the last two years, there were no significant differences found in the forage yield of the ten varieties tested (Table 2). In 2022, the highest yielding varieties were Everleaf 126 and Paul at 4.56 and 4.36 tons/acre, respectively. The lowest yielding varieties were Newburg and Souris at 3.57 and 3.38 tons/acre, respectively.

Table 2. Height, days to heading, days to soft dough, and forage yield of select varieties of oats.

Variety	Days to Heading	Days to Soft Dough	Height	Forage Yield	
			--in--	-----tons/acre-----	
				2021	2022
Paul	55	74	34	1.65	4.36
Everleaf 126	71	74	34	1.62	4.56
Jerry	51	70	31	1.37	4.31
Newburg	54	74	36	1.28	3.57
ND000461	62	74	32	1.26	3.68
Beach	52	67	35	1.25	3.59
Mustang 120	55	74	31	1.22	na
Souris	52	66	30	1.21	3.38
Goliath	55	74	40	1.16	3.94
Everleaf 114	68	70	31	na	4.26
LSD				NS	NS

Significant varietal differences were found for all of the feed quality parameters measured except for magnesium (Table 3). ND000461 and Everleaf 126 were the top varieties in terms of quality. ND000461 had the highest crude protein, total digestible nutrients (TDN), and calcium as well as the lowest acid detergent fiber (ADF) and lignin. ND000461 also performed in the top three for all minerals measured. Everleaf 126 and Souris had the second and third lowest lignin contents, respectively. Newburg and Souris both had the second and third lowest ADF and second and third highest TDN measurements.

Table 3. Feed quality of select varieties of oats planted at CGREC in 2022.

Variety	Crude Protein	ADF	NDF	Lignin	TDN	Ca	P	K	Mg	Sulfur
	-- % Dry Matter--									
Beach	10.74bc[a]	37.31a	60.45ab	7.02ab	59.83b	0.34b	0.29bc	1.74ab	0.18	0.17d
Goliath (SD)	10.11c	37.68a	60.21ab	7.88a	59.54b	0.35b	0.29bc	1.63b	0.18	0.16cd
Newburg	11.15abc	36.36a	59.17ab	7.34ab	60.57b	0.38ab	0.30abc	1.85ab	0.18	0.17cd
Paul	10.23bc	38.03a	59.85ab	8.11a	59.27b	0.39ab	0.27c	1.53b	0.20	0.17cd
ND000461	13.98a	33.93b	57.58b	5.62b	62.46a	0.43a	0.32ab	1.90ab	0.20	0.23ab
Souris	12.54abc	36.40a	60.64ab	6.45ab	60.54b	0.39ab	0.30abc	1.92ab	0.21	0.21abc
Jerry	11.63abc	37.09a	60.33ab	7.13ab	60.00b	0.40ab	0.29bc	1.56b	0.20	0.20abcd
Everleaf 126	13.25a	37.45a	61.13a	6.09ab	59.72b	0.36ab	0.33a	2.42a	0.19	0.24a
Everleaf 114	11.17abc	37.88a	62.67a	7.29ab	59.39b	0.38ab	0.29bc	1.85ab	0.18	0.18bcd
LSD	3.05*	2.31*	3.50*	2.05*	1.80*	0.07*	0.036*	0.69*	NS	0.055*

[a] Values in the same column followed by the same letter are not significantly different by the t-test at the 95% level of confidence.

Literature Cited

Gill, K. S., A. Omokanye, J. D. Pettyjohn and M. Elsen. 2013. Agronomic performance and beef cattle nutrition suitability of forage oat varieties grown in the Peace Region of Alberta, Canada. The Journal of Agricultural Science 5:128.

Forage Production, Quality and Cost Comparison for Selected Varieties of Forage Oats, Forage Barley, Forage Wheat, and Spring Triticale

Kevin Sedivec[1], Scott Alm[1], Justin Leier[1], Michael Undi[1], and Mike Ostlie[2]
North Dakota State University, Central Grasslands[1] and Carrington[2] Research Extension Center; Crystal Schaunaman, McIntosh Extension Agent; Sheldon Gerhardt, Logan Extension Agent; Emily Leier, Emmons Extension Agent

Summary

Forage oats was the highest-producing cereal crop at the Central Grasslands Research Extension Center (CGREC) from 2019 to 2022, ranging from 1.66 to 3.65 tons/acre; and two of three years at the Tri-county Agronomy Site (TCAP) near Wishek, ranging from 1.25 to 2.75 tons/ac from 2020 to 2022. During the drought years in 2020 and 2021, no differences were found between the forage types (oats, barley, triticale, wheat) at the TCAP or CGREC. In 2021, no cereal crop type performed better than another, but Merlin Max and BYS FT were the highest producing varieties while the wheat species lowest. In 2022, most varieties produced 3 to 4.5 ton/ac; however, Haymaker forage barley, and Flex 719 and Thor spring triticale were the lowest producing.

The spring triticale varieties had the highest crude protein content, with all over 11% at the early dough stage in 2019 and all but BYS FT in 2020. Among the oat varieties, only the forage oat Goliath had a crude protein content greater than 11% in 2019.

The forage barley varieties, along with BYS FT spring triticale, contained the lowest levels of acid detergent lignin (ADL) and less than 4% in 2019 and 2020, with all forage oats lees than 4% in 2020. Total digestible nutrients (TDN) also were highest in the forage barley varieties and BYS FT spring triticale in 2019 and highest in the forage wheat in 2020.

On average (year, location and variety), forage oats produced 2.37 ton/ac, 10.0 % crude protein, 62.9 % TDN, 4.1 % ADL, 0.29 % calcium, and 0.23 % phosphorus. Average forage barley production was 1.77 ton/ac, 10.3 % crude protein, 64.4 % TDN, 3.4 % ADL, 0.33 % calcium, and 0.22 % phosphorus. Average for spring triticale production was 1.91 ton/ac, 11.5 % crude protein, 62.2 % TDN, 4.4 % ADL, 0.25 % calcium, and 0.27 % phosphorus.

Study Area

This study was conducted on the Central Grasslands Research Extension Center (CGREC) in 2019, 2021 and 2022; and the Tri-county Agronomy Plots near Wishek (TCAP) in 2020, 2021 and 2022. Experimental plots at CGREC were on soils of the Hecla-Ulen soil series, classified as loamy fine sands; and plots at TCAP on soils of the Lehr-Bowdle soil series and classified as loamy (USDA, Natural Resources Conservation Service, 2020).

Precipitation was above average for 2019 and below average for 2021 and 2022 at the CGREC (**Table 1**). Precipitation was below average in 2020 and 2021, and near normal in 2022 at the TCAP (**Table 1**).

Procedures

- The trial was planted on May 28, 2019; May 12, 2020; May 19, 2021; and June 3, 2022.
- All nutritional analysis was conducted at the North Dakota State University Nutrition Lab using AOAC standards (AOAC, 2019).
- Total digestible nutrients (TDN) were determined using acid detergent fiber and energy equation (98.625-[1.048*ADF]).
- Study design was a randomized block design with four replications and analyzed used a general linear model in SAS.

Results

Forage oats was the highest producing forage type at CGREC in 2019, but similar to spring triticale in 2021 and 2022. Forage oats was the highest producing forage at TCAP in 2022, but similar to spring triticale in 2021 and lower than forage barley in 2020 (**Table 2**).

<u>Forage Oats</u>

With the exception to 2019, there was no difference in yield between varieties at either location or in 2020-2022. In 2019 at CGREC, Everleaf 126 was higher in production than Mustang 120 and BYS FO.

The was no difference between varieties for any year or location in 2019 and 2020 for crude protein or TDN. Everleaf 126 was higher than all other varieties for calcium in 2020, and higher than Mustang 120 and Goliath for phosphorus in 2020. BYS FO was the only variety to have an acid detergent lignin (ADL) content of 4.0 percent or lower in 2019, and was significantly lower than Everleaf 126. There was no difference between varieties for ADL in 2020, with all four varieties less than 4.0 percent (**Table 3**).

<u>Forage Barley</u>

There was no difference in forage production among varieties for all years and locations except at CGREC in 2022. Hayes produced 3.18 ton/ac compared to 1.71 ton/ac for Haymaker in 2022 (**Table 2**).

There was no varietal difference for crude protein, TDN, ADL, or phosphorus levels for all years and locations. Axcel and Haymaker contained higher phosphorus levels than Hayes at TCAP in 2020 (**Table 3**).

<u>Spring Triticale</u>

There were no varietal differences in 2019 and 2021 at CGREC for forage production. However, Hybrid Merlin Max and Pronghorn produced greater forage than Flex 719 in 2022. There were no varietal differences at TCAP in 2020 for production. BYS FT and Hybrid Merlin Max produced more forage than Flex 719, Thor and Gunner at TCAP in 2021; and Flex 719 and Surge were lower than Pronghorn and Gunner in 2022 (**Table 2**).

There were no varietal differences in crude protein, ADL, TDN, calcium or phosphorus in 2019. BYS FT and Exp. 2063 were the lowest in crude protein; however, BYS FT and Thor lowest in ADL in 2020. Flex 719 was highest in TDN, calcium and phosphorus in 2020 (**Table 3**).

Table 1. Precipitation during the study period May through August at the Central Grasslands Research Extension Center near Streeter in 2019, 2021, and 2022; and Tri-county Agronomy Plots near Wishek in 2020, 2021, and 2022 (NDAWN, 2023).

Month	Precipitation (inches)			Percent of Normal			Precipitation (inches)			Percent of Normal		
				Central Grasslands Research Extension Center near Streeter			Tri-county Agronomy Site near Wishek					
	2019	2021	2022	2019	2021	2022	2020	2021	2022	2020	2021	2022
May	2.99	2.01	3.82	122	82	137	1.69	3.38	3.82	66	131	131
June	3.47	1.20	2.68	102	35	74	1.57	1.53	3.71	52	51	102
July	4.15	0.32	1.28	130	10	38	3.10	1.57	1.67	113	57	52

Table 2. Yield for selected varieties of forage oats, forage barley, spring triticale and forage wheat at Central Grasslands Research Extension Center (CGREC) in 2019, 2021 and 2022, and Wishek Tri-county Agronomy Plot (TCAP) in 2020 - 2022.

Cereal Crop[1]	Variety		Yield (100% DM) (ton/acre)[2]						
		CGREC[3]	CGREC	CGREC	CGREC	TCAP	TCAP	TCAP	TCAP
		2019	2021	2022	3-yr Mean	2020	2021	2022	3-yr Mean
FO	Everleaf 126	3.68^{a}	1.82^{a}	3.36^{a}	2.95	1.99^{ab}	1.10^{bcde}	2.47^{abc}	1.85
FO	Goliath	3.24^{ab}	1.61^{a}	3.46^{a}	2.77	1.71^{ab}	1.37^{abc}	2.66^{ab}	1.91
FO	Mustang 120	2.67^{bc}	1.31^{a}	-------	------	2.03^{ab}	1.29^{abcd}	------	------
FO	BYS FO	2.57^{bcd}	1.90^{a}	3.22^{a}	2.56	1.65^{ab}	1.23^{abcde}	3.11^{a}	2.00
FO	Everleaf 114	-------	------	4.55^{a}	------	------	------	2.57^{abc}	------
	Mean	***3.04^{x}***	***1.66^{y}***	***3.65^{x}***		***1.85^{y}***	***1.25^{y}***	***2.75^{x}***	
FB	Axcel	1.45^{e}	1.39^{a}	------		2.00^{ab}	1.02^{de}	------	------
FB	Haymaker	1.34^{e}	1.49^{a}	1.71^{c}	1.51	2.17^{a}	1.07^{cde}	2.29^{bcd}	1.84
FB	Hayes	-------	1.53^{a}	3.18^{ab}		1.93^{ab}	1.00^{de}	2.15^{bcde}	1.69
	Mean	***1.40^{y}***	***1.47^{y}***	***2.45^{z}***		***2.03^{yz}***	***1.03^{y}***	***2.22^{z}***	
ST	BYS FT	1.88^{cde}	1.48^{a}	3.22^{ab}	2.19	1.69^{ab}	1.42^{ab}	1.75^{def}	1.62
ST	Hybrid Merlin Max	1.75^{de}	1.47^{a}	4.28^{a}	2.50	1.51^{ab}	1.44^{a}	1.78^{cdef}	1.58
ST	Hybrid Surge	-------	------	4.05^{ab}	------	------	------	2.16^{bcde}	------
ST	Bunker	1.41^{e}	1.96^{a}	------	1.69^{y}	1.40^{b}	1.18^{abcde}	-------	------
ST	Flex 719	-------	1.55^{a}	2.16^{bc}	1.86^{y}	1.46^{ab}	0.96^{de}	1.24^{f}	1.22
ST	Surge	-------	1.58^{a}	3.18^{ab}	2.38^{y}	1.58^{ab}	1.14^{abcde}	1.45^{ef}	1.39
ST	Thor	-------	1.69^{a}	2.56^{abc}	2.13^{y}	1.44^{ab}	1.08^{cde}	2.01^{bcdef}	1.51
ST	Pronghorn	-------	1.87^{a}	4.38^{a}	3.13^{y}	-------	1.21^{abcde}	2.54^{abc}	------
ST	Gunner	-------	1.58^{a}	3.75^{ab}	2.67^{y}	-------	1.08^{cde}	2.64^{ab}	------
	Mean	***1.68^{y}***	***1.65^{y}***	***3.45^{x}***		***1.51^{y}***	***1.19^{y}***	***1.95z***	
FW	3119A	-------	1.57^{a}	------	------	-------	0.92^{e}	------	------
FW	3099A	-------	1.39^{a}	------	------	1.80^{ab}	1.06^{cde}	------	------
	Mean		***1.48^{y}***			***1.80^{y}***	***0.99^{y}***		

[1] FO = Forage Oat, ST = Spring Triticale, FB = Forage Barley, FW – Forage Wheat.
[2] Varieties within the same row with the same letter (a, b, c, d, e) are not statistically different (P>0.05).
[3] Forage type (FO, FB, ST, FW) mean within the same row with the same letter (x, y, z) are not statistically different (P>0.05).

Table 3. Forage quality content for selected varieties of forage oats, forage barley, spring triticale and forage wheat at Central Grasslands Research Extension Center in 2019 and Wishek Tri-county Agronomy Plot in 2020.

Cereal Crop[1]	Variety	Crude Protein[2] (%)		Acid Detergent Fiber[2] (%)		Acid Detergent Lignin[2] (%)		Total Digestible Nutrients[2] (%)		Calcium[2,3] (%)		Phosphorus[2,3] (%)	
		2019[4]	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
FO	Everleaf 126	8.8^{b}	10.5^{d}	35.2^{ab}	32.9^{bcd}	4.6^{a}	3.8^{fgh}	61.9^{ab}	64.8^{abc}	0.27	0.40^{a}	0.21	0.26^{bcde}
FO	Mustang 120	9.5^{ab}	10.1^{d}	35.2^{ab}	34.2^{abcd}	4.2^{ab}	3.9^{efg}	61.8^{ab}	63.9^{abcd}	0.24	0.29^{bcde}	0.21	0.19^{h}
FO	BYS FO	9.9^{ab}	10.0^{d}	35.5^{ab}	34.9^{abc}	4.0^{b}	3.8^{fgh}	61.4^{ab}	63.8^{bcd}	0.27	0.33^{b}	0.27	0.23^{efgh}
FO	Goliath	11.0^{ab}	10.0^{d}	37.2^{a}	32.1^{cd}	4.5^{ab}	3.7^{ghi}	59.7^{b}	65.4^{ab}	0.22	0.29^{bcde}	0.21	0.20^{gh}
	Mean	***9.8^{x}***	***10.2^{x}***	***35.8^{x}***	***33.5^{x}***	***4.3^{x}***	***3.8^{x}***	***61.2^{x}***	***64.5^{x}***	***0.25^{x}***	***0.33^{x}***	***0.23^{x}***	***0.22^{x}***
FB	Axcel	10.5^{ab}	10.4^{d}	32.3^{b}	32.3^{bcd}	3.5^{c}	3.5^{hi}	64.8^{a}	65.2^{abc}	0.28	0.42^{a}	0.22	0.22^{efgh}
FB	Haymaker	9.7^{ab}	10.7^{cd}	33.4^{ab}	34.4^{abcd}	3.4^{c}	3.4^{i}	63.7^{ab}	63.8^{abcd}	0.28	0.40^{a}	0.22	0.21^{fgh}
FB	Hayes	-------	10.3^{d}	-------	33.1^{abcd}	-----	3.4^{i}	-------	64.7^{abcd}		0.32^{bc}		0.24^{defg}
	Mean	***10.1^{xy}***	***10.5^{x}***	***32.8^{y}***	***33.3^{x}***	***3.4^{y}***	***3.4^{y}***	***64.3^{y}***	***64.6^{x}***	***0.28^{x}***	***0.38^{y}***	***0.22^{x}***	***0.22^{x}***
ST	BYS FT	11.0^{ab}	10.2^{d}	33.7^{ab}	34.2^{abcd}	4.3^{ab}	4.0^{edf}	63.4^{ab}	63.9^{abcd}	0.23	0.22^{fg}	0.27	0.24^{cdef}
ST	Bunker	12.0^{a}	11.2^{bcd}	35.8^{ab}	34.6^{abcd}	4.3^{ab}	4.4^{bc}	61.1^{ab}	63.6^{abcd}	0.22	0.25^{ef}	0.27	0.24^{cdef}
ST	Merlin Max	11.4^{ab}	11.9^{bc}	36.6^{ab}	35.3^{abc}	4.7^{a}	4.6^{b}	60.2^{ab}	63.1^{bcd}	0.27	0.31^{bcd}	0.27	0.28^{bc}
ST	141	10.4^{ab}	--------	36.7^{a}	-----	4.4^{ab}	----	60.2^{b}	------	0.25	-----	0.23	-----
ST	Flex 719	-------	13.5^{a}	-------	32.6^{bcd}	-----	4.2^{cd}	-------	65.0^{abc}		0.32^{bc}		0.35^{a}
ST	Surge	-------	12.3^{ab}	-------	35.9^{ab}	-----	4.4^{bc}	-------	62.7^{cd}		0.26^{cdef}		0.28^{bc}
ST	Thor	-------	12.3^{ab}	-------	35.6^{abc}	-----	4.1^{cde}	-------	62.9^{bcd}		0.26^{def}		0.29^{b}
ST	Exp. 2063	-------	11.0^{cd}	-------	36.8^{a}	-----	5.0^{a}	-------	62.1^{d}		0.21^{fg}		0.27^{bcd}
	Mean	***11.2^{y}***	***11.8^{y}***	***35.7^{x}***	***35.0^{y}***	***4.4^{x}***	***4.4^{z}***	***61.2^{x}***	***63.3^{x}***	***0.24^{x}***	***0.26^{z}***	***0.26^{y}***	***0.28^{y}***
FW	3099	-------	11.0^{cd}	-------	30.9^{d}	-----	4.2^{cde}	-------	66.2^{a}		0.19^{g}		0.24^{cdef}

[1] FO = Forage Oat, ST = Spring Triticale, FB = Forage Barley, FW = Forage Wheat.
[2] Varieties with the same letter (a, b, c, d, e, f, g, h) are not statistically different (P>0.05).
[3] We found no difference (P>0.05) among varieties in calcium or phosphorus content in 2019.
[4] Forage type (FO, FB, ST, FW) mean within the same row with the same letter (x, y, z) are not statistically different (P>0.05).

References

AOAC. 2019. Official Methods of Analysis. 21st ed. Gaithersburg, Md.: Association of Official Analytical Chemists.

NDAWN 2023. North Dakota Agricultural Weather Network. https://ndawn.ndsu.nodak.edu

USDA, Natural Resources Conservation Service. 2020. Web Soil Survey. https://websoilsurvey.nrcs.usda.gov/app/HomePage.htm. Accessed Jan. 29, 2019.

Breeding Bird Communities and Nesting Survival in a Heterogeneity-based Rotation Grazing System

Justin Clarke[1], Torre Hovick[1], and Kevin Sedivec[1,2]

[1] School of Natural Resource Sciences, North Dakota State University
[2] NDSU - Central Grasslands Research Extension Center

Summary

Traditional grazing management focuses on maximizing cattle production through uniform utilization of forage resulting in reduced vegetation structure and composition. This homogenization decreases avian niche diversity, contributing to ongoing declines in grassland bird communities. Patch-burn grazing can restore vegetation heterogeneity, but a cultural aversion to fire warrants alternative heterogeneity-based management.

In 2018, we established a modified rotation grazing system that varies grazing intensity to create heterogeneity across paddocks. Our treatment structure includes four replicates, each split into four paddocks based on percent utilization: heavy (60+%), full (40-60%), moderate (20-40%), and rested (0%). We assessed the efficacy of this system to achieve heterogeneity and the subsequent impacts on grassland birds by quantifying grazing intensity impacts on 1) vegetation structure, 2) avian community composition, and 3) nest survival. We conducted vegetation sampling to quantify vegetation structure, and rope dragging to locate nests within paddocks. Nests were subsequently monitored to determine fate. We incorporated vegetation structure and composition measurements taken at each nest into a hierarchical modeling scheme using RMark to assess nest survival.

We found that modifying grazing intensity within a pasture creates heterogeneity ranging from tall and dense rested paddocks to short and sparse heavy-use paddocks. Grazing intensity did not directly alter avian nesting community composition in either 2021 or 2022 (p = 0.06, 0.099, respectively). However, nest survival of grassland birds may be indirectly impacted by grazing through the manipulation of key structural components associated with nest survival including litter depth and vegetation height. Responses to these structural components were species-specific, reflecting the importance of heterogeneity when managing for diverse grassland birds.

Our results demonstrate the potential for an alternative management practice that increases heterogeneity and can inform grassland bird management. When fire cannot be applied, this management practice can incorporate conservation needs into a livestock production system.

Introduction

Historically, fire and grazing shaped North American grasslands and avian communities by creating a shifting mosaic of vegetation structure and composition (Fuhlendorf & Engle, 2001). In contrast, current rangeland management focuses on uniform utilization of forage to maximize cattle production, resulting in reduced variation in vegetation structure and composition (Becerra et al., 2017; Fuhlendorf et al., 2009). Homogenization of rangelands decreases avian niche diversity, contributing to ongoing grassland bird declines (Rosenberg et al., 2019; Sauer et al., 2013). Since grassland birds evolved in heterogeneous landscapes shaped by the interaction of large herbivores and fire, restoring vegetation structural variability in rangelands is a crucial part of avian conservation on working landscapes (Christensen, 1997; Fuhlendorf & Engle, 2001; Ostfeld et al., 1997; Wiens, 1997).

Heterogeneity-based management practices can blend the needs of conservation while simultaneously promoting cattle production (Fuhlendorf et al., 2006). Management focused on creating heterogeneous vegetation structure can increase avian prey availability, decrease brood parasite abundance, and increase potential habitat for specialist grassland bird species (Churchwell et al., 2008; Coppedge et al., 2001; Engle et al., 2008). Diversity in vegetation structure is especially beneficial for grassland birds that rely on the far ends of the vegetation structural gradient. For example, the upland sandpiper relies on dense vegetation for nesting but forages in open patches (Sandercock et al., 2015). Additionally, species such as the chestnut-collared longspur and Northern pintail rely on the sparser end of the vegetation spectrum whereas Le Conte's Sparrows can be found at the denser end (Beauchamp et al., 1996; Davis et al., 1999; Hovick et al., 2014).

Patch-burn grazing has emerged as the most effective method for achieving heterogeneity in rangelands (Duchardt et al., 2016; Fuhlendorf & Engle, 2001; McNew et al., 2015). This management practice relies on the patchy application of fire within a pasture to manipulate the grazing patterns of livestock (Fuhlendorf et al., 2009). However, many land managers in the northern Great Plains are hesitant to use fire as a management strategy (Sliwinski et al., 2018). Reluctance to the use of prescribed fire creates a need for innovative methods to promote grassland heterogeneity for the conservation of declining grassland birds.

We have found that twice-over rest-rotation grazing, a common practice in North Dakota, can be modified to achieve heterogeneity in vegetation structure in the absence of fire (Duquette et al., 2022). This study utilizes a unique modified twice-over rest-rotation grazing (MTORG) system to create vegetation heterogeneity using varying grazing intensities to maximize conservation potential and cattle production (Duquette et al., 2022). Varying grazing intensities creates a vegetation structural gradient that will alter grassland bird species composition, specifically benefiting specialist grassland species at the far ends of the structural gradient (Coppedge et al., 2008; Holcomb et al., 2014; Pillsbury et al., 2011).

We hypothesize that avian nesting communities, densities, and nest survival will vary across paddocks, with the lowest community diversity and nest survival in the highest-stocked paddock. Nesting diversity should be lowest at the extreme ends of this structural gradient because relatively few specialized species, including species of special concern like the chestnut-collared longspur, rely on short vegetation structure (Churchwell et al., 2008). Our objectives are to assess the efficacy of this system in achieving heterogeneity and the subsequent impacts on grassland birds by quantifying grazing intensity impacts on 1) vegetation structure, 2) avian nesting community composition, and 3) nest survival.

Methods

Study Area

Central Grasslands Research Extension Center (CGREC) is located in the Missouri Coteau ecoregion and the central part of North Dakota along the border of Kidder and Stutsman counties. The study area has a temperate, continental climate with an average growing season precipitation of 36.4 cm and average growing season temperatures of 14.8° C (NDAWN, 2022). However, 2021 was a drought year with lower-than-average precipitation (25.4 cm) and higher-than-average temperatures (16.4° C).

Rangeland at CGREC is classified as Northern mixed-grass prairie, with an herbaceous community comprised of perennial, cool season (C_3) grasses including western wheatgrass (*Pascopyrum smithii)* and green needlegrass (*Nassella viridula*), although invasive plants including Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) have become dominant in most of the paddocks (Limb et al., 2018; Patton et al., 2007).

The forb community is diverse and includes goldenrods (*Solidago* spp.), sages (*Artemisia* spp.), prairie coneflower (*Ratibida columnifera*), thistles (*Cirsium* spp.), as well as many other herbaceous species. The woody vegetation is predominately western snowberry (*Symphoricarpos occidentalis*) with patches of silverberry (*Eleagnus commutata*) and wild rose (*Rosa arkansana*) (Limb et al., 2018; Patton et al., 2007).

Treatment Structure

The MTORG system is designed to create heterogeneity in vegetation structure by varying grazing intensities within a pasture. The study system includes four replicates with each replicate split into quarters, herein referenced to as paddocks, based on percent grazing utilization. The four paddocks within each of the four experimental replicates and their level of utilization are as follows: rested (0%), moderate (20-40%), full (40-60%), and heavy (60+%). Throughout the treatment, a moderate stocking rate (2.76 AUM/ha) has been used with varied lengths of grazing periods to achieve the desired utilization percentage (Duquette et al., 2022).

Paddocks rotate each year, with the rested paddock becoming the moderate paddock, the moderate to full, the full to heavy, and the heavy to rest. Cattle movement within the 65-hectare pasture is constrained to each paddock (approximately 16 hectares) using interior fencing (Duquette et al., 2022). The system completed one full cycle prior to 2021.

Vegetation Surveys

We measured vegetation structure within each grazing intensity using three 25-m transects in each paddock. Vegetation measurements were taken at 0, 12.5, and 25-m along each transect. Structural measurements included visual obstruction readings (VOR) and litter depth.

