Central Grasslands Research Extension Center

2021 Annual Report

Range – Forage – Livestock

NDSU | NORTH DAKOTA AGRICULTURAL EXPERIMENT STATION

NDSU | EXTENSION

Summary of the Year

Welcome to the 2021 CGREC Annual Report

The year 2021 marked the second year of a severe drought, reminding me of the last two-year from 1988-1989. The drought created shortages in grazing days for most treatments and a hay crop of roughly 40% of normal. The center has a drought management plan in place that includes selective culling, delayed pasture turn-out (about 8 days), emergency grazing areas, and early weaning.

Like most livestock producers in North Dakota, we culled about ¼ of the herd and bought hay from local growers. We did keep all of our 2021 heifers (we need them for research trials) and retained 107 bred heifers. Our strategy over the past 5 years was to create a younger herd with smaller frame scores, and improve our genetics to create a uniform set of cows. The drought year helped speed up the process. Approximately 90% of our brood cows will be under the age of 7 in 2022.

We were fortunate to receive great moisture in late August through October (170% of normal), setting us up to have a good spring for forage production, normal pasture turn-out for all of our grazing trials, “hopefully” normal hay production, and good moisture conditions for the annual forage trials if we receive normal precipitation this spring. We had good snow cover (not too much, not too little) this year, with winter precipitation at 106% of normal through late March.

Even with the dry summer, our research projects achieved our objectives for 2021. We had pull cows off pasture on the patch-burn grazing and season-long grazing pastures by early September (normal is late October) and rotation grazing treatment by early October. Our annual forage trials (silage, forage cereals, warm-season forages, and cover crop) actually performed well, providing excellent data on which species and varieties performed best in dry conditions.

We were blessed to receive special funding from the North Dakota legislative session to build working corrals within our pasture trials that will allow us conduct innovative, safe research. We also received funding for a new livestock research laboratory and working facility, and new research pens to conduct research in a safe facility for our staff, students and livestock. I want to acknowledge our local legislatures for supporting these projects, especially Senators Eberle, Wanzek and Klein, and representatives Brandenburg for their continued support.

Our 2022 annual field day is scheduled for July 11. We will run two tours, one focusing on forages and livestock research from 10:00 am to noon, and the second focusing on grazing management and ecosystem service (pollinators and wildlife) projects from 1:00 – 3:00 pm. We will provide a free lunch between the tours. All are welcome!

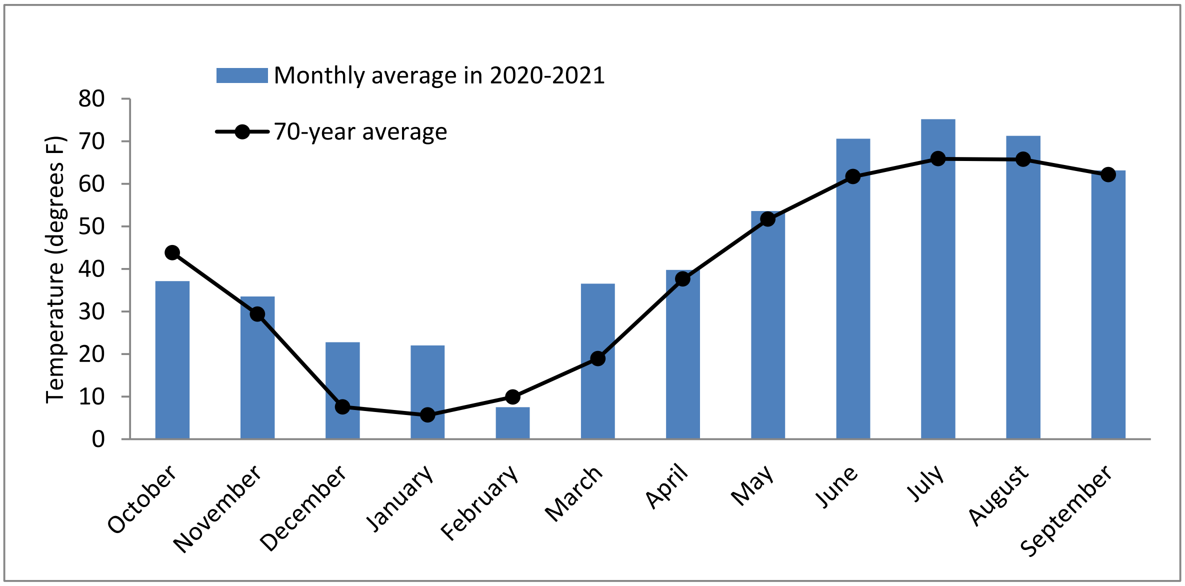
We hope to continue serving you for many years to come. You are always welcome to stop by anytime and visit.

Kevin Sedivec, Interim Director

Table of Contents

Animal Sciences

Monthly Temperatures for the 2020-2021 Crop Year



Last spring frost: May 11 (28°F)

First fall frost: Oct. 21 (21°F)

163 frost-free days

Average[1] last spring frost: May 13

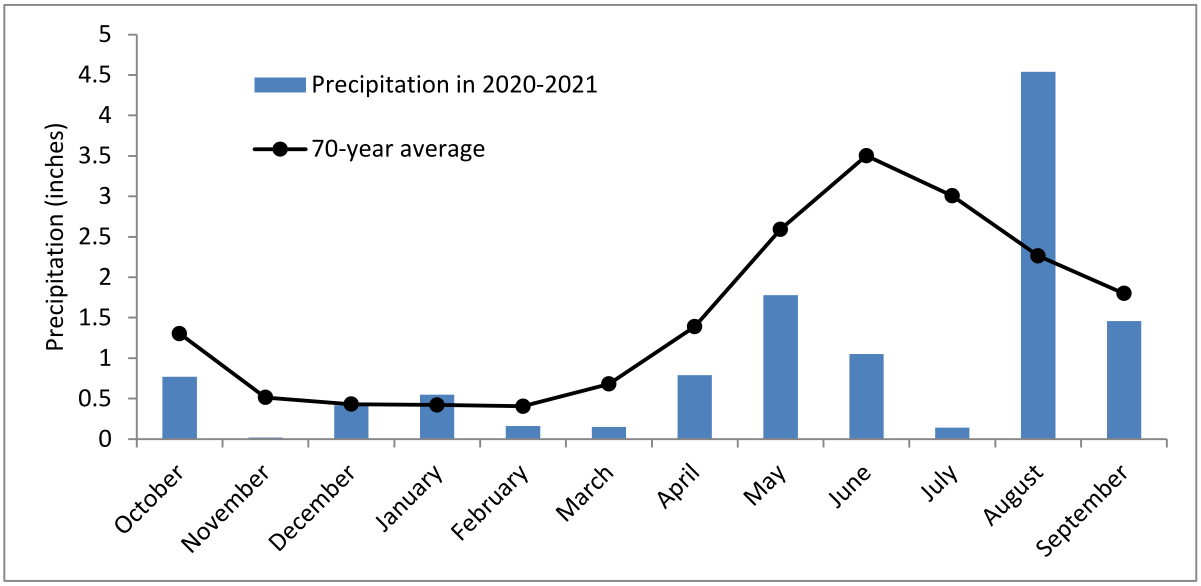
Average first fall frost: Sept. 22

Average: 132 frost-free days

Month	Maximum temperature[2]	Minimum temperature	Average temperature	Long-term[1] average temperature	2020-2021 deviation from long-
October	76	7	37.2	43.8	-6.6
November	72	9	33.5	29.3	4.2
December	54	-12	22.8	7.6	15.2
January	43	-4	22.1	5.6	16.4
February	49	-32	7.5	9.9	-2.4
March	69	1	36.5	18.9	17.6
April	76	12	39.8	37.6	2.1
May	79	24	53.7	51.7	2.0
June	100	44	70.7	61.7	9.0
July	100	48	75.2	65.9	9.3
August	99	48	71.3	65.7	5.6
September	89	37	63.2	62.1	1.1

[1] 1951-2021; 70 years [2] Degrees F

Monthly Precipitation for the 2020-2021 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	0.77	1.30	-0.53	59	0.77	1.30	9
November	0.02	0.51	-0.49	4	0.79	1.82	0
December	0.42	0.43	-0.01	98	1.21	2.25	5
January	0.55	0.42	0.13	131	1.76	2.67	6.5
February	0.16	0.40	-0.24	40	1.92	3.07	3.5
March	0.15	0.68	-0.53	22	2.07	3.75	0.5
April	0.79	1.39	-0.60	57	2.86	5.14	1
May	1.78	2.59	-0.81	69	4.64	7.74	0
June	1.05	3.50	-2.45	30	5.69	11.24	0
July	0.14	3.01	-2.87	5	5.83	14.24	0
August	4.54	2.26	2.28	200	10.37	16.51	0
September	1.46	1.80	-0.34	81	11.83	18.31	0
Total	**11.83**	**18.32**	**-6.49**	**65**	**11.83**	**18.31**	**25.5**

[1] Rain and melted snow in inches [2] 1951-2021; 70 years [3] Depth in inches

Plant Community Responses to Different Rangeland Management Practices

Esben L. Kjaer[1], Ryan F. Limb[1], Kevin Sedivec[1,2]

[1]School of Natural Resources, North Dakota State University, Fargo, N.D., USA[2]Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D., USA

Summary

Historically, the Great Plains was an area where fire and grazing were common disturbances. The interaction between fire and grazing created a shifting mosaic of vegetation patches each at different successional stages. Much of this heterogeneity has been lost due to changes in grazing and fire regimes, causing many of the rangelands in the region to become degraded and less diverse. Structural heterogeneity can be restored to these landscapes through patch-burn grazing and modification of conventional management strategies. Using a working landscape, we examine how plant communities respond to different management techniques. We collected plant community data across 12 pastures with equal stocking rates managed with patch-burn grazing, season-long grazing, or modified twice-over rest-rotational grazing. We found that in general, management strategies that increased landscape-level heterogeneity also increased plant diversity and available niche space. Our results suggest that any management strategy that increases structural heterogeneity should also increase plant species richness.

Introduction

The Great Plains is a heterogeneous landscape made up of a shifting mosaic of vegetation patches that vary in species composition and structure (Fuhlendorf and Smeins 1999, Fuhlendorf and Engle 2001, Bond and Keeley 2005, Bowman et al. 2009). Historically, this heterogeneity was created and maintained by the interaction of fire and grazing by large herbivores, or pyric-herbivory (Fuhlendorf and Engle 2001, Fuhlendorf et al. 2009). The heterogeneity created by the coupling of fire and grazing helped to maintain relatively high levels of diversity that would not have been possible in a more homogenous landscape (Fuhlendorf and Engle 2001, Lundholm 2009). Much of the historic heterogeneity that was present in the Great Plains has now been lost (Samson and Knopf 1994, Briske et al. 2003, Fuhlendorf et al. 2009). An appreciable amount of landscape-level heterogeneity has been lost as prairie and rangelands have been developed for human settlement or converted to row-crop agriculture (Samson and Knopf 1994). However, even for those parts of the Great Plains that remain as either prairies or rangeland, heterogeneity has decreased (Fuhlendorf and Engle 2001, Fuhlendorf et al. 2009). This loss in heterogeneity is largely due to conventional management strategies, such as season-long and rotational grazing, that promote uniform utilization and fire suppression (Fuhlendorf and Engle 2001, Briske et al. 2003, Fuhlendorf et al. 2009). Likely due to the decoupling of fire and grazing, these now homogenous landscapes have become degraded and susceptible to invasion by non-native plants such as Kentucky bluegrass (*Poa pratensis* L.) and smooth brome (*Bromus inermis* Leys.) (Melbourne et al. 2007, Limb et al. 2018). While the homogenization of rangelands has decreased the diversity of plants and animals on those landscapes (DeKeyser et al. 2009), restoring heterogeneity has been shown to positively influence diversity (Fuhlendorf et al. 2006, McGranahan et al. 2012, Hovick et al. 2015, Baer et al. 2020).

Patch-burn grazing is an increasingly common management strategy used to increase landscape level heterogeneity while having little negative impacts on cattle production (Fuhlendorf and Engle 2004, Fuhlendorf et al. 2009, Hovick et al. 2015, Spiess et al. 2020). Rotational grazing can also be modified in such a way creates structural heterogeneity (Sedivec et al. 2019). Aside from affecting plant biomass, it is relatively unknown howheterogeneity created through differing grazing intensities impacts plant communities. Additionally, many years of season-long grazing can create static heterogeneity through the creation of persistant grazing lawns (McNaughton 1984). Heterogeneity that has been restored through patch-burn grazing has been shown to promote diversity (Fuhlendorf and Engle 2001, Allred et al. 2011, Hovick et al. 2015), stabilize the abundance of invasive species, such as Kentucky bluegrass (Dornbusch et al. 2020), ameliorate the effects of drought on livestock (Spiess et al. 2020), and either neutrally or postively affect livestock production (Limb et al. 2011, Winter et al. 2014). It is likely that heterogeneity created by manually altering grazing intensity or through grazing lawns will impact plant communities in a similar manner to patch-burn grazing. However, there is no evidence to support this claim.

With that in mind, we examined how plant communities in rangelands respond to patch-burn grazing, modified twice-over rest-rotation grazing, and season-long grazing. In particular, we focused on how plant species richness, evenness, diversity, and identity varied between these three management types.

Methods

This study took place at the North Dakota State University Central Grasslands Research Extension Center (CGREC) in Stutsman and Kidder counties near Streeter, N.D. USA (46°45’N, 99°28’W). This site is located in the Missouri Coteau ecoregion, which primarily consists of rolling hills interspersed with small glacial lakes (USDA Soil Conservation Service 1982). Average temperatures range from -12.3 ºC in January to 20.3 ºC in July. The site averages 399 mm of precipitation annually (30-year average from 1991-2021) with the majority of precipitation occurring between May and September each year (NDAWN, 2021; Table 1). The year this study took place (2021), CGREC experienced drought and received only 333 mm of precipitation, with less than 90 mm falling between May 1st and August 1st (NDAWN 2021).

Historically, these sites consisted of mixed-grass prairie dominated primarily by cool-season grasses, such as western wheatgrass (*Pascopyrum smithii,* [Rydb.] À. Löve.), and green needlegrass (*Nasella viridula,* [Trin.] Barkworth) (USDA Soil Conservation Service 1982). Warm-season grasses, like little bluestem (*Schizachyrium scoparium*, [Michx.] Nash), and various forbs (*Artemisia* spp. and *Solidago* spp.), and sedges (primarily *Carex* spp.) are also common in this landscape (USDA Soil Conservation Service 1982, Limb et al. 2018). Fire suppression and changes in grazing regimes have allowed these prairies to be invaded by western snowberry (*Symphoricarpos occidentalis* Hook.), smooth brome (*Bromus inermis* Leyss.), and Kentucky bluegrass (*Poa pratensis* L.) (Limb et al. 2018).

Our study utilized twelve 65-hectare pastures, each managed with season-long grazing, patch-burn grazing, or modified twice-over rest rotational grazing (MTORG). Grazing of the season-long and burning and grazing of the patch-burn pastures began in 2017, while the grazing of the MTORG pastures began in 2018. Neither the patch-burn nor the season-long pastures contained interior fencing; additionally, season-long pastures were never burned. Each spring, one quarter (16 ha) of each patch-burn pasture was burned. Each year the quarter of the pasture that is burned changes so that a shifting mosaic of patches is established (see Fuhlendorf et al., [2009]). Each MTORG pasture is split into four paddocks (approx. 16 ha) using interior fencing. The amount of time spent grazing each paddock varies to achieve different levels of plant utilization and vegetation structure in each paddock. The paddocks include a rested paddock (0% utilization), a moderate paddock (20-40% utilization), a full paddock (40-60% utilization) and a heavy paddock (>60% utilization). Each year the paddocks change their utilization category (i.e. rested becomes moderate, moderate become full, full becomes heavy, heavy becomes rested). Cattle are rotated through pastures (heavy to full to moderate) once early in the growing season (May – July) and once in the middle to late-growing season (August – September). All pastures with stocked with a similar stocking rate (Table 1).

Data were collected from July 2021 to August 2021. To determine community composition across our treatments, we set up 128 sixty-meter transects (32 per pasture) on loamy ecological sites (USDA NRCS, 2003). Our transects were set up in such a way that each 16-ha paddock within a pasture had two transects within them. Within a transect, plant communities were sampled every other meter (n=31). At each sample point we set up a 1-m^2 quadrat, identified every plant species and recorded a measure of aerial cover using modified Daubenmire cover classes for each species (Floyd and Anderson 1987).