We determined VOR using the height at which a Robel pole was 50% obscured at a 4-m distance with the viewer's eye-level 1-m above the ground (Robel et al., 1970). This measurement was taken in each cardinal direction and averaged together for each location along the transect. Litter depth was measured in the northwestern corner of a 0.5-m x 1-m quadrat centered at each transect location (Daubenmire, 1959; Duquette et al., 2019). Vegetation measurements were taken at the end of the breeding season during the first two weeks of August.

Nest Searching/Monitoring

We searched for nests by dragging a 30-m rope with aluminum can bundles attached every 3-m (Winter et al., 2003). As we surveyed each paddock, we placed flagging marking one end of the rope at approximately 50-m intervals to ensure complete coverage of the paddocks (Hovick et al., 2012). We repeated this process from 20 May to 15 July between 0530 to 1100 in the morning, with each paddock searched four times in 2021 and three times in 2022.

When a bird flushed from the rope, we identified the species and began searching for the nest. We recorded nest locations with a global positioning system (GPS) and placed flags approximately 5-m to the north and south of the nest and low in the vegetation to prevent trampling and avoid attracting predators (Winter et al., 2003). If we were unable to locate the nest but observed secondary indicators (chipping, broken wing display, adults nearby), we marked the approximate location on a GPS and searched again within three days (Hovick et al., 2012; Shew et al., 2019).

We candled two representative eggs from each nest to determine the age and subsequently monitored nests every 2-4 days (Johnson & Temple, 1990; Lokemoen & Koford, 1996). We recorded the nesting stage (laying, incubating, nestling), number of host eggs, and number of brown-headed cowbird (*Molothrus ater*) eggs (a common brood parasite) during each monitoring event (Johnson & Temple, 1990).

We continued monitoring until the nest was fledged, depredated, or abandoned (Hovick et al., 2012; Winter et al., 2005). We considered nests successful if they fledged at least one conspecific individual (Hovick et al., 2012; Shew et al., 2019). We confirmed fledging by resighting a fledgling or using adult behavioral indicators such as nearby adults appearing agitated/chipping or adults carrying food to a nearby area (Duquette et al., 2019; Hovick et al., 2012; Shew et al., 2019). Nests that lacked these indicators or that were clearly disturbed, such as being ripped from the vegetation or trampled, were considered failures.

We calculated expected fledge dates using known incubation and nestling dates as well as the current age of the nest, determined upon discovery. This standardizes vegetation data collection and prevents bias by collecting data, regardless of the outcome, at a standardized time relative to nest completion for each nest (McConnell et al., 2017).

We measured vegetation using a 0.5 m^2 quadrat centered on the nest bowl. Vegetation was assessed based on functional groups using the midpoint of the following cover classes: 0%, 1-4%, 5-24%, 25-49%, 50-74%, 75-95%, and 95-100% (Duquette, 2020). We split Kentucky bluegrass and smooth brome from the other grasses due to their unique structure and invasiveness (Duquette, 2020). Structural measurements included VOR, vegetation height, and litter depth.

Analysis

Generalized linear mixed-effects models were used to determine whether vegetation structure differed among grazing intensities. We controlled for non-independence while maximizing sampling points by incorporating transect ID as a random effect.

Avian species were divided into functional groups based on habitat preferences. Obligate grassland birds rely exclusively on grasslands for their life history, whereas facultative grassland birds rely on grasslands in conjunction with other habitat types (Vickery et al., 1999). Wetland species are those that rely on wetlands for the majority of their life history. Species richness and Simpson's Diversity Index were calculated and compared across grazing intensities using generalized linear models. Nonmetric multi-dimensional scaling with Bray-Curtis dissimilarity was used with the VEGAN package in R to evaluate how nesting communities differed across each of the grazing intensities within the MTORG system (Oksanen et al., 2020; R Core Team, 2021). PERMANOVA was used to determine any statistical difference in the nesting communities in each grazing intensity.

Nest survival was analyzed using the RMark interface which utilizes a maximum-likelihood estimator and logit function to calculate daily survival rates (DSR) (Dinsmore et al., 2002; Laake, 2011; Laake, 2013). We assessed grazing intensity impacts on DSR using a hierarchical modeling scheme with the top models from each model set included in the subsequent model set (Burnham & Anderson, 2004; Dinsmore & Dinsmore, 2007; Hovick et al., 2012; Winter et al., 2006). We assessed management and vegetation impacts on nest survival in four steps: 1) grazing intensity and year impacts, 2) temporal impacts, 3) parasitism (only passerines), grazing presence, and days grazed, and 4) nest site vegetation. Top models were based on Akaike's information criterion, adjusted for a small sample size (AIC_c; Burnham & Anderson, 2004).

Results

Objective 1: Vegetation Structure Changes

Vegetation density was not significantly different among grazing intensities in 2021 ($p > 0.05$). However, 2022 showed significant variation in VOR among grazing intensities. Vegetation densities in the rested paddock and moderate paddocks were significantly higher than those in the full and heavy paddocks ($p < 0.03$; Figure 1).

Litter depth was significantly higher in the moderate paddock than in the heavy or rested paddocks in both 2021 ($p = 0.04$ and 0.0083, respectively) and 2022 ($p = 0.04$ and 0.04, respectively). The full paddock was not significantly different from any of the other paddocks ($p > 0.05$, Figure 1).

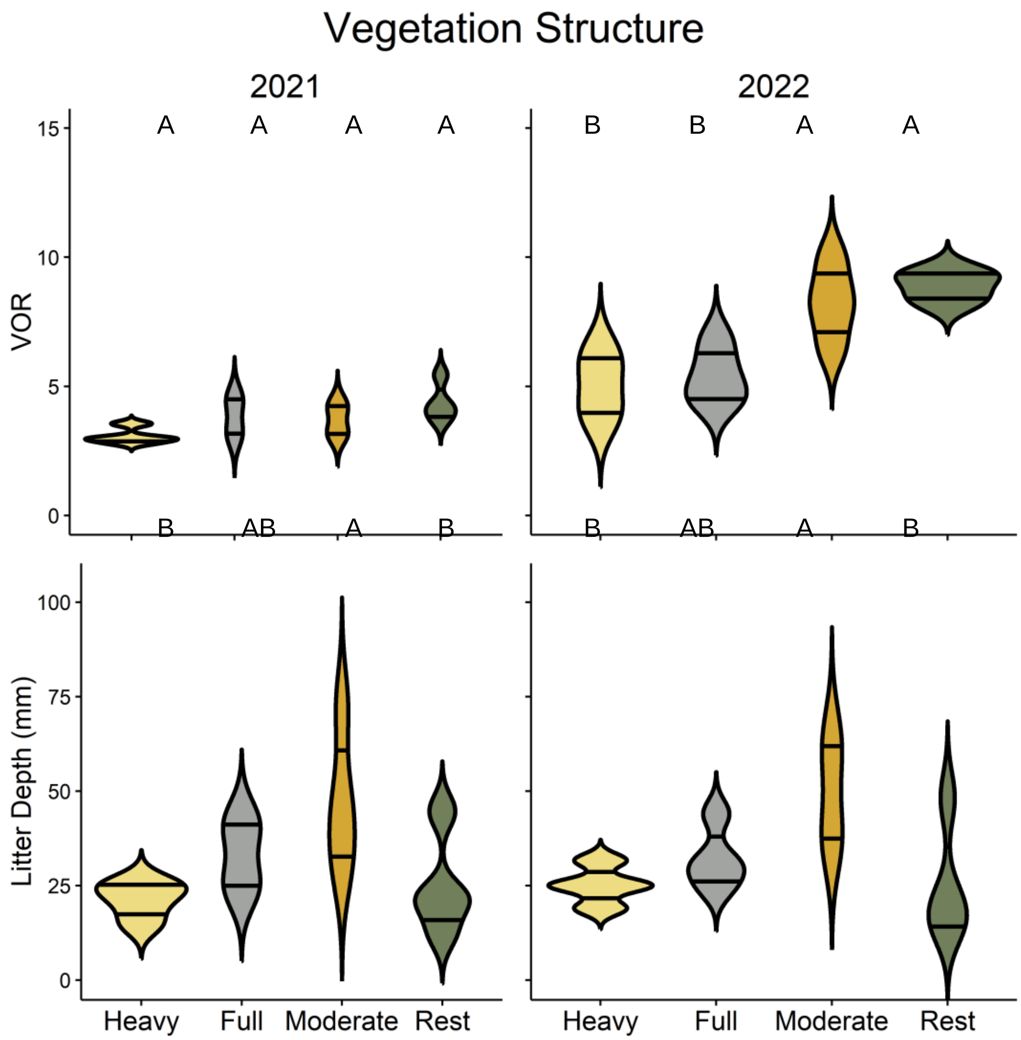


Figure 1. Violin plots showing two vegetation structural measurements taken in a modified twice-over rest-rotation grazing system at the Central Grasslands Research Extension Center in North Dakota. Measurements included litter depth and visual obstruction reading (VOR), a measure of vegetation density, and were taken in August of 2021 and 2022 within four replicates of each grazing intensity. Colors represent each grazing intensity, and the shape indicates the distribution of values where wider sections represent the accumulation of data points. Letters indicate statistical significance with shared letters indicating non-significance and unique letters indicating a significant difference.

Objective 2: Avian Nesting Community Composition

More nests were found in 2021 than in 2022 (437 and 426, respectively). In 2021, we found 44 nests belonging to 8 obligate species, 389 nests belonging to 13 facultative species, and 4 nests belonging to 3 wetland species. In 2022, we found 56 nests belonging to 8 obligate species, 357 nests belonging to 13 facultative species, and 13 nests belonging to 6 wetland species (Table 1).

Table 1. Summary of nest data collected at the Central Grasslands Research Extension Center from mid-May to mid-July in 2021 and 2022. Heavy, full, moderate, and rest correspond to grazing intensities within a modified twice-over rest-rotation grazing system. Obligate (OBL) grassland species rely exclusively on grassland for their life history. Facultative (FAC) grassland species may use grassland habitats in conjunction with other habitats. Wetland (WET) species are those that nest within wetlands.

Species	Heavy	Full	Moderate	Rest	Totals	Group
American Wigeon	1	1	2	0	4	FAC
Green-winged Teal	1	0	1	0	2	FAC
Blue-winged Teal	12	22	19	16	69	FAC
Gadwall	8	14	17	10	49	FAC
Mallard	3	5	11	1	20	FAC
Northern Pintail	5	10	22	12	49	FAC
Northern Shoveler	1	10	10	1	22	FAC
Sharp-tailed Grouse	1	3	1	0	5	OBL
Pied-billed Grebe	0	2	0	0	2	WET
Sora	0	1	0	0	1	WET
American Coot	1	4	0	0	5	WET
Mourning Dove	10	6	10	11	37	FAC
Killdeer	1	0	0	1	2	FAC
Upland Sandpiper	0	0	1	2	3	OBL
Willet	0	0	1	0	1	FAC
Wilson’s Phalarope	1	3	0	1	5	WET
Wilson’s Snipe	0	1	0	0	1	WET
Eastern Kingbird	0	2	3	3	8	FAC
Marsh Wren	0	1	0	0	1	WET
Chestnut-collared Longspur	2	1	4	0	7	OBL
Clay-colored Sparrow	78	113	124	55	370	FAC
Grasshopper Sparrow	5	2	3	2	12	OBL
Savannah Sparrow	1	1	0	1	3	OBL
Bobolink	0	3	5	2	10	OBL
Red-winged Blackbird	3	30	28	17	78	FAC
Brewer’s Blackbird	2	8	15	9	34	FAC
Western Meadowlark	8	11	14	16	49	OBL
Yellow-headed Blackbird	1	0	1	0	2	WET
Common Grackle	0	0	1	0	1	FAC
Dickcissel	0	3	4	4	11	OBL
Totals	145	257	297	164	863	

Species richness did not vary significantly between grazing intensities or years ($p > 0.05$; Figure 2). Simpson's diversity did not vary significantly between treatments but was significantly higher in 2022 than 2021 ($p = 0.02$; Figure 22). Avian breeding communities were not significantly different between grazing intensities in either year (PERMANOVA; p=0.06 and 0.10; respectively, Figure 3).

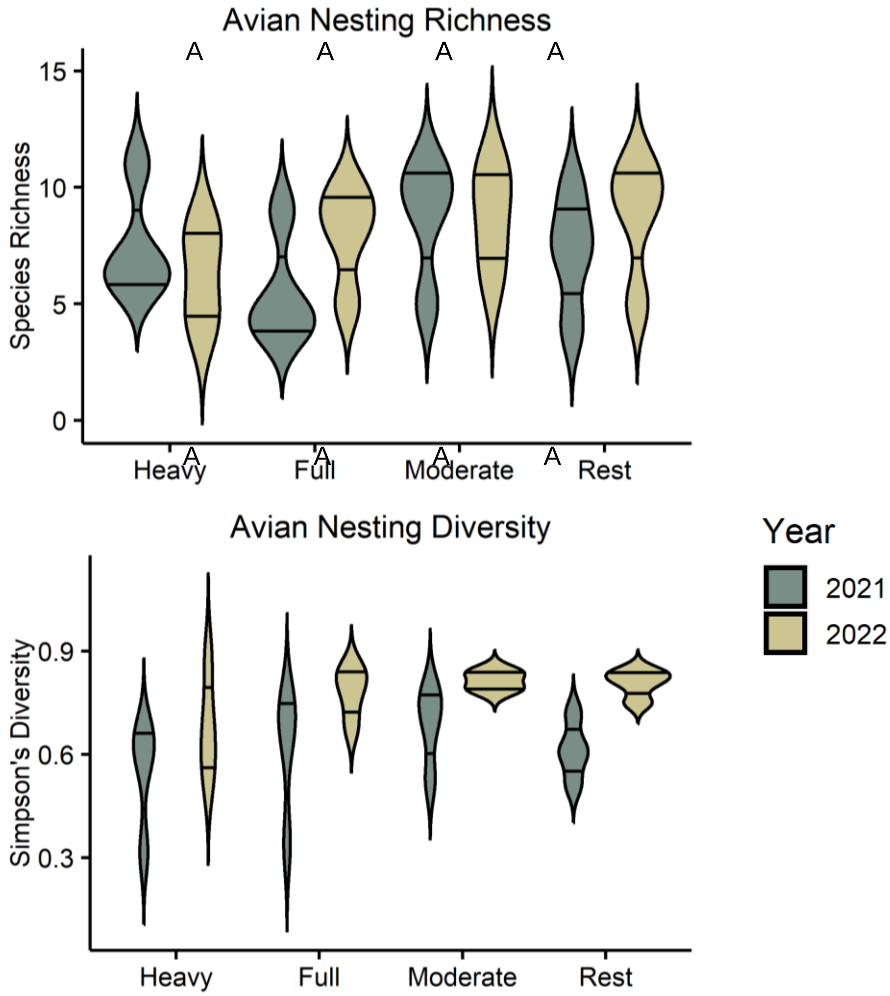


Figure 2. Violin plots showing two indices, species richness and Simpson's diversity, based on breeding bird communities within a modified twice-over rest-rotation grazing system at the Central Grasslands Research Extension Center in North Dakota. Breeding bird communities were assessed from mid-May to mid-July in 2021 and 2022. The shape of each plot indicates the distribution of values where wider sections represent the accumulation of data points. Letters indicate statistical significance with shared letters indicating non-significance and unique letters indicating a significant difference. Species richness and Simpson's diversity were not significantly different between grazing intensities ($p > 0.05$). However, Simpson's diversity was significantly different between years ($p = 0.02$).

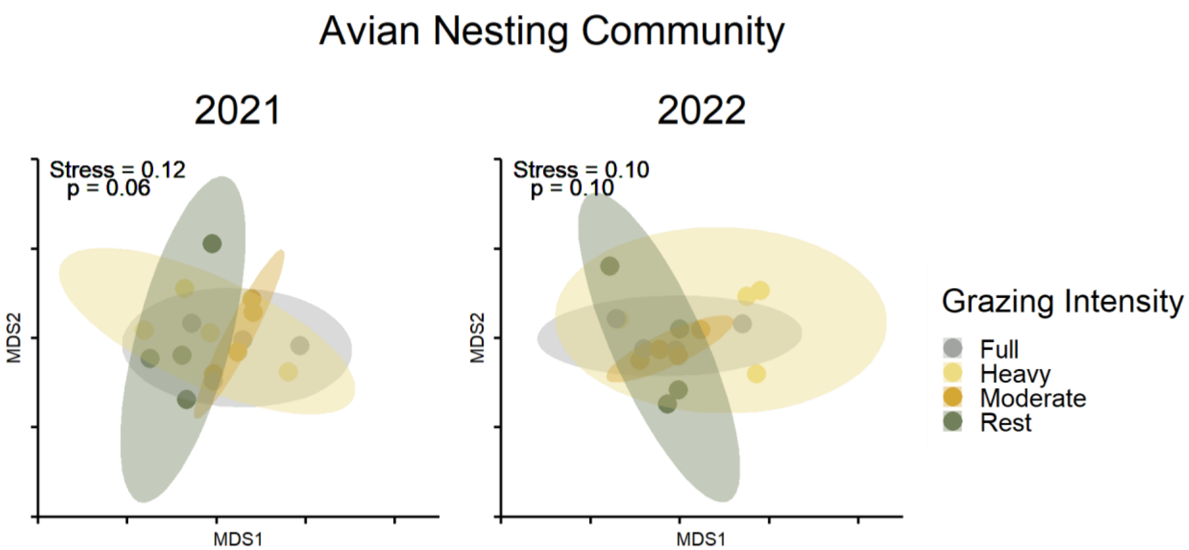


Figure 3. Non-metric multidimensional ordinations comparing avian nesting communities within a modified twice-over rest-rotation grazing system at the Central Grasslands Research Extension Center. Avian communities were assessed from mid-May to mid-July in 2021 and 2022. Points represent avian communities within each replicate where closer points are more similar. Ellipses show 95% confidence intervals. There was no significant difference in nesting communities between grazing intensities for 2021 or 2022.

Objective 3: Avian Nest Survival

We were able to assess daily nest survival metrics on every species with more than 30 total nests (seven species, Table 2). We excluded the Red-winged Blackbird because they were rarely found in the heavy treatment and are more closely associated with water than other facultative grassland species. Species that included grazing intensity or year in the top model have daily survival rates for each grouping variable. The average daily survival rate across the breeding season is reported for models that included a temporal covariate (Table 2).

Blue-winged Teal (*Anas discors*) nests had an average daily survival rate of 1.00 in rested paddocks and 0.97 in moderate, full, and heavy paddocks. This corresponds with a 1.00 and 0.48 period survival rate, respectively. Blue-winged teal nest daily survival decreased with time and litter depth at the nest site.

Gadwall (*Mareca strepera*) nests had a constant daily survival rate of 0.98, corresponding with a period survival rate of 0.60. The nest daily survival rate increased with increasing litter depth at the nest site.

Northern Pintail (*Anas acuta*) nests had a constant daily survival rate of 0.93, corresponding with a period survival rate of 0.19. The nest daily survival rate decreased with increasing litter cover at the nest site.

Mourning Dove (*Zenaida macroura*) nests had an average daily survival rate of 0.92 corresponding with a 0.10 period survival rate. Increasing Kentucky bluegrass cover at the nest site enhanced nest survival. However, increasing litter depth at the nest site resulted in lower nest survival. Mourning Dove nest survival varied across time with higher daily survival rates at the beginning and end of the breeding season.

Clay-colored Sparrow (*Spizella pallida*) nests had a daily nest survival rate of 0.87 in 2021 and 0.90 in 2022. This corresponds with a period survival rate of 0.06 and 0.12, respectively. The nest daily survival rate was enhanced by increasing vegetation height but decreased with the presence of Brown-headed Cowbird (*Molothrus ater*) eggs in the nest. Nest daily survival rate throughout the breeding season.

Table 2. Daily survival rates and final hierarchical model coefficients for avian nesting data collected at the Central Grasslands Research Extension Center from mid-May to mid-July in 2021 and 2022. Coefficient directionality is represented by a + or - with parentheses indicating confidence limits that overlap 0. Models that included treatment or year show DSR for each treatment and/or year. Models that varied across time show average DSR across the breeding season. Only species with greater than 30 nests between the two years were included in the nest survival analysis.

Species	Daily Survival Probability	Model Covariates
Blue-winged Teal	Rest: 1.00 Moderate: 0.98 Full: 0.97 Heavy: 0.98	Treatment Time – Litter Depth –
Gadwall	0.98	Litter Depth +
Northern Pintail	0.93	Litter Cover –
Mourning Dove	0.92	Time (Quadratic) Kentucky Bluegrass + Litter Depth (–)
Clay-colored Sparrow	2021: 0.87 2022: 0.90	Year Time (–) BHCO (–) Veg Height +
Brewer’s Blackbird	2021: 0.87 2022: 0.86	Year Time – VOR +
Western Meadowlark	0.91	Grazed (–) Kentucky Bluegrass (–) Veg Height (–)

Brewer’s Blackbird (*Euphagus cyanocephalus*) nests had an average daily survival rate of 0.87 and 0.86 in 2021 and 2022, respectively. This corresponds with a 0.03 and 0.02 overall period survival. Nest daily survival rate decreased throughout the breeding season but improved with increasing VOR.

Western Meadowlark (*Sturnella neglecta*) nests had a constant daily survival rate of 0.91 corresponding to a 0.09 period survival rate. The nest daily survival rate decreased with the number of days a paddock was grazed. Increasing vegetation height and Kentucky bluegrass cover also reduced nest daily survival rates.

Discussion

While we did not see a significant change in 2021, the 2022 data suggests that a heterogeneity-based rest-rotation grazing system can create variation in vegetation structure. Lower-than-average precipitation during the 2021 field season may have impacted the vegetation structural gradient observed between grazing intensities (Derner & Hart, 2007; NDAWN, 2022; Scasta et al., 2016). A reduced structural gradient results in reduced available niche space, which is correlated with lower avian diversity (Coppedge et al., 2008).

We did not observe any significant differences between grazing intensities for nesting richness, diversity, or community composition among grazing intensities. We did see significantly lower diversity in 2021 than in 2022, despite an additional round of nest dragging in 2021. This further suggests that lower-than-average precipitation may have impacted nesting diversity within our grazing system.

We found that daily nest survival is often impacted by vegetation structural components that are manipulated through our heterogeneity-based rest-rotation grazing system. However, responses were generally species-specific and reflect the importance of maintaining structural heterogeneity on rangelands.

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

References

Beauchamp, W. D., Koford, R. R., Nudds, T. D., Clark, R. G., & Johnson, D. H. (1996). Long-term declines in nest success of prairie ducks. *The Journal of Wildlife Management*, *60*(2), 247–257.

Becerra, T. A., Engle, D. M., Fuhlendorf, S. D., & Elmore, R. D. (2017). Preference for grassland heterogeneity: Implications for biodiversity in the Great Plains. *Society and Natural Resources*, *30*(5), 601–612. https://doi.org/10.1080/08941920.2016.1239293

Burnham, K. P., & Anderson, D. R. (2004). Multimodel inference: Understanding AIC and BIC in model selection. *Sociological Methods and Research*, *33*(2), 261–304. https://doi.org/10.1177/0049124104268644

Christensen, N. L. (1997). Managing for heterogeneity and complexity on dynamic landscapes. In S. T. A. Pickett, R. S. Ostfeld, M. Shachak, & G. E. Likens (Eds.), *The Ecological Basis for Conservation: Heterogeneity, Ecosystems, and Biodiversity* (pp. 167–186). Chapman and Hall.

Churchwell, R. T., Davis, C. A., Fuhlendorf, S. D., & Engle, D. M. (2008). Effects of patch-burn management on dickcissel nest success in a tallgrass prairie. *The Journal of Wildlife Management*, *72*(7), 1596–1604. https://doi.org/10.2193/2007-365

Coppedge, B. R., Engle, D. M., Masters, R. E., & Gregory, M. S. (2001). Avian response to landscape change in fragmented southern Great Plains grasslands. *Ecological Applications*, *11*(1), 47–59. https://doi.org/10.1890/1051-0761(2001)011[0047:ARTLCI]2.0.CO;2

Coppedge, B. R., Fuhlendorf, S. D., Harrell, W. C., & Engle, D. M. (2008). Avian community response to vegetation and structural features in grasslands managed with fire and grazing. *Biological Conservation*, *141*, 1196–1203. https://doi.org/10.1016/j.biocon.2008.02.015

Daubenmire, R. (1959). A canopy coverage method of vegetation analysis. *Northwest Science*, *33*, 43–64.

Davis, S. K., Duncan, D. C., & Skeel, M. (1999). Distribution and habitat associations of three endemic grassland songbirds in Southern Saskatchewan. *The Wilson Bulletin*, *111*(3), 389–396.

Derner, J. D., & Hart, R. H. (2007). Grazing-induced modifications to peak standing crop in northern mixed-grass prairie. *Rangeland Ecology and Management*, *60*(3), 270–276. https://doi.org/10.2111/1551

Dinsmore, S. J., & Dinsmore, J. J. (2007). Modeling avian nest survival in program MARK. *Studies in Avian Biology*, *34*, 73–83.

Dinsmore, S. J., White, G. C., & Knopf, F. L. (2002). Advanced techniques for modeling avian nest survival. *3476 Ecology*, *83*(12), 3476–3488.

Duchardt, C. J., Miller, J. R., Debinski, D. M., & Engle, D. M. (2016). Adapting the fire-grazing interaction to small pastures in a fragmented landscape for grassland bird conservation. *Rangeland Ecology and Management*, *69*(4), 300–309. https://doi.org/10.1016/j.rama.2016.03.005

Duquette, C. A. (2020). Restoring Heterogeneity-Based Management to Rangelands for the Benefit of Grassland Birds and Floral Resources [North Dakota State University]. In *Dissertation*. https://doi.org/10.4324/9781315721606-101

Duquette, C. A., Hovick, T. J., Limb, R. F., McGranahan, D. A., & Sedevic, K. K. (2019). Restored fire and grazing regimes influence nest selection and survival in Brewer's blackbirds *Euphagus cyanocephalus*. *Acta Ornithologica*, *54*(2), 171–180. https://doi.org/10.3161/00016454AO2019.54.2.004

Duquette, C., McGranahan, D. A., Wanchuk, M., Hovick, T., Limb, R., & Sedivec, K. (2022). Heterogeneity-based management restores diversity and alters vegetation structure without decreasing invasive grasses in working mixed-grass prairie. *Land*, *11*(8), 1135. https://doi.org/10.3390/land11081135

Dyke, S. R., Johnson, S. K., & Isakson, P. T. (2015). *North Dakota State Wildlife Action Plan*. North Dakota Game and Fish Department. https://doi.org/10.1177/104747570201700614

Engle, D. M., Fuhlendorf, S. D., Roper, A., & Leslie, D. M. (2008). Invertebrate community response to a shifting mosaic of habitat. *Rangeland Ecology and Management*, *61*(1), 55–62. https://doi.org/10.2111/06-149R2.1

Fuhlendorf, S. D., & Engle, D. M. (2001). Restoring heterogeneity on rangelands: Ecosystem management based on evolutionary grazing patterns. *BioScience*, *51*(8), 625–632. https://doi.org/10.1641/0006-3568(2001)051[0625:RHOREM]2.0.CO;2

Fuhlendorf, S. D., Engle, D. M., Kerby, J., & Hamilton, R. (2009). Pyric herbivory: Rewilding landscapes through the recoupling of fire and grazing. *Conservation Biology*, *23*(3), 588–598. https://doi.org/10.1111/j.1523-1739.2008.01139.x

Fuhlendorf, S. D., Harrell, W. C., Engle, D. M., Hamilton, R. G., Davis, C. A., & Leslie, D. M. (2006). Should heterogeneity be the basis for conservation? Grassland bird response to fire and grazing. *Ecological Applications*, *16*(5), 1706–1716. https://doi.org/10.1890/1051-0761(2006)016[1706:SHBTBF]2.0.CO;2

Holcomb, E. D., Davis, C. A., & Fuhlendorf, S. D. (2014). Patch-burn management: Implications for conservation of avian communities in fire-dependent sagebrush ecosystems. *Journal of Wildlife Management*, *78*(5), 848–856. https://doi.org/10.1002/jwmg.723

Hovick, T. J., Elmore, R. Dwayne., & Fuhlendorf, S. D. (2014). Structural heterogeneity increases diversity of non-breeding grassland birds. *Ecosphere*, *5*(5), 62. https://doi.org/10.1890/ES14-00062.1

Hovick, T. J., Miller, J. R., Dinsmore, S. J., Engle, D. M., Debinski, D. M., & Fuhlendorf, S. D. (2012). Effects of fire and grazing on grasshopper sparrow nest survival. *The Journal of Wildlife Management*, *76*(1), 19–27. https://doi.org/10.1002/jwmg.243

Johnson, R. G., & Temple, S. A. (1990). Nest predation and brood parasitism of tallgrass prairie birds. *The Journal of Wildlife Management*, *54*(1), 106–111.