All data were analyzed using R 4.1.1 (R Core Team 2021). Richness and Simpson's Diversity were analyzed and modeled using linear mixed effect models, while Simpson's evenness was analyzed using a generalized linear mixed effect model to account for a non-normal distribution (Bates et al. 2015). Mixed effect models were used because they allowed us to account for random effects that were not due to our treatments (Bates et al. 2015). In every model, transect ID and pasture were treated as random variables. Indicator Species Analyses (ISA) were used to examine the amount of available niche space in each treatment by identifying whether species sorting occurred between treatments (De Caceres and Legendre 2009). An ISA assesses species sorting by determining what treatment a species occurs in most often and what treatment it is most abundant in. For a species to be reported as a result of an ISA, it must show up more frequently and in higher abundances in exactly one treatment than it does in others.

Results

Richness, Evenness, and Diversity

Plant species richness did not significantly differ between patch-burn grazing and modified twice-over rest-rotation grazing (MTORG) with an average of nine species per quadrat ($p = 0.97$; Figure 1). However, both patch-burn and MTORG pastures had higher species richness than season-long grazing ($p < 0.001$; Figure 1), which averaged seven species per quadrat. Season-long pastures had significantly higher evenness than patch-burn pastures (0.34 and 0.27, respectively; $p < 0.001$), but not the MTORG pastures (0.30, $p = 0.33$; Figure 2). The MTORG pastures had significantly higher Simpson diversity than either the patch-burn or season-long pastures (2.66, 2.30, and 2.12 respectively, $p < 0.001$; Figure 3). Diversity in our patch-burn and season-long pastures did not differ significantly ($p = 0.25$; Figure 3).

Indicator Species Analysis

We found evidence that species sorting occurred in every treatment of our study and across multiple functional groups (Table 2). This means that every treatment had multiple species that appeared more often and in higher abundances in it than in all other treatments. In general, more species were indicators of patch-burn grazing than any other treatment, and the MTORG pastures had more indicator species than the season-long treatment (Table 2). This trend also held true for the functional groups of indicator species. Patch-burn grazing had more forb, graminoid, and legume indicators than did MTORG pastures, which had more indicators than season-long pastures (Table 2).

Discussion

Restoring heterogeneity to rangelands through various management techniques is expected to increase diversity (Fuhlendorf et al. 2009). Utilizing a working landscape, we examined how different rangeland management techniques designed to create heterogeneity influenced plant communities. Our results suggest that modified twice-over rest-rotation grazing (MTORG) and patch-burn grazing increase plant species richness (Figure 1), decrease evenness (Figure 2), and have mixed efffects on diversity (Figure 3). Additionally, management strategies that create landscape-level heterogeneity increase the amount of available niche space in a plant community (Table 2). In particular, the patch-burn pastures experienced more species sorting, and thus had more available niche space than MTORG pastures, which experience more species sorting than season-long pastures.

Our results support the idea that increasing landscape-level heterogeneity leads to an increase in plant richness and available niche space (Lundholm 2009). This effect should also translate to plant diversity (Lundholm 2009), but only our MTORG pastures saw increased plant diversity when compared to the relatively homogenous season-long pastures (Figure 3). The reason our patch-burn pastures did not see higher diversity than our season-long pastures is likely a combination of two factors. The drought that persisted in the area during the early growing season likely hampered plant germination and re-emergence in these pastures. However, all of our pastures experienced this drought, it is more likely that changes to our burn regime had a stronger negative impact on our patch-burn pastures. Due to weather restrictions and county burn bans, we had to burn these pastures later than normal, well into the growing season. Traditionally, burns in a patch-burn system are conducted during the dormant season because it clears away dead plant material, increasing light availabilty for new and emergent plants (Fuhlendorf and Engle 2004). By burning in the early growing season (as opposed to late in the dormant season) we likely removed the existing growth of any emergent plants that would have otherwise been sampled, decreasing plant evenness and diversity in our patch-burn pastures. While our patch-burn pastures had more available niche space (i.e. had more indicator species), it is worth noting that one of the indicator species for that treatment was Kentucky bluegrass. Kentucky bluegrass was recorded in all but one quadrat (which happened to be in a patch-burn pasture), which means that Kentucky bluegrass had higher abundance in patch-burn pastures than any other treatment. Patch-burn grazing has been shown to be an effective tool in stabilizing Kentucky bluegrass abundance (Dornbusch et al. 2020). This indicates that Kentucky bluegrass has higher abundances in the patch-burn grazing pastures for some other reason than pasture design. The most likely culprit for this higher abundance is land-use history. Prior to being enrolled in our study, half of the patch-burn pastures were involved in a grazing intensity study (see Limb et al. [2018]). Portions of the pasture experienced both severe over- or undergrazing at one time (Limb et al. 2018). Both of these scenarios create opportunities for Kentucky bluegrass expansion (Palit et al. 2021), meaning that Kentucky bluegrass abundance was likely substantially higher in these pastures when they were enrolled in patch-burn grazing. Without looking at multiple years of data, it is impossible to say what effect patch-burning has on Kentucky bluegrass abundance, but it is likely that Kentucky bluegrass has stabilized or decreased in abundance over time in these pastures (Dornbusch et al. 2020).

Our study provides evidence that increasing heterogneiety through patch-burn grazing or MTORG results in increased plant species richness and niche availabilty. Additionally, we found that heterogeneity created through MTORG can result in higher plant diversity than season-long grazing even in the face of severe drought. These results are consistent with other studies that suggest that increasing heterogeneity increases plant diversity and available niche space (Fuhlendorf and Engle 2004, Lundholm 2009, Hovick et al. 2015). We have shown that heterogeneity created through either modified twice-over rest-rotation grazing or patch-burn grazing can increase plant species richness and niche availability, and that patch-burn grazing increases niche availabilty more than other management strategies.

Literature Cited

Allred, B. W., S. D. Fuhlendorf, D. M. Engle, and R. D. Elmore. 2011. Ungulate preference for burned patches reveals strength: Of fire-grazing interaction. Ecology and Evolution 1:132–144.

Baer, S. G., T. Adams, D. A. Scott, J. M. Blair, and S. L. Collins. 2020. Soil heterogeneity increases plant diversity after 20 years of manipulation during grassland restoration. Ecological Applications 30.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting Linear Mixed-Effects Models using lme4. Journal of Statistical Software 67:1–48.

Bond, W. J., and J. E. Keeley. 2005. Fire as a global 'herbivore': the ecology and evolution of flammable ecosystems. Trends in Ecology & Evolution 20:387–394.

Bowman, D. M. J. S., J. K. Balch, P. Artaxo, W. J. Bond, J. M. Carlson, M. A. Cochrane, C. M. D'Antonio, R. S. DeFries, J. C. Doyle, S. P. Harrison, F. H. Johnston, J. E. Keeley, M. A. Krawchuk, C. A. Kull, J. B. Marston, M. A. Moritz, I. C. Prentice, C. I. Roos, A. C. Scott, T. W. Swetnam, G. R. van der Werf, and S. J. Pyne. 2009. Fire in the Earth System. Science.

Briske, D. D., S. D. Fuhlendorf, and F. E. Smeins. 2003. Vegetation Dynamics on Rangelands: A Critique of the Current Paradigms. Journal of Applied Ecology 40:601–614.

De Caceres, M., and P. Legendre. 2009. Associations between species and groups of sites: indices and statistical inference. Ecology.

DeKeyser, S., G. Clambey, K. Krabbenhoft, and J. Ostendorf. 2009. Are Changes in Species Composition on Central North Dakota Rangelands Due to Non-Use Management? Rangelands 31:16–19.

Dornbusch, M. J., R. Limb, and K. K. Sedivec. 2020. Alternative Grazing Management Strategies Combat Invasive Grass Dominance. Natural Areas Journal 40:86–95.

Floyd, D. A., and J. E. Anderson. 1987. A Comparison of Three Methods for Estimating Plant Cover. Journal of Ecology 75:221–228.

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

Fuhlendorf, S. D., and D. M. Engle. 2004. Application of the fire-grazing interaction to restore a shifting mosaic on tallgrass prairie. Journal of Applied Ecology 41:604–614.

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.

Fuhlendorf, S. D., W. C. Harrell, D. M. Engle, R. G. Hamilton, C. A. Davis, and D. M. Leslie Jr. 2006. Should heterogeneity be the basis for conservation? Grassland bird response to fire and grazing. Ecological Applications 16:1706–1716.

Fuhlendorf, S. D., and F. E. Smeins. 1999. Scaling effects of grazing in a semi-arid grassland. Journal of Vegetation Science 10:731–738.

Hovick, T. J., R. D. Elmore, S. D. Fuhlendorf, D. M. Engle, and R. G. Hamilton. 2015. Spatial heterogeneity increases diversity and stability in grassland bird communities. Ecological Applications 25:662–672.

Limb, R. F., S. D. Fuhlendorf, D. M. Engle, J. R. Weir, R. D. Elmore, and T. G. Bidwell. 2011. Pyric-herbivory and cattle performance in grassland ecosystems. Rangeland Ecology and Management 64:659–663.

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 & Environment 257:113–119.

Lundholm, J. T. 2009. Plant species diversity and environmental heterogeneity: Spatial scale and competing hypotheses. Journal of Vegetation Science 20:377–391.

Mcgranahan, D. A., D. M. Engle, S. D. Fuhlendorf, S. J. Winter, J. R. Miller, and D. M. Debinski. 2012. Spatial heterogeneity across five rangelands managed with pyric-herbivory. Journal of Applied Ecology 49:903–910.

McNaughton, S. J. 1984. Grazing Lawns: Animals in Herds, Plant Form, and Coevolution. The American Naturalist 124:863–886.

Melbourne, B. A., H. V. Cornell, K. F. Davies, C. J. Dugaw, S. Elmendorf, A. L. Freestone, R. J. Hall, S. Harrison, A. Hastings, M. Holland, M. Holyoak, J. Lambrinos, K. Moore, and H. Yokomizo. 2007. Invasion in a heterogeneous world: resistance, coexistence or hostile takeover? Ecology Letters 10:77–94.

NDAWN. 2021. North Dakota Agricultural Weather Network (NDAWN). North Dakota State University.

Palit, R., G. Gramig, and E. S. Dekeyser. 2021. Kentucky bluegrass invasion in the northern great plains and prospective management approaches to mitigate its spread. Plants 10.

R Core Team. 2021. R: A Language and Environment for Statistical Computing. R, R Foundation for Statistical Computing, Vienna, Austria.

Samson, F., and F. Knopf. 1994. Prairie conservation in North America. BioScience 44:418–421.

Sedivec, K., E. Gaugler, M. Hamel, R. Limb, D. A. McGranahan, and T. J. Hovick. 2019. Aboveground Cumulative Production with Rotational Grazing: Assessing a Modified Twice-over Rest-rotation Treatment. Central Grasslands Research Extension Center Annual Report:8.

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

USDA NRCS. 2003. Grazing Lands Ecological Sites and Forage Suitability Groups. Page 120 National Range and Pasture Handbook. Second edition. United States Departments of Agriculture Natural Resources Conservation Service.

USDA Soil Conservation Service. 1982. Land resource regions and major land resource areas of the United States. 156 p.

Winter, S. L., S. D. Fuhlendorf, and M. Goes. 2014. Patch-Burn Grazing Effects on Cattle Performance: Research Conducted in a Working Landscape. Rangelands 36:2–7.

Table 1: Stocking rates (AUMs/acre), grazing season, and precipitation (inches) during our study in 2021. Stocking rates were calculated under the assumption that cattle would achieve a forage efficiency of 30 percent (USDA NRCS 2003).

Treatment	**Stocking Rate (AUMs/ha)**	**Grazing Season**	**Yearly Precipitation (inches)**
Patch-burn Grazing	3.93	May 25 - September 6	13.1
Modified Rotational Grazing	5.16	May 25 - September 29	
Season-Long Grazing	3.93	May 25 - September 6	

Table 2: Indicator species analysis results. All reported results are significant indicators of each treatment. Green rows are indicators of patch-burn pastures, orange-yellow rows are indicators of modified twice-over rest-rotation pastures, and blue rows represent indicators of season-long pastures.

Species	Functional Group	Indicator Value	*p*-value	Treatment	Species	Functional Group	Indicator Value	*p*-value	Treatment
Artemisia ludoviciana	Forb	0.594	0.005	Patch-Burn	*Andropogon gerardii*	Graminoid	0.113	0.005	Patch-Burn
Solidago rigida	Forb	0.583	0.005	Patch-Burn	*Elymus trachycaulus*	Graminoid	0.061	0.025	Patch-Burn
Achillea millefolium	Forb	0.402	0.005	Patch-Burn	*Clycyrrhiza lepidota*	Legume	0.344	0.005	Patch-Burn
Solidago canadensis	Forb	0.394	0.005	Patch-Burn	*Melilotus officinalis*	Legume	0.181	0.005	Patch-Burn
Cirsium flodmanii	Forb	0.359	0.005	Patch-Burn	*Oxytropis lambertii*	Legume	0.078	0.01	Patch-Burn
Comandra umbellata	Forb	0.337	0.005	Patch-Burn	*Solidago mollis*	Forb	0.33	0.005	Rotational
Helianthus pacuiflorus	Forb	0.321	0.005	Patch-Burn	*Ambrosia psilostachya*	Forb	0.291	0.045	Rotational
Cirsium undulatum	Forb	0.304	0.005	Patch-Burn	*Solidago missouriensis*	Forb	0.291	0.005	Rotational
Grindelia squarrosa	Forb	0.289	0.005	Patch-Burn	*Artemisia campestris*	Forb	0.24	0.005	Rotational
Ratibida columnifera	Forb	0.261	0.01	Patch-Burn	*Lygodesmia juncea*	Forb	0.105	0.01	Rotational
Artemisia absinthium	Forb	0.224	0.01	Patch-Burn	*Tragopogon dubius*	Forb	0.097	0.045	Rotational
Anemone cylindrica	Forb	0.213	0.005	Patch-Burn	*Apocynum cannabinum*	Forb	0.09	0.005	Rotational
Lithospermum occidentale	Forb	0.205	0.005	Patch-Burn	*Oenothera suffrutescens*	Forb	0.078	0.005	Rotational
Geum triflorum	Forb	0.196	0.005	Patch-Burn	*Symphyotrichum lanceolatum*	Forb	0.073	0.05	Rotational
Traxacum erythrospermum	Forb	0.165	0.005	Patch-Burn	*Schizachrrium scoparium*	Graminoid	0.178	0.005	Rotational
Anemone patens	Forb	0.158	0.005	Patch-Burn	*Hesperostipa spartea*	Graminoid	0.055	0.05	Rotational
Echniacea angustifolia	Forb	0.134	0.015	Patch-Burn	*Pediomelum argophyllum*	Legume	0.38	0.005	Rotational
Equisetum hyemale	Forb	0.126	0.005	Patch-Burn	*Pediomelum esculentum*	Legume	0.195	0.005	Rotational
Liatris punctata	Forb	0.119	0.05	Patch-Burn	*Lichen*	Other	0.153	0.005	Rotational
Heterotheca villosa	Forb	0.103	0.01	Patch-Burn	*Convolvulus arvensis*	Forb	0.117	0.005	Season-Long
Helianthus maximiliani	Forb	0.099	0.005	Patch-Burn	*Toxicodendron rydbergii*	Forb	0.101	0.005	Season-Long
Anemone canadensis	Forb	0.09	0.04	Patch-Burn	*Potentilla arguta*	Forb	0.088	0.005	Season-Long
Taraxacum officinale	Forb	0.09	0.05	Patch-Burn	*Sphaeralcea coccinea*	Forb	0.084	0.005	Season-Long
Poa pratensis	Graminoid	0.723	0.005	Patch-Burn	*Bromus inermis*	Graminoid	0.697	0.005	Season-Long
Nassella viridula	Graminoid	0.367	0.045	Patch-Burn	*Argopyron cristatum*	Graminoid	0.253	0.005	Season-Long
Carex heliophila	Graminoid	0.297	0.005	Patch-Burn	*Phleum pratense*	Graminoid	0.083	0.01	Season-Long
Bouteloua curtipendula	Graminoid	0.172	0.005	Patch-Burn	*Poa compressa*	Graminoid	0.065	0.015	Season-Long
Bouteloua gracilis	Graminoid	0.145	0.005	Patch-Burn	*Rosa woodsii*	Sub-shrub	0.14	0.005	Season-Long
Dichanthelium wilcoxianum	Graminoid	0.139	0.015	Patch-Burn					

Figure 1: Species richness at the quadrat level. Error bars represent standard error.

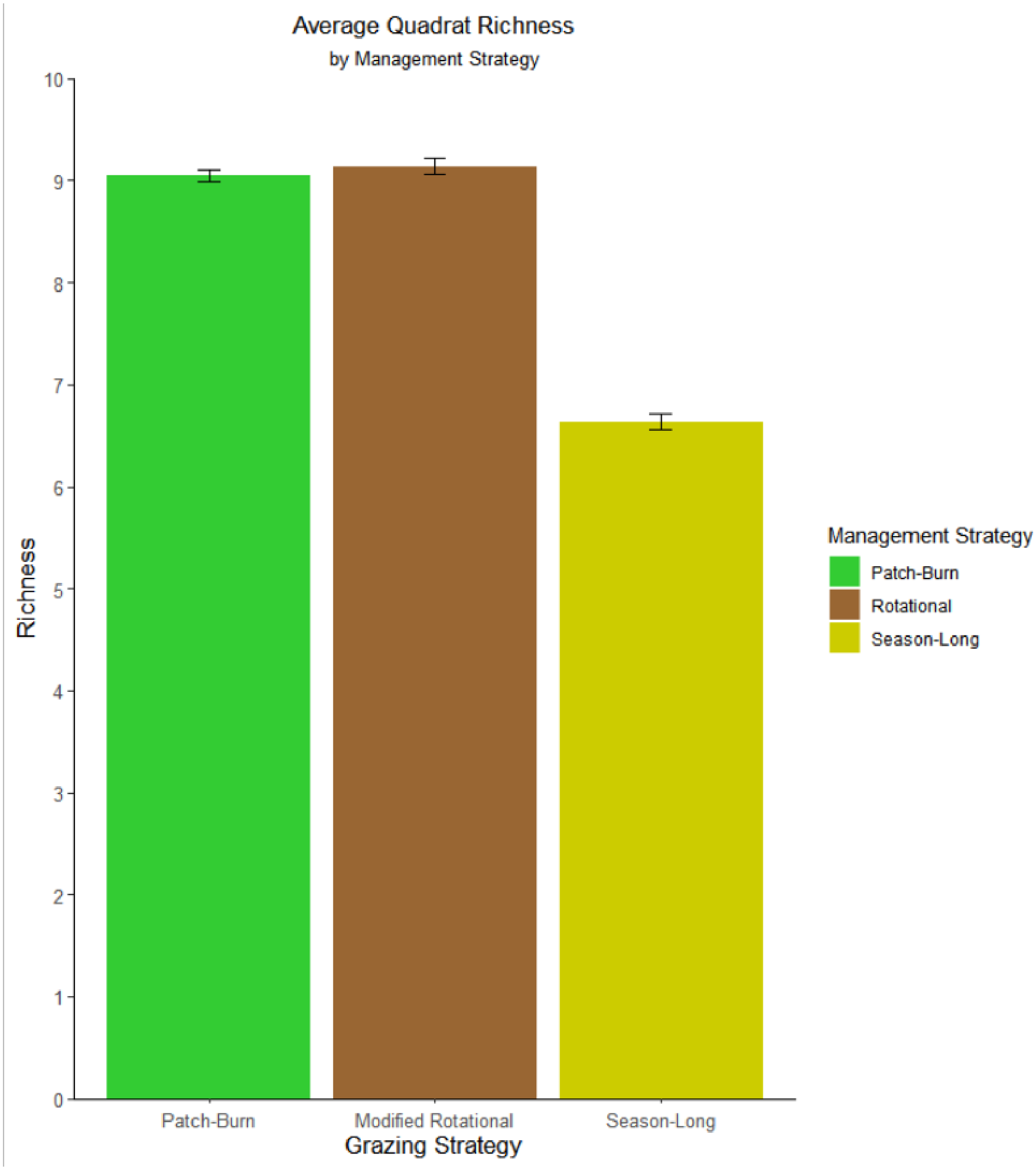


Figure 2: Simpson's Evenness. Error bars represent standard error. Despite appearing different based on their standard error, there is no statistical difference in evenness between the rotational treatment and either patch-burn or season-long treatment. However, season-long grazing resulted in higher evenness than patch-burn grazing.

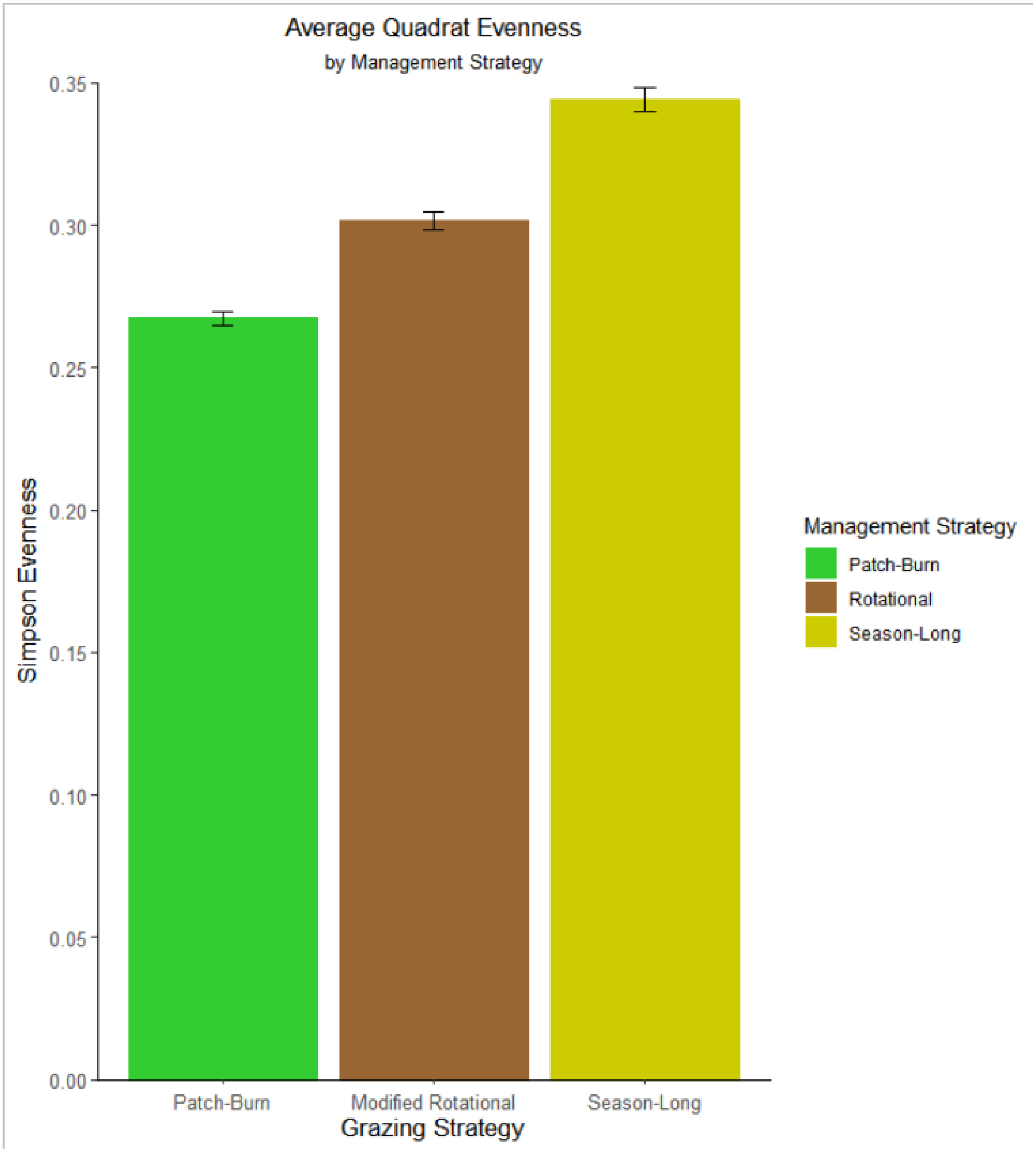
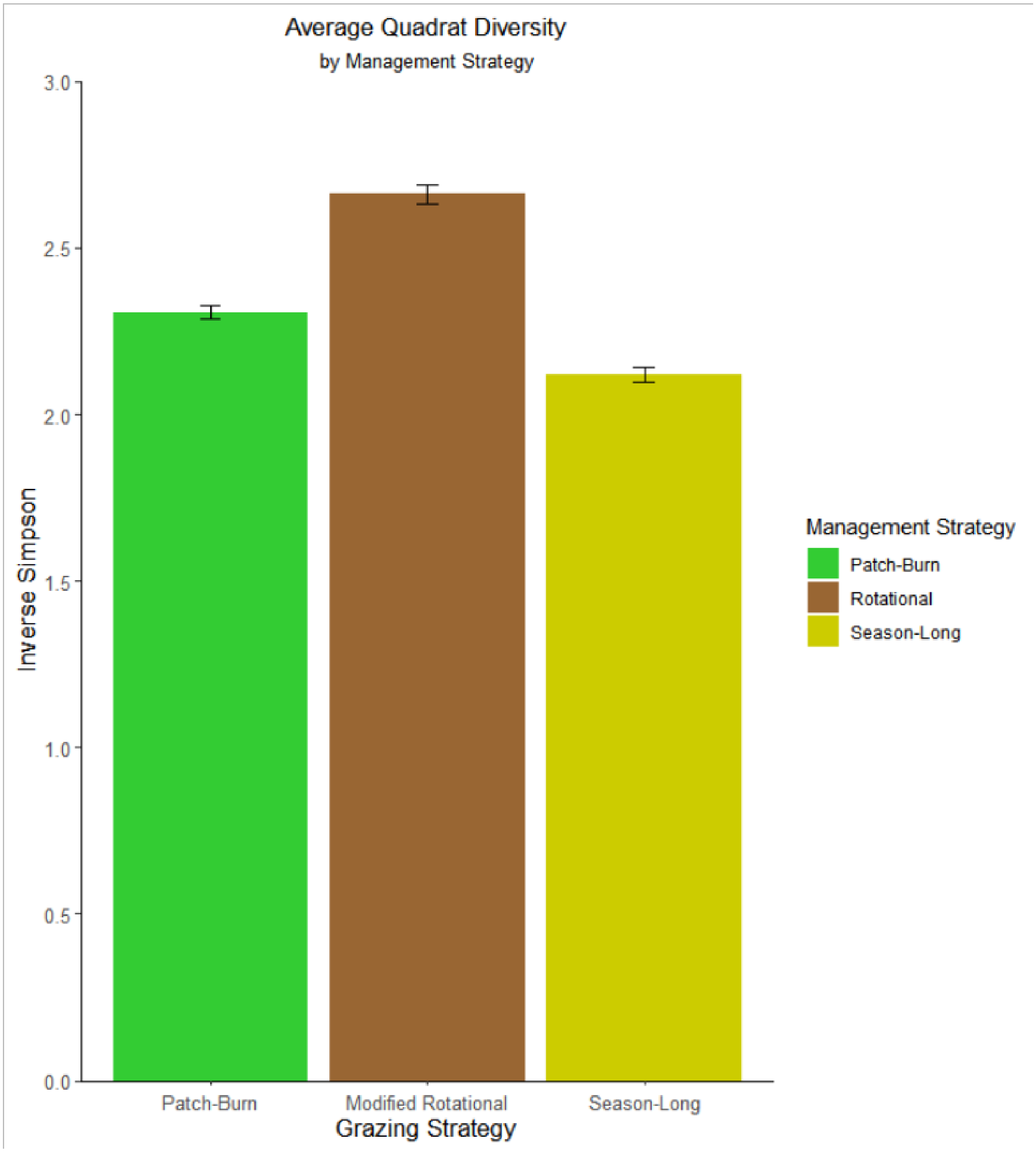


Figure 3: Simpson's Diversity Error bars represent standard error. Despite appearing different based on their standard error, there is no statistical difference in diversity between patch-burn grazing and season-long grazing. The rotational treatment had the highest diversity.



Fire Drives Patch Selection by Cattle in a Patch-Burn Grazing System

Esben L. Kjaer[1], Ryan F. Limb[1], Kevin Sedivec[1,2]

[1]School of Natural Resources, North Dakota State University, Fargo, N.D., USA
[2]Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D., USA

Summary

Patch-burn grazing in the northern Great Plains is gaining traction as a potential tool for rangeland management. As an ecologically-based method for rangeland management, patch-burn grazing increases landscape-level heterogeneity which can promote biodiversity and moderate the effects of weather variability on livestock performance. While many studies investigate the benefits of patch-burn grazing, one key assumption of the theory behind this management strategy lacks support as there is no direct empirical evidence that animals preferentially consume more biomass on recently burned areas than other areas in a patch-burn grazing system. To test this, we collected data from 2018 to 2020 on the utilization rate of patches by cattle in a patch-burn grazing system and compared them to utilization rates in a traditional season-long grazing system. We found that plant consumption by cattle was highest (approx. 10 – 20%) in recently burned patches and decreased as time-since-fire increased ($p \leq 0.05$). We also found that in every year except 2019, patch utilization in patch-burn systems increased following fire. However, patch utilization in season-long systems stayed relatively consistent across years such that patches in season-long pastures with high utilization (> 60%) one year had high utilization in subsequent years. These results suggest that in the absence of additional disturbances, grazing patterns from previous years drive patch selection and grazing patterns in the current year. However, disturbances that remove dead plant material exposing new green growth override the influence of previous grazing patterns, driving patch selection. Our results provide empirical evidence that disturbances, such as fire, have a stronger influence on site selection by cattle than do previous grazing patterns. This work is among the first to provide evidence of selection for recently burned areas by cattle through the consumption of plant material.

Introduction

Understanding where and why animals choose to forage is crucial to rangeland and ecosystem management. Failure to understand the distribution of grazing animals on rangelands can create numerous issues, such as increasing existing soil erosion (Blackburn 1984), forcing wild animals to use marginal habitat (Yeo et al. 1993), reduce livestock growth (Lacey et al. 1993), and create opportunities for interactions between big game and livestock (Holechek et al. 1995). Conversely, understanding where animals choose to forage allows land managers to better make decisions that can improve watershed quality, promote biodiversity (Allred et al. 2011, Hovick et al. 2015), and increase or maintain livestock production (Limb et al. 2011, Winter et al. 2014). While it is accepted that understanding grazing animal distribution is important, there is inconclusive evidence about how previous grazing events and disturbances drive grazing animal distribution and subsequent utilization (McNaughton 1985, Westoby 1985, Ruess and McNaughton 1987, Fuls 1992, Plumb and Dodd 1993, Bailey et al. 1996) particularly in landscapes managed with fire (Fuhlendorf and Engle 2001, McGranahan et al. 2012, Duchardt et al. 2016).

The initial grazing patterns created by cattle in either season-long or continuous grazing systems are influenced by a combination of abiotic and biotic factors (Bailey et al. 1996, Bailey and Welling 1999). The decisions on where to graze made by cattle unfamiliar with their surroundings are influenced by factors like distance from water, slope, forage quality, and forage quantity (Bailey and Welling 1999). However, over time the grazing patterns from the previous year can begin to influence the grazing patterns of the current year. Cattle create vegetation patches with short vegetation and little litter by visiting these different areas, multiple times per grazing season (McNaughton 1984). These areas of short vegetation persist between years and in subsequent years cattle will return to these areas where they had previously heavily grazed first because the new growth will be more readily accessible than in other, less intensely grazed areas. However, additional disturbances, such as fire, that remove plant litter and/or promote new plant growth are likely to over-write the influences of previous grazing events causing cattle to preferentially graze on these recently disturbed areas instead of areas they grazed in previous years.

Pyric herbivory, where herbivores preferentially select for the most recently burned sites in a landscape is demonstrated across multiple ecosystems (Archibald et al. 2005, Staver et al. 2009, Allred et al. 2011, 2013, Augustine and Derner 2014, Leverkus et al. 2018). Nearly all studies of pyric-herbivory and patch-burn assess animal distribution, often with a great deal of precision (Knapp et al. 1999, Augustine and Derner 2014, Leverkus et al. 2018, Spiess et al. 2020). However, data on what or how much plant biomass they are consuming is lacking (Augustine and Derner 2014, Leverkus et al. 2018). A simple way to show site selection in grazing animals that shows not only where animals are located, but also what they are consuming, is to monitor plant biomass production and utilization.