Laake, J. (2011). RMark: R Code for MARK Analysis. R package version 2.0.7. *Http://CRAN.R-Project.Org/Package=RMark*, *January 2008*.

Laake, J. L. (2013). *RMark: An R Interface for analysis of capture-recapture data with MARK* (p. AFSC Processed Rep 2013-01, 25 p). Alaska Fisheries Science Center, NOAA, National Marine Fisheries Service.

Limb, R. F., Hovick, T. J., Norland, J. E., & Volk, J. M. (2018). Grassland plant community spatial patterns driven by herbivory intensity. *Agriculture, Ecosystems and Environment*, *257*(February), 113–119. https://doi.org/10.1016/j.agee.2018.01.030

Lokemoen, J. T., & Koford, R. R. (1996). Using candlers to determine the incubation stage of passerine eggs. *Journal of Field Ornithology*, *67*(4), 660–668.

McConnell, M. D., Monroe, A. P., Burger, L. W., & Martin, J. A. (2017). Timing of nest vegetation measurement may obscure adaptive significance of nest-site characteristics: A simulation study. *Ecology and Evolution*, *7*(4), 1259–1270. https://doi.org/10.1002/ece3.2767

McNew, L. B., Winder, V. L., Pitman, J. C., & Sandercock, B. K. (2015). Alternative rangeland management strategies and the nesting ecology of greater prairie-chickens. *Rangeland Ecology and Management*, *68*(3), 298–304. https://doi.org/10.1016/j.rama.2015.03.009

NDAWN. (2022, February 14). *North Dakota Agricultural Weather Network*. https://ndawn.ndsu.nodak.edu/

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O’Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., Szoecs, E., & Wagner, H. (2020). *vegan: Community Ecology Package*. https://cran.r-project.org/package=vegan

Ostfeld, R., Pickett, S., Shachak, M., & Lickens, G. (1997). Defining scientific issues. In S. T. A. Pickett, R. S. Ostfeld, M. Shachak, & G. E. Likens (Eds.), *The Ecological Basis for Conservation: Heterogeneity, Ecosystems, and Biodiversity* (pp. 3–10). Chapman and Hall.

Patton, B. D., Dong, X., Nyren, P. E., & Nyren, A. (2007). Effects of grazing intensity, precipitation, and temperature on forage production. *Rangeland Ecology and Management*, *60*(6), 656–665. https://doi.org/10.2111/07-008R2.1

Pillsbury, F. C., Miller, J. R., Debinski, D. M., & Engle, D. M. (2011). Another tool in the toolbox? Using fire and grazing to promote bird diversity in highly fragmented landscapes. *Ecosphere*, *2*(3), 1–14. https://doi.org/10.1890/ES10-00154.1

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. http://www.r-project.org/

Robel, R. J., Briggs, J. N., Dayton, A. D., & Hulbert, L. C. (1970). Relationships between visual obstruction measurements and weight of grassland vegetation. *Journal of Range Management*, *23*(4), 295. https://doi.org/10.2307/3896225

Rosenberg, K. V., Dokter, A. M., Blancher, P. J., Sauer, J. R., Smith, A. C., Smith, P. A., Stanton, J. C., Panjabi, A., Helft, L., Parr, M., & Marra, P. P. (2019). Decline of the North American avifauna. *Science*, *366*(6461), 120–124. https://doi.org/10.1126/science.aaw1313

Sandercock, B. K., Alfaro-Barrios, M., Casey, A. E., Johnson, T. N., Mong, T. W., Odom, K. J., Strum, K. M., & Winder, V. L. (2015). Effects of grazing and prescribed fire on resource selection and nest survival of upland sandpipers in an experimental landscape. *Landscape Ecology*, *30*(2), 325–337. https://doi.org/10.1007/s10980-014-0133-9

Sauer, J. R., Hines, J. E., Fallon, J. E., Pardieck, K. L., Ziolkowski Jr., D. J., & Link, W. A. (2013). *The North American Breeding Bird Survey, results and analysis 1966-2011 (Version 07.03.2013)*. USGS Patuxtent Wildlife Research Center 2012.

Scasta, J. D., Duchardt, C., Engle, D. M., Miller, J. R., Debinski, D. M., & Harr, R. N. (2016). Constraints to restoring fire and grazing ecological processes to optimize grassland vegetation structural diversity. *Ecological Engineering*, *95*, 865–875. https://doi.org/10.1016/j.ecoleng.2016.06.096

Shew, J. J., Nielsen, C. K., & Sparling, D. W. (2019). Finer-scale habitat predicts nest survival in grassland birds more than management and landscape: A multi-scale perspective. *Journal of Applied Ecology*, *56*(4), 929–945. https://doi.org/10.1111/1365-2664.13317

Sliwinski, M. S., Burbach, M. E., Powell, L. A., & Schacht, W. H. (2018). Factors influencing ranchers' intentions to manage for vegetation heterogeneity and promote cross-boundary management in the northern Great Plains. *Ecology and Society*, *23*(4), 45.

Vickery, P. D., Tubaro, P. L., Cardoso da Silva, J. M., Peterjohn, B. G., Herkert, J. R., & Cavalcanti, R. B. (1999). Conservation of grassland birds in the Western Hemisphere. *Studies in Avian Biology*, *19*, 2–26.

Wiens, J. A. (1997). The Emerging Role of Patchiness in Conservation Biology. In S. T. A. Pickett, R. S. Ostfeld, M. Shachak, & G. E. Likens (Eds.), *The Ecological Basis for Conservation: Heterogeneity, Ecosystems, and Biodiversity* (pp. 93–107). Chapman and Hall. https://doi.org/10.1007/978-1-4615-6003-6_10

Winter, M., Hawks, S. E., Shaffer, J. A., & Johnson, D. H. (2003). Guidelines for finding nests of passerine birds in tallgrass prairie. *The Prairie Naturalist*, *35*(3), 197–211.

Winter, M., Johnson, D. H., & Shaffer, J. A. (2005). Variability in vegetation effects on density and nesting success of grassland birds. *Journal of Wildlife Management*, *69*(1), 185–197. https://doi.org/10.2193/0022-541x(2005)069<0185:viveod>2.0.co;2

Winter, M., Johnson, D. H., Shaffer, J. A., Donovan, T. M., & Svedarsky, W. D. (2006). Patch size and landscape effects on density and nesting success of grassland birds. *Journal of Wildlife Management*, *70*(1), 158–172. https://doi.org/10.2193/0022

Can grazed rangelands support monarch conservation? An evaluation of cattle interaction with milkweed host plants

Ellysa R. Johnson[1], Jason P. Harmon[1], Torre J. Hovick[1], and Kevin K. Sedivec[1,2]
[1]School of Natural Resource Sciences, North Dakota State University, Fargo, ND.
[2]Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND

Summary
Monarch butterflies (*Danaus plexippus* L.) are a pollinator of high conservation concern due to recent population declines. Milkweed (*Asclepias* spp.) is the required host for monarch larvae, making it a high conservation focus. To help counteract recent monarch loss, conservation efforts aim to establish ≥1.3 billion additional milkweed stems. While much of current research focuses on roadsides and small-scale urban property, rangelands offer a unique opportunity for milkweed promotion within the eastern migratory monarch range. In grazed rangelands, however, limited research exists on the possible differences in cattle use of milkweed across management strategies, timing within the grazing season, or milkweed species. This information will allow for more informed and targeted milkweed and monarch conservation in rangelands. We quantified bitten and intact milkweed stems by species in North Dakota mixed-grass prairie rangelands throughout the grazing season of 2021 and 2022 across three grazing management strategies: 1) season-long grazing, 2) patch-burn grazing, and 3) modified twice-over rest-rotation grazing. The proportion of stems that were grazed by cattle did not change from treatment to treatment, but we did observe a temporal difference, with the proportion of bitten-off stems increasing throughout the grazing season. In addition, the proportion of stems that were grazed differed by species, with oval-leaf (*A. ovalifolia*) being grazed less often than common or showy milkweed (*A. syriaca* and *A. speciosa*, respectively). Although monarchs rely on common milkweed more in late summer in the northern Great Plains, cattle-grazed milkweed stems constituted less than 11% of total available milkweed despite treatment. In addition, milkweed may be able to grow back if grazed in the active growing season, allowing the stem to still serve monarchs. For these reasons, rangelands may remain a viable option to promote milkweed stems for monarch conservation, especially if coupled with future research on quantifying hazards to monarchs and milkweed regrowth.

Introduction
Milkweed (*Asclepias* spp.) abundance in North America dropped by 40% from 1999 to 2014 (Pitman et al., 2018) and continues to decrease at a rate of 2 million stems annually due to ongoing agricultural practices (Pleasants, 2017). This loss has direct implications for the eastern migratory monarch butterfly (*Danaus plexippus* L; hereafter "monarch") population. Milkweed serves as the exclusive food resource for monarchs during their larval stage (Oberhauser, USDA; Image 1a). In reaction to milkweed loss, the monarch is now considered a species of concern (Walker et al., 2022). To counteract such losses, current conservation goals aim to establish ≥1.3 billion additional milkweed stems (Thogmartin et al., 2017a), though it is disputed where these efforts should be placed.

While the Midwest corn belt makes up the primary portion of monarch habitat, this also coincides with where the majority of milkweed loss occurred as a result of the 1990s glyphosate herbicide boom (Thogmartin et al., 2017b). For this reason, these fields are no longer able to serve as conservation sites to promote milkweed. Roadsides and pollinator gardens have been proposed as substitutes, but the former may lead to increased monarch mortality and the latter operates on too small a scale to logistically meet current goals. Rangelands have the potential to aid in milkweed promotion as they cover more acreage than row crop agriculture (Theobold, 2014; Bigelow & Borchers, 2017). However, rangelands are livestock grazed, which may hinder milkweed development and reproduction via stem destruction or removal (Roels, 2011).

It is unclear how livestock, particularly cattle (*Bos taurus*; Image 1b), interact with milkweed in rangelands. Some believe certain milkweed species to be highly palatable "ice cream" plants that herbivores preferentially graze (Reppert, 1960; Roels, 2011), while others are cautious of the toxicity effect on cattle (Fleming et al., 1920). In the northern Great Plains, the primary milkweed species, common (*Asclepias syriaca*) and showy (*A. speciosa*), have relatively low cardiac glycoside concentrations (Malcolm, 1991), which suggests reduced potential for toxicity problems. In addition, cattle in a rangeland setting are unlikely to intake enough milkweed to experience negative health side effects. It is generally known that cattle graze milkweed to some extent, but this tendency has not yet been quantified.

Cattle grazing patterns depend strongly on land management. The traditional management strategy of the Great Plains region is season-long, or continuous, grazing, which leads to landscape-level homogeneity over time if stocked too lightly or heavily. In contrast, heterogeneity-focused management, such as patch-burn grazing, has resulted in a more diverse forb community and higher forb abundance (Duquette, 2022; Ricketts & Sandercock, 2016), by incentivizing or manipulating cattle to graze some areas more than others, effectively managing the landscape to favor heterogeneity.

Apart from land management impacting behavior, cattle have inherent tendencies in their grazing. For example, cattle have an increased reliance on forbs, if present, later in the growing season (Mohammad et al., 1996; Schwartz & Ellis, 1981), and preferentially graze certain plant species over others ("ice cream" plants). Given the peak of monarch reproduction occurs in July to August, increased forb (i.e. milkweed in this instance) grazing could be of concern during that time. Additionally, common milkweed is disproportionately used by monarchs over other milkweed species during migration (Malcolm et al., 1993), so if cattle preferentially eat more of this species than others, that could also hinder conservation success.

Overall, our study assesses the viability of rangelands to help meet the ≥1.3 billion milkweed establishment goal and if the presence of cattle may be counterintuitive to said goal. To do so, we must assess the abundance of milkweed under a variety of management approaches, as well as evaluate how cattle interact with (i.e. graze) milkweed within those management approaches, throughout the grazing season, and by milkweed species. As such, our objectives are as follows:

1. Determine which grazing management strategy results in the highest milkweed abundance
2. Quantify cattle grazing of milkweed by
    a. Management strategy
    b. Timing within the grazing season
    c. Milkweed species

3. Determine the overall level of cattle herbivory on milkweed compared to available milkweed stems

Procedures

We conducted our research at the Central Grasslands Research Extension Center (CGREC) near Streeter, ND (46°45'N, 99°28'W) during part of the grazing season (June-August) of 2021 and 2022. The climate in this region is considered to be temperate, with average temperatures ranging from -12.3°C (9.86°F) in January to 20.3°C (68.54°F) in July (NDAWN, 2021). The average growing season rainfall is 36.14cm (14.23 in; NDAWN 1991-2022).

Our study utilized four, 64ha replicates for each treatment: 1) season-long grazing, 2) patch-burn grazing, and 3) modified twice-over rest-rotation grazing. Each replicate was divided into four, 16ha plots, each with three transects randomly placed at least 30m apart from one another to avoid overlap and 50m from fences to limit edge effects. Season-long grazing (SLG; or continuous) has no interior treatments. Patch-burn grazing (PBG) operates with a four-year spring fire return interval, though unfavorable conditions resulted in no burns in 2022. Cattle are able to visit any patch as there is no interior fencing. The modified twice-over rest-rotation grazing (MTORG) has four fenced-off paddocks, each with a unique grazing utilization identity (No grazing, 0%; moderate, 20-40%; full, 40-60%; heavy, 60-80%). All treatments include cow-calf pairs grazing with similar 2-year average stocking rates, ranging from 1.59-2.39 animal unit months per hectare (AUMs/ha) for the duration of the growing season (May to October), aimed at an overall 30-40% disappearance.

To better understand rangelands as a potential solution or contributor to the milkweed establishment goal of ≥1.3 billion additional stems, we monitored intact (i.e. not grazed) and cattle grazed (hereafter "bitten-off"; Image 1c) milkweed stems within the three management strategies. We surveyed 3 transects per plot, making a total of 48 transects per replicate within each treatment, which we surveyed 3 times throughout the field season in both 2021 and 2022. Each round of observations was categorized as early-, mid-, or late-season, with surveys lasting from June to August. Each transect was 150m in length. We counted all milkweed stems within 2.5m to either side, noting if the stem was intact or bitten-off. To calculate available milkweed stems, intact and bitten-off stem counts were combined. For both available and bitten-off milkweed stems, we tallied how many were counted on 3 transects and averaged to find the average number of milkweed stems in a standardized 16-ha plot (4 plots per replicate, 4 replicates per treatment).

We identified the milkweed to species in our surveys. Common (*Asclepias syriaca*) and showy (*A. speciosa*) milkweed are similar in appearance unless flowering and often hybridize in our location (Adams et al., 1987). Therefore, for more attuned accuracy across seasons and observers, we combined those two species into one category labelled 'common/showy'. Other species in our surveys had extremely low observations (<5 total), so we only analyzed the most observed species, common/showy and oval-leaf (*A. ovalifolia*).

For analysis, the distribution of data warranted using nonparametric statistical tests in JMP (JMP®, Version Pro 15. SAS Institute Inc., Cary, NC, 1989–2022) to determine if land management strategy, timing within the grazing season, and/or milkweed species could explain the observed proportion of bitten-off to available milkweed trends. There was an instance where there were no counts of oval-leaf milkweed in a plot, which means there were no stems for cattle to graze and therefore does not permit the use of proportion. In these instances, we removed these plots from further analyses. If there were significant results, we used nonparametric multiple comparisons (Wilcoxon) on each pair to determine the differences between treatments (SLG, PBG, and MTORG) and timing within the grazing season (early-, mid-, and late-season). The rested (or no grazing) paddocks within the MTORG were excluded as cattle were not present the entirety of the grazing season and all bitten-off stem counts were likely due to native herbivory.

Results

Objective 1. *Determine which grazing management strategy promotes the highest milkweed abundance*

We counted a total of 26,873 milkweed stems across all three treatments (excluding rested paddocks within MTORG) in two years. Though MTORG tended to have more milkweed stems across the three grazed sub-treatments, the sub-treatments were not statistically different from one another (P>0.1; Figure 1).

Objective 2. *Quantify cattle grazing of milkweed by management strategy, timing within the grazing season, and milkweed species*

We observed 3,304 bitten-off stems across the three treatments in two years (excluding NG paddocks within MTORG). There was no significant treatment effect (Figure 2a). The proportion of stems that were grazed increased in mid- and late-season (p=0.0021; Figure 2b) compared to what was grazed in the early-season. Lastly, cattle ate more common/showy stems than oval-leaf stems in relation to what was available (p<0.001; Figure 2c).

Objective 3. Determine the overall level of cattle herbivory of milkweed compared to available stems

We observed a full spectrum of cattle herbivory of milkweed, ranging from 0-100% of average number of stems that were available on a 16-ha plot basis. However, bitten-off stems in four out of every five plots had less than 11% of milkweed grazed at any one time (Figure 3).

Discussion

Rangelands cover 30% of the U.S. (Theobold, 2014), and offer potential to support species of conservation concern, such as the monarch butterfly, by providing milkweed resources. On account of recent population declines, conservation goals are set to establish ≥1.3 billion additional milkweed stems (Thogmartin et al., 2017a). Since rangelands are primarily used for cattle production, the presence of cattle and how they are managed must be considered when evaluating the viability of rangelands to support milkweed and monarchs.

We found that management strategy did not seem to influence milkweed availability or the proportion of stems grazed by cattle. Others have found that these management treatments influence heterogeneity, or diversity, of vegetation (Duquette et al., 2022), and an assortment of floral resources that can benefit monarchs (Nestle et al., 2020). From this, we speculate that the presence of cattle seems to contribute less to overall milkweed presence and may instead be more influenced by seed bank reserves and the abiotic environment.

One hesitancy of plant conservation in grazed systems is reproductive failure. Grazing can limit plant reproduction through the reallocation of resources to damaged sections or physical removal of reproductive parts. High rates of herbivory can delay or inhibit plant recovery. For example, mammalian herbivory has been implicated in up to 50% of mead's milkweed (*Asclepias meadii*) reproductive failures (Roels, 2011). However, this may be species specific and requires additional research. Roels (2011) found that herbivory only accounted for a small portion of common milkweed reproductive failures, while Gustafson et al. (2022) determined that insect herbivory may impact the floral display and nectar quality of common milkweed.

Whether reproductive failure occurs for milkweed likely depends on timing. If a grazing event occurs early in the season, the plant may still have time to reach the reproductive stage. We found that cattle graze milkweed at an increased level later in the season, which may impede milkweed growth and eventual reproduction cycles, especially during the mid- to late-summer when monarch reproduction is highest in North Dakota. To date, most milkweed re-growth studies occur in a mowing setting, which cuts the entire stem (Fischer et al., 2015; Haan & Landis, 2019). Future research should focus on milkweed species-specific regrowth after a grazing event, as well as how re-growth ability and reproduction is altered depending on the point in time within the growing season.

While different species of milkweed seem to be used distinctly by monarchs, monarchs are reared on common milkweed most often during migration (Malcolm et al., 1993). We found that cattle graze common and showy milkweed more than their oval-leaf counterparts. While this indicates competition between monarchs and cattle, the vast majority of plots had less than 11% of milkweed grazed at any one time, likely leaving enough for the number of monarchs in the area.

A factor that was not considered in our study but may be nonetheless important is direct monarch mortality. Monarch larvae have a propensity to reside in the tops of milkweed plants, making direct fatality via cattle grazing of these resources a possible concern. At the same time, it appears that monarch oviposition occurs more often on tender, new milkweed leaves, as these are easier for early instar consumption (Haan & Landis, 2020). Though difficult to monitor, especially when in relatively low densities, future research should also attempt to quantify if the benefits of grazing and subsequent increased oviposition offset any direct mortalities.

Ultimately, it seems clear there is the potential for cattle and milkweed to interact. We determined that stems that were grazed by cattle constituted a fragment of available stems, which may or may not have implications for monarch reproduction in rangelands. Future research should focus on milkweed regrowth and potential monarch mortality as a result of cattle grazing to more accurately determine the relative feasibility of rangelands to help reach the ≥1.3 billion stem goal to aid overall monarch conservation.

Literature Cited

Adams, R.P., A.S. Tomb, and S.C. Price. 1987. Investigation of hybridization between *Asclepias speciosa* and *A. syriaca* using alkanes, fatty acids, and triterpenoids. *Biochemical systematics and Ecology* 15(4): 395-399.

Bigelow, D.P. and A. Borchers. 2017. Major uses of land in the United States, 2012, EIB-178, U.S. Department of Agriculture, Economic Research Service.

Duquette, C. D.A. McGranahan, M. Wanchuk, T. Hovick, R. Limb, and K. Sedivec. 2022. Heterogeneity-Based Management Restores Diversity and Alters Vegetation Structure without Decreasing Invasive Grasses in Working Mixed-Grass Prairie. *Land* 11: 1135 https://doi.org/10.3390/land11081135

Fischer, S.J., E.H. Williams, L.P. Brower, and P.A. Palmiotto. 2015. Enhancing monarch butterfly reproduction by mowing fields of common milkweed. *The American Midland Naturalist* 173: 229-240.

Fleming, C.E., N.F. Peterson, M.R. Miller, L.R. Vawter, L.R., and L.H. Wright. 1920. The narrow-leaved milkweed (*Asclepias mexicana*) and the broad-leaved or showy milkweed (*Asclepias speciosa*) plants poisonous to live stock in Nevada, The University of Nevada Agricultural Experiment Station Bulletin No. 99.

Gustafson, N.W., J.J. Couture, and H.J. Dalgleish. 2022. Herbivory, plant traits and nectar chemistry interact to affect the community of insect visitors and pollination in common milkweed, *Asclepias syriaca*. *Oecologia* https://doi.org/10.1007/s00442-022-05290-w

Haan, N.L. and D.A. Landis. 2019. Grassland disturbance increases monarch butterfly oviposition and decreases arthropod predator abundance. *Biological Conservation* 233: 185-192.

Haan, N.L. and D.A. Landis. 2020. Grassland disturbance effects on first-instar monarch butterfly survival, floral resources, and flower-visiting insects. Biological Conservation 243: e108492.

Malcolm, S.B. 1991. Cardenolide-Mediated Interactions between Plants and Herbivores, in: Rosenthal, G.A., Berenbaum, M.R. (Eds.), Herbivores: *Their Interactions with 546 Secondary Plant Metabolites*. Academic Press, San Diego, pp. 251–296.

Malcolm, S.B., B.J. Cockrell, and L.P. Brower. 1993. Spring recolonization of eastern North America by the monarch butterfly: successive brood or single sweep migration? In: Malcolm S.B. and M.P. Zalucki, editors. *Biology and conservation of the monarch butterfly*. Los Angeles: Natural History Museum of Los Angeles County. p 253–67.

Mohammad, A.G., C.A. Ferrando, L.W. Hurray, R.D. Pieper, and J.D. Wallace. 1996. Season and sex influences on botanical composition of cattle diets in southern New Mexico. *Journal of Range Management* 49: 204-208

NDAWN, North Dakota Agricultural Weather Network. 2021. North Dakota Agricultural Weather Network (NDAWN) Station. Available from https://ndawn.ndsu.nodak.edu/station-info.html?station=48 (accessed October 1, 2021).

Nestle, R., J.C. Daniels, and A.G. Dale. 2020. Mixed-Species Gardens Increase Monarch Oviposition without Increasing Top-Down Predation. *Insects* 11(9):648-665.

Oberhauser, K. Monarch Butterfly Frequently Asked Questions (FAQs). USDA, U.S. Forest Services. https://www.fs.fed.us/wildflowers/pollinators/Monarch_Butterfly/faqs.shtml. Accessed 25 Oct 2022.

Pitman, G.M., D.T. Flockhart, and D.R. Norris. 2018. Patterns and causes of oviposition in monarch butterflies: Implications for milkweed restoration. *Biological Conservation* 217: 54-65.

Pleasants, J. 2017. Milkweed restoration in the Midwest for monarch butterfly recovery: estimates of milkweeds lost, milkweeds remaining and milkweeds that must be added to increase the monarch population. *Insect Conserv. Divers*. 10: 42–53.

Reppert, J. N. 1960. Forage preference and grazing habits of cattle at the Eastern Colorado Range station. *Rangeland Ecology & Management/Journal of Range Management Archives* 13(2): 58-65.

Ricketts, A.M. and B.K. Sandercock. 2016. Patch-burn grazing increases habitat heterogeneity and biodiversity of small mammals in managed rangelands. Ecosphere 7(8): e01431.

Roels, S.M. 2011. Not easy being Mead's: comparative herbivory on three milkweeds, including threatened mead's milkweed (*Asclepias meadii*), and seedling ecology of mead's milkweed (Master's thesis, University of Kansas).

Schwartz, C.C. and J.E. Ellis. 1981. Feeding ecology and niche separation in some native and domestic ungulates on the shortgrass prairie. *Journal of Applied Ecology* 18(2): 343-353.

Theobald, D.M. 2014. Development and Applications of a Comprehensive Land Use Classification and Map for the US. *PLoS ONE* 9(4): e94628.doi:10.1371/journal.pone.0094628

Thogmartin W.E., L. López-Hoffman, J. Rohweder, J. Diffendorfer, R. Drum, D. Semmens, S. Black, I. Caldwell, D. Cotter, P. Drobney, L.L. Jackson, M. Gale, D. Helmers, S.Hilburger, E. Howard, K. Oberhauser, J. Pleasants, B. Semmens, O. Taylor, P. Ward, J.F.Weltzin, and R. Wiederholt. 2017a. Restoring monarch butterfly habitat in the Midwestern US: 'all hands on deck'. Environ. Res. Lett. 12(7):1-9.