With that in mind, no one has yet shown whether grazing is driven by previous grazing patterns or if it is driven by fire within a patch-burn grazing system directly monitored by utilization. Therefore, in a grassland landscape managed with both continuous grazing and patch-burn grazing, we monitored grazing utilization in replicated pastures across multiple years and time-since-fire. We predict that grazing in pastures with continuous grazing will be influenced by previous grazing events (heavily grazed areas in one year, will be heavily grazed in subsequent years). Also, cattle in patch-burn pastures will preferentially graze the most recently burned patch in a patch-burn grazing system. Additionally, we predict that differences in utilization within patch-burn pastures will decrease as time-since-fire increases.

Methods

This study took place over three years (2018 to 2020) at the North Dakota State University Central Grasslands Research Extension Center (CGREC) in Stutsman and Kidder Counties northwest of Streeter, N.D. USA (46°45'N, 99°28'W). The study site is located in the Missouri Coteau ecoregion, which primarily consists of rolling hills interspersed with small glacial lakes (USDA - SCS, 1982). Average temperatures range from -12.3 ºC in January to 20.3 ºC in July. The site averages 401 mm of precipitation annually (29-year average from 1991-2020) with the majority of precipitation occurring between May and September each year (NDAWN, 2021; Table 1). Over the course of our study, the sites received 479 mm of precipitation in 2018 (78 mm above average), 552 mm in 2019 (151 mm above average), and 234 mm in 2020 (168 mm below average) (NDAWN, 2021; Table 1).

Our study utilized four 65-ha pastures with patch-burn grazing and four 65-ha pastures with season-long grazing (Table 1). All pastures were established and grazing and patch-burn treatments began one year before data collection in 2017 and contain no interior fencing. Each pasture was divided up into eight 8-ha subunits. In the patch-burn pastures (n=4), two subunits were combined to form four distinct burn units (16 ha; Figure 1). Each spring one 16-ha unit from each pasture was burned. Pastures in the season-long grazing treatment (n=4) were never burned but were divided into four distinct (16 ha) units within each pasture. Each pasture was stocked with cow-calf pairs (*Bos taurus* L.) at a stocking rate between 2.10 and 2.45 AUMs/ha (Table 1). This stocking rate was based on an assumed 30 percent harvest efficiency of the mean relative forage value for each ecological site found in the treatment pastures (USDA - NRCS, 2003). Cattle grazed each pasture each year from mid-May to mid-to-late October (Table 1).

Exclosures (1-m^2) were established in each field to allow us to examine the difference between aboveground biomass in the presence and absence of grazing pressure. Each 8-ha subunit contained four exclosures randomly placed within loamy ecological sites (USDA - NRCS, 2003). This meant that each 16-ha unit had eight exclosures. Each pasture, regardless of grazing treatment, contained 32 exclosures in total. Each year before the start of the growing season, exclosures were rotated roughly 180 degrees so that the same area would not be clipped or excluded from grazing each year.

Each year (2018-2020) we collected three 0.25 m^2 quadrats of standing crop biomass (living and dead plants) within and outside of each exclosure towards the end of the growing season (September-October). Standing crop biomass was collected by clipping and collecting all vegetation (alive and dead) within a quadrat to 1 cm height. Plants were then dried (in bags) in a drying oven at 70^{o} C for at least 48 hours to a constant weight. Average standing crop biomass for both inside and outside each exclosure was then calculated by averaging the three samples together. We then calculated utilization by cattle by measuring the difference between the in- and out-of-exclosure average biomass for each exclosure.

In order to test for differences in utilization between patches in our treatments (patch-burn and season-long pastures), we had to first group our sample points. Points in our patch-burn pastures were grouped into patches based on the burn unit that they occurred in. Sample points in our season-long pastures were grouped into patches by randomly assigning each point a unique identifier and then assigning each point a utilization rate. Points were then grouped based on their utilization rate, those with utilization rates between zero and 20 percent utilization were labeled as "Light" utilization, those between 20 and 40 percent utilization were "Moderate", between 40 and 60 percent utilization was "Full" and any point with greater than 60 percent utilization was labeled as "Heavy". Group assignments remained the same throughout the study.

We tested for differences in utilization within (between patches) and between our treatments (patch-burn and season-long pastures) using linear mixed-effect models (LMM) from the package *lme4* in R 4.1.2 (Bates et al. 2015, R Core Team 2021). Any instances of missing data or negative utilization were excluded from these models, as they were due to sampling error. To account for year-to-year variation in rainfall, differences due to stocking rate, and differences in land-use history, yearly precipitation, stocking rate, and pasture identity were treated as random variables in our models. If there were significant interactions or results, posthoc pairwise comparisons were conducted using the package *multcomp* (Hothorn et al. 2008).

Results

We found that areas in our season-long pastures that experienced the heaviest grazing in 2018 also experienced the heaviest grazing in 2019 and 2020 (Figure 2 and Figure 3), however, this difference was only significant in 2019 ($p \leq 0.001$) and not 2020 ($p = 0.96$). Despite initial significant differences in utilization ($p \leq 0.001$), by 2019, all patches that had been categorized as "Light", "Moderate" or "Full" grazing had roughly the same utilization rate ($p > 0.99$). Overall, patch-burn pasture utilization was similar to the utilization under season-long grazing in 2018 ($p = 0.232$). Within patch-burn pastures, cattle preferentially grazed the most recently burned patches ($p \leq 0.03$; Figure 3, Row 1). Utilization in all other patches in 2018 did not differ (Figure 3, Row 1). Utilization in patch-burn pastures in 2019 was highest in the most recently burned patches ($p \leq 0.001$), and lower in all other patches, which saw no significant difference in utilization (Figure 3, Row 2). Our patch-burn system completed its first rotation in 2020, and a clear pattern had emerged where the most recently burned patch in our patch-burn pastures had the highest rates of utilization by cattle (*p*<0.001; Figure 3, Row 3). As in previous years, in 2020, patch-utilization in the patch-burn pastures decreased as time-since-fire increased (*p*<0.001, Figure 3 Row 3). However, utilization was roughly equal in patches burned in 2017 and 2018 (*p*<0.99, Figure 3 Row 3).

Discussion

Herbivory is a large-scale disturbance that influences many processes in grassland ecosystems. Understanding the drivers of grazing patterns enables land managers to create management scenarios that promote biodiversity and ecosystem stability. In a working landscape grazed by livestock using both season-long and patch-burn grazing management strategies, we assessed grazing patterns across multiple seasons. Our results within the season-long pastures were mostly consistent with the idea that previous grazing patterns drive current patch selection and grazing (McNaughton 1984). Most studies that demonstrate that herbivore distribution post-fire is concentrated on recently burned areas suggest that these herbivores are also consuming more plant material on these recently burned areas than other areas. (Allred et al. 2011, Augustine and Derner 2014). The results from our patch-burn pastures provide evidence that supports these suggestions. Utilization was consistently highest in the most recently burned areas and decreased as time-since-fire increased in our patch-burn system (Figure 3). Patches in our patch-burn grazing pastures did not consistently have the same utilization (i.e. patches burned in 2018 had the highest utilization in 2018, but not 2019 or 2020). Instead, the fact that utilization was consistently highest in the most recently burned areas provides evidence that fire can drive grazing patterns by over-writing the influence of grazing patterns from the previous year. Our data provide strong evidence that without additional disturbances, grazing patterns from the previous year drive patch selection and grazing in the current year, but disturbances, such as fire, override the influence of previous grazing patterns.

Our study is the first to provide evidence that in the absence of additional disturbances, grazing patterns from the previous year drive grazing and patch selection in the current year and that disturbances that remove dead biomass and promote plant growth, such as fire, can over-write the influences of previous grazing. Additionally, we found that cattle preferentially consume more plant material in recently burned areas and that utilization or cattle preference for a patch decreases as time-since-fire increases. This is consistent with other studies that suggest cattle preferentially graze recently burned areas using either GPS collars or fecal pat counts (Allred et al. 2011, Augustine and Derner 2014, Spiess et al. 2020). Regardless, we have directly shown through utilization that cattle preferentially utilize recently burned areas over areas that they previously grazed in a patch-burn grazing system.

References

Allred, B. W., S. D. Fuhlendorf, D. M. Engle, and R. D. Elmore. 2011. Ungulate preference for burned patches reveals strength: Of fire-grazing interaction. Ecology and Evolution 1:132–144.

Allred, B. W., S. D. Fuhlendorf, T. J. Hovick, R. D. Elmore, D. M. Engle, and A. Joern. 2013. Conservation implications of native and introduced ungulates in a changing climate. Global Change Biology 19:1875–1883.

Archibald, S., W. J. Bond, W. D. Stock, and D. H. K. Fairbanks. 2005. Shaping the Landscape: Fire–Grazer Interactions in an African Savanna. Ecological Applications 15:96–109.

Augustine, D. J., and J. D. Derner. 2014. Controls over the strength and timing of fire–grazer interactions in a semi-arid rangeland. Journal of Applied Ecology 51:242–250.

Bailey, D. W., J. E. Gross, E. A. Laca, L. R. Rittenhouse, M. B. Coughenour, D. M. Swift, and P. L. Sims. 1996. Mechanisms That Result in Large Herbivore Grazing Distribution Patterns. Journal of Range Management 49:386–400.

Bailey, D. W., and G. R. Welling. 1999. Modification of Cattle Grazing Distribution with Dehydrated Molasses Supplement. Journal of Range Management 52:575–582.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. Fitting Linear Mixed-Effects Models using lme4. Journal of Statistical Software 67:1–48.

Blackburn, W. H. 1984. Impacts of grazing intensity and specialized grazing systems on watershed characteristics and responses. Westview Press.

Duchardt, C. J., J. R. Miller, D. M. Debinski, and D. M. Engle. 2016. Adapting the Fire-Grazing Interaction to Small Pastures in a Fragmented Landscape for Grassland Bird Conservation. Rangeland Ecology & Management 69:300–309.

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

Fuls, E. R. 1992. Ecosystem modification created by patch-overgrazing in semi-arid grassland. Journal of Arid Environments 23:59–69.

Holechek, J. L., R. D. Pieper, and C. H. Herbel. 1995. Range management: principles and practices. Range management: principles and practices.

Hothorn, T., F. Bretz, and P. Westfall. 2008. Simultaneous Inference in General Parametric Models. Biometrical Journal 50:346–363.

Hovick, T. J., R. D. Elmore, S. D. Fuhlendorf, D. M. Engle, and R. G. Hamilton. 2015. Spatial heterogeneity increases diversity and stability in grassland bird communities. Ecological Applications 25:662–672.

Knapp, A. K., J. M. Blair, J. M. Briggs, S. L. Collins, D. C. Hartnett, L. C. Johnson, and E. G. Towne. 1999. The keystone role of bison in North American tallgrass prairie. BioScience 49:39–50.

Lacey, J. R., K. Jamtgaard, L. Riggle, and T. Hayes. 1993. Impacts of Big Game on Private Land in South-Western Montana: Landowner Perceptions. Journal of Range Management 46:31.

Leverkus, S. E. R., S. D. Fuhlendorf, M. Geertsema, B. W. Allred, M. Gregory, A. R. Bevington, D. M. Engle, and J. D. Scasta. 2018. Resource selection of free-ranging horses influenced by fire in northern Canada. Human-Wildlife Interactions 12:85–101.

Limb, R. F., S. D. Fuhlendorf, D. M. Engle, J. R. Weir, R. D. Elmore, and T. G. Bidwell. 2011. Pyric-herbivory and cattle performance in grassland ecosystems. Rangeland Ecology and Management 64:659–663.

McGranahan, D. A., D. M. Engle, S. D. Fuhlendorf, S. J. Winter, J. R. Miller, and D. M. Debinski. 2012. Spatial heterogeneity across five rangelands managed with pyric-herbivory. Journal of Applied Ecology 49:903–910.

McNaughton, S. J. 1984. Grazing Lawns: Animals in Herds, Plant Form, and Coevolution. The American Naturalist 124:863–886.

McNaughton, S. J. 1985. Ecology of a Grazing Ecosystem: The Serengeti. Ecological Monographs 55:259–294.

NDAWN. 2021. North Dakota Agricultural Weather Network (NDAWN). North Dakota State University.

Plumb, G. E., and J. L. Dodd. 1993. Foraging Ecology of Bison and Cattle on a Mixed Prairie: Implications for Natural Area Management. Ecological Applications 3:631–643.

R Core Team. 2021. R: A Language and Environment for Statistical Computing. R, R Foundation for Statistical Computing, Vienna, Austria.

Ruess, R. W., and S. J. McNaughton. 1987. Grazing and the Dynamics of Nutrient and Energy Regulated Microbial Processes in the Serengeti grasslands. Oikos 49:101–110.

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

Staver, A. C., W. J. Bond, W. D. Stock, S. J. van Rensburg, and M. S. Waldram. 2009. Browsing and fire interact to suppress tree density in an African savanna. Ecological Applications 19:1909–1919.

USDA NRCS. 2003. Grazing Lands Ecological Sites and Forage Suitability Groups. Page 120 National Range and Pasture Handbook. Second edition. United States Departments of Agriculture Natural Resources Conservation Service.

USDA Soil Conservation Service. 1982. Land resource regions and major land resource areas of the United States. 156 p.

Westoby, M. 1985. Does Heavy Grazing Usually Improve the Food Resource for Grazers? The American Naturalist 126:870–871.

Winter, S. L., S. D. Fuhlendorf, and M. Goes. 2014. Patch-Burn Grazing Effects on Cattle Performance: Research Conducted in a Working Landscape. Rangelands 36:2–7.

Yeo, J. J., J. M. Peek, W. T. Wittinger, and C. T. Kvale. 1993. Influence of rest-rotation cattle grazing on mule deer and elk habitat use in east-central Idaho. Journal of Range Management 3:245–250.

Table 1: Stocking rates (AUMs/acre), grazing season, and precipitation (inches) per treatment for each year of the experiment, and one year prior. Our stocking rates were calculated under the assumption that cattle would achieve a forage efficiency of 30 percent per hectare (USDA - NRCS, 2003). This stocking rate aimed to achieve a total degree of disappearance between 40 and 50 percent each year. This operates under the assumption that cattle will graze roughly 30 percent of available forage and damage another 10 to 20 percent during non-grazing behaviors (walking, resting, defecating, etc.).

2017

Treatment	Stocking Rate (AUMs/acre)	Grazing Season	Annual Precipitation (inches)
Patch-burn Grazing	5.49	May 18 - October 19	11.6
Season-long Grazing	5.66		

2018

Treatment	Stocking Rate (AUMs/acre)	Grazing Season	Annual Precipitation (inches
Patch-burn Grazing	5.73	May 23 - October 18	18.9
Season-long Grazing	5.19		

2019

Treatment	Stocking Rate (AUMs/acre)	Grazing Season	Annual Precipitation (inches)
Patch-burn Grazing	5.73	May 22 - October 22	21.8
Season-long Grazing	5.19		

2020

Treatment	Stocking Rate (AUMs/acre)	Grazing Season	Annual Precipitation (inches)
Patch-burn Grazing	5.86	May 19 - October 22	9.2
Season-long Grazing	6.05		

Figure 1: A hypothetical 65-ha patch-burn pasture. The pasture is made up of four burn units that consist of two 8-ha subunits.

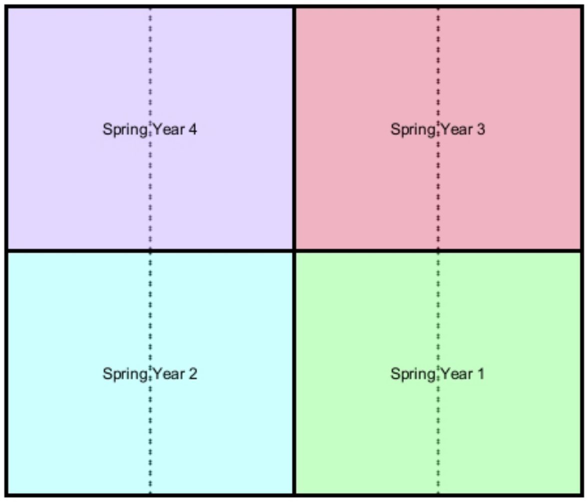


Figure 2: Utilization per patch type from 2018 to 2020. The x-axis represents two management strategies, patch-burn, and season-long grazing during the three-year study period. The y-axis is percent utilization.