Thogmartin, W.E., R. Wiederholt, K. Oberhauser, R.G. Drum, J.E. Diffendorfer, S. Altizer, O.R. Taylor, J. Pleasants, D. Semmens, B. Semmens, R. Erickson, K. Libby, and L. Lopez-Hoffman. 2017b. Monarch butterfly population decline in North America: identifying the threatening processes. Royal Society Open Science 4(9):1-9.

Walker, A., W.E. Thogmartin, K.S. Oberhauser, E.M. Pelton, and J.M. Pleasants. 2022. Danaus plexippus. The IUCN Red List of Threatened Species 2022: e.T159971A806727. https://dx.doi.org/10.2305/IUCN.UK.2022-1.RLTS.T159971A806727.en. Accessed on 13 October 2022.

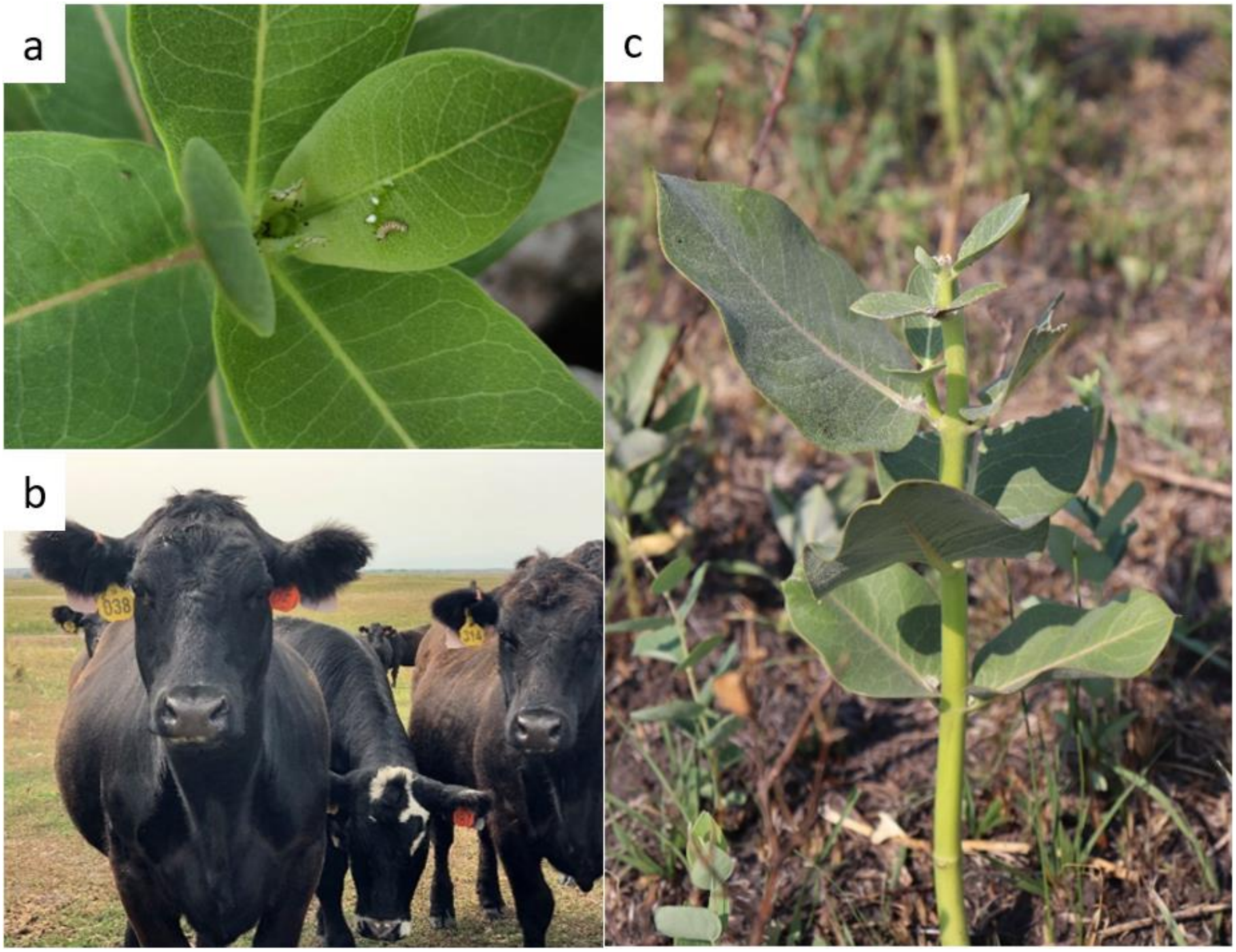


Image 1*. An example of (a) second instar monarch caterpillar in the upper leaves of common milkweed, (b) cattle on pasture, and (c) bitten-off milkweed stem with visible bite marks on leaves and/or absence of upper stem.*

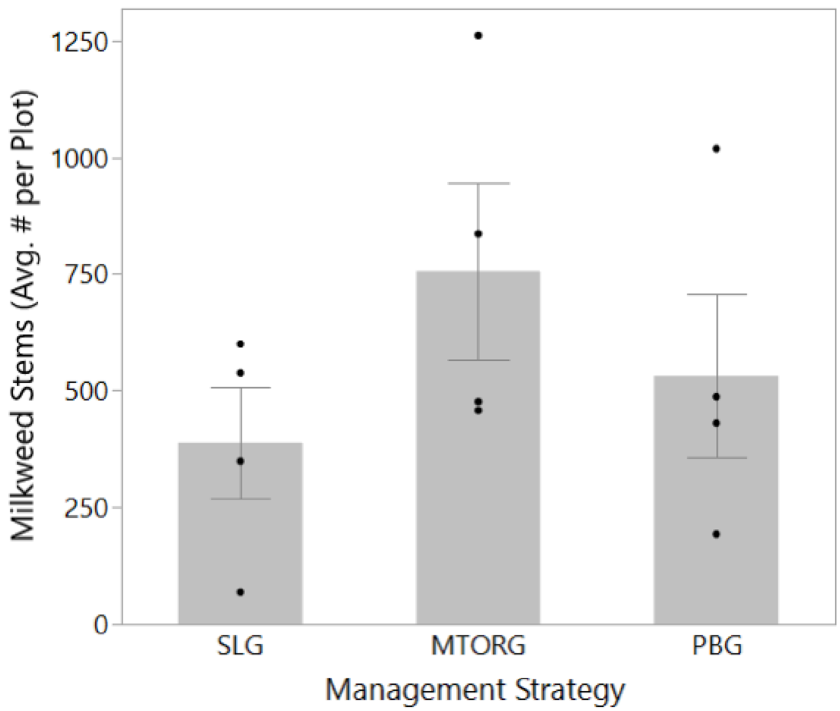


Figure 1. *Average available milkweed stem counts per 16-ha plot within each management strategy. Error bars constructed using 1 standard error from mean. Rested paddocks not included in MTORG. Each dot represents one replicate.*

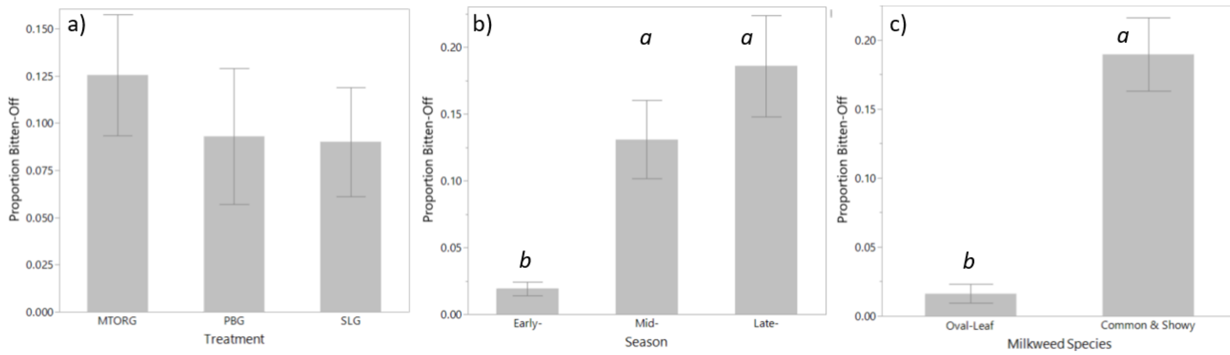


Figure 2. *a) Proportion of bitten-off stems in each treatment, b) the proportion of bitten-off milkweed stems observed in the season (early-, mid-, and late- season each approximately consist of one of three sampling rounds), averaged across treatment and replicate (12 points for each bar)., and c) the proportion of bitten-off stems of each species. For each graph, bars represent the mean, error bars constructed using 1 standard error from the mean, and means with different letters are significantly different.*

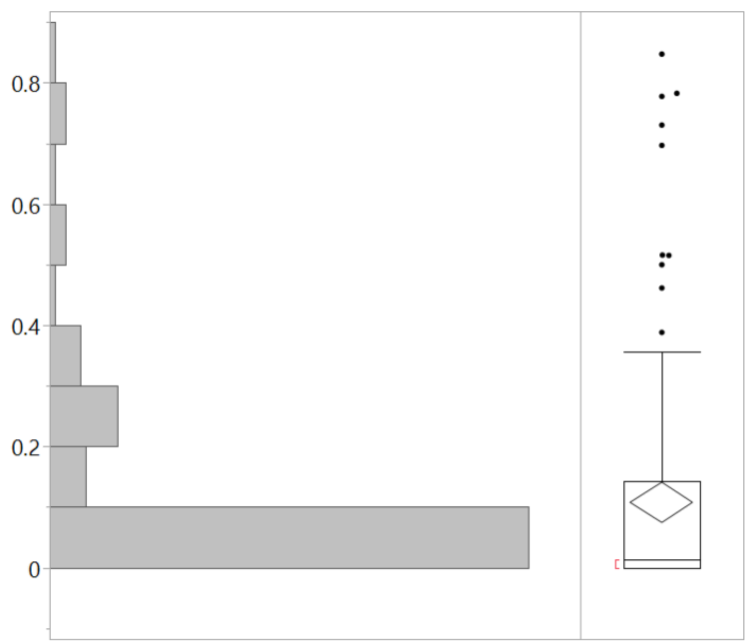


Figure 3. *A histogram of bitten-off stems in proportion to total available milkweed stems per plot. The majority of observation plots did not exceed 11% cattle herbivory of milkweed. Box plot to right includes outliers (black dots) and line extending away from the box is the variability beyond the majority (75%) of observations. The diamond within the box is the average amount of milkweed bitten by cattle with 95% confidence.*

Heterogeneity-based rotational grazing benefits monarchs (*Danaus plexippus* L.) in rangelands

Ellysa R. Johnson[1], Jason P. Harmon[1], Torre J. Hovick[1], and Kevin K. Sedivec[1,2]

[1]School of Natural Resource Sciences, North Dakota State University, Fargo, ND.
[2]Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND

Summary
Eastern migratory monarch butterfly (*Danaus plexippus* L.) populations have declined by 80% in the last few decades, primarily due to agricultural expansion and intensification. While row-crop agricultural fields have widely removed monarch food and shelter resources, the opportunity to re-establish such resources remains in rangelands. Specifically, rangelands have the capacity to provide monarch host plants (milkweed, *Asclepias* spp.) and flowering forbs for nectar. In response, we are evaluating different grazing management strategies in North Dakota rangelands for their ability to simultaneously accommodate human needs in the form of cattle production as well as promote biodiversity conservation. We examined the abundances of milkweed, flowering forbs, and monarchs (adults and juveniles) in three grazing strategies: (1) modified twice-over rest-rotational grazing, (2) patch-burn grazing, and (3) continuous grazing. During both drought and average conditions, the heterogeneity-based rotational grazing strategy resulted in higher abundances of milkweed and juvenile monarchs than patch-burn grazing. Flowering forb abundance increased fourfold from drought conditions compared to average rainfall in the patch-burn grazing system, while remaining constant in the heterogeneity-based rotational and continuous grazing systems. Monarch adults did not exhibit a penchant for any one grazing strategy, but higher abundance trended towards the heterogeneity-based grazing system. In the face of increasingly variable weather conditions, providing consistency and resilience, such as with a heterogeneity-based rotational grazing strategy, could be key to monarch, and overall wildlife, conservation in rangelands.

Introduction

The eastern migratory monarch butterfly (hereafter "monarch") population has been in decline for the last two decades, primarily due to the loss of food resources in the form of milkweed (*Asclepias* spp.), their obligate host plant, and nectar-rich forbs (Stenoien et al., 2018; Brower et al., 2006). The Midwest corridor, which is now primarily row crop agriculture, hosted over 50% of breeding monarchs (Malcolm, 1993), but due to common pesticide application practices, these fields are no longer suitable for monarch utilization (Pleasants & Oberhauser, 2013). Although rangelands constitute more the western edge of the monarch range and are generally used for livestock production, they cover more acreage than row crop agriculture (Bigelow & Borchers, 2017). Thus, rangelands may have potential to aid in milkweed and forb promotion, but it is currently unclear how the abundances of each may differ between grazing strategies.

Historically, disturbance in the form of coupled fire and ungulate grazing, or pyric herbivory, maintained rangelands by creating heterogeneity at the landscape level (Samson & Knopf, 1994). This was accomplished by incentivizing grazers to concentrate on recently burned areas over others so as to obtain nutritious re-growth (Mola & Williams, 2018). Today, continuous grazing is most common in the modern-day Great Plains region, which tends to minimize heterogeneity in favor of cattle production. We modeled our study to compare current rangeland grazing practices with heterogeneity-based alternatives that more closely mimic historic disturbance regimes so as to investigate the viability of rangelands to promote monarch food resources.

We assessed three different grazing management strategies in North Dakota mixed-grass prairie rangelands in the summers of 2021 and 2022: (1) modified twice-over rest-rotation grazing, (2) patch-burn grazing, and (3) continuous grazing. In order to accurately determine which of these grazing strategies promote monarch resources, we monitored milkweed (obligate host plant) and flowering forbs (nectar resources), as well as monarch adult butterflies and juveniles (eggs and caterpillars). We then compared abundances of each organism across grazing strategies to determine which grazing strategy may most benefit monarch conservation.

Procedures

Study Site
The Central Grasslands Research Extension Center (CGREC) is located in Stutsman and Kidder counties in North Dakota. This region is considered mixed-grass prairie, consisting of native cool-season grasses such as western wheatgrass (*Pascopyrum smithii*). Invasive grasses, Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*), are prominent in every section of CGREC (Limb et al., 2018). Western snowberry (*Symphoricarpos occidentalis*), though native, is also dominant in many areas. Common native forbs include prairie coneflower (*Ratibida columnifera*) and yarrow (*Achillea millefolium*) (Rogers et al., 2005). The climate at CGREC is classified as temperate and has an average growing season rainfall of 36.14cm (14.23in; NDAWN, 2022). However, the summer of 2021 was classified as a severe drought (Fuchs, 2021), receiving only 24.03cm (9.46in) during data collection (June-August; NDAWN, 2021).

Treatment Structure
Our study consists of three, 64-ha pastures, each replicated four times. The treatments consist of: (1) modified twice over rest-rotational grazing (MTORG), (2) patch-burn grazing (PBG), and (3) continuous grazing (CG).

The MTORG system aims at creating heterogeneity in the absence of fire by incorporating four, fenced-in paddocks, each with varying degrees of utilization: rested/no-grazing (NG; 0%), moderate grazing (MG; 20-40%), full-use grazing (FG; 40-60%), and heavy grazing (HG; 60-80%). The percentages are derived by the cumulative duration of time the cattle are present in the paddock. The longer the plot is grazed, the larger the impact on the vegetation, hence the increase in grazing degree of utilization. Being a rotational system, the cattle are moved from one paddock identity (e.g. MG) to the next twice within the grazing season. Additionally, the paddock identity rotates annually, so the NG plot will become the MG plot the following year, MG becomes FG, etc. (Fig. 1a).

The PBG system is designed to promote pyric herbivory. A PBG system uses the fire-grazing interaction to create contrast among patches within a pasture. Livestock are attracted to the most recent post-fire vegetation growth, leading to reduced grazing in other patches (Vermeire et al., 2004). As a consequence, vegetation grows taller in non-grazed patches than in their grazed counterparts, attributing to structural complexity (Fuhlendorf et al., 2009). A quarter of the PBG field (16-ha total) is burned annually on a 4-year fire return interval. Unfavorable conditions in 2022 prevented any burns. As a consequence, the time since fire (TSF) identities range from 0 to 4 years (Fig. 1b).

The CG system acts as the control, as it is the default management strategy of the area. As with PBG but without fire, the cattle in each 16-ha pasture of the CG system are allowed to graze the entire section throughout the grazing season (Fig. 1c).

All grazing strategies include cattle grazing by cow-calf pairs with a similar 5-year average stocking rate, ranging from 1.59 to 2.39 animal unit months per hectare (AUMS/ha) for the duration of the growing season (May to October) to achieve an average 30% forage utilization for each treatment.

Transect surveys

From June to August in 2021 and 2022, we surveyed a total of 144, 150m transects (3 transects per plot x 4 plots per replicate x 4 replicates per treatment x 3 treatments) three times each year. On each transect we conducted a 10-minute adult butterfly survey down the transect and juvenile, milkweed, and forb surveys on the return (Fig. 1d).

Analysis

We used ANOVA in JMP (JMP®, Version Pro 15. SAS Institute Inc., Cary, NC, 1989–2022) to analyze the treatment, year, and treatment by year interaction effects for each variable.

Results

We counted a total of 182 adults, 165 juveniles, 33,893 milkweed stems, and 185,375 flowering forbs across all treatments, encompassing five milkweed and 117 forb species. Milkweed species included *Asclepias syriaca*, *A. speciosa*, *A. ovalifolia*, *A. incarnata*, and *A. viridiflora*, which are all native to North Dakota. The highest abundances of both monarch juveniles and milkweed occurred in MTORG (p=0.021 and 0.0047, respectively; Fig. 2d; Fig. 2a), regardless of drought. In 2021, flowering forb abundance in MTORG was slightly higher than CG, which was slightly higher than PBG, though not significantly. While flowering forb abundance was highest in the MTORG system in 2021, it was superseded by PBG in 2022, though these varied insignificantly across treatments in both 2021 and 2022. Forb abundance increased four-fold within the PBG system across the two years of the study (p=0.0059; Fig. 2b). While the MTORG system had the highest monarch adult counts, we did not find any significant differences in adult counts between grazing strategies or years (Fig. 2c).

Discussion

We tested three rangeland grazing strategies in North Dakota to see which promotes monarchs and their food resources so as to understand how rangelands can contribute to monarch conservation efforts. While recognizing a drought occurred during our first year of data collection, the lack of precipitation did not seem to affect monarchs or milkweed as numbers were similar across years. Monarchs are migratory, so their population is not solely dependent on resources within one location, while milkweed may not have been impacted by the lack of precipitation on account of its drought tolerance and rhizomatous growth. However, in the patch-burn grazing system, increased precipitation drastically increased flowering forb abundance between years. Perhaps in an already water stressed system, the inclusion of fire adds too much strain to the vegetation and ultimately prevents re-growth. However, this may be the case for severe and extreme drought as in lighter drought periods, floral resource availability quickly rebounds after a fire (Mola & Williams, 2018).

In both drought and normal conditions, the heterogeneity-based modified twice-over rest rotation grazing system resulted in relatively higher abundances of monarchs, milkweed, and flowering forbs. Given that droughts are likely to become prolonged, more extreme, and more frequent (Frankson et al., 2017), a management strategy that adheres to the heterogeneity framework by offering both disturbance and rest should be utilized so as to contribute to monarch conservation.

Literature Cited

Bigelow, D.P. and A. Borchers. 2017. Major uses of land in the United States, 2012, EIB-178, U.S. *Department of Agriculture*, Economic Research Service.

Brower, L.P., L.S. Fink, and P. Walford. 2006. Fueling the Fall Migration of the Monarch Butterfly. Integrative and Comparative Biology 46(6):1123–1142.

Frankson, R., K. Kunkel, L. Stevens, D. Easterling, M. Shulski, A. Akyuz. 2017. North Dakota State Climate Summary. NOAA Technical Report NESDIS 149-ND, https://statesummaries.ncics.org/chapter/nd/, 2017 (accessed 28 Sept 2021).

Fuchs, B. 2021. U.S. Drought Monitor. National Drought Mitigation Center, https://droughtmonitor.unl.edu/. Accessed 5 Oct 2021.

Fuhlendorf, S. D., D. M. Engle, J. Kerby, and R. Hamilton. 2009. Pyric herbivory: rewilding landscapes through the recoupling of fire and grazing. Conservation Biology 23: 588–598.

Limb, R. F., T.J. Hovick, J.E. Norland, & J.M. Volk. 2018. Grassland plant community spatial patterns driven by herbivory intensity. Agriculture, Ecosystems and Environment, 257:113–119.

Malcolm S.B., B.J. Cockrell, and L.P. Brower. 1993. Spring recolonization of eastern North America by the monarch butterfly: successive brood or single sweep migration? In: Malcolm SB, Zalucki MP, editors. *Biology and conservation of the monarch butterfly*. Los Angeles: Natural History Museum of Los Angeles County. P 253–67.

Mola, J.M. and N.M. Williams. 2018. Fire-induced change in floral abundance, density, and phenology benefits bumble bee foragers. Ecosphere 9(1): 1-8.

NDAWN, North Dakota Agricultural Weather Network. 2021. North Dakota Agricultural Weather Network (NDAWN) Station. Available from https://ndawn.ndsu.nodak.edu/station-info.html?station=48 (accessed October 1, 2021).

NDAWN, North Dakota Agricultural Weather Network. 2022. North Dakota Agricultural Weather Network (NDAWN) Station. Available from https://ndawn.ndsu.nodak.edu/station-info.html?station=48 (accessed September 14, 2022).

Pleasants, J.M. and K.S. Oberhauser. 2013 Milkweed loss in agricultural fields because of herbicide use: effect on the monarch butterfly population. Insect Conser. Diver. 6: 135–144.

Rogers, W.M., D.R. Kirby, P.E. Nyren, B.D. Patton, and E.S. Dekeyser. 2005. Grazing intensity effects on northern plains mixed grass prairie. *Prairie Naturalist* 37: 73-83.
Samson, F. and F. Knopf. 1994. Prairie conservation in North America. BioScience 44(6): 418-421.
Stenoien, C., K.R. Nail, J.M. Zalucki, H. Parry, K.S. Oberhauser, and M.P. Zalucki. 2018. Monarchs in decline: a collateral landscape-level effect of modern agriculture. Insect Science 25(4): 528-541.
Vermeire, L.T., R.B. Mitchell, S.D. Fuhlendorf, and R.L. Gillen. 2004. Patch burning effects on grazing distribution. J. of Range Management 57(3): 248-252.

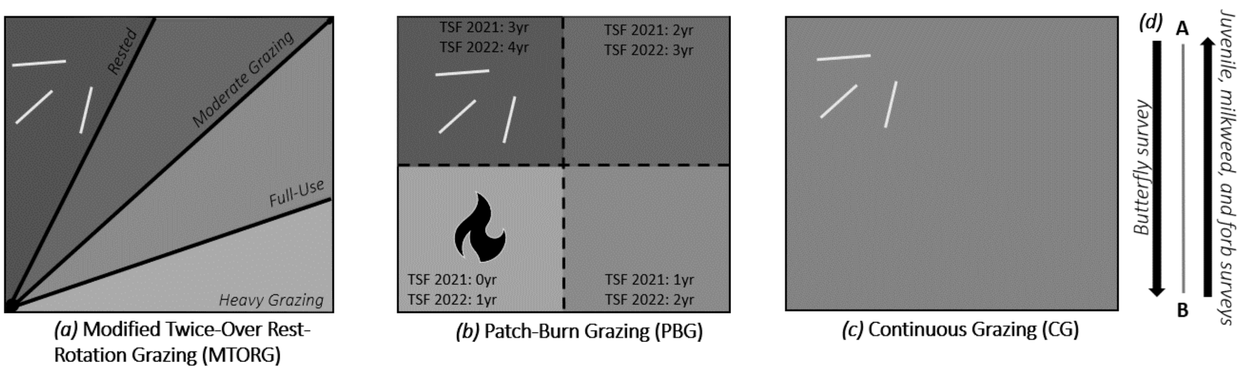


Figure 1.The layout of a) MTORG, b) PBG, and c) CG, and d) the order of events for an individual transect. White lines represent a set of three transects within one 16-ha area. Solid black lines represent fences while dashed black lines are fire breaks. TSF = time since fire.

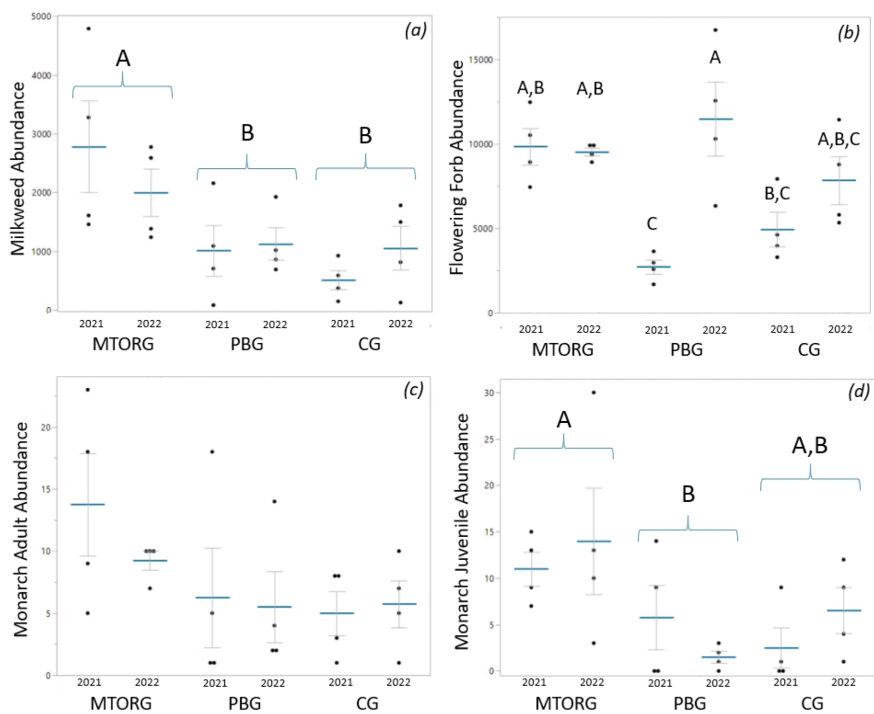


Figure 2. The abundances of a) milkweed, b) flowering forbs, c) monarch adults, and d) monarch juveniles in each treatment and year of the study. Blue lines are the average abundance, while black dots are counts in each individual replicate field. Grey bars are standard error bars. Means with different letters are significantly different.