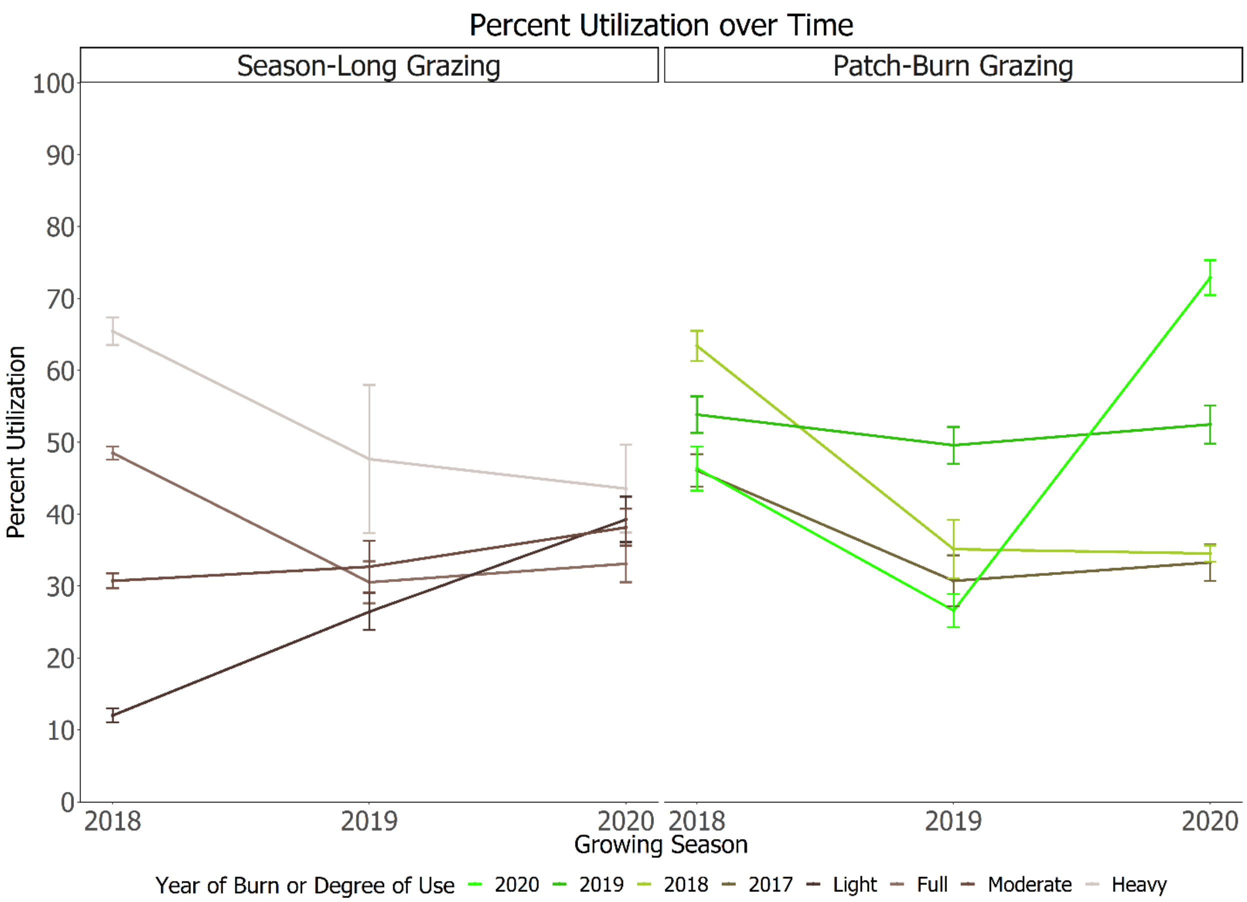


Figure 3: Percent utilization per patch type from 2018 to 2020. This figure is divided up into three rows, each row representing data from a different year of the study. Each row represents a year of the study (2018, 2019, and 2020 from top-to-bottom), and is then divided up into two panels. One panel for patch-burn grazing (right) and one panel for season-long grazing (left). On the x-axis for the patch-burn panel (right) is the year each patch was burned and on the x-axis for season-long grazing (left) is the degree of utilization for each patch. On the y-axis for all panels is percent utilization. The grey line in each panel represent the degree of disappearance for the whole pasture in a given year.

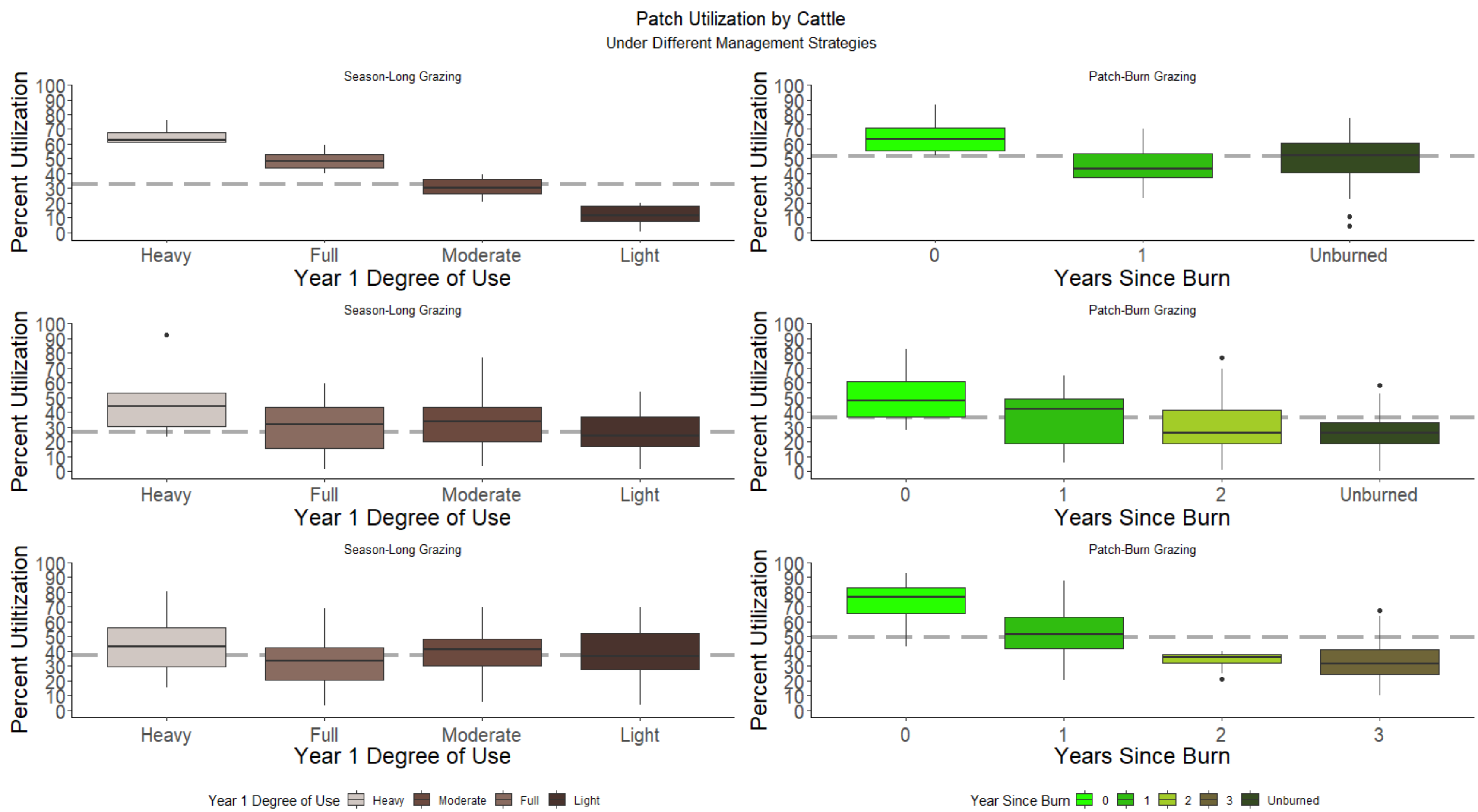
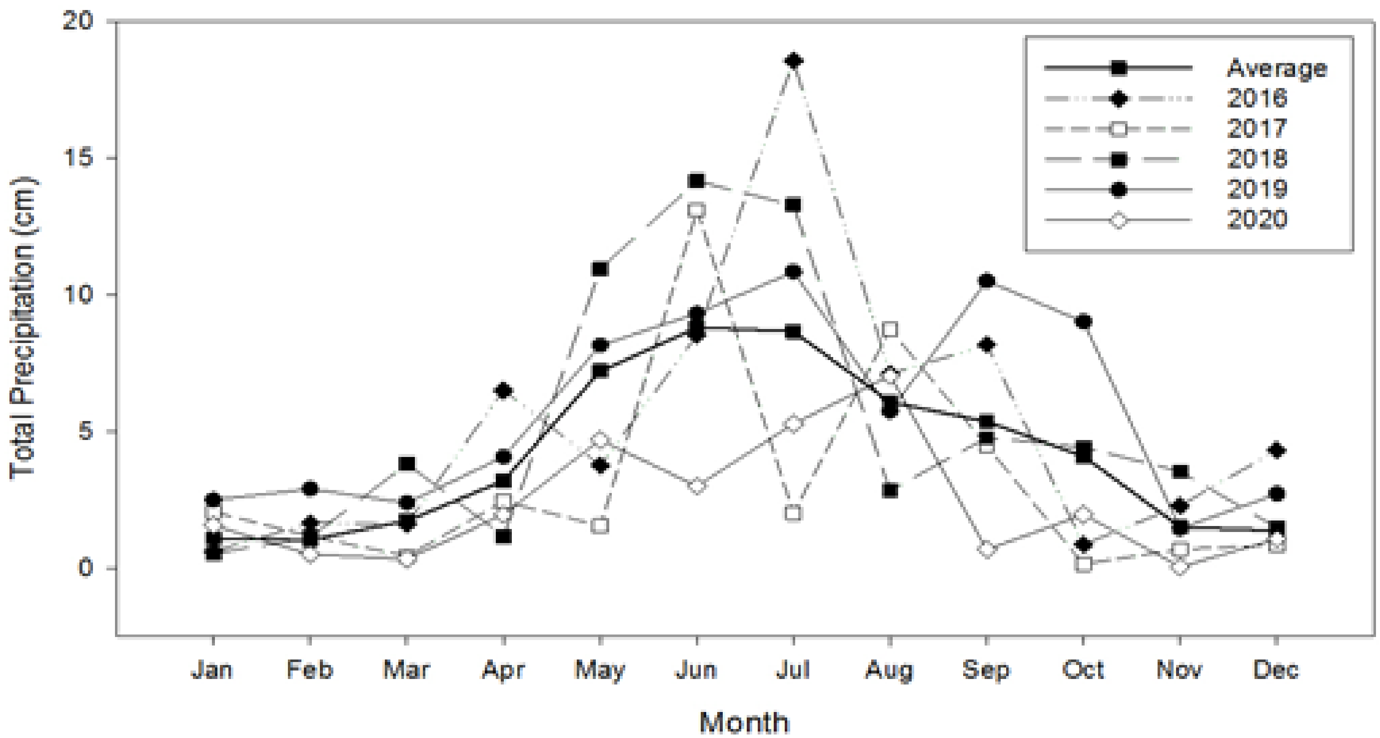


Figure 4: Monthly precipitation (cm) throughout the study. Average precipitation is based on a 29-year average from the North Dakota Agricultural Weather Network (NDAWN, 2021).



Management Strategies to Reduce the Thatch Layer Created by an Invasive Grass Species

Esben L. Kjaer[1], Ryan F. Limb[1], Kevin Sedivec[1,2]

[1]School of Natural Resources, North Dakota State University, Fargo, N.D., USA
[2]Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D., USA

Summary

Kentucky bluegrass, one of the most influential exotic grasses in the northern Great Plains, invades native communities and suppresses native species. This process is primarily achieved through the build-up of a thatch layer that alters water infiltration and prevents seed recruitment and germination by native plants. While manual thatch removal can reduce the impact of Kentucky bluegrass, it is impractical at large scales. We examined alternatives to manual thatch removal in the form of conventional rangeland management techniques, such as patch-burn grazing, rotational grazing, and season-long grazing. To test these different strategies, we measured thatch depth at multiple points across different pastures invaded by Kentucky bluegrass in southcentral North Dakota. Each pasture was managed with patch-burn grazing, modified twice-over rest-rotational grazing, or season-long grazing. Both the patch-burn grazing and the rotational grazing pastures were designed to increase landscape-level heterogeneity. However, the rotational grazing was designed to create heterogeneity through differential grazing intensities as opposed to fire. We found no difference in thatch depth between rotational and season-long grazing (2.59 and 2.60 cm respectively, $p>0.05$). However, pastures managed with patch-burn grazing had a thinner thatch layer (1.79 cm) than those managed with rotational or season-long grazing ($p<0.05$). Thatch depth did not vary consistently with time-since-fire or grazing intensity. These results suggest that patch-burn grazing is an effective tool in reducing thatch accumulation and may lessen the impact of Kentucky bluegrass on prairies. More research is needed to demonstrate how a reduced thatch layer impacts these prairie communities.

Introduction

One of the most influential exotic grasses in the northern Great Plains is Kentucky bluegrass (*Poa pratensis* L.; hereafter bluegrass). Native to Eurasia, this grass invades native communities and suppresses native species through a variety of mechanisms, such as the accumulation of low-lignin litter (Printz and Hendrickson, 2015), propagule pressure (Palit et al., 2021), by using other organisms to facilitate its own growth (Dornbusch et al., 2018), and through the build-up of a novel thatch layer (Printz and Hendrickson, 2015). Of these mechanisms, thatch accumulation is thought to be the primary driver of bluegrass's expansion (Printz and Hendrickson, 2015). Once established in native prairie, bluegrass accumulates thatch through litter compression. Bluegrass litter is naturally low in lignin (Hockensmith et al., 1997), so as each year's growth senesces, the newly created litter falls over onto the already existing litter, compressing it. Over time, this compression forms a novel thatch layer (see Figure 1) that alters soil hydrology, nutrient cycling, soil temperature, and suppresses native species growth and germination (Hendrickson et al., 2021; Nouwakpo et al., 2019; Printz and Hendrickson, 2015). Because thatch is crucial to bluegrass expansion, anything that limits or reduces thatch accumulation should also reduce or limit the impact of bluegrass on native prairies.

Manual thatch removal can positively impact plant communities by creating opportunities for native forbs and grasses to germinate, establish, or grow (Hilfer and Limb, 2020). These manual methods are highly damaging to existing native species and are impractical at large scales. Ideally, land managers would prefer to reduce the thatch accumulation (and the impact) of bluegrass in native prairies through more conventional management strategies. To test how conventional rangeland management strategies, such as season-long grazing, rotational grazing, and patch-burn grazing, affect bluegrass thatch accumulation, we measured bluegrass thatch depth in prairies invaded by bluegrass under different management strategies. We hypothesize that the interaction of fire and grazing present in a patch-burn system will reduce thatch accumulation more than either season-long or rotational grazing. Additionally, we expect that thatch depth will vary with time-since-fire and grazing intensity.

Methods

Site Description

This study took place from July 2021 to August 2021 at the North Dakota State University Central Grasslands Research Extension Center in Stutsman and Kidder counties near Streeter, N.D., USA (46°45’N, 99°28’W). The study sites are comprised of rolling hills dotted with small glacial lakes, a landscape typical of the Missouri Coteau ecoregion (USDA - SCS, 1982). In a typical year, the site experiences average temperatures ranging from -12.3 ºC in January to 20.3 ºC in July, and 401 mm of precipitation (based on 29-year average from 1991-2020) (NDAWN, 2021).

Historically, the study sites were comprised of 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, changes in grazing regime and fire suppression have allowed western snowberry (*Symphoricarpos occidentalis* Hook.), and bluegrass to invade and dominate these sites.