Bee Abundance, Diversity, and Floral Visitation for Two Summers Across Three Grazing Regimes

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

[1]School of Natural Resource Sciences, North Dakota State University, Fargo, ND
[2]Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND
[3]Hettinger Research Extension Center, North Dakota State University, Hettinger, ND

Summary

Bees are important insects that provide pollination benefits to rangelands and, in turn, rely on rangelands for floral resources and nesting sites. To better understand the relationship between bees and rangeland management, we have been evaluating the effects of three grazing regimes on bee community abundance, diversity, and floral use from June through August of 2021 and 2022. The study site experienced drought conditions in 2021 with higher-than-average daily temperatures and low rainfall in comparison to previous years which may have impacted the results. Results show that the modified twice-over rest rotational grazing treatment (MTORG) had the greatest abundances of bees for both years in comparison to the patch-burn grazing treatment (PBG) and the season-long grazing treatment (SLG). Within the MTORG, the most bees, as well as flowers, were observed in the rested paddocks for both years. During the summer of 2021, the PBG had the fewest bees out of the three treatments, but it had the second highest bee abundance in 2022, while the SLG showed the exact opposite. As far as bee diversity, we identified bees to genus for 2021 and to species for 2022. Similar genera were observed across all three treatments in 2021, but for 2022, the highest number of species was in MTORG followed by PBG and then SLG. We found fewer bees in almost all bee families in 2022 except for bumble bees, which increased from 7 individuals in 2021 to 46 in 2022. Following the 2021 drought, we saw a large increase in flowering abundance and diversity in 2022 as well as more species of flowering plants being visited by bees. Although more flowers were available in 2022 for bees to visit, western snowberry was the most visited plant species in both years and was visited by 11 out of 14 identified bee genera. This suggests that western snowberry may be an important flowering species for bees to visit in rangelands during and after a drought. Results support the theory that rested paddocks in a MTORG treatment may benefit bee abundance and diversity during years of variable climate conditions, but that PBG may also be beneficial throughout years with more ideal weather patterns.

Introduction

Bees are important pollinators that provide essential services to natural and agricultural plant communities (Kremen et al. 2002, Klein et al. 2007, Park et al. 2010). Both honey bees and native bees are vital to native and agro-ecosystems, but their populations have undergone global declines due to habitat loss, agricultural intensification, and climate change (Brown and Paxton 2009, Potts et al. 2010). Native bees especially require support due to their contribution to long-term crop yield and landowner profit (Garibaldi et al. 2014). Rangelands are becoming of more interest in bee conservation because they are a crucial source of pollinator food sources and nesting sites (Black et al. 2011), making these areas critical for pollinator conservation (Cole et al. 2017). Therefore, grazing management techniques are essential to study for both bees and livestock production.

One of the contributing factors to bee decline is habitat loss, including the conversion of more land to agricultural landscapes (Kline and Joshi 2020). As native, solitary bees are needed to pollinate agricultural fields and, in some cases, can be extremely efficient crop pollinators (Garibaldi et al. 2014), actions must be done to help support these insects (Kline and Joshi 2020). As with crop production, livestock grazing also takes up a large area of land. In the United States, about 33% of land is taken up by production grazing (Theobald 2014). If we are to use this land to support bee communities, we must explore grazed rangeland management techniques that can create sustainable habitat for bees while also maximizing livestock production.

Grazed rangelands can be managed in different ways including rotational grazing, continuous grazing, and patch-burn grazing (Fuhlendorf and Engle 2001). Grazing management can impact bees in many ways depending on the level of grazing intensity, timing of grazing, and landscape (Sjödin et al. 2008, Lázaro et al. 2016, Smith et al. 2016, Buckles and Harmon-Threatt 2019). For example, patch-burn grazing may negatively or positively impact nesting sites for bees depending on the parameters of specific studies (Buckles and Harmon-Threatt 2019, Bruninga-Socolar et al. 2021). Research specifically carried out in North Dakota has found that grazing can shift bee-plant network structure and composition as well as floral availability (Bendel et al. 2019). Bees depend on floral resources to fill nutritional needs and select flowers based on food source quality (Cnaani et al. 2006, Somme et al. 2015), so it is important to continue studies on bee communities and the floral resources they use across different rangeland management techniques.

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

Procedures

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.).

The first summer of data collection experienced a drought with higher average daily temperatures and about 30% less rainfall from a normal year (interpolated data from 1991-2020 reported in the North Dakota Agricultural Weather Network (NDAWN) from the National Weather Service) between the months of May and August (Figures 1 and 2; NDAWN 2000-2023). This first field season also experienced less rainfall during the beginning of the summer (May through July) in comparison to the previous early summer of 2020 (NDAWN 2000-2023).

The second field season in 2022 had average temperatures that were more normal but still had a slight decrease in total rainfall than a normal year (Figures 1 and 2; NDAWN 2000-2023).

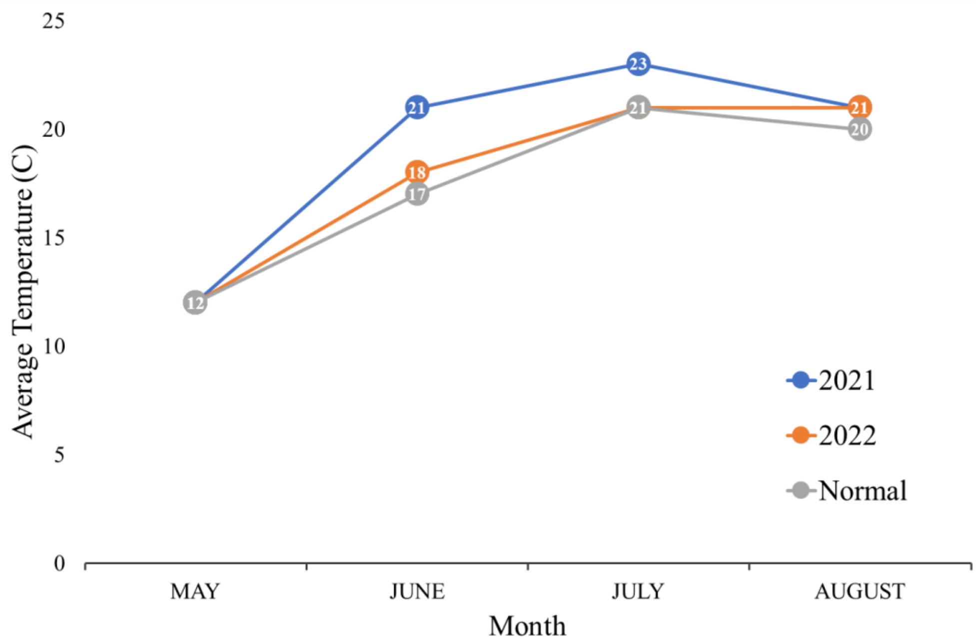


Figure 1. The average temperatures (ºC) from May through August for 2021, 2022, and a normal year (interpolated data from 1991-2020 reported in NDAWN).

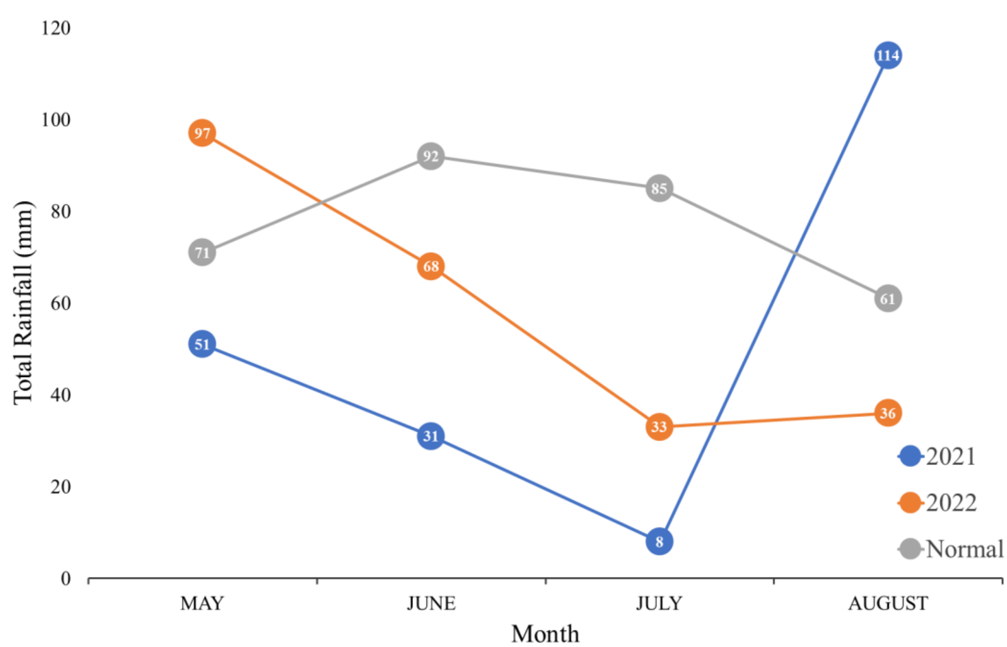


Figure 2. The total rainfall (mm) from May through August for 2021, 2022, and a normal year (interpolated data from 1991-2020 reported in NDAWN).

Treatment Structure

We used three treatments of approximately 260 hectares each (Figure 3): modified twice-over rest rotational grazing (MTORG), patch-burn grazing (PBG), and season-long grazing (SLG). Each treatment has four replicates of equal pasture size (65 ha). Within the modified twice-over rest rotational treatment, there are different intensities of grazing including heavy, full, moderate, and rested paddocks. The patch-burn grazing treatment is burned on a four-year rotation with a quarter of each pasture being burned every spring. The season-long grazing acts as a control to reflect common regional management.

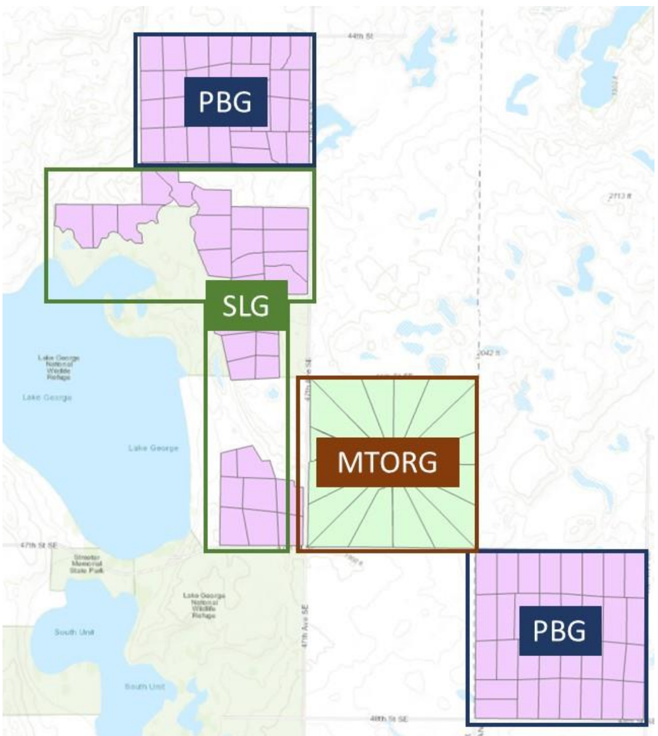


Figure 3. The three grazing treatments used at the CGREC: modified twice-over rest rotational grazing (MTORG, outlined in red), patch-burn grazing (PBG, outlined in blue), and season-long grazing (SLG, outlined in green).

Objective 1: Bee abundance and diversity

To sample abundance and diversity of bees, we surveyed a 100-m transect in every 8-ha subplot three times within each treatment (Figure 4). In 2021, we surveyed from June 17th to August 14th, and in 2022, we surveyed from June 9th to August 18th. We caught all bees within reach using a sweep net and photographed them for identification. In 2021, all bees were caught, photographed, swabbed for a pollen sample, and released. In 2022, honey bees were not caught or photographed, but were identified directly in the field. Bumble bees were swabbed for a pollen sample after being photographed and released live. All other bees were collected to help better identify them to species and to swab them for pollen samples in the lab. For the preliminary results, we grouped bees by family but separated honey bees (*Apis mellifera*) and bumble bees (*Bombus* sp.) from the other members of Apidae because this is a particularly large bee family that is very abundant in this area. After finishing the bee survey, we followed the same 100-m transect in the opposite direction (Figure 4). We counted and identified each individual flowering plant within 2.5 meters on either side of the transect.

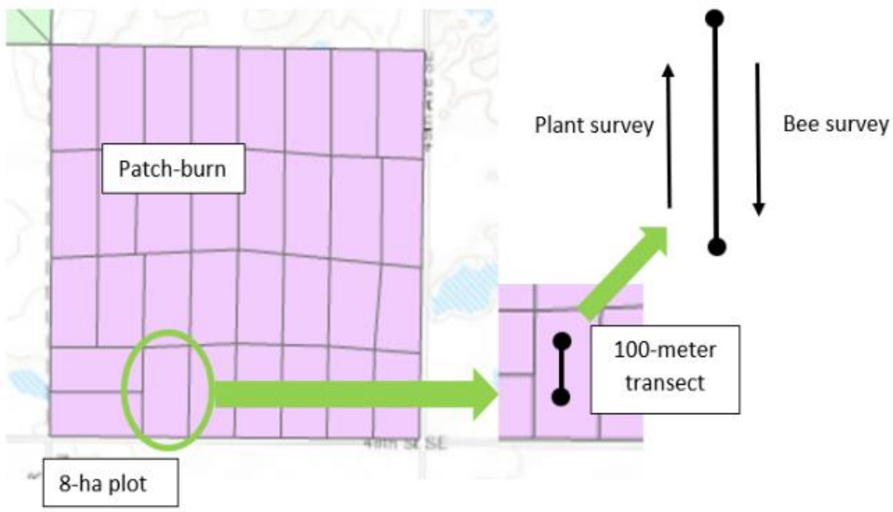


Figure 4. Example of a 100-m transect survey in an 8-ha plot within the patch-burn grazed treatment. Bee surveys were conducted along one direction of the transect while a floral plant survey was done in the opposite direction to record the abundance and diversity of floral species throughout the summer.

Objective 2: Bee floral visitation

For each observed or caught bee along the transect, we recorded the flowering species that the bee was visiting as well as the plant height.

Results

Objective 1: Bee abundance and diversity

The greatest number of bees were found in the MTORG in 2021 and 2022 (Figure 5A). Bee abundance was significantly lower in PBG for 2021 and in SLG for 2022. We observed that the most bees were caught within the rested paddocks of the MTORG for both years but only had significantly more bees than the moderately grazed paddocks in 2021 ($p = 0.033$) (Figure 5B). Observationally, in 2021, bee genera were similar across the treatments, but for 2022, there were more bee species found in the MTORG treatment (13 species) followed by PBG (11 species) and then SLG (9 species). For both years, the honey bee (*Apis mellifera)* was the most abundant bee species detected in each treatment (Figure 6). There was a decrease in bees caught within each bee family in 2022 compared to 2021, however bumble bees (*Bombus* spp., within Apidae) increased from 7 individuals in 2021 to 46 in 2022 (Figure 6).

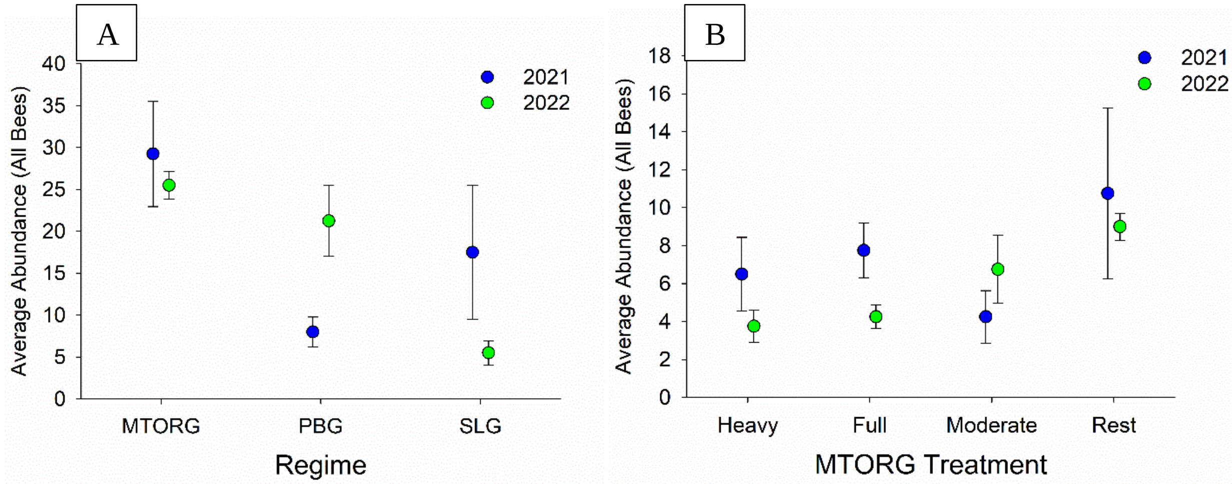


Figure 5. Average abundance of bees within A) each grazing treatment and B) within the paddocks of the modified twice-over rest rotational treatment.

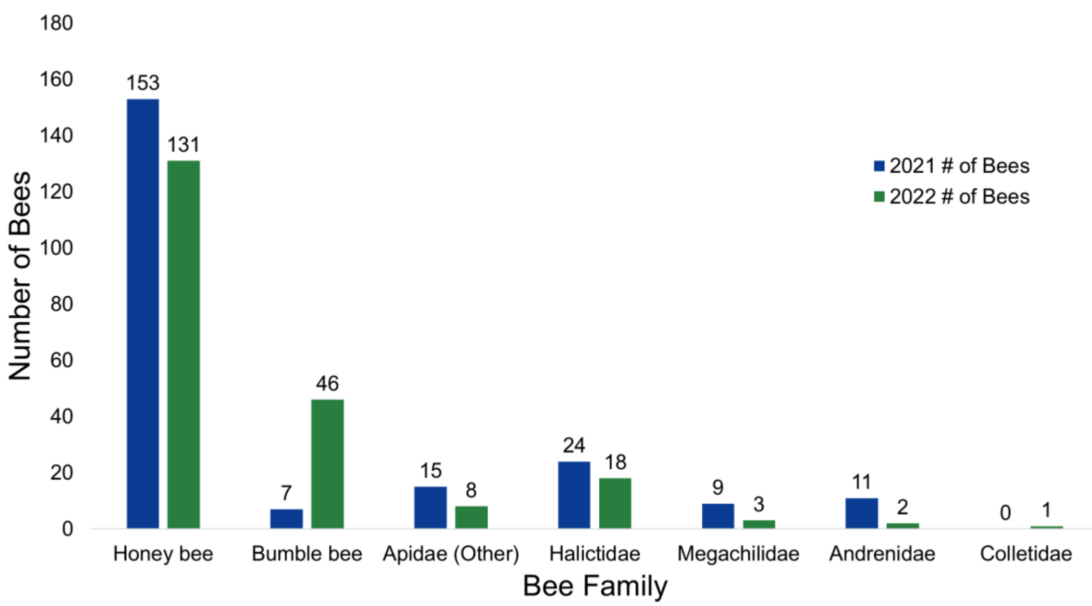


Figure 6. The actual counts of bees for each family. Honey bees (*Apis mellifera*) and bumble bees (*Bombus* spp.) were separated from their family Apidae because of their higher abundances in comparison to the other bee families detected.

Objective 2: Bee floral visitation

We recorded the number of floral species visited by each bee family and found that more flowering species were visited by members within Apidae and Halictidae in 2022 than in 2021 (Figure 7). Although honey bees were the most abundant bee species caught, they only visited a total of 18 flower species between the two years which was not much more than other bee groups that were caught in lower abundances. The most common flower species that bees were caught on for both years was western snowberry (*Symphoricarpos occidentalis* Hook.), which was visited by 11 out of the 14 genera identified in 2021 and 2022.

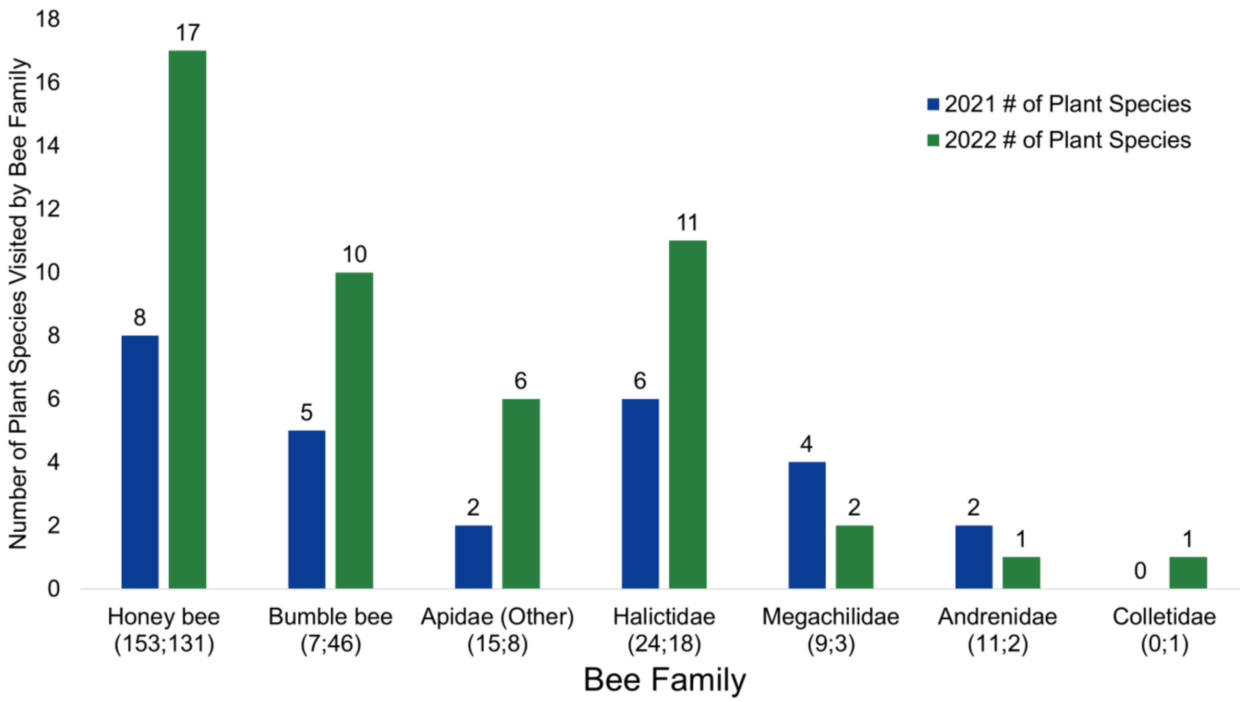


Figure 7. The number of plant species visited by bees within each family. The numbers below each bee family are the actual numbers of individuals caught for each year for reference. Honey bees (*Apis mellifera*) and bumble bees (*Bombus* spp.) were separated from their family Apidae because of their higher abundances in comparison to the other bee families detected.

Discussion

Objective 1: Bee abundance and diversity

Results show that the most bees were caught in the rested paddocks within the modified twice-over rest rotational grazing treatment. Although the PBG treatment had the fewest bees in 2021, it was the second most abundant in 2022. For 2021, bee genera were similar across all treatments, but for 2022, we saw more bee species in MTORG followed by PBG, which was a comparable pattern to bee abundance. The treatment data shows that rested paddocks may potentially benefit bees during years of less-than-ideal climate conditions, but that PBG may also benefit bees during years of more normal temperatures and precipitation for the area.

We are potentially seeing an impact of the 2021 drought on the abundances for 2022 except for bumble bees. Bumble bees are strong fliers with the ability to travel further distances (Osborne et al. 2008, Hagen et al. 2011, Rao and Strange 2012), so it is possible that they left the area more readily than smaller bee species during the drought and were attracted back to the pastures the following year when more flowering plant species were available. Honey bees were the most commonly caught bee. This may be because of the proximity of honey bee hives in the area. However, we also rarely observed only one honey bee at a time on a survey because they were often foraging in groups, which would have increased our counts of them within the transects.

Objective 2: Bee floral visitation

In general, we saw an increase in floral species visitation in 2022 compared to 2021, which was more than likely a result of increased floral abundance and species in 2022. Additionally, more flower species were visited overall despite total bee abundance being similar between the two years. Although we caught fewer bees of the Apidae and Halictidae in 2022, members of these two families visited more plant species than the year before. For the other bee families, we observed fewer flower species being visited, but the differences between the two years were only by a factor of 1 or 2 plant species which may be a result of catching so few bee individuals within each family.

Finally, the most commonly visited flowering species was western snowberry, which appeared to withstand the drought well in 2021 and was abundant in all treatments for both years. This could highlight the potential usefulness of snowberry, a native shrub that is typically unwanted by ranchers, during years of unfavorable climate conditions. It was visited by almost every genus of bee identified in the surveys. However, it was not visited by every species that was identified and was not visited at all by the common genus *Melissodes*, which are associated with flowers in the family Asteraceae. We suggest that having multiple management regimes that actively sustain floral abundance and diversity, such as utilizing both rested pastures and patch-burn grazing, may support the most bee species in the long-term.

Future Work

We will be conducting these surveys again in the summers of 2023 and 2024. Our goals are to not only add to the data on bee abundance, diversity, and floral visitation that we already have, but to also characterize the flowering plant community, identify floral species visited by bees using pollen samples, and calculate visitation rates between treatments with time-lapse video cameras. We are currently analyzing collected pollen samples and videos in the lab at NDSU as well as finishing the identification of photographed and caught bees from the surveys.

Significance

This research is necessary because there is an increasing need for more study on bee responses across different management regimes and across multiple bee taxa (Brown and Paxton 2009). Researchers can use this information to help manage rangelands for multiple uses, including promoting bees and their needed resources. So far, preliminary data from these two field seasons suggest that multiple management regimes may benefit bees by providing resources across years of variable climate conditions. Bees are essential for multiple ecosystems services (Klein et al. 2007, Lautenbach et al. 2012, Patel et al. 2021), so it is more important than ever to conserve these pollinators. Because of the large areas utilized as rangelands (Foley et al. 2005) and the increasing global need for livestock products (Thornton 2010), findings from studies like this can contribute to a larger goal of benefiting both production and habitat for a variety of wildlife.

Acknowledgements

We would like to acknowledge Kevin Sedivec, Director of the CGREC, and thank our technicians for data collection and processing: Kirsten Warcup, Lauren Berman, Kyle Vernot, Charlie Staff, and Rory Running.

Literature Cited

Bendel, C. R., K. C. Kral-O'Brien, T. J. Hovick, R. F. Limb, and J. P. Harmon. 2019. Plant–pollinator networks in grassland working landscapes reveal seasonal shifts in network structure and composition. Ecosphere 10:e02569.

Black, S. H., M. Shepherd, and M. Vaughan. 2011. Rangeland management for pollinators. Journal of Range Management 33:9–13.

Brown, M. J. F., and R. J. Paxton. 2009. The conservation of bees: A global perspective. Apidologie 40:410–416.

Bruninga-Socolar, B., S. R. Griffin, Z. M. Portman, and J. Gibbs. 2021. Variation in prescribed fire and bison grazing supports multiple bee nesting groups in tallgrass prairie. Restoration Ecology:e13507.

Buckles, B. J., and A. N. Harmon-Threatt. 2019. Bee diversity in tallgrass prairies affected by management and its effects on above- and below-ground resources. Journal of Applied Ecology 56:2443–2453.

Cnaani, J., J. D. Thomson, and D. R. Papaj. 2006. Flower choice and learning in foraging bumblebees : effects of variation in nectar volume and concentration. Ethology 112:278–285.