Experimental Design

Our study utilized twelve 65-hectare pastures. Four pastures were managed with season-long grazing, four with patch-burn grazing, and four with a modified twice-over rest rotational grazing (MTORG). Grazing of the season-long, and burning and grazing of the patch-burn pastures began in 2017, while the grazing of the MTORG pastures began in 2018. Each season-long pasture was never burned and contained no interior fencing. Patch-burn pastures also contained no interior fencing, but each spring, one quarter (16 ha) of each pasture was burned. Each year the quarter of the pasture that is burned changes so that a shifting mosaic of patches is established (see Fuhlendorf et al., [2009]). Each MTORG pasture is split into four paddocks (approx. 16 ha) using interior fencing. Cattle spend a different amount of time in each paddock to achieve different levels of plant utilization. The paddocks include a rested paddock (0% utilization), a moderate paddock (20-40% utilization), a full paddock (40-60% utilization) and a heavy paddock (>60% utilization). Each year the paddocks change their utilization category (i.e. rested becomes moderate, moderate become full, full becomes heavy, heavy becomes rested.) Cattle are rotated through pastures (heavy to full to moderate) once early in the growing season (May – July) and once in the middle to late-growing season (August – September).

Data Collection

Data were collected from July 2021 to August 2021. To measure thatch depth across our treatments, we set up 128 sixty-meter transects (32 per pasture) on loamy ecological sites (USDA - NRCS, 2003). Transects were set up in such a way that each 16-ha paddock within a pasture had two transects. Within a transect, thatch depth was recorded every other meter (n=31). This data was collected by collecting soil cores to a depth of 20 cm and measuring the depth of the thatch present in that sample. For the purpose of our study, we define thatch as the compacted layer between the aboveground standing dead and litter and the belowground root mass (Figure 1).

Data Analysis

Data were analyzed using generalized linear mixed models (GLMM) using the *lme4* package in R 4.1.1. GLMM was used to account for random differences that were not intentionally created by design, such as blocking effects (Bates et al., 2015; R Core Team, 2021). As such, the transect that each sample point was located on was treated as a random variable. Additionally, data were analyzed using the negative binomial distribution to account for a non-normal data distribution.

Results

Across all treatments, average thatch depth was 2.33 cm. There was no difference between thatch depth in either our season-long pastures or MTORG pastures (2.59 and 2.60 cm respectively, $p>0.05$, Figure 2). Pastures managed with patch-burn grazing had a significantly thinner thatch layer (1.79 cm) than those managed with either rotational or season-long grazing ($p<0.001$, Figure 2). Additionally, we found that thatch depth did not vary consistently with time-since-fire or grazing intensity (Figure 3). However, regardless of time-since-fire or grazing intensity, there was less thatch in the patch burn pastures than the MTORG pastures ($p < 0.001$).

Discussion

Thatch accumulation is considered to be the primary mechanism used by bluegrass to suppress and outcompete native plant species in the Northern Great Plains. Manual removal of this thatch is possible, however, it is impractical at large scales and potentially damaging to the surrounding plant community (Hilfer and Limb, 2020). We examined alternatives to manual thatch removal in the form of three common rangeland management strategies: patch-burn grazing, rotational grazing, and season-long grazing. Neither the season-long nor MTORG treatments had an impact on thatch depth (Figure 2). However, patch-burn grazing resulted in a thinner thatch layer than other management strategies (Figure 2). Additionally, thatch depth did not consistently vary with either grazing intensity or time-since-fire (Figure 3). This suggests that grazing, regardless of intensity, is not a substantial enough disturbance to halt thatch accumulation, let alone decrease the existing thatch layer. However, the decrease in bluegrass thatch in our patch-burn pastures suggests that grazing, coupled with fire, can reduce bluegrass thatch. Thatch depth did not increase with time-since-fire suggesting that a single fire followed by grazing can halt thatch accumulation for several years by removing plant biomass. Likely, because biomass is removed from the system, preventing the creation of new thatch, while the existing thatch is converted into mineral soil.

The combination of fire and grazing decreased thatch depth (Figure 2). However, we did not have a pasture that was burned and not grazed, so we cannot draw any solid conclusions about the effects of fire by itself on thatch depth. Fire is likely the main driver behind the decrease in thatch depth, as the main difference between our season-long pastures and patch-burn pastures is the presence of annual burns. However, the interaction between fire and grazing likely increases the impact of fire on thatch depth. In patch-burn systems, cattle display pyric herbivory and preferentially graze on the recently burned areas (Allred et al., 2011; Fuhlendorf et al., 2009). By preferentially grazing recently burned areas, cattle are removing additional plant material that would have eventually been turned into thatch, furthering the effects that fire likely had on the existing thatch.

Our results suggest that patch-burn grazing is an effective mechanism for reducing bluegrass thatch accumulation. Thatch accumulation is crucial to bluegrass's expansion in the Northern Great Plains (Printz and Hendrickson, 2015). Therefore, anything that reduces the amount of bluegrass thatch in prairies should also reduce the effects of bluegrass on otherwise native prairies. As such, patch-burn grazing should not only be an effective tool for reducing bluegrass thatch accumulation, but also for reducing the impact of bluegrass on prairies in the Northern Great Plains. However, more research is needed to determine exactly how a reduction in bluegrass thatch impacts the surrounding plant communities.

Literature Cited

Allred, B.W., Fuhlendorf, S.D., Engle, D.M., Elmore, R.D., 2011. Ungulate preference for burned patches reveals strength: Of fire-grazing interaction. Ecol. Evol. 1, 132–144. https://doi.org/10.1002/ece3.12

Bates, D., Maechler, M., Bolker, B., Walker, S., 2015. Fitting Linear Mixed-Effects Models using lme4. J. Stat. Softw. 67, 1–48. https://doi.org/10.18637/jss.v067.i01

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

Fuhlendorf, S.D., Engle, D.M., Kerby, J., Hamilton, R., 2009. Pyric Herbivory: Rewilding Landscapes through the Recoupling of Fire and Grazing. Conserv. Biol. 23, 588–598. https://doi.org/10.1111/j.1523-1739.2008.01139.x

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. Rangel. Ecol. Manag. 79, 36–42. https://doi.org/10.1016/j.rama.2021.07.005

Hilfer, H., Limb, R., 2020. Thatch Removal: A New Method for Managing Kentucky Bluegrass in the Northern Great Plains. Cent. Grassl. Res. Ext. Cent. Annu. Rep. 6.

Hockensmith, R.L., Sheaffer, C.C., Marten, G.C., Halgerson, J.L., 1997. Maturation effects on forage quality of Kentucky bluegrass. Can. J. Plant Sci. 77, 75–80. https://doi.org/10.4141/P95-200

Limb, R.F., Hovick, T.J., Norland, J.E., Volk, J.M., 2018. Grassland plant community spatial patterns driven by herbivory intensity. Agric. Ecosyst. Environ. 257, 113–119. https://doi.org/10.1016/j.agee.2018.01.030

NDAWN, 2021. North Dakota Agricultural Weather Network (NDAWN). North Dakota State University.

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

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, 2021. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

USDA NRCS, 2003. Grazing Lands Ecological Sites and Forage Suitability Groups, in: National Range and Pasture Handbook. United States Departments of Agriculture Natural Resources Conservation Service, p. 120.

USDA Soil Conservation Service, 1982. Land resource regions and major land resource areas of the United States. 156 p.

Figure 1. 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.

Figure 2. Differences in thatch depth between management strategies. The error bars on the bar graph represents standard error. The right panel of this figure is a violin plot. The width of each violin plot represents the number of data points at that given y value. Within each violin are three lines. The upper and lower lines represent the upper and lower quartiles, while the middle line represents the mean (analogous to a box and whisker plot).

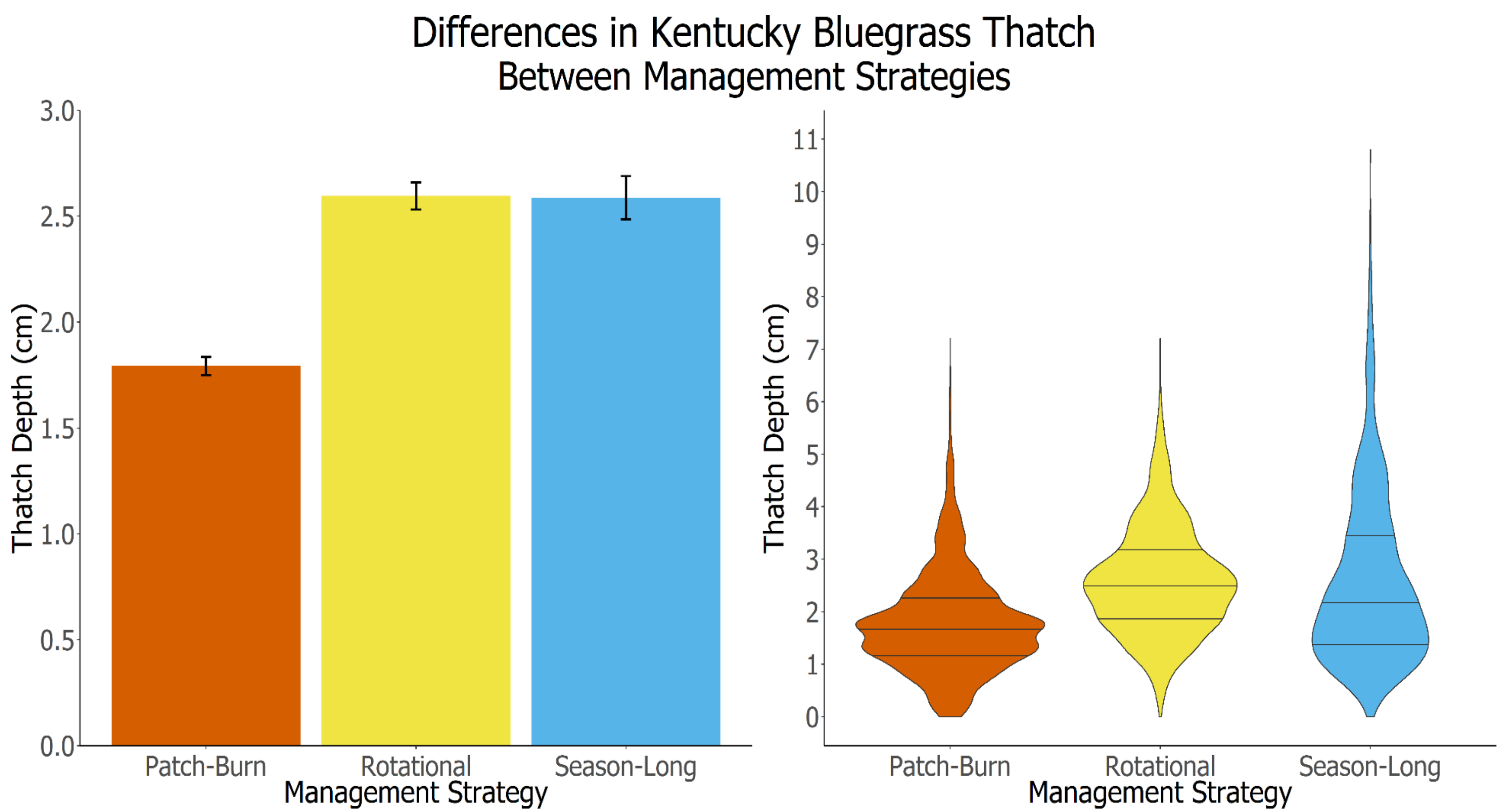
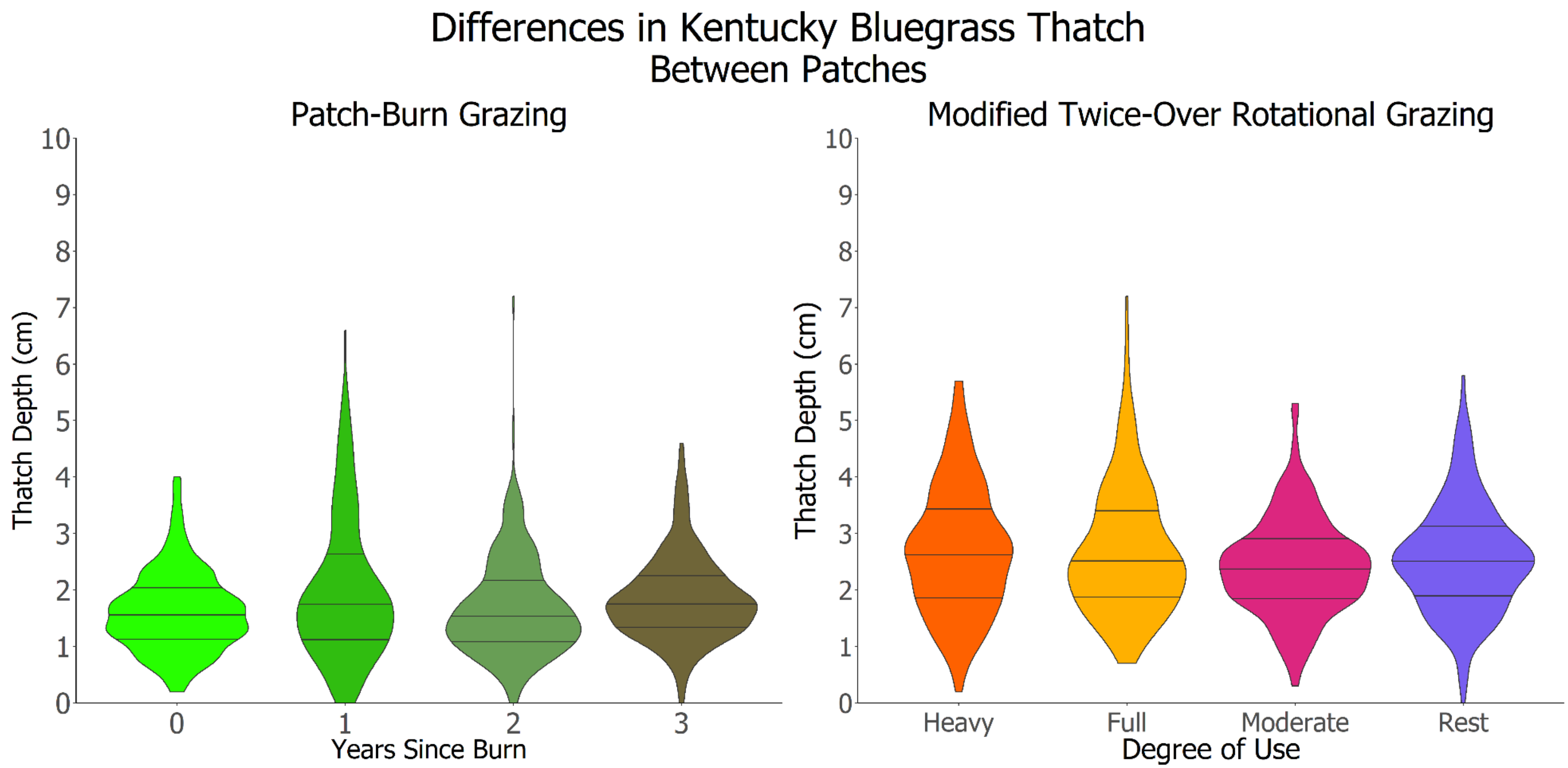


Figure 3. Thatch depth within different patches of the patch-burn grazing pastures and the modified twice-over rest rotation grazing systems (MTORG). On the x-axis for the left panel is time-since-fire, and the x-axis on the right panel is the degree of use within our MTORG pastures. Each panel is a violin plot. The width of each violin plot represents the number of data points at that given y value. The upper and lower lines represent the upper and lower quartiles, while the middle line represents the mean (analogous to a box and whisker plot).



Forage mineral content under patch-burn grazing

Megan Wanchuk[1], Kendall Swanson[2] and Kevin Sedivec[1,3]
[1]School of Natural Resource Sciences, [2]Animal Sciences, North Dakota State University, Fargo, N.D., USA
[3]Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D., USA

Summary

Patch-burn grazing is a livestock management practice that provides several benefits for conservation and livestock production. The mineral content in forage on grazing rangelands is useful for producers to know in order to ensure that livestock nutritional requirements are being met. We collected forage samples from spring-burned areas, one year-since-fire, two year-since-fire, and unburned areas during late spring and late summer. We then analyzed the samples for calcium, phosphorus, potassium, magnesium, copper, iron, manganese, and zinc content. In general, forage mineral content was higher in burned areas than in unburned areas. Phosphorous, potassium, copper and zinc concentrations were higher in burned areas in late spring and summer, while calcium, magnesium and manganese were higher only during the late summer. Iron concentration only appears to have increased by late season in the longer time since fire patches.

Introduction

North Dakota rangelands evolved with fire and grazing, which are important for maintaining disturbance-driven heterogeneity. Patch-burn grazing is the combination of fire in discrete patches within a pasture and ungulate grazing. The forage regrowth in the most recently burned patch is high in protein content and low in structural fibers, which attracts livestock. Fire and grazer attraction to the recently burned patch results in heterogeneity through contrasts in vegetation structure, quality and quantity. This offers several advantages for conservation through maintaining ecosystem functioning, wildlife habitat, and species diversity (Fuhlendorf et al., 2017; Hobbs et al., 2009).

Patch-burn grazing also has benefits for livestock production. Managing for heterogeneity decouples the relationship between precipitation and livestock gains by buffering forage resource and providing high quality regrowth, which stabilizes livestock production during drought years (Allred et al., 2014; Spiess et al., 2020).

Minerals are an essential part of livestock nutrition and must not be overlooked when assessing whether nutritional requirements are being met during the grazing season. Rangeland forage is not always able to satisfy the requirements of grazing cattle (McDowell, 1996). Macro and trace minerals are important for reproduction, health and growth of livestock. Cattle almost always require supplementation, but needs vary with forage and water sources, age, stress, breed, and gestational status of the animal (Paterson and Engle, 2005).

Although minerals are an important component of livestock nutrition, no previous studies have examined the impacts of patch-burn grazing management on mineral concentration in forage. With knowledge regarding the forage mineral content in patch-burn grazing systems, producers can ensure that their current supplementation strategy is meeting mineral requirements effectively. This article builds on preliminary analysis comparing forage minerals in burned and unburned patches at Central Grasslands Research Extension Center (Wanchuk et al., 2021).

Objectives

Our objective was to determine if patch-burning can increase mineral availability in rangeland pastures. We expect post-fire regrowth in patches following spring fire to have greater forage mineral content than vegetation in unburned patches, with mineral content decreasing as time since fire increases.

Study Area

This study was conducted on the NDSU Central Grasslands Research Extension Center (CGREC) near Streeter, N.D. CGREC pastures are mixed-grass prairie comprised of native and introduced C_3 grasses, native C_4 grasses, legumes and other forbs, and shrubs. Samples were collected from 2017 to 2020 on three pastures managed with patch-burn grazing. These pastures undergo a spring burning treatment where a quarter of the pasture (15 ha) is burned each spring (early May), creating a four-year fire return interval.

Procedures

To determine forage mineral content at the beginning and end of the grazing season, above ground biomass was clipped from a 25-cm x 25-cm frame during late spring (late May- June) and late summer (August- September). All plant material above the crown was clipped to minimize contamination from soil and litter, but still include the live and standing dead material. Samples were from thin-loamy ecological sites to minimize the effect of different soil type on mineral content. Samples were dried for 48 hours at 60^{o} C, and ground with a Wiley mill using a 1-mm screen. Samples were analyzed for calcium, phosphorus, potassium, magnesium, copper, iron, manganese, and zinc content using wet-chemistry analysis at the North Dakota State University Animal Sciences laboratory.

Results and Discussion

Phosphorous, potassium, and zinc concentration in forage were higher in the most recently burned patches than all other patches (Figure 1). Calcium and magnesium contents were higher in the recently burned patches than all other patches only during late grazing season. During early grazing, copper content was higher in the recently burned and one year-since-fire patches than longer time since fire patches. However, by the late grazing season, forage copper concentration was higher in recently burned and two year-since-fire patches than all other patches. Manganese content in recently burned and one year-since-fire patches was higher than unburned patches only. Iron forage content patterns are less clear and patch-burning does not appear to have a consistent effect; however, iron appears to have increased by late season in the longer time since fire patches.

In general, fire increases regrowth forage mineral content, providing forage that is more likely to meet cattle mineral requirements. It is important to note that meeting the recommended mineral levels does not indicate that requirements are being met. Forage in the most recently burned patches was deficient in copper throughout the grazing season, and deficient in magnesium during the early grazing season.

Mineral ratios are an important consideration when determining cattle mineral requirements since many minerals interact with each other. Calcium to phosphorous ratios in the early grazing were below the recommended minimum of 1.5:1. Ratios of potassium to calcium plus magnesium are important to consider in early grazing season for the prevention of grass tetany. In the recently burned patch the tetany ratio was 4:1, well above the recommended maximum of 2.2:1. As a result, mineral supplementation to cattle grazing patch-burn pastures is still required to adequately meet requirements.

The results seen in patch-burn grazing are consistent with studies using fire and excluding grazing (Van de Vijver et al., 1999; Vermeire et al., 2020). Higher mineral concentration in recently burned patches is caused by younger age of plant tissue, increased leaf to stem ratio, and nutrients distributed over less biomass of post-fire vegetation. Increased mineral content in forage appears to last longer with patch-burn grazing than just fire alone, likely due to grazing delaying plant maturity (Van de Vijver et al., 1999).

Increased mineral concentration in forage on burned areas relative to unburned areas is another benefit of patch-burn grazing management. Livestock production and producer profitability can potentially be increased through reduced mineral supplementation costs, and increased cow performance from enhanced immune functioning and reproductive performance.

Conclusions

Recently burned patches in a patch-burn grazing system were shown to have greater forage mineral concentration than unburned patches for the eight minerals tested. With this information, producers can be sure that their mineral supplementation strategy is effectively meeting livestock requirements.

Literature Cited

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

Fuhlendorf, S.D., Fynn, R.W.S., McGranahan, D.A., Twidwell, D., 2017. Heterogeneity as the Basis for Rangeland Management, in: Briske, D.D. (Ed.), Rangeland Systems, Springer Series on Environmental Management. Springer International Publishing, Cham, pp. 169–196. https://doi.org/10.1007/978-3-319-46709-2_5

Hobbs, R.J., Higgs, E., Harris, J.A., 2009. Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution 24, 599–605. https://doi.org/10.1016/j.tree.2009.05.012

McDowell, L.R., 1996. Feeding minerals to cattle on pasture. Animal Feed Science and Technology 60, 247–271. https://doi.org/10.1016/0377-8401(96)00983-2

Paterson, J.A., Engle, T., 2005. Trace Mineral Nutrition in Beef Cattle. University of Tennessee Nutrition Conference 22.

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

Van de Vijver, C.A.D.M., Poot, P., Prins, H.H.T., 1999. Causes of increased nutrient concentrations in post-fire regrowth in an East African savanna. Plant and Soil 214, 173–185. https://doi.org/10.1023/A:1004753406424

Vermeire, L.T., Strong, D.J., Gates, E.A., Marlow, C.B., Waterman, R.C., 2020. Can Mowing Substitute for Fire in Semiarid Grassland? Rangeland Ecology & Management 73, 97–103. https://doi.org/10.1016/j.rama.2019.08.006

Wanchuk, M.R., McGranahan, D.A., Sedivec, K.K., Swanson, K.C., Hovick, T.J., Limb, R.F., 2021. Contrasts in forage mineral concentration with patch-burn grazing: a preliminary analysis. Translational Animal Science 5, S75–S79. https://doi.org/10.1093/tas/txab173

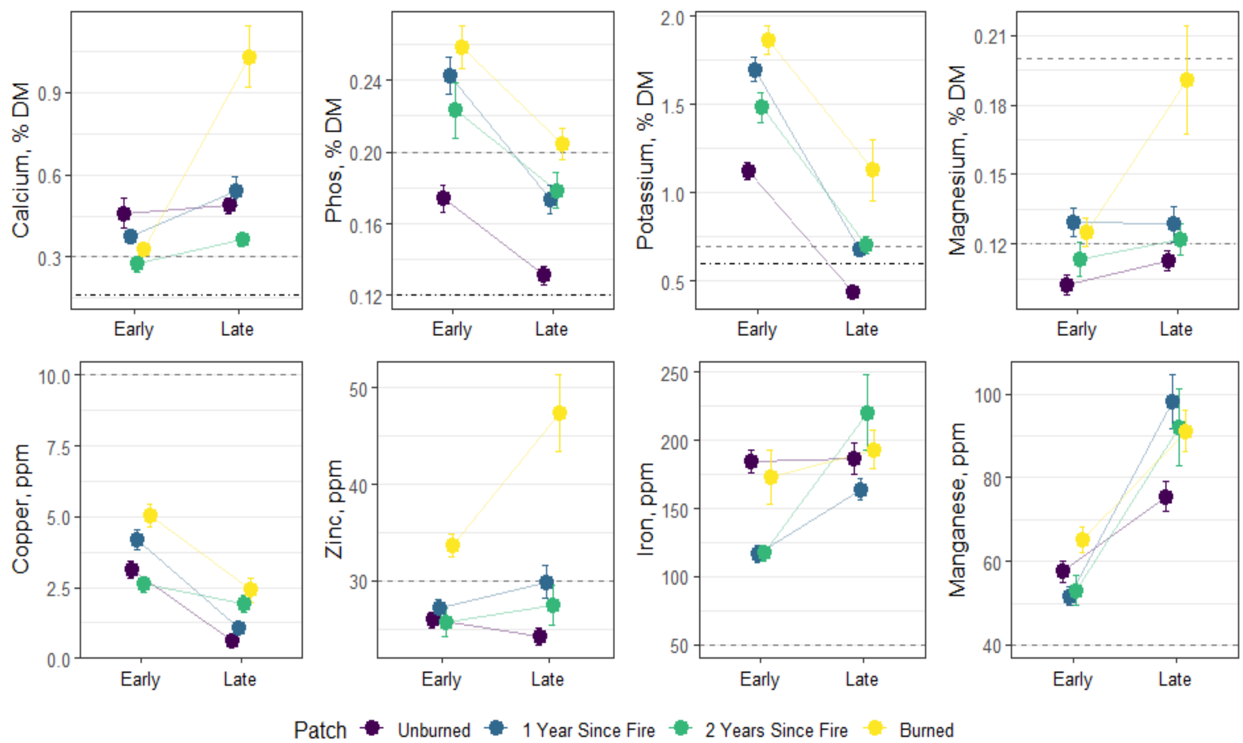


Figure 1. Calcium, phosphorous, potassium, magnesium, copper, zinc, iron and manganese contents in forage by sampling date in burned, one year-since-fire, two year-since-fire and unburned patches at CGREC from 2017-2020. Grey dashed lines in calcium, phosphorous, potassium and magnesium graphs represent cow requirements at the beginning of the grazing season, and black dash-dot lines represent late season cow requirements. Dashed lines in copper, zinc, iron and manganese represent general season-long cow requirements. Copper, zinc, potassium, and phosphorous contents were higher in the burned patches compared longer time since fire during the late spring and late summer. Calcium and magnesium content were higher in the burned patches during the late summer only.

Patch-burn grazing as a grazing management practice for livestock production

Megan Wanchuk[1], Kendall Swanson[2], and Kevin Sedivec[1,3]
[1]School of Natural Resource Sciences, [2]Animal Sciences, North Dakota State University, Fargo, N.D., USA
[3]Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D., USA

Summary

Patch-burn grazing is a livestock management practice that has been well studied for conservation benefits. However, patch-burn grazing has been less studied from a livestock production standpoint. We compared patch-burn grazing forage nutritive value and cattle performance on patch-burn, continuous and rotational grazing systems. Cows and calves were weighed prior to pasture turnout and after removal from pasture to determine performance. We collected forage samples from each of the grazing systems on a monthly basis. We then analyzed forage samples for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), lignin and NDF digestibility. Forage nutritive value was greater in the recently burned patches of the patch-burning system than the longer time since fire patches or other grazing systems, and had the highest proportion of points that met grazing cattle requirements. Cow and calf performance were higher in patch-burning and continuous grazing systems than in the rotational grazing system.

Introduction

North Dakota rangelands evolved with fire and grazing disturbances. However, alterations to pre-colonial fire regimes and grazing for uniform forage utilization has increased homogeneity in vegetation structure, reducing wildlife habitat (Fuhlendorf et al., 2009).

Patch-burn grazing is a conservation-based grazing management strategy that aims to replicate heterogeneous pre-settlement vegetation patterns with spatially patchy prescribed fire and livestock grazing. Livestock are attracted to recently burned areas of the landscape in response to the high crude protein forage regrowth and concentrate grazing in these areas (Fuhlendorf and Engle, 2004). While conservation grazing strategies are generally viewed to reduce livestock production, patch-burn grazing has been proposed as a management strategy that maintains livestock production.

Forage nutritional composition has a direct impact on livestock performance as it sets the upper limits for livestock weight gains, and influences reproductive success (Sollenberger and Vanzant, 2011). Nutritional content of forage on rangelands can be extremely variable over the grazing season and across grazing systems. Forage quality generally declines as the grazing season progresses. However, factors such as weather and management can affect the rate of forage quality decline, changing the expected quality trends.

Few patch-burn grazing studies have been conducted in North Dakota, and the studies that have been conducted only report crude protein and minimal livestock performance results (Spiess et al., 2020). A more complete picture of forage composition at frequent intervals through the grazing season is required in order to understand how livestock nutrition and performance is impacted by patch-burn grazing.

Objectives

Our objective was to determine if patch-burning grazing can be used as a conservation management practice without sacrificing livestock production and performance. We expect patch-burn grazing pastures to produce the highest forage nutritive value, which will better meet cattle requirements and produce weight gains similar to conventional grazing strategies.

Study Area

This study was conducted on the NDSU Central Grasslands Research Extension Center (CGREC) near Streeter, N.D. CGREC pastures are mixed-grass prairie comprised of native and introduced C_3 grasses, native C_4 grasses, legumes and other forbs, and shrubs.

Samples were collected on four pastures managed with patch-burn grazing (PBG) and four pastures managed with continuous grazing from 2017-2020. Four pastures managed with rotational grazing were added to the study for 2018-2020 grazing seasons. Patch-burn pastures undergo a spring burning treatment where a quarter of the pasture (15 ha) is burned each spring, creating a four-year fire return interval. Cattle are then allowed access to the entire pasture for the grazing season.

The rotational grazing system is a modified twice-over rest rotational system. Each paddock is assigned to one of four target grazing intensities: heavy use (60 to 80% disappearance), full use (40 to 60% disappearance), moderate use (20 to 40% disappearance) and rested. Cattle rotated twice within the pasture throughout the grazing season at 74, 54 and 27-day intervals on the heavy use, full use, and moderate use paddocks, respectively. The grazing intensity of each sub-pasture is rotated each year so that each sub-pasture is treated with each of the four grazing intensities over a four-year period. After each season of grazing, in the following year, heavy use pastures are transitioned to rested, full use to heavy use, moderate to full use and rested to moderate use.

Procedures

To determine livestock performance, cow and calf weigh gains were determined for the 2018-2020 grazing seasons. Cows were grouped into pastures in May based on age and weight. Cows in their first to third parity (calf number) were grouped in young age class pastures and all other cows were grouped in old age class pastures. Cows were weighed on two consecutive days and calves on one day before turnout. These weights were used to sort animals while maintaining consistent stocking rates and average cow weight across pastures. Following removal from the pastures in mid-October, animals were weighed for two consecutive days again. Average daily gain (ADG) was calculated by subtracting the average turnout weight from the average final weight then dividing by the number of days spent grazing.

To determine forage nutritive value throughout the grazing season, above ground biomass was clipped from a 25-cm x 25-cm frame at fixed points during monthly intervals from May to September. All plant material above the crown was clipped to minimize contamination from soil and litter, but still include the live and standing dead material. Samples were dried for 48 hours at 60° C and ground with a Wiley mill using a 1-mm screen. Samples were analyzed for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), NDF digestibility (NDFD) and lignin. Net energy of maintenance (NE_m) was calculated using ADF. Requirements are based on NASEM (2016) Nutrient Requirements of Beef Cattle.

Results and Discussion

Nutritive composition in the burn patches of PBG pastures was different from the patches with greater time since fire and other grazing systems (Figure 1). Crude protein, NDFD and NE_m content were highest in the burn patches relative to other patches and systems throughout the majority of the grazing season. The recently burned patch had lower amounts of ADF and NDF compared to other patches and grazing systems. Lignin content was not different among time since fire patches or grazing treatments. Seasonality trends were generally visible across all time since fire gradients and grazing systems, with forage nutritive value decreasing as maturity advances. The exceptions were NDF and ADF content in the recently burned patch, which remained relatively stable throughout the grazing season.