Cole, L. J., S. Brocklehurst, D. Robertson, W. Harrison, and D. I. McCracken. 2017. Exploring the interactions between resource availability and the utilisation of semi-natural habitats by insect pollinators in an intensive agricultural landscape. Agriculture, Ecosystems and Environment 246:157–167.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty, and P. K. Snyder. 2005. Global consequences of land use. Science 309:570–574.

Fuhlendorf, S. D., and D. M. Engle. 2001. Restoring heterogeneity on rangelands: Ecosystem management based on evolutionary grazing patterns. BioScience 51:625–632.

Garibaldi, L. A., L. G. Carvalheiro, S. D. Leonhardt, M. A. Aizen, B. R. Blaauw, R. Isaacs, M. Kuhlmann, D. Kleijn, A. M. Klein, C. Kremen, L. Morandin, J. Scheper, and R. Winfree. 2014. From research to action: Enhancing crop yield through wild pollinators. Frontiers in Ecology and the Environment 12:439–447.

Hagen, M., M. Wikelski, and W. D. Kissling. 2011. Space use of bumblebees (*Bombus* spp.) revealed by radio-tracking. PLoS ONE 6:e19997.

Klein, A.-M., B. E. Vaissiere, J. H. Cane, I. Steffan-Dewenter, S. A. Cunningham, C. Kremen, and T. Tscharntke. 2007. Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B: Biological Sciences 274:303–313.

Kline, O., and N. K. Joshi. 2020. Mitigating the effects of habitat loss on solitary bees in agricultural ecosystems. Agriculture 10.

Kremen, C., R. L. Bugg, N. Nicola, S. A. Smith, R. W. Thorp, and N. M. Williams. 2002. Native bees, native plants, and crop pollination in California. Fremontia 30:41–49.

Lautenbach, S., R. Seppelt, J. Liebscher, and C. F. Dormann. 2012. Spatial and temporal trends of global pollination benefit. PLoS ONE 7:e35954.

Lázaro, A., T. Tscheulin, J. Devalez, G. Nakas, and T. Petanidou. 2016. Effects of grazing intensity on pollinator abundance and diversity, and on pollination services. Ecological Entomology 41:400–412.

Limb, R. F., T. J. Hovick, J. E. Norland, and J. M. Volk. 2018. Grassland plant community spatial patterns driven by herbivory intensity. Agriculture, Ecosystems and Environment 257:113–119.

NDAWN North Dakota Agricultural Weather Network. 2000-2023. Station: Streeter ND: Monthly Weather Data. North Dakota State University. https://ndawn.ndsu.nodak.edu/weather-data-monthly.html Last Accessed January 1, 2023.

Osborne, J. L., A. P. Martin, N. L. Carreck, J. L. Swain, M. E. Knight, D. Goulson, R. J. Hale, and R. A. Sanderson. 2008. Bumblebee flight distances in relation to the forage landscape. Journal of Animal Ecology 77:406–415.

Park, M. G., M. C. Orr, and B. N. Danforth. 2010. The role of native bees in apple pollination. New York Fruit Quarterly 18:21–25.

Patel, V., N. Pauli, E. Biggs, L. Barbour, and B. Boruff. 2021. Why bees are critical for achieving sustainable development. Ambio 50:49–59.

Potts, S. G., J. C. Biesmeijer, C. Kremen, P. Neumann, O. Schweiger, and W. E. Kunin. 2010. Global pollinator declines: Trends, impacts and drivers. Trends in Ecology and Evolution 25:345–353.

Rao, S., and J. P. Strange. 2012. Bumble bee (Hymenoptera: Apidae) foraging distance and colony density associated with a late-season mass flowering crop. Environmental Entomology 41:905–915.

Sjödin, N. E., J. Bengtsson, and B. Ekbom. 2008. The influence of grazing intensity and landscape composition on the diversity and abundance of flower-visiting insects. Journal of Applied Ecology 45:763–772.

Smith, G. W., D. M. Debinski, N. A. Scavo, C. J. Lange, J. T. Delaney, R. A. Moranz, J. R. Miller, D. M. Engle, and A. L. Toth. 2016. Bee abundance and nutritional status in relation to grassland management practices in an agricultural landscape. Environmental Entomology 45:338–347.

Somme, L., M. Vanderplanck, D. Michez, I. Lombaerde, R. Moerman, B. Wathelet, R. Wattiez, G. Lognay, and A. L. Jacquemart. 2015. Pollen and nectar quality drive the major and minor floral choices of bumble bees. Apidologie 46:92–106.

Theobald, D. M. 2014. Development and applications of a comprehensive land use classification and map for the U.S. PLoS ONE 9:e94628.

Thornton, P. K. 2010. Livestock production: Recent trends, future prospects. Philosophical Transactions of the Royal Society B: Biological Sciences 365:2853–2867.

Supplementing trace minerals to beef heifers during gestation: Impacts on mineral status of the dam, neonate and placental tissues, colostrum characteristics, and performance of the offspring through weaning

J. L. Hurlbert[*], F. Baumgaertner[*], A. C. B. Menezes[*], K. A. Bochantin[*], W. Diniz[†], S. R. Underdahl[*], S. T. Dorsam[*], J. D. Kirsch[*], K. K. Sedivec[‡], C. R. Dahlen[*]

[*]Department of Animal Sciences and Center for Nutrition and Pregnancy, North Dakota State University, Fargo, ND, USA 58108
[†]Department of Animal Sciences, Auburn University, Auburn, AL, USA 36849
[‡]Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND, USA 58483

Abstract

Crossbred Angus-based heifers (n = 72; 14 to 15 months of age, initial body weight [**BW**] 838.6 ± 2.42 pounds [**lbs**]) were estrus synchronized, bred with female-sexed semen, and heifers maintaining female pregnancies were randomly assigned to either a basal diet targeting gain of 1 pound/heifer/day (**CON**; n = 14) or the basal diet plus a vitamin and mineral supplement (**VTM**; n = 17; ounces [**oz**] per heifer/day of Purina Wind & Rain Storm All-Season 7.5 Complete, Land O' Lakes, Inc., Arden Hills, MN). Liver biopsies were obtained from dams at breeding, d 84 and 180 of gestation. At calving, liver biopsies were taken from dams and calves. Additionally, calf BW was recorded at birth, and body measurements were recorded at 24 h after birth measurements. Colostrum samples were collected within 2 h post-calving and placental cotyledons collected after calving.

In maternal liver, concentrations of selenium (Se) and copper (Cu) were affected by a treatment × day interaction ($P < 0.0001$), being greater ($P < 0.001$) for VTM than CON at all post-breeding timepoints and decreasing ($P \leq 0.05$) from d 84 to calving; while zinc (Zn), molybdenum (Mo) and manganese (Mn) were not ($P \geq 0.20$) affected by treatment. Cobalt in maternal liver also tended ($P = 0.06$) to be affected by the interaction of treatment and day of gestation for VTM compared to CON dams during pregnancy. In calves, concentrations of liver Se, Cu, Zn, and Co were greater for VTM than CON ($P \leq 0.05$). Calf BW at birth and 24 h of age and body measurements at 24 h of age were not affected by treatment ($P = 0.45$). Furthermore, colostrum quantity and total mineral concentrations of Se, Cu, Zn, and Mn in collected colostrum were greater ($P \leq 0.04$) in VTM heifers compared with CON heifers and placental cotyledons from VTM heifers had greater ($P = 0.005$) Se concentrations compared to CON heifers. Additionally, calves born to VTM dams were 15.4 lbs heavier ($P = 0.05$) at pasture turnout and 36.3 lbs heavier ($P = 0.07$) than their CON cohorts at weaning, and post-weaning measurements detected greater ($P \leq 0.05$) chest and abdominal circumference measurements and a tendency ($P \leq 0.07$) for greater ribeye area and liver cobalt concentrations. These results suggest that as gestation progresses, maternal liver stores decrease to provide for the gestating calf, but calf BW and body measurements at birth are unaffected by maternal mineral supplementation. However, performance differences at pasture turnout and weaning and at post-weaning timepoints indicate a response to *in utero* vitamin and mineral supplementation via fetal programming during gestation.

Introduction

During gestation, the fetus relies heavily on the dam for transfer of nutrients across the placenta. Vitamins and minerals especially contribute to processes related to fetal growth and development, protein synthesis, structural integrity, lipid metabolism, and immune function and health (Harvey et al., 2021; Hidiroglou & Knipfel, 1981; Hostetler et al., 2003). Thus, maternal nutritional status during pregnancy has the potential to impact the development and health of the offspring pre- and postnatally. However, the effects of vitamin and mineral supplementation (**VTM**) during gestation and the long-term postnatal impacts on the offspring has not been fully elucidated. Furthermore, variation in management decisions to offer a VTM supplement to cow-calf herds is substantial. The primary goal of the current study is to evaluate the impacts of providing or not providing a VTM supplement during the entire gestation on the dam and her offspring. Thus, objectives were to evaluate the effects of feeding a vitamin and mineral supplement to heifers throughout gestation on trace mineral status of the dam and calf, calving parameters, calf morphometric characteristics and performance, and colostrum production. We hypothesized that VTM throughout gestation would enhance mineral status in the dam and offspring at birth and positively impact calf morphometric characteristics, performance, and colostrum production.

Materials and Methods

Animals, Housing, and Diet

Crossbred Angus-based heifers (n = 72; 14 to 15 months of age, initial body weight [**BW**] 838.6 ± 2.42 pounds [**lbs**]) were group-housed and individually fed at the NDSU Animal Nutrition and Physiology Center (Fargo, ND). Heifers were ranked by BW and placed into one of 12 pens (n = 6 per pen) and fed individually via an electronic head-gate facility (American Calan; Northwood, NH). After a 14-day adaptation/training period, all heifers were subjected to a 7-day Co-Synch + CIDR estrus synchronization protocol and bred via artificial insemination (AI) using female-sexed semen from a single sire. At breeding, heifers were randomly assigned within pen to one of two treatments: 1) a basal diet (n = 36; **CON**) or 2) a basal diet plus the addition of a vitamin and trace mineral supplement (n = 36; **VTM**). The VTM supplement used was a loose product (4 ounces [**oz**] of Purina Wind & Rain Storm All-Season 7.5 Complete, Land O' Lakes, Inc., Arden Hills, MN; Table 1) and was top dressed over the basal diet. The basal diet at ANPC consisted of 53% grass hay, 37% corn silage, and 10% modified corn distillers' grains plus solubles with a crude protein (CP) concentration of 10.6% on a dry-matter basis. Heifers were weighed biweekly and feed deliveries were adjusted as needed to achieve target gains of 1 lb/heifer/day, which is similar to the gain observed on pasture from the heifer herd of origin (McCarthy et al., 2022).

Pregnancy diagnosis was conducted via transrectal ultrasonography on d 35 following AI with fetal sex determined at d 65 following AI, and 14 CON heifers and 17 VTM heifers that maintained female pregnancies were considered our experimental units. At d 104 of gestation these pregnant heifers that maintained female pregnancies were transported to the NDSU Beef Cattle Research Complex (Fargo, ND) where they were group-housed, individually fed (Insentec Feeding System; Hokofarm B.V., Marknesse, The Netherlands), and remained on their respective dietary treatments. Diets consisted of 59% grass hay, 30% corn silage, 6% modified corn distillers' grains with solubles, and 5% ground corn premix with a CP concentration of 11.7% on a dry-matter basis. Heifers in the VTM treatment received the loose VTM supplement incorporated into the total mixed ration. Heifers continued to be weighed biweekly and feed deliveries were adjusted as needed to achieve target gain throughout gestation.

Liver Biopsies, Calving Procedures, and Sample Collection

Liver biopsies were collected at breeding, d 84 and 180 of pregnancy, and at calving using the biopsy procedure outlined by (McCarthy et al., 2021). Briefly, heifers were restrained in a squeeze chute, the biopsy site - between the 10^{th} and 11^{th} ribs - was clipped followed by a 3-ml subcutaneous lidocaine injection and scrubbed with betadine and 70% ethanol. A stab incision was made at the targeted site, liver samples were collected via a Tru-Cut biopsy trochar (14 ga, Merit Medical, South Jordan, UT, USA), placed in tubes designed for trace mineral analysis (potassium ethylenediaminetetraacetate; Becton Dickinson Co., Franklin Lakes, NJ, USA) and stored at –20 °C until further analysis. The biopsy incision site was closed using a surgical staple and a topical antiseptic agent was applied to prevent infection.

Heifers were allowed to calve in group pens and cow-calf pairs were moved inside the calving barn for sample collections. Immediately after calving, cows were allowed to remain with calves until the calf was able to stand, at which time calves were separated from dams for pre-suckling blood and liver biopsy collection. Calves were placed on a table with their legs restrained and ultrasound guidance was used to verify the location of the liver. An area was clipped on the calf's ribs on the right side of the body and scrubbed with betadine and 70% ethanol, followed by a 3-mL subcutaneous injection of a local anesthetic. A small, 1-cm stab incision was made in the skin between the 11^{th} and 12^{th} ribs just large enough to admit the trocar (14 ga Tru-cut biopsy trocar model, Merit Medical, South Jordan, UT, USA). Liver samples were then placed in tubes designed for trace mineral analysis (potassium ethylenediaminetetraacetate; Becton Dickinson Co., Franklin Lakes, NJ, USA) and stored at –20 °C. The incision was closed with a surgical staple and a topical antiseptic agent was applied to prevent infection.

Colostrum production was determined on a single quarter from each heifer using a portable milking machine (InterPuls, Albinea, Italy). Heifers were administered 1 mL of oxytocin (20 IU) intramuscularly immediately prior to colostrum collection to induce colostrum letdown. Each teat was stripped 3 times prior to attaching the portable milk machine to only the right-front quarter. The udder was massaged during colostrum collection until colostrum flow ceased to ensure that the quarter was fully milked out. The colostrum sample (n = 26) was placed into a 1000 mL graduated cylinder, measured, and weighed using a bench top scale, and subsamples were collected for trace mineral analysis and stored at -20℃ until analysis.

Following pre-suckling sample collections, dams and calves were rejoined in individual maternity pens and observed for nursing within 1 hour of sampling procedures. At this time, neonatal calves were assigned a calf vigor score (adapted from Riley et al., 2004) in which calves received a score of 1 – 5 based on ability to stand and suckle independently. Calves received vigor scores of 1) normal, vigorous calf; 2) weak calf but nursed without assistance; 3) weak calf that was assisted to nurse; 4) weak calf that was assisted to nurse but died; or 5) stillborn. Calves were assisted to nurse if needed and pairs were managed in individual pens for at least 24 hours after parturition.

Dams were closely observed in order to collect the placenta after calving in which placentas from all heifers were expelled within 24 h of parturition. Upon retrieval, placentas (n = 24) were arranged on a table and the largest cotyledon closest to the umbilicus on the pregnant horn was removed. The excised cotyledon was rinsed with saline to remove any foreign material that may have attached to the placenta, pat dry, and placed into tubes designed for mineral analysis and stored at -20°C (potassium ethylenediaminetetraacetate; Becton Dickinson Co., Franklin Lakes, NJ, USA).

At 24 h of age, calves were weighed, and body measurements were recorded including crown-rump length (CRL), hip height (HH), hip width (HW), and chest circumference (CC). After 24 h measurements, pairs from each treatment were moved back to the group pens and all cows received a common diet including the VTM supplement. Once all heifers calved, pairs were transported to the Central Grasslands Research Extension Center (CGREC; Streeter, ND). Pairs were grazed on a single pasture with free choice access to a trace mineral supplement. Calves were weighed at pasture turnout and weaning to evaluate the impacts of gestational mineral supplementation on postnatal growth. On d 58 and d 59 after weaning, body measurements including hip height (HH), hip width (HW), chest circumference (CC) and abdominal circumference (AC) were also recorded. Liver biopsies were performed to assess mineral status using adapted methods from (McCarthy et al., 2021) and carcass ultrasound was performed to determine rib fat, ribeye area, intramuscular fat, and rump fat (Wall et al., 2004).

Sample Processing and Laboratory Analysis

Liver, colostrum, placental cotyledon, and feed samples were sent to the Diagnostic Center for Population and Animal Health at Michigan State University and analyzed using inductively coupled plasma mass spectrometry to determine the concentrations of cobalt (Co), copper (Cu), manganese (Mn), molybdenum (Mo), selenium (Se) and zinc (Zn). Results of concentrations of individual minerals in colostrum samples were also multiplied by the weight of colostrum in the front right quarter to obtain an estimate of total mineral in the colostrum. Carcass ultrasound images were analyzed by the Central Ultrasound Processing Lab (CUP Lab, Ames, IA) and reported variables included rump fat thickness, 12^{th}-13^{th} rib fat thickness, ribeye area, and percentage of intramuscular fat.

Statistical Analysis

Data were analyzed as a completely randomized design with the individual animal as the experimental unit. The MIXED procedure in SAS (SAS Inst., Cary, NC) was used to analyze concentrations of liver minerals in F0 heifers throughout gestation and at calving with repeated measures in time. Data collected at calving, including concentrations of mineral in the liver of the dam, liver of the calf, cotyledon, and colostrum characteristics, as well as calf morphometric characteristics were analyzed for effect of treatment using the MIXED procedure. Furthermore, postnatal performance, carcass ultrasound characteristics, and liver mineral after weaning were analyzed using the MIXED procedure. Significance was considered at $P \leq 0.05$ and tendencies were identified at $P > 0.05$ and $P < 0.1$ for all analyses.

Results and Discussion

Mineral Concentrations During Gestation and at Parturition

In maternal liver, concentrations of Se and Cu were affected ($P < 0.0001$) by a treatment × day interaction, being greater ($P < 0.0001$) for VTM dams compared to CON dams at all post-breeding timepoints and decreasing ($P \leq 0.05$) from d 84 to calving (Figures 1 and 2). In addition, a treatment × day interaction was observed for liver Co in VTM dams compared to CON dams during gestation ($P = 0.07$; data not shown). The concentrations of Zn, Mo and Mn in the dam were not influenced ($P \geq 0.20$) by dietary treatment during gestation. In the calf, liver concentrations of Se, Cu, Zn, and Co were greater ($P \leq 0.05$) in calves born to VTM dams compared with calves born to CON dams (Table 2). Liver concentrations of Mo tended (P = 0.06) to be greater for calves from VTM dams compared to calves from CON dams, but liver Mn in the calf was not impacted (P = 0.40) by dietary treatment of the gestating dam (Table 2). Additionally, concentrations of Se in the cotyledon of the placenta were greater (P = 0.005) from F0 dams receiving VTM throughout gestation compared with CON, but concentrations of cotyledonary Cu, Zn, Mo, Mn and Co were not impacted ($P \geq 0.41$; Table 2). Supplementing VTM throughout gestation in beef heifers successfully enhanced Se and Cu liver concentrations in both maternal and neonatal liver. The treatment × day interaction observed for Se, Cu and Co in the dam and calf also suggests that as gestation progresses, the growing calf accumulates trace minerals important for the establishment of a postnatal mineral reserve as well as for normal growth, development, and ultimately, survival. Although it is well understood that trace minerals pass across the placenta during pregnancy, the accumulation of Se in the cotyledon is less understood.

Total colostrum weight and volume collected from the right front quarter of the udder were greater ($P \leq 0.03$) for VTM heifers compared with CON heifers. Although concentrations of Se, Cu, Zn, Mo, Mn and Co in colostrum samples were similar ($P \geq 0.10$) among treatments, the estimated total mineral content of Se, Cu, Zn, Mn and Co in colostrum were greater ($P \leq$ 0.04) for F0 dams receiving VTM throughout gestation compared to CON heifers, but Mo concentrations in colostrum were unaffected (P = 0.08; Table 4). Colostrum intake by the nursing calf is the primary source of trace mineral consumption until calves begin to graze alongside their dams; however, mineral content in milk throughout lactation was not evaluated in this report. Analysis of the minerals available in the milk of the lactating dam may provide additional context to other postnatal effects in the suckling calf.

Calving Characteristics, Cow-Calf Performance, and Colostrum Production

At calving, maternal body weight was not different (CON = 1200.7 ± 41.91 lbs; VTM = 1265.9 ± 37.99 lbs; P = 0.26) for heifers receiving the VTM or the CON treatments throughout gestation. Intakes were controlled during gestation to reach targeted BW gains; thus, similar BW between treatment groups was not unexpected.

Calf birth weights (CON = 70.0 ± 2.05 lbs; VTM = 70.8 ± 1.87 lbs) and 24-hour weights (CON = 73.1 ± 2.03 lbs; VTM = 73.8 ± 1.85 lbs) were not impacted ($P \geq 0.78$) by maternal VTM treatment during pregnancy. Stanton et al. (2000) and Marques et al. (2016) also reported no differences in birth weights of calves when supplementing pregnant beef cows during late gestation with organic or inorganic trace minerals. In addition, calf morphometric characteristics of CRL, HH, HW and CC were similar ($P \geq 0.45$) for calves born to VTM and CON F0 dams (CRL: CON = 77.7 ± 1.10 cm, VTM = 78.5 ± 1.0 cm; HH: CON = 74.9 ± 0.72 cm, VTM = 75.2 ± 0.65 cm; HW: CON = 12.5 ± 0.26 cm, VTM = 12.7 ± 0.24 cm; CC: CON = 74.1 ± 0.71 cm, VTM = 74.8 ± 0.64 cm). Furthermore, calf vigor scores were similar (P = 0.28) in F1 offspring regardless of maternal dietary treatment (CON = 1.1 ± 0.05, VTM = 1.0 ± 0.04).

Although no differences were observed in calf body measurements and BW at birth, evaluation of F1 heifer calves at pasture turnout and throughout further postnatal development suggests further long-term impacts as a result of maternal mineral supplementation during pregnancy. Because all cow-calf pairs were fed the same diet post-calving and throughout weaning, we can evaluate the *in utero* nutritional impacts on the F1 offspring through the development period on pasture with their dams. At pasture turnout, calves from VTM heifers were 15.4 lbs heavier ($P = 0.05$) than calves from CON heifers (data not shown). At weaning, calves born to VTM dams tended to be 36.3 lbs heavier ($P = 0.07$) than CON cohorts. Marques et al. (2016) also observed similar improvements in offspring performance at weaning in calves born to organic trace mineral supplemented cows during late gestation compared to calves born to non-supplemented dams.

F1 Heifer Development Evaluation

At the initiation of the heifer development evaluation measured on d 58 and d 59 post-weaning, no differences ($P \geq 0.15$) were observed in ultrasound body composition traits of F1 including rump fat thickness, 12^{th} – 13^{th} rib fat thickness or percentage of intramuscular fat (Table 3). However, F1 heifers from VTM dams tended ($P = 0.06$) to have greater ribeye area measurements compared to heifers from CON dams. Despite the lack of differences observed in HH and HW measurements ($P \geq 0.23$), CC and AC were greater ($P \leq 0.05$; Table 3) in F1 heifers from dams receiving VTM supplementation throughout gestation compared with CON heifers. Additionally, concentrations of Se, Cu, Zn, Mo or Mn in the liver of F1 heifers at the initiation of the development evaluation were not impacted ($P \geq 0.10$; Table 3) by treatment of their F0 dams. However, F1 heifers from VTM fed dams tended to have greater ($P = 0.07$) liver Co concentrations post-weaning compared to offspring from nonsupplemented dams. Certainly, trace mineral supplementation during pregnancy contributed to enhancements in performance traits that may ultimately program herd production traits including postnatal gain, body composition characteristics and body size. Evaluations of these F1 offspring further throughout postnatal development may reveal additional programming outcomes as a result of maternal diet during pregnancy.

Conclusion

These results imply that impacts of trace mineral nutrition during pregnancy in the F0 generation are observed as enhanced mineral status during gestation and at calving and enhanced postnatal performance of F1 generation calves. Certainly, developmental programming outcomes have been identified in terms of performance and body composition in F1 offspring; however, further investigation into the extent of post-weaning impacts is warranted to determine mechanisms behind the differences in F1 offspring observed, as well as the long-term production impacts of gestational trace mineral supplementation.

Acknowledgements

We appreciate the support from the North Dakota SBARE, Zoetis, ST Genetics, and staff and students at the Beef Cattle Research Complex, Animal Nutrition and Physiology Center, and Central Grasslands Research Extension Center.

Literature Cited

Harvey, K. M., Cooke, R. F., and Marques, R. S. 2021. Supplementing Trace Minerals to Beef Cows during Gestation to Enhance Productive and Health Responses of the Offspring. 11(4), 1159. https://doi.org/10.3390/ani11041159

Hidiroglou, M. and Knipfel, J. E. 1981. Maternal-fetal relationships of copper, manganese, and sulfur in ruminants. A review. *Journal of Dairy Science*, *64*(8), 1637–1647. https://doi.org/10.3168/JDS.S0022-0302(81)82741-5

Hostetler, C. E., Kincaid, R. L., and Mirando, M. A. 2003. The role of essential trace elements in embryonic and fetal development in livestock. *Veterinary Journal*, *166*(2), 125–139. https://doi.org/10.1016/S1090-0233(02)00310-6

Marques, R. S., Cooke, R. F., Rodrigues, M. C., Cappellozza, B. I., Mills, R. R., Larson, C. K., Moriel, P., and Bohnert, D. W. 2016. Effects of organic or inorganic cobalt, copper, manganese, and zinc supplementation to late-gestating beef cows on productive and physiological responses of the offspring. *Journal of Animal Science*, *94*, 1215–1226. https://doi.org/10.2527/jas2015-0036

McCarthy, K. L., Underdahl, S. R., Undi, M., and Dahlen, C. R. 2022. Using precision tools to manage and evaluate the effects of mineral and protein/energy supplements fed to grazing beef heifers. *Translational Animal Science*, 7. https://doi.org/10.1093/tas/txad013

McCarthy, K. L., Undi, M., Becker, S., and Dahlen, C. R. 2021. Utilizing an electronic feeder to measure individual mineral intake, feeding behavior, and growth performance of cow-calf pairs grazing native range. *Translational Animal Science*, *5*(1). https://doi.org/10.1093/TAS/TXAB007

Riley, D. G., Chase, C. C., Olson, T. A., Coleman, S. W., and Hammond, A. C. 2004. Genetic and nongenetic influences on vigor at birth and preweaning mortality of purebred and high percentage Brahman calves. *J. Anim. Sci.*, *82*, 1581–1588. https://academic.oup.com/jas/article/82/6/1581/4790208

Stanton, T. L., Whittier, J. C., Geary, T. W., Kimberling, C. V., and Johnson, A. B. 2000. Effects of trace mineral supplementation on cow-calf performance, reproduction, and immune function. *The Professional Animal Scientist*, *16*(2), 121–127. https://doi.org/10.15232/S1080-7446(15)31674-0

Wall, P. B., Rouse, G. H., Wilson, D. E., Tait, R. G., and Busby, W. D. 2004. Use of ultrasound to predict body composition changes in steers at 100 and 65 days before slaughter. *J. Anim. Sci*, *82*, 1621–1629. https://academic.oup.com/jas/article/82/6/1621/4790232

Table 1. Composition of VTM supplement[1] provided to beef heifers at breeding until calving[2]; company guaranteed analysis.

Item	Assurance levels	
Minerals[1]	Min	Max
Calcium, g/kg of DM	135.0	162.0
Phosphorus, g/kg of DM	75.0	-
Sodium Chloride, g/kg of DM	180.0	216.0
Magnesium, g/kg of DM	10.0	-
Potassium, g/kg of DM	10.0	-
Manganese, mg/kg of DM	3,600.0	-
Cobalt, mg/kg of DM	12.0	-
Copper, mg/kg of DM	1200.0	-
Iodine, mg/kg of DM	60.0	-
Selenium, mg/kg of DM	27.0	-
Zinc, mg/kg of DM	3,600.0	-
Vitamins, IU/kg of DM		
A		661,500.0
D_3		66,150.0
E		661.5

[1]Purina Wind and Rain Storm All Season 7.5 Complete Mineral (Land O' Lakes, Inc., Arden Hills, MN); ingredients: dicalcium phosphate, monocalcium phosphate, processed grain by-products, plant protein products, calcium carbonate, molasses products, salt, mineral oil, potassium chloride, magnesium oxide, ferric oxide, vitamin E supplement, vitamin A supplement, lignin sulfonate, cobalt carbonate, manganese sulfate, ethylenediamine dihydroiodide, zinc sulfate, copper chloride, vitamin D_3 supplement, natural and artificial flavors, and sodium selenite.
[2]VTM supplement provided at a rate of 4 oz/heifer/day/.

Table 2. Concentrations of minerals in F0 dam liver, F1 offspring liver, and placental cotyledon at calving after F0 beef heifers were fed a vitamin/mineral supplement through gestation (VTM) or that received no supplement (CON).

	Treatment			
Concentrations, ug/g dry	CON	VTM	SEM	*P*-value
F0 Dam Liver				
Selenium	1.259	1.748	0.062	<0.0001
Copper	28.74	145.68	8.244	<0.0001
Zinc	161.59	134.17	20.698	0.36
Molybdenum	4.233	4.036	0.161	0.40
Manganese	11.94	11.94	0.526	1.00
Cobalt	0.218	0.234	0.008	0.21
F1 Calf Liver[1]				
Selenium	2.528	5.306	0.375	<0.0001
Copper	327.63	414.16	29.667	0.05
Zinc	208.71	361.10	52.997	0.05
Molybdenum	1.057	1.272	0.077	0.06
Manganese	6.295	6.781	0.398	0.40
Cobalt	0.085	0.100	0.005	0.04
Placental Cotyledon				
Selenium	1.128	1.279	0.034	0.005
Copper	4.557	4.567	0.195	0.97
Zinc	48.92	53.39	3.794	0.41
Molybdenum	0.332	0.313	0.020	0.52
Manganese	2.839	2.518	0.297	0.45
Cobalt	0.101	0.103	0.004	0.69

[1]Liver samples were collected via biopsy at birth prior to suckling.

[2]Treatments of gestating F0 heifers were: 1) received the basal diet from breeding through calving (**CON**; n = 14); 2) received the basal diet plus the addition of a vitamin and mineral supplement (**VTM**; n = 17) provided at a rate of 4 oz/heifer/day.

[3]Significance considered at $P \leq 0.05$ and tendencies identified at $P > 0.05$ and $P < 0.1$.

Table 3. Ultrasound body composition characteristics, body measurements, and liver mineral concentrations at the initiation of the development period of F1 heifers that were gestated in F0 dams receiving a vitamin/mineral supplement trough gestation (VTM) or in dams that received no supplement (CON)[1]

	Treatment			
Item	CON	VTM	SE	P-Value[4]
Body composition characteristics[2]				
Rump fat thickness	0.120	0.129	0.0103	0.48
12th – 13th rib fat thickness	0.124	0.147	0.0116	0.15
Ribeye area, in^2	6.383	6.977	0.2282	0.06
Intramuscular fat, %	3.266	3.680	0.2700	0.25
Body measurements				
Hip height, cm	112.40	113.10	1.111	0.63
Hip width, cm	26.38	28.82	1.513	0.23
Chest circumference, cm	146.79	151.41	1.546	0.03
Abdominal circumference, cm	173.00	180.53	2.840	0.05
Liver mineral concentrations, µg/g dry[3]				
Selenium	1.93	1.98	0.064	0.54
Copper	248.12	229.53	16.621	0.40
Zinc	200.70	171.95	13.053	0.10
Molybdenum	3.42	3.35	0.143	0.74
Manganese	7.56	7.53	0.395	0.94
Cobalt	0.27	0.25	0.011	0.07

[1]Measured on d 58 and d 59 post-weaning.

[2]Body composition characteristics from carcass ultrasound images sent to the Central Ultrasound Processing Lab (CUP Lab, Ames, IA) for analysis and measured by a single, trained technician.

[3]Liver biopsies were sent to the Diagnostic Center for Population and Animal Health at Michigan State University and analyzed using inductively coupled plasma mass spectrometry to determine concentrations of Co, Cu, Mn, Mo, Se and Zn.

[4]Significance considered at $P \leq 0.05$ and tendencies identified at $P > 0.05$ and $P < 0.1$.

Table 4. Volume, weight, concentrations of mineral, and total mineral in colostrum from F0 beef heifers fed a vitamin/mineral supplement trough gestation (VTM) or that received no supplement (CON).

	Treatment[1]			
Item	CON	VTM	SE	*P*-value
Colostrum volume, mL	235.23	352.69	35.103	0.03
Colostrum weight, g	234.95	357.94	35.067	0.02
Concentrations, ng/mL				
Se	74.02	85.27	4.665	0.10
Cu	0.5	0.7	0.10	0.33
Zn	10.3	12.1	0.98	0.22
Mo	47.73	46.33	3.253	0.76
Mn	31.69	27.10	3.341	0.34
Co	2.527	2.524	0.0093	0.75
Total colostrum mineral, ng[2]				
Se	18378.53	30079.76	3451.880	0.02
Cu	118.9	223.2	33.44	0.04
Zn	2460.9	4267.6	494.22	0.02
Mo	11102.48	15828.35	1807.280	0.08
Mn	6609.25	9399.75	827.290	0.03
Co	594.320	902.490	88.5052	0.02

[1]Treatments of gestating F0 heifers were: 1) received the basal diet from breeding through calving (CON; n = 14); 2) received the basal diet plus the addition of a vitamin and mineral supplement (VTM; n = 17) provided at a rate of 113 g•heifer^{-1}•day^{-1}.

[2] Calculated by multiplying colostrum volume by respective concentrations of mineral.

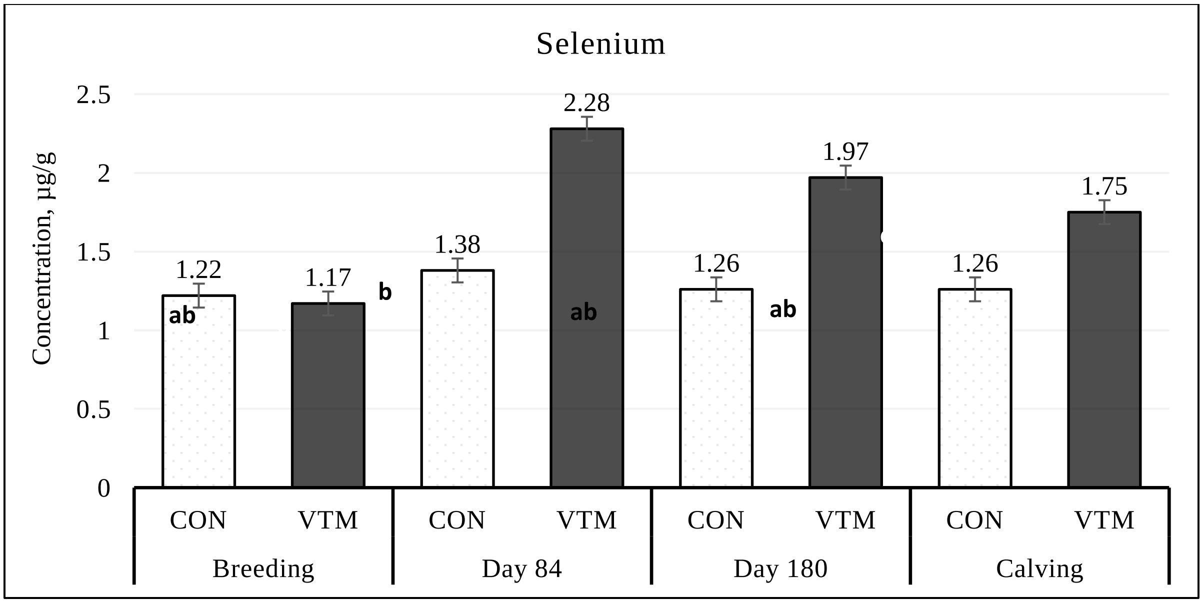


Figure 1. Selenium concentrations in the liver of beef heifers fed either a basal diet (**CON**) or the basal diet plus a vitamin and mineral supplement (**VTM**) throughout gestation. Heifers were assigned to their respective dietary treatment at breeding and continued receiving their treatments through calving. Liver biopsies were collected at breeding, d 84 and 180 of pregnancy, and at calving. A treatment × day interaction was detected ($P < 0.0001$). Means lacking common letter differ ($P \leq 0.05$).

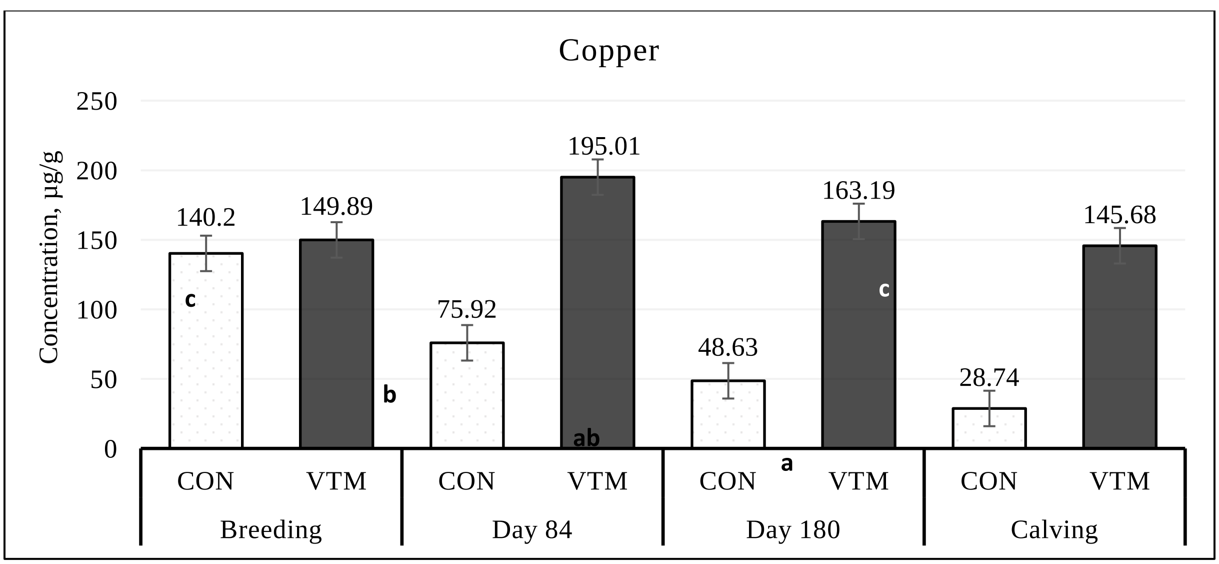


Figure 2. Concentrations of copper in the liver of beef heifers receiving a basal diet (**CON**) or the basal diet plus a vitamin and mineral supplement (**VTM**) throughout gestation. Heifers were assigned to their respective dietary treatments at breeding and continued receiving their treatments through calving. Liver biopsies were collected at breeding, d 84 and 180 of pregnancy, and at calving. A treatment × day interaction was detected ($P < 0.0001$). Means lacking common letter differ ($P \leq 0.05$).

Impacts of vitamin and mineral supplementation to beef heifers during gestation on performance measures of the neonatal calf, trace mineral status, and organ weights at 30 hours after birth

Jennifer L. Hurlbert[1], Ana Clara B. Menezes[1], Friederike Baumgaertner[1], Kerri A. Bochantin[1], James D. Kirsch[1], Sheri Dorsam[1], Samat Amat[2], Kevin K. Sedivec[3], Kendall C. Swanson[1], and Carl R. Dahlen[1]

[1]Center for Nutrition and Pregnancy, Department of Animal Sciences, North Dakota State University, Fargo, ND 58108
[2]Department of Microbiology, North Dakota State University, Fargo, ND 58108
[3]Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND 58483

Lay Summary
The objectives were to evaluate the impacts of vitamin and mineral supplementation in beef heifers throughout gestation on calf size at birth, mineral status, and organ weights of the calf at 30 hours of age. Calf body measurements, body weight, and organ weights were not different between treatments. However, concentrations of cobalt (Co) in the serum of the dam, selenium (Se) and Co in calf serum, and calf liver mineral status were influenced by trace mineral supplementation.

Abstract
Objectives were to evaluate the effects of feeding a vitamin and mineral (**VTM**) supplement to beef heifers during gestation on calf performance, body measurements, trace mineral status, and organ weights at 30 h after birth. We hypothesized that VTM supplementation during gestation would improve mineral status in the neonatal calf, but not impact calf performance parameters and body and organ weights at 30 hours after birth. Crossbred Angus-based heifers (n = 72; 14 to 15 months of age, initial body weight [**BW**] 838.6 ± 2.42 pounds [**lbs**]) were randomly assigned to receive either a basal diet (**CON**; n = 19) or a basal diet plus a VTM supplement (**VTM**; n = 18; 4 oz/heifer/d, targeting gain of 1.0 lb/day) from 60 d pre-breeding through gestation. Following 60 d of dietary treatment, heifers were estrus synchronized and bred to female sexed semen from a single sire. Heifers that maintained female pregnancies were considered the experimental units (**CON**, n = 7; **VTM**, n = 7) and remained on the respective dietary treatments through calving. Immediately after calving, blood samples were collected from dams and calves, then calves were separated from their dams. Calves were fed one feeding of colostrum replacer, followed by milk replacer every 12 h, then euthanized at 30 h. Body weight and measurements were recorded, then organs and viscera were removed, weighed, and sampled. Dam serum and neonatal serum, liver, and blood were analyzed for concentrations of minerals. Data were analyzed using the GLM Procedure of SAS with individual animal as the experimental unit. Dietary treatments did not impact calf weight (0 h or 30 h), calf body measurements, or body weight of the dam at calving ($P \geq 0.32$). Further, neonatal organ weights were not influenced ($P \geq 0.21$) by maternal VTM treatment. Concentrations of Se and Co in calf serum and Se in calf liver were increased ($P \leq 0.02$) by VTM treatment; however, concentrations of copper (Cu), manganese (Mn), molybdenum (Mo), zinc (Zn) in calf muscle, liver, and serum were not impacted ($P \geq 0.07$) by VTM treatment.

Concentrations of Co in serum of the dam was the only mineral affected by dietary treatments, being greater ($P = 0.001$) in VTM than CON dams. In the current experiment, providing trace mineral supplementation throughout gestation did not impact calf weight or body measurements at birth. However, the implications of altered mineral status of the neonatal calves at birth, and presumably throughout gestation, may have additional postnatal effects that warrant further investigation.

Introduction

Trace minerals serve essential roles in cow-calf production with specific influences on reproduction, immune function, and skeletal development (Davy et al., 2019; Hansen et al., 2006; Kegley et al., 2016). Trace mineral nutrition is an integral component of fetal growth and development, as the fetus relies on maternal transfer of trace elements across the placenta for development and the establishment of a postnatal mineral reserve (Hidiroglou & Knipfel, 1981; Hostetler et al., 2003). However, management decisions to provide beef cattle with trace minerals vary widely (Davy et al., 2019) and little is known regarding the impacts of providing a trace mineral supplement to heifers throughout gestation on the neonatal calf. Therefore, the primary goal of this study was to evaluate the hypothesis that vitamin and trace mineral (VTM) supplementation to beef heifers during gestation would improve mineral status of the neonatal calf, but not influence body weight, body measurements, or organ weights at 30 hours after birth.

Materials and Methods

All animal procedures were approved by the North Dakota State University (Fargo, ND) Institutional Animal Care and Use Committee (#A21047).

Animals, Housing, and Diet

Crossbred Angus-based heifers (n = 72; 14 to 15 months of age, initial body weight [**BW**] 838.6 ± 2.42 pounds [**lbs**]) were group-housed and individually fed via an electronic head-gate facility (American Calan; Northwood, NH) at the NDSU Animal Nutrition and Physiology Center (ANPC; Fargo, ND). Heifers were randomly assigned to receive either a basal diet (**CON**; n = 19) or a basal diet plus a VTM supplement (**VTM**; n = 18; 4 oz/heifer/d, targeting gain of 1.0 lb/day) from 60 d pre-breeding through gestation. The VTM supplement was a loose product (4 oz of Purina Wind & Rain Storm All-Season 7.5 Complete, Land O'Lakes, Inc., Arden Hills, MN) top dressed over the basal diet (Table 1). The basal diet at ANPC included 53% grass hay, 37% corn silage, and 10% modified corn distillers' grains plus solubles containing 10.63% crude protein. The diet was formulated targeting gains of 1.0 lbs/heifer/day.

All heifers were subjected to a 7-d Co-Synch + CIDR estrus synchronization protocol (Lamb et al., 2010) and AI bred to female sexed semen from a single sire on d 60 of dietary treatment. Transrectal ultrasonography was used for pregnancy diagnosis at d 35 following AI, and fetal sex was determined at d 65 after AI to confirm pregnancies with female fetuses. Heifers that maintained female pregnancies were considered the experimental units (**CON**, n = 7; **VTM**, n = 7) and remained on the respective dietary treatments through calving. During late-gestation, heifers were transferred to the NDSU Beef Cattle Research Complex (BCRC; Fargo, ND) where they were group-housed, individually fed via the Insentec feeding system (Hokofarm Group B.V., the Netherlands), and continued to receive their respective dietary treatments. The basal diet at BCRC was fed *ad libitum* with 25% corn silage, 66% alfalfa hay, 4% modified corn distillers grains plus solubles, 5% corn-based premix, and contained 17.5% crude protein.

Throughout the study, heifers were weighed biweekly in the morning before feeding and individual feed deliveries were adjusted to achieve targeted BW gains.

Maternal and Neonatal Sample Collection

Heifers were allowed to calve in group pens and calves were separated from dams immediately after birth; thus, not being allowed to suckle. Within 2 hours after birth, body weight was recorded and blood samples were collected via jugular venipuncture from dams and calves.

Following separation from dams, calves were fed 1.42 L of a commercial colostrum replacer containing a total of 150 g IgG (LifeLine Rescue High Level Colostrum Replacer, APC, Ankeny, IA) via esophageal feeder within 2 hours of birth, then housed in individual pens. At 12 hours and 24 hours after colostrum feeding, calves were fed 2 L of a common source milk replacer (Duralife 20/20 Optimal Non-Medicated Milk Replacer, Fort Worth, TX) via esophageal feeder. At 30 h of age, BW was recorded and body measurements including crown-rump length, shoulder-hip length, chest circumference, abdominal circumference, hip width, and hip height were recorded, followed by euthanasia via captive-bolt and exsanguination. At tissue collection, the following organs and viscera were removed, weighed, and sampled: liver (gallbladder removed), small intestine, large intestine, stomach complex, kidneys (both), spleen, heart, lungs, reproductive tract (uterus, ovaries, cervix, and vagina), and the right femur.

Sample Processing and Laboratory Analysis

Blood samples were collected via jugular venipuncture using serum vacutainer tubes designed for mineral analysis (Becton Dickinson HealthCare, Franklin Lakes, NJ). Blood samples were centrifuged at 1,500 x *g* for 20 min at 4℃, aliquoted into 2 mL microtubes, and stored at -20℃ until mineral analysis. Samples (approximately ~ 30 mg) from the left longissimus dorsi muscle and liver were collected and placed in 6 mL mineral analysis tubes (Becton Dickinson HealthCare, Franklin Lakes, NJ). Serum, liver, and muscle samples were analyzed for concentrations of cobalt (Co), copper (Cu), manganese (Mn), molybdenum (Mo), zinc (Zn), and selenium (Se) via inductively coupled plasma mass spectrometry by the Veterinary Diagnostic Laboratory at Michigan State University.

Statistical Analysis

Data were analyzed as a completely randomized design with individual animal as the experimental unit for all variables. All data were analyzed using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) with treatment as the fixed effect. Data were considered significant at $P \leq 0.05$.

Results and Discussion

Body Weights, Morphometric Characteristics, and Neonatal Organ Weights

Dietary treatment did not impact dam body weight (CON = 1229.3 ± 108.34 lbs; VTM = 1177.9 ± 75.93 lbs; $P = 0.32$), calf birth weight (CON = 72.7 ± 9.19 lbs; VTM = 75.2 ± 8.40 lbs; $P \geq 0.60$), or calf BW at harvest (CON = 78.2 ± 9.08 lbs; VTM = 82.1 ± 9.29 lbs; $P = 0.47$). Similarly, calf morphometric characteristics at harvest were not impacted ($P \geq 0.47$) by treatment, which included measurements of crown-rump length (CON = 81.7 ± 5.50 cm; VTM = 80.6 ± 4.47 cm), shoulder-hip length (CON = 34.5 ± 3.29 cm; VTM = 34.0 ± 3.01 cm), chest circumference (CON = 75.3 ± 2.93 cm; VTM = 76.1 ± 2.98 cm), abdominal circumference (CON = 77.4 ± 3.23 cm; VTM = 78.6 ± 2.69 cm), hip width (CON = 13.3 ± 1.03 cm; VTM = 13.3 ± 0.91 cm) and hip height (CON = 75.4 ± 2.54 cm; VTM = 76.4 ± 4.08 cm). The findings of the current study corroborate the results reported by Sprinkle et al. (2006) and Stanton et al. (2000) in that no differences were found in calf BW at birth or cow BW after calving as a result of trace mineral supplementation.

Maternal nutritional status during gestation can affect the growth rate and trajectory of fetal tissues (Funston et al., 2010). Previous research from our group (Menezes et al., 2022 submitted) has demonstrated that maternal VTM supplementation during the first trimester of gestation resulted in greater fetal liver mass at d 83 of gestation. However, weights of organs and viscera (absolute weight and as a percentage of body weight) were not impacted ($P \geq 0.21$) by maternal diet treatment (Table 2). These findings indicate that fetal growth was not impacted by gestational VTM supplementation.

Mineral Concentrations in Serum, Liver, and Muscle

In the dam, concentrations of Co in serum were greater ($P = 0.001$) for VTM heifers compared to CON heifers (Table 3), but no other minerals were influenced ($P \geq 0.32$) by treatment. Maternal VTM treatment contributed to greater ($P \leq 0.02$) concentrations of Co and Se in serum, and greater ($P = 0.001$) concentrations of Se in the liver of calves born to VTM dams (Table 3). However, concentrations of Cu, Mn, Mo, and Zn were not impacted ($P \geq 0.07$) in calf serum, liver, or muscle. Further, concentrations of Co in calf liver and muscle were not influenced ($P \geq 0.15$) by treatment. Stokes et al. (2019) reported greater plasma Se levels in trace mineral injected (TMI) dams as well as increased liver Cu and Se at birth in calves born to TMI dams. The increase in calf liver Se status in both studies may be a contributor to modifications to postnatal calf health and performance (Abdelrahman & Kincaid, 1995).

Implications

These results indicate that gestational vitamin and trace mineral supplementation did not impact fetal growth or calf size at birth. However, the implications of altered mineral status of the neonatal calves at birth, and presumably throughout gestation, may have additional postnatal effects that warrant further investigation.

Acknowledgements

This study was supported by the North Dakota State Board of Agricultural Research and Education and the AFRI Award number 2022-67106-36479 from the USDA National Institute of Food and Agriculture.

Literature Cited

Abdelrahman, M. M., and Kincaid, R. L. 1995. Effect of selenium supplementation of cows on maternal transfer of selenium to fetal and newborn calves. *Journal of Dairy Science*. *78*:625–630. https://doi.org/10.3168/JDS.S0022-0302(95)76673-5.

Davy, J. S., Forero, L. C., Shapero, M. W. K., Rao, D. R., Becchetti, T. A., Koopman Rivers, C., Stackhouse, J. W., Deatley, K. L., and McNabb, B. R. 2019. Mineral status of California beef cattle. *Translational Animal Science*. *3*:1–8. https://doi.org/10.1093/tas/txy114.

Funston, R. N., Larson, D. M., and Vonnahme, K. A. 2010. Effects of maternal nutrition on conceptus growth and offspring performance: Implications for beef cattle production. *J. Anim. Sci. 88*:E205–E215. https://doi.org/10.2527/jas.2009-2351.

Hansen, S. L., Spears, J. W., Lloyd, K. E., and Whisnant, C. S. 2006. Feeding a low manganese diet to heifers during gestation impairs fetal growth and development. *Journal of Dairy Science*, *89*:4305–4311. https://doi.org/10.3168/jds.S0022-0302(06)72477-8

Hidiroglou, M., and Knipfel, J. E. 1981. Maternal-fetal relationships of copper, manganese, and sulfur in ruminants. A review. *Journal of Dairy Science*. *64*:1637–1647. https://doi.org/10.3168/JDS.S0022-0302(81)82741-5.

Hostetler, C. E., Kincaid, R. L., and Mirando, M. A. 2003. The role of essential trace elements in embryonic and fetal development in livestock. *Veterinary Journal*. 166:125-139. https://doi.org/10.1016/S1090-0233(02)00310-6.

Kegley, E. B., Ball, J. J., and Beck, P. A. 2016. Bill E. Kunkle Interdisciplinary Beef Symposium: Impact of mineral and vitamin status on beef cattle immune function and health. *J. Anim. Sci.* 94:5401–5413. https://doi.org/10.2527/jas2016-0720.

Lamb, G. C., Dahlen, C. R., Larson, J. E., Marquezini, G., Stevenson, J. S., and Arnold, S. 2010. Control of the estrous cycle to improve fertility for fixed-time artificial insemination in beef cattle: A review 1. *J. Anim. Sci*. 88:181–192. https://doi.org/10.2527/jas.2009-2349.

Menezes, A. C. B., McCarthy, K. L., Kassetas, C. J., Baumgaertner, F., Kirsch, J. D., Dorsam, S., Neville, T. L., Ward, A. K., Borowicz, P. P., Reynolds, L. R., Sedivec, K. K., Forcherio, J. C., Scott, R., Caton, J. S., and Dahlen, C. R. Vitamin and mineral supplementation and rate of gain in beef heifers: effects on dam hormonal and metabolic status, fetal tissue and organ mass, and concentration of glucose and fructose in fetal fluids at day 83 of gestation. *Animals*. Submitted 2022.

Sprinkle, J. E., Cuneo, S. P., Frederick, H. M., Enns, R. M., Schafer, D. W., Carstens, G. E., Daugherty, S. B., Noon, T. H., Rickert, B. M., and Reggiardo, C. 2006. Effects of a long-acting, trace mineral, reticulorumen bolus on range cow productivity and trace mineral profiles. *J. Anim. Sci*. 84. http://www.wrcc.dri.edu/.

Stanton, T. L., Whittier, J. C., Geary, T. W., Kimberling, C.V., and Johnson, A. B. 2000. Effects of trace mineral supplementation on cow-calf performance, reproduction, and immune function. *The Professional Animal Scientist*, 16:121–127. https://doi.org/10.15232/S1080-7446(15)31674-0.

Stokes, R. S., Ireland, F. A., and Shike, D. W. 2019. Influence of repeated trace mineral injections during gestation on beef heifer and subsequent calf performance. *Translational Animal Science.* 3:493–503. https://doi.org/10.1093/TAS/TXY105.

Table 1. Composition of VTM supplement[1] provided to beef heifers 60 days pre-breeding until calving[2]; company guaranteed analysis.

Item	Assurance levels	
Minerals[1]	**Min**	**Max**
Calcium, g/kg of DM	135.0	162.0
Phosphorus, g/kg of DM	75.0	-
Sodium chloride, g/kg of DM	180.0	216.0
Magnesium, g/kg of DM	10.0	-
Potassium, g/kg of DM	10.0	-
Manganese, mg/kg of DM	3,600.0	-
Cobalt, mg/kg of DM	12.0	-
Copper, mg/kg of DM	1200.0	-
Iodine, mg/kg of DM	60.0	-
Selenium, mg/kg of DM	27.0	-
Zinc, mg/kg of DM	3,600.0	-
Vitamins, IU/kg of DM		
A		661,500.0
D_3		66,150.0
E		661.5

[1]Purina Wind and Rain Storm All Season 7.5 Complete Mineral (Land O' Lakes, Inc., Arden Hills, MN); ingredients: dicalcium phosphate, monocalcium phosphate, processed grain by-products, plant protein products, calcium carbonate, molasses products, salt, mineral oil, potassium chloride, magnesium oxide, ferric oxide, vitamin E supplement, vitamin A supplement, lignin sulfonate, cobalt carbonate, manganese sulfate, ethylenediamine dihydroiodide, zinc sulfate, copper chloride, vitamin D_3 supplement, natural and artificial flavors, and sodium selenite.
[2]VTM supplement provided at a rate of 4 oz/heifer/d.

Table 2. Effect of feeding a vitamin and mineral supplement (VTM) to beef heifers during gestation on neonatal body weight and organ mass at 30 h after birth.

Item	Treatment		SEM	*P*-value[3]
	CON[1]	VTM[2]		
Body weight, kg	32.96	34.10	15.09	0.60
Organ mass, g				
Liver	772.33	821.34	39.26	0.41
Small intestine	762.03	825.46	55.94	0.46
Large intestine	233.27	213.13	22.54	0.54
Stomach complex	461.13	425.00	24.09	0.31
Kidneys	149.87	149.01	6.13	0.92
Spleen	60.40	65.06	2.78	0.26
Lungs	376.80	417.37	24.26	0.26
Heart	266.86	273.90	7.22	0.52
Reproductive tract	10.69	11.97	0.89	0.35
Femur	363.67	377.59	17.82	0.61
Organ mass, % of neonatal BW				
Liver	2.17	2.21	0.09	0.75
Small intestine	1.71	1.78	0.10	0.66
Large intestine	0.60	0.57	0.05	0.66
Stomach complex	1.26	1.15	0.06	0.25
Kidneys	0.43	0.40	0.02	0.26
Spleen	0.17	0.18	0.006	0.35
Lungs	1.04	1.12	0.04	0.21
Heart	0.76	0.71	0.03	0.27
Reproductive tract	0.03	0.03	0.003	0.57
Femur	1.01	1.01	0.02	0.91

[1]CON: No vitamin and mineral supplement incorporated with the basal TMR throughout gestation.

[2]VTM: Vitamin mineral supplement incorporated in the TMR at a rate of 4 oz/heifer/day which was included in a ground corn premix throughout gestation.

[3]Significance considered at $P \leq 0.05$.

Table 3. Serum, liver, and muscle mineral concentrations of neonatal calves at harvest born to dams that were either provided with the basal diet (CON) or the basal diet plus the addition of a vitamin and trace mineral supplement (VTM) throughout gestation.

	Treatment			
Mineral concentration	CON[1]	VTM[2]	SEM	*P*-value[3]
Dam serum, ng/ml				
Cobalt	0.15	0.24	0.013	0.001
Copper	1.04	1.11	0.068	0.49
Manganese	1.09	1.03	0.064	0.54
Molybdenum	20.59	19.69	1.479	0.67
Zinc	1.22	1.34	0.084	0.32
Selenium	123.14	129.71	5.647	0.43
Calf serum, ng/ml				
Cobalt	0.12	0.19	0.018	0.02
Copper	0.21	0.24	0.022	0.36
Manganese	1.00	1.02	0.020	0.34
Molybdenum	14.70	15.94	1.675	0.61
Zinc	1.92	1.47	0.174	0.09
Selenium	62.57	77.57	3.305	0.01
Calf liver, µg/g dry				
Cobalt	0.22	0.23	0.023	0.73
Copper	262.10	270.44	12.411	0.64
Manganese	10.53	10.85	0.950	0.82
Molybdenum	0.73	0.87	0.050	0.07
Zinc	343.55	244.03	58.821	0.25
Selenium	2.20	2.86	0.101	0.001
Calf muscle, µg/g dry				
Cobalt	0.07	0.06	0.004	0.15
Copper	3.92	3.48	0.186	0.12
Manganese	1.40	1.40	0.113	0.98
Molybdenum	0.07	0.06	0.005	0.21
Zinc	119.54	107.62	7.937	0.31
Selenium	0.87	0.93	0.050	0.42

[1]CON: No vitamin and mineral supplement included with the basal diet throughout gestation.
[2]VTM: Basal diet plus the addition of a vitamin mineral supplement fed at a rate of 4 oz/heifer/day.
[3]Significance considered at $P \leq 0.05$.

Comparative Value of Field Peas as an Alternative to Corn Distillers Dried Grain with Solubles (DDGS) in Beef Heifer Growing Diets

Michael Undi, Tim Long and Kevin Sedivec
Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D.

Field peas can effectively replace corn DDGS in growing heifer diets. However, the high price of field peas normally limits utilization of field peas. This study was conducted to determine a price point at which field peas would competitively replace corn DDGS in diets of growing heifers. Growing heifers were fed corn DDGS-based and field peas-based diets formulated to produce similar heifer performance. The study showed that field peas can economically replace corn DDGS in growing heifer diets when the price of field peas is less than or equal to 84% of the price of corn DDGS. At the current speculative price of field peas of $294 to $404/t ($8 to 11/bushel) and corn DDGS at $275/t, field peas are not an attractive alternative to corn DDGS in beef heifer growing diets.

Summary

Corn distillers' dry grains with solubles (DDGS) is one of the most common supplements for cattle in North Dakota. Utilization of corn DDGS will likely be affected by availability and pricing, thus, there is continual need to evaluate alternative feed ingredients. Field peas can effectively replace corn DDGS in cattle rations. This study was conducted to determine a price point at which field peas can competitively replace corn DDGS in diets of growing heifers. The study was conducted with growing heifers that were fed corn DDGS-based and field peas-based diets formulated to produce similar heifer performance. This response allowed a comparative ration cost analysis to be conducted without the need to account for differences in animal performance. Compared to corn DDGS, approximately 43% more field peas by weight were required in a field peas-based diet to meet nutrient requirements of growing heifers. At this level of incorporation, field peas would economically replace corn DDGS when the price of field peas is less than or equal to 84% of the price of corn DDGS. At the current speculative price of field peas of $294 to $404/t ($8 to 11/bushel) and corn DDGS at $275/t, field peas are not an attractive alternative to corn DDGS in beef heifer growing diets.

Introduction

Corn distillers' dry grains with solubles (DDGS) is one of the most common supplements used across the Great Plains region of the United States (Troyer et al. 2020). Corn DDGS compares favorably with supplements such as soybean meal and canola meal as a good source of protein, fat, phosphorus, and readily digestible fiber (Klopfenstein et al., 2008). Continued utilization of corn DDGS in cattle rations will likely be affected by availability and pricing. Availability and pricing of corn DDGS is influenced by oil prices. As oil prices continue to fluctuate, the demand for alternative feed ingredients that can replace corn DDGS as sources of energy and protein in livestock diets will also increase.

Field peas are a palatable source of protein and energy, which makes them a valuable livestock feed (Anderson et al., 2007). In field pea growing areas such as North Dakota and Montana, utilization of field peas in livestock diets presents a realistic, on-farm value-adding opportunity for field pea growers (Lardy et al., 2009). Compared to other feedstuffs, the price of field peas is likely to be a major factor in determining utilization of field peas in cattle rations (Anderson et al., 2007). However, identifying a price for field peas as livestock feed presents quite a challenge since field peas are normally priced for human food and pet food markets (Lardy et al., 2009; Troyer et al. 2020). Situations that result in excess production of field peas, resulting in lower prices of field peas, might offer opportunities for utilizing field peas in cattle diets. This study was conducted to determine a competitive price point for field peas relative to corn DDGS for inclusion into diets of growing heifers.

Procedures

Animal handling and care procedures were approved by the North Dakota State University Animal Care and Use Committee.

The study extended over two years. Starting in the fall of each year, 162 growing Angus heifers (2020/2021, body weight = 312 ± 38 kg; 2021/2022, 283 ± 32 kg) were divided into two groups of similar average body weight (BW) and the groups were randomly assigned to six dry lot pens. Three groups of heifers (27 heifers/pen) were then assigned randomly to either a field pea-based or corn DDGS-based total mixed ration (TMR). The diets were formulated to be isocaloric and isonitrogenous and to meet nutrient requirements of growing heifers. The diets were fed as a total mixed ration using cane molasses to minimize ingredient separation from forages. Field peas were coarse-rolled through a roller mill before incorporation into the TMR.

The heifers were fed once daily at approximately 09:00 each day and feed bunks were targeted to be empty of feed by 16:00. Amount of feed delivered to bunks each week was based on bunk clearance from the previous week. Feeding heifers was accomplished using a “clean bunk” feeding management. The goal of clean bunk management is for all feed delivered to a pen to be consumed daily, with bunks being empty for a certain period of time prior to next feeding, without restricting feed intake. Heifers had *ad libitum* access to fresh water, mineral supplement, and salt blocks. Heifer performance was assessed from average of two-day body weights taken at the start and end of the study.

Economic Analysis

Comparative economic analysis of rations was conducted with two assumptions. Firstly, the price of corn DDGS and field peas would fluctuate from $200 to $400/t depending market supply and demand for these commodities. This range was selected to encompass price fluctuations of both corn DDGS and field peas. Secondly, the decision to utilize these ingredients in diets would depend on the total commodity price including the cost of transportation.

At the time of analysis, corn grain, hay, and silage were priced at $275, $88, and $34/t, respectively. Corn DDGS was priced to fluctuate from $220 to $400/t since USDA Agricultural Marketing Service suggests a range of 80 to 100% or more the price of corn (Buckner et al., 2008). The price of silage was based on local production and was estimated from corn production (LaPorte, 2019). Identifying a price for field peas as livestock feed presents quite a challenge since field peas are normally priced for human food and pet food markets (Lardy et al., 2009; Troyer et al. 2020). At the time of this study, we speculated, through conversations with field peas producers, that the price of field peas was in the range of $294 and $404/t ($8 to 11/bushel).

All ingredient prices were expressed in metric tons (t). Ration costs ($/head/day), which were utilized as the basis for comparative economic analysis, were calculated from daily ingredient intake and ingredient prices. Ingredient intake was calculated from feed delivered (kg/head/d) and diet composition. During the two-year study, an average of 4.2% DDGS and 6% field peas were required in the corn DDGS-based and field peas-based diets, respectively (Table 2). At a feed intake of 13.25 and 13.28 kg/day for corn DDGS-based and field peas-based diets, respectively, 0.56 and 0.80 kg/day of corn DDGS and field peas, respectively, were included in the respective diets.

Comparative economic analysis under two scenarios a) comparing ration costs resulting from inclusion of corn DDGS or field peas into corn DDGS-based and field peas-based diets at similar corn DDGS and field peas price points, and b) identifying a price point at which field peas would competitively replace corn DDGS in growing heifer diets. To compare ration costs resulting from inclusion of corn DDGS or field peas at similar price points, ration costs were generated in Microsoft Excel (Microsoft, Redmond, WA) over a common price range of $220 to $400/t, in $20/t increments, for both corn DDGS and field peas. To test if there was a significant difference between the generated ration costs, a paired t-test was performed in SAS (SAS Institute Inc., 2008). Identifying a price point at which field peas would competitively replace corn DDGS in growing heifer diets was accomplished by calculating corresponding price points of corn DDGS and field peas that would produce rations with similar ration costs. Price points were estimated in Microsoft Excel (Microsoft, Redmond, WA) over a range of $200 to $400/t for both corn DDGS and field peas.

Results and Discussion

The chemical composition of field peas and corn DDGS utilized in total mixed rations fed to replacement heifers is shown in Table 1. The nutrient profile of field peas reported in this study was within expected ranges reported by others (Anderson et al., 2007; Gilbery et al., 2007; Troyer et al., 2020). Chen et al (2003) reported a lower crude protein (CP) content (20%) in field peas. The chemical composition of corn DDGS is comparable to previous reports from other studies (Widyaratne and Zijlstra 2007; Troyer et al., 2020).

The diets offered to heifers in this study were formulated to be isonitrogenous and isocaloric (Table 2). In 2020, approximately 3.9 and 5.8% of DDGS and field peas, respectively, were required to produce diets containing 12% CP and net energy for gain (NEg) of 0.7 Mcal/kg. In 2021, approximately 4.5 and 6.2% of DDGS and field peas, respectively, was required to produce diets containing 13.5% CP and NEg of 0.6 Mcal/kg.

Table 1. Chemical composition[1] of corn DDGS and field peas utilized in total mixed rations fed to growing heifers.

	Corn DDGS	Field peas
Chemical composition, % DM		
Crude protein	30.5	25.7
Net energy for gain, Mcal/kg	1.35	1.41
Neutral detergent fiber	27.4	6.9
Acid detergent fiber	15.3	5.0
Ether extract	9.8	1.7
Calcium	0.04	0.12
Phosphorus	0.91	0.40
Magnesium	0.40	0.15
Potassium	1.24	1.06
Sulfur	0.62	0.25

[1]Two-year average values from 2020/2021 and 2021/2022 study years.

Table 2. Ingredients and chemical composition of total mixed rations fed to growing heifers.

	Year			
	2020/2021		2021/2022	
	Corn DDGS	Field peas	Corn DDGS	Field peas
Ingredients, % as fed				
Hay	37.9	36.7	42.3	43.1
Corn silage	40.7	40.6	41.3	39.6
Corn grain	14.4	13.8	9.1	8.3
Peas	-	5.8	-	6.2
DDGS	3.9	-	4.5	-
Cm30[1]	3.1	3.1	2.8	2.8
Chemical composition, % DM				
CP	12.2	12.3	13.4	13.6
Net energy for gain, Mcal/kg	0.71	0.67	0.65	0.61
Neutral detergent fiber	42.9	42.1	47.7	44.7
Acid detergent	29.4	29.0	32.1	31.3
Ether extract	2.9	2.0	3.2	2.7
Calcium	0.82	0.86	1.2	1.1
Phosphorus	0.27	0.27	0.35	0.29
Magnesium	0.35	0.21	0.30	0.28
Potassium	1.57	1.43	1.88	1.86
Sulfur	0.24	0.19	0.23	0.20

[1]Core Max 30 liquid protein supplement (30 % CP, 0.1 % CF, 11.3 to 13.5 % Ca, 0.08 % P, 4.4 to 5.4 % salt, 2 % K, 5.5 ppm Se, 50,000 IU/LB Vit A., 8 % total sugars, 33.0 % moisture).

Dry matter intake (DMI) was not influenced by treatment (P = 0.72) and averaged 8 kg/d (Table 3). When expressed as a percentage of body weight (BW), DMI was not influenced (P = 0.38) by treatment, with intakes of 2.6% for both treatments (Table 3). Heifers were well-balanced between treatments for initial BW which were similar (P = 0.255) between treatments. Final BW and average daily gain were not influenced ($P \geq 0.05$) by treatment, which was expected since diets were formulated to be isocaloric and isonitrogenous.

Table 3. Performance of growing heifers consuming field peas-based or corn DDGS-based total mixed rations.

	Diet (D)[1]			Year (Y)			*P*-value		
	DDGS	FP	SE	2020/21	2021/22	SE	D	Y	D x Y
DMI, kg/d	8.0	8.0	0.05	8.0[a]	7.8[b]	0.05	0.72	0.003	0.97
DMI, % BW	2.6	2.6	0.03	2.5[b]	2.7[a]	0.03	0.38	<0.001	0.25
Initial BW, kg	298	294	3.6	312[a]	279[b]	3.6	0.26	<0.001	0.13
Final BW, kg	332	330	3.7	347[a]	316[b]	3.7	0.57	<0.001	0.34
ADG, kg/d	0.78	0.76	0.02	0.84[a]	0.71[b]	0.02	0.41	<0.001	0.79

[1]Corn DDGS and field peas.

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

Reducing feed costs while optimizing animal production is essential for maintaining a profitable beef operation. Feed costs can be reduced through the use of cost-effective ingredients in cattle diets. Diets fed in this study were formulated to be isocaloric and isonitrogenous which resulted in similar performance between treatments. This response allowed comparative ration cost analysis without the need to account for differences in animal performance. Heifer performance was similar when 0.56 kg/d and 0.80 kg/d of corn DDGS and field peas, respectively, were incorporated into corn DDGS-based and field peas-based diets (Table 4).

Table 4. Amount of feed (kg/head/day, as fed) offered to growing heifers.

	Diets[1]	
	Corn DDGS	Field peas
Hay	5.31	5.29
Silage	5.43	5.33
Corn grain	1.56	1.47
Field peas	-	0.80
DDGS	0.56	-
Cm30	0.39	0.39
Total	13.25	13.28

[1]Corn DDGS-based and field peas-based total mixed rations.

When both corn DDGS and field peas were priced \$220/t, ration costs were greater for the field peas-based diet relative to the DDGS-based diet (Table 5). When the price of corn DDGS and field peas increased to \$400/t, ration costs increased to \$1.44 and \$1.51/head/day for corn DDGS-based and field peas-based diets, respectively (Table 5). As the price of corn DDGS and field peas increased, contribution of hay, silage, and corn grain to total ration costs decreased, reflecting the greater contribution of field peas to the field peas-based ration. Inclusion of field peas into livestock diets will likely increase total feed costs due to the relatively high price of field peas (Chen et al., 2003).

The relative value of field peas in diets for growing heifers was mainly driven by the two factors, the level of incorporation of field peas into the diet and the price of field peas. When compared to a corn DDGS-based diet, a field peas-based diet that met nutrient requirements of growing heifers required approximately 43% more field peas (Table 5). Moreover, the price of field peas would have to be consistently lower than the price of corn DDGS for the corn DDGS-based and field peas-based diets to produce similar ration costs (Table 5). The relative price of field peas decreased from 88% to 81% as the price of corn DDGS increased from $200 to $400/t (Table 5). On average, corn DDGS-based and field peas-based diets produced diets with similar ration costs when field peas were priced at approximately 84% of the price of corn DDGS (Table 5). At the current price of $275/t for corn DDGS, field peas, priced at $294 to $404/t, would not be a competitive supplement for use in heifer rations.

Results from this study support studies that have shown a competitive economic advantage of corn DDGS relative to feeds such as dry-rolled corn (Buckner et al., 2008) or field peas (Troyer et al. 2020). Inclusion of corn DDGS in the diet resulted in higher profits relative to a dry-rolled corn-based diet (Buckner et al., 2008). A recent economic evaluation of field peas and corn DDGS as a supplement for heifers grazing crested wheatgrass (Troyer et al. 2020), showed that field peas can be utilized as a supplement when the peas are competitively priced at 90% of the price of corn DDGS. Due to lower costs relative to feeds such as wheat, barley, corn, canola meal, and soybean meal, feed co-products such as DDGS will likely continue to be common and cost-effective ingredients in beef and dairy diets (Paz et al., 2013). Situations that result in excess production of field peas, resulting in drastically lower prices of field peas, might offer opportunities for competitively-priced field peas for use in cattle diets.

This study shows that field peas can competitively replace corn DDGS in cattle diets when the price of field peas is less than or equal to 84% of the price of corn DDGS. At the current price of field peas of $294 to $404/t ($8 to 11/bushel) and corn DDGS at $275/t, field peas are not an attractive alternative to corn DDGS in beef heifer growing diets.

Acknowledgements
We thank Cody Wieland and Rick Bohn for technical assistance.

Literature Cited

Anderson, V. L., Lardy, G. P. and Ilse, B. R. 2007. Review: Field pea grain for beef cattle. Prof. Anim. Sci. 23: 1-7.

Buckner, C. D., Mader, T. L., Erickson, G. E., Colgan, S. L., Mark, D. R., Bremer, V. R., Karges, K. K. and Gibson, M. L. 2008. Evaluation of dry distillers grains plus solubles inclusion on performance and economics of finishing beef steers. Prof. Anim. Sci. 24: 404 -410.

Chen, J. Q., E. K. Okine, M. A. Price, and G. R. Khorasani. 2003. Feeding value of peas for backgrounding beef heifers. Can. J. Anim. Sci. 83: 779 -786.

Gilbery, T. C., Lardy, G. P. Soto-Navarro, S. A., Bauer, M. L. and Anderson, V. L. 2007. Effect of field peas, chickpeas, and lentils on rumen fermentation, digestion, microbial protein synthesis, and feedlot performance in receiving diets for beef cattle. J. Anim. Sci. 85: 3045 - 3053.

Klopfenstein, T. J., Ericson, G. E. and Bremer, V. R. 2008. Board invited review: Use of distillers by-products in the beef cattle feeding industry. J. Anim. Sci. 86:1223 -1231. https://doi.org/doi:10.2527/jas.2007-0550

LaPorte, J. 2019. Pricing standing corn silage. Michigan State University Extension. https://www.canr.msu.edu/news/pricing-standing-corn-silage

Lardy, G. P., Loken, B. A., Anderson, V. L., Larson, D. M., Maddock-Carlin, K. R., Ilse, B. R., Maddock, R., Leupp, J. L., Clark, R., Paterson, J. A. and Bauer, M. L. 2009. Effects of increasing field pea (*Pisum sativum*) level in high-concentrate diets on growth performance and carcass traits in finishing steers and heifers. J. Anim. Sci. 87: 3335 - 2341.

Paz, H. A., Castillo-Lopez, E., Ramirez-Ramirez, H. A., Christensen, D. A., Klopfenstein, T. J. and Kononoff, P. J. 2013. Invited Review: Ethanol co-products for dairy cows: there goes our starch ... now what? Can. J. Anim. Sci. 93: 407 - 425.

Troyer, B. C., Greenwell, H. L., Watson, A. K., MacDonald, J. C., and Wilke, K. H. 2020. Relative value of field pea supplementation compared with distillers grains for growing cattle grazing crested wheatgrass. Applied Animal Science 36:615 - 621. https://doi.org/10.15232/aas.2020-02026

Widyaratne, G. P. and Zijlstra, R. T. 2007. Nutritional value of wheat and corn distiller's dried grain with solubles: Digestibility and digestible contents of energy, amino acids and phosphorus, nutrient excretion and growing performance of grower-finisher pigs. Can. J. Anim. Sci. 87: 103-114.

Table 5. Relative ration costs ($/head/day) when corn DDGS and field peas are priced at similar and different price points.

Common ingredient price[1] ($/t)	Ration cost ($/head/day)		Cost difference (DDGS – FP)	Ingredient price[2] ($/t)		Ration cost ($/head/day)	Relative FP price (% DDGS price)
	DDGS-based diet	FP-based diet		Corn DDGS	Field peas		
220	1.34	1.36	-0.02	220	194	1.34	88
240	1.35	1.38	-0.03	240	209	1.35	87
260	1.36	1.40	-0.04	260	223	1.36	86
280	1.37	1.41	-0.04	280	237	1.37	85
300	1.39	1.43	-0.04	300	252	1.38	84
320	1.40	1.44	-0.04	320	266	1.39	83
340	1.41	1.46	-0.05	340	280	1.40	82
360	1.42	1.48	-0.06	360	295	1.42	82
380	1.43	1.49	-0.06	380	309	1.43	81
400	1.44	1.51	-0.07	400	324	1.44	81

[1]Corn DDGS and field peas at the same price.

[2]Prices used: hay, $88/t; silage, $34/t; corn grain, $275/t; and Cm30, $352/t.

CGREC Staff and Advisory Board

Current Staff – 2023

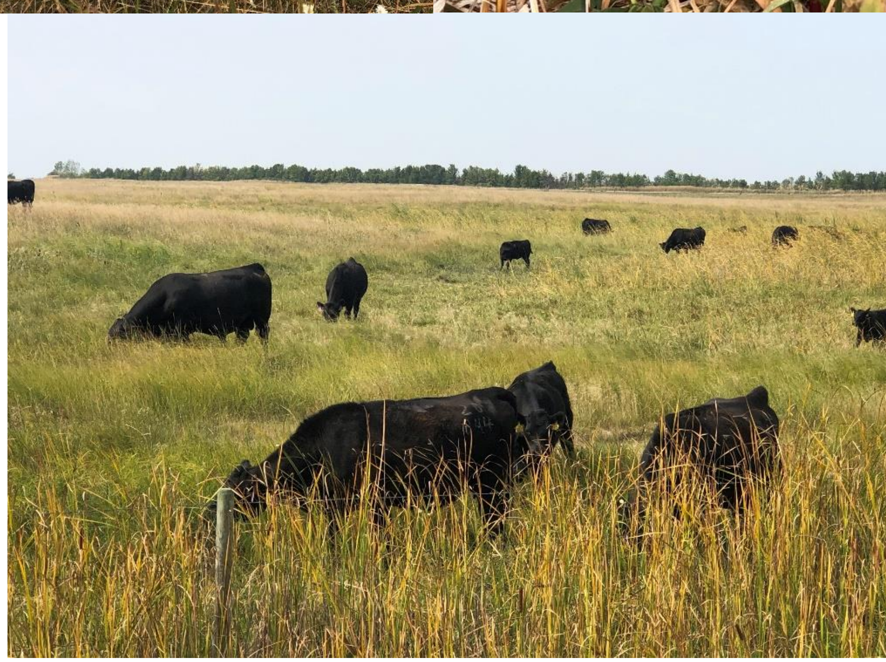
Kevin Sedivec	Interim Director
Michael Undi	Animal Scientist
Sandi Dewald	Administrative Assistant
Timothy Long	Beef Herdsman
Cody Wieland	Livestock Technician
Erin Gaugler	Range Research Specialist
Rick Bone	Range Technician
Lisa Pederson	Ext. Livestock-Beef Quality Assurance Specialist
Janet Patton	Research Technician
Bonnie Wieland	Office Maintenance

Advisory Board – 2022

Jayce Doan, Hazelton
Charlotte Heim, Bismarck
Richie Heinrich, Medina
Gerald Horner, Napoleon
Christof Just, Berlin
Cody Kreft, Streeter
David Toledo, Mandan
Robert Weigel, Kintyre
Jeff Williams, Streeter
Gary Aichele, Steele
Gregory Lardy, Fargo

The CGREC Annual Field Day will be held on July 10, 2023 and open to the public





NDSU Central Grasslands Research Extension Center

4824 48th Ave SE, Streeter, ND 58483
701-424-3606
www.ag.ndsu.edu/CentralGrasslandsREC