Forage nutritive value increases seen in the recently burned patches are similar to those in other studies examining CP (Allred et al., 2011; Sensenig et al., 2010; Spiess et al., 2020). These increases are due to younger age of plant tissue, increased leaf to stem ratio, and nutrients distributed over less biomass of post-fire vegetation.

A higher proportion of forage samples met or exceeded lactating cow requirements for NE_m and CP in the recently burned patches than longer time since fire patches and other grazing systems (Figure 2). Recently burned patches, had the lowest proportion of sample points that met nutrition requirements in July, but was still greater than other patches and grazing systems. All other patches had the lowest proportion of forage that meet requirements in June. It is important to note that hand clipping does not consider grazer selection, and therefore cattle are likely consuming higher quality forage than hand clipping estimates.

Cow and calf ADGs were significantly greater in patch-burning and continuous grazing compared to rotational grazing (Figure 3). Similar ADGs were observed between patch-burning and continuous grazing management practices for cows and calves. For cow ADG there was no difference between the old and young age class cows. However, calf ADG was significantly greater for old age class cows regardless of the grazing system. Similar results have been found comparing livestock performance in patch-burn grazing to continuous grazing or whole pasture-yearly fire grazing systems (Farney et al., 2017; Limb et al., 2011; Scasta et al., 2016).

Conclusions

Patch-burn grazing systems can provide forage to meet the needs of grazing livestock throughout the summer grazing season. As a result, cow and calf weight gains are not negatively affected by patch-burning. Therefore, patch-burn grazing can be used as a management practice to achieve conservation goals without sacrificing livestock production or profitability.

Literature Cited

Allred, B.W., Fuhlendorf, S.D., Engle, D.M., Elmore, R.D., 2011. Ungulate preference for burned patches reveals strength of fire-grazing interaction. Ecology and Evolution 1, 132–144. https://doi.org/10.1002/ece3.12

Farney, J.K., Rensink, C.B., Fick, W.H., Shoup, D., Miliken, G.A., 2017. Patch burning on tall-grass native prairie does not negatively affect stocker performance or pasture composition. The Professional Animal Scientist 33, 549–554. https://doi.org/10.15232/pas.2016-01574

Fuhlendorf, S.D., Engle, D.M., 2004. Application of the fire-grazing interaction to restore a shifting mosaic on tallgrass prairie. Journal of Applied Ecology 41, 604–614. https://doi.org/10.1111/j.0021-8901.2004.00937.x

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, 588–598. https://doi.org/10.1111/j.1523-1739.2008.01139.x

Limb, R.F., Fuhlendorf, S.D., Engle, D.M., Weir, J.R., Elmore, R.D., Bidwell, T.G., 2011. Pyric-Herbivory and Cattle Performance in Grassland Ecosystems. Rangeland Ecology and Management; Lawrence 64, 659–663.

NASEM, 2016. Nutrient Requirements of Beef Cattle, 8th Revised Edition. National Academies Press, Washington, D.C. https://doi.org/10.17226/19014

Scasta, J.D., Thacker, E.T., Hovick, T.J., Engle, D.M., Allred, B.W., Fuhlendorf, S.D., Weir, J.R., 2016. Patch-burn grazing (PBG) as a livestock management alternative for fire-prone ecosystems of North America. Renew. Agric. Food Syst. 31, 550–567. https://doi.org/10.1017/S1742170515000411

Sensenig, R.L., Demment, M.W., Laca, E.A., 2010. Allometric scaling predicts preferences for burned patches in a guild of East African grazers. Ecology 91, 2898–2907. https://doi.org/10.1890/09-1673.1

Sollenberger, L.E., Vanzant, E.S., 2011. Interrelationships among Forage Nutritive Value and Quantity and Individual Animal Performance. Crop Sci. 51, 420–432. https://doi.org/10.2135/cropsci2010.07.0408

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

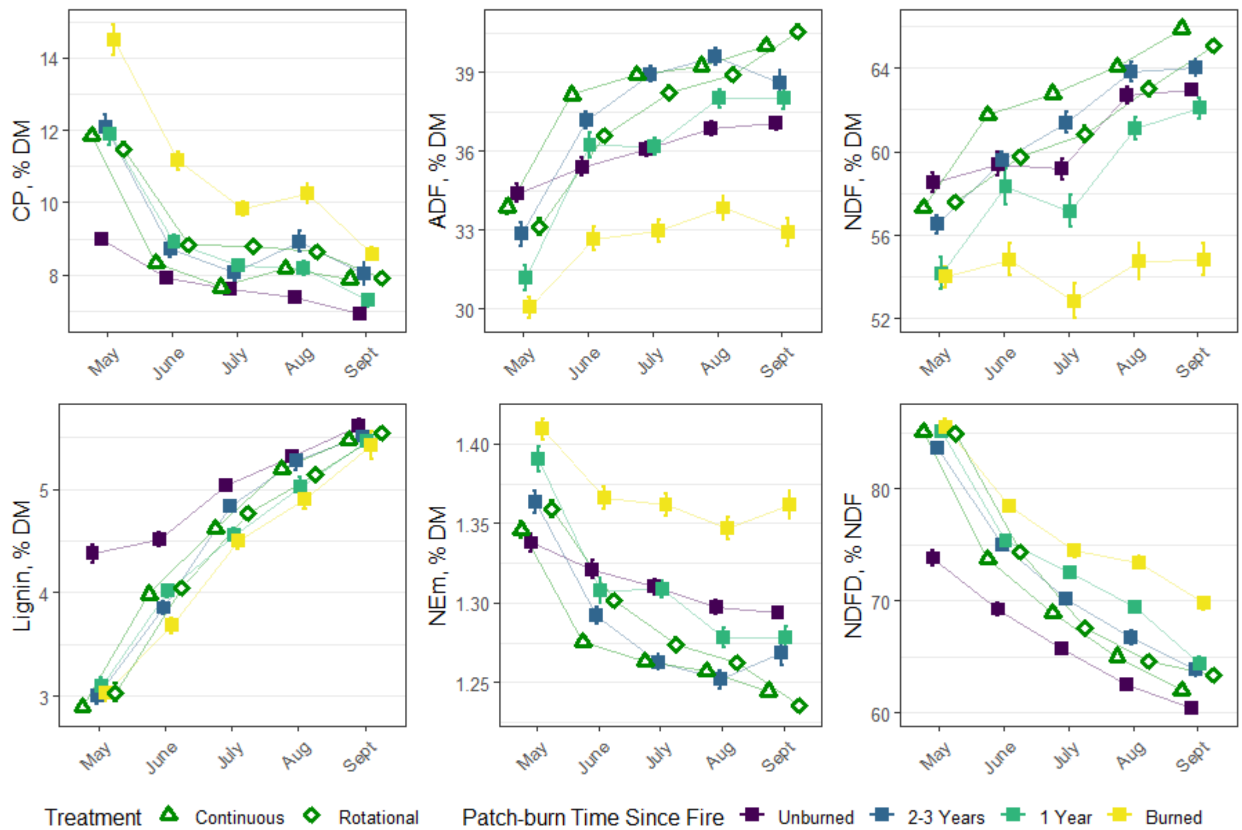


Figure 1. Mean and standard error of each forage nutrient component across patch-burn, continuous and rotational grazing treatments. The PBG treatment has been split by time since fire. Lines connect each treatment or time since fire across months. The recently burned patches had the greatest crude protein (CP), net energy of maintenance (NE_m), and NDF digestibility (NDFD), and the lowest amounts of ADF and NDF compared to longer time since fire patches or grazing treatments.

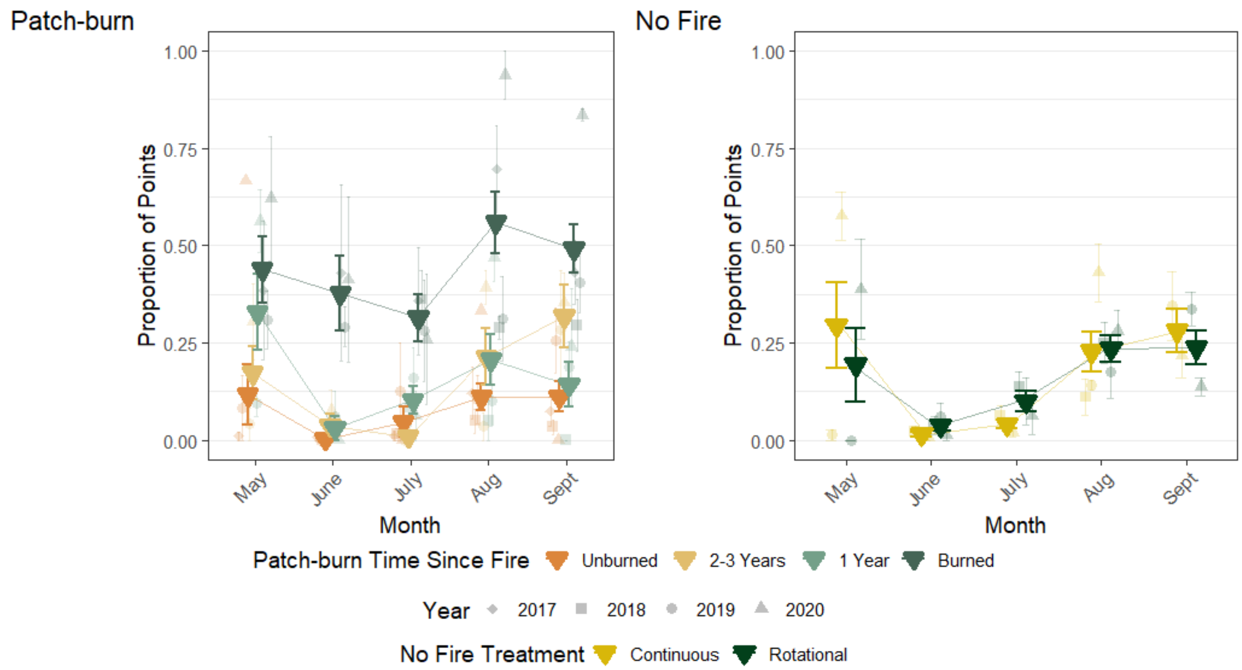


Figure 2. Proportion of sample points in each pasture that met or exceeded cow crude protein and net energy of maintenance requirements each month. The left figure is the patch-burning system split by time since fire. The right figure is the no fire grazing treatments, which are the continuous and rotational grazing systems. Points in bold are the average by month over the multiyear study, and points in the background indicate the mean for each year. Requirements are based on NASEM (2016) Nutrient Requirements of Beef Cattle for a 572 kg cow with 8 kg/day peak milk production and 40 kg calf birth weight. Net energy of maintenance was calculated from ADF. Throughout the grazing season, the recently burned patches in the PBG treatment provided a higher proportion of forage that met or exceeded cow nutrient requirements compared to the other treatments.

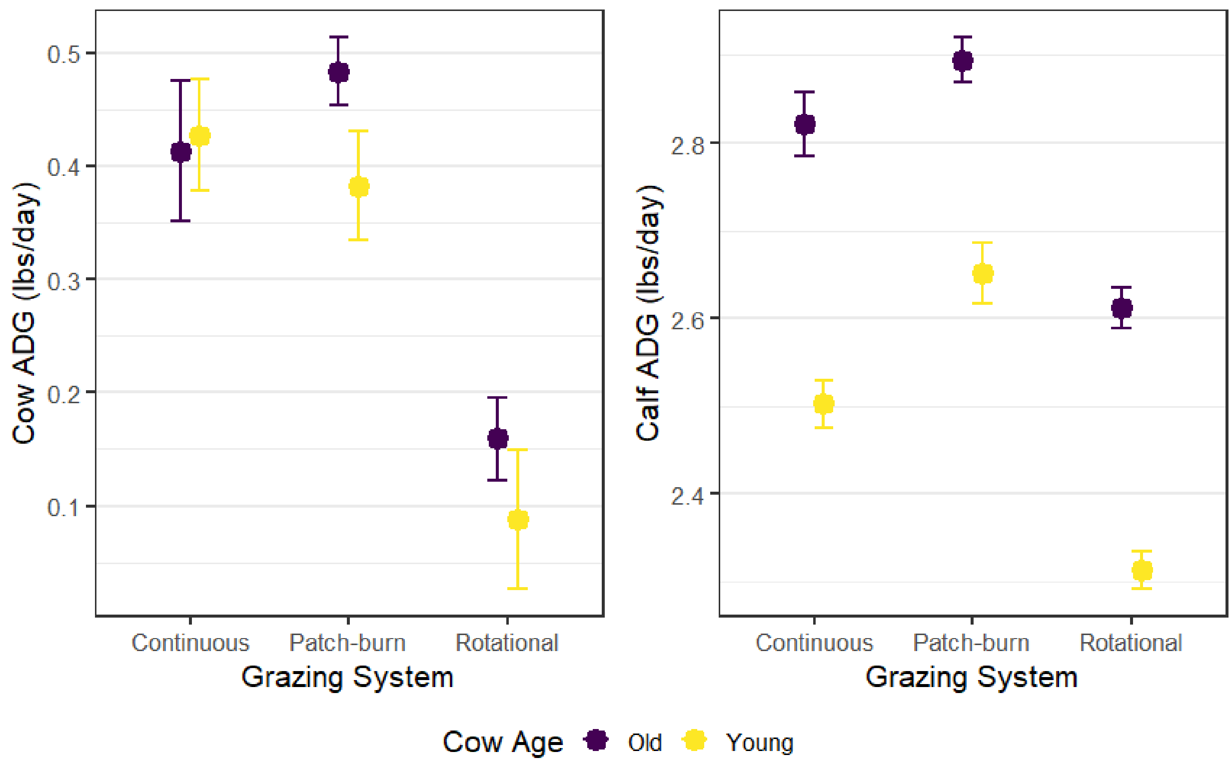


Figure 3. Average daily gain (ADG) of livestock in the continuous, patch-burn and rotational grazing systems. The figure on the left is cow ADG and the figure on the right is calf ADG. Purple represents cows in the old age class which have had four or more calves, and yellow represents young age class cows which have had one to three calves. The continuous and patch-burn grazing systems produced larger calf and cow ADG than the rotational grazing system.

Impacts of patch burn, rotational and continuous grazing on livestock performance and conception rates on Kentucky bluegrass invaded mixed-grass prairie

Kevin Sedivec[1,2], Michael Hamel[1], Erin Gaugler[2], Timothy Long[2], Ryan Limb[1], and Torre Hovick[1]

[1]*School of Natural Resource Sciences–Range Science Program, North Dakota State University, Fargo, ND*
[2]*Central Grasslands Research Extension Center, North Dakota State University, Streeter, ND*

Controlled livestock distribution and reduced grazing intensity can be implemented to enhance wildlife habitat and promote conservation of certain landscapes and some wildlife species. However, traditional approaches to rangeland management to enhance conservation are generally thought to reduce profits from livestock grazing enterprises because traditional approaches reduce the number of grazing animals (Dunn et al. 2010). Current rangeland management decouples fire from grazing. Further, the decoupling decreases feedbacks created through disturbances leading to homogeneity in rangeland ecosystems. When these disturbances are suppressed, restricted vegetation succession creates stagnant and homogeneous landscapes. Homogeneity reduces the number structural and compositional habitats needed to sustain plant and animal populations therefore resulting in loss of biological diversity. Therefore, conservation-based livestock grazing practices that are both profitable and promote biodiversity are clearly needed (O'Connor et al. 2010). Combining the spatial and temporal interaction of fire and grazing (pyric-herbivory) is a conservation-based approach to management that increases rangeland biodiversity trophic levels and taxonomic orders by creating heterogeneous vegetation structure and composition (Fuhlendorf et al. 2006; Churchwell et al. 2008; Coppedge et al. 2008; Engle et al. 2008; Fuhlendorf et al. 2010). Discrete fires shifting in time across a landscape concentrates grazing while leaving unburned portions of the landscape largely undisturbed. The undisturbed areas have relatively tall and dense vegetation. Focal grazing on the recently burned areas maintains relatively short vegetation, and transition areas recovering from focal disturbance support diverse vegetation. The three different patch-types create a structurally and compositionally heterogeneous landscape (Fuhlendorf and Engle 2001 and 2004). Conservation based livestock grazing and restoration practices that are both profitable, reduce exotic plant species and promote biodiversity are clearly needed (O'Connor et al. 2010). Therefore, this project will focus on **1)** Developing methods to reduce exotic grass species and restore native species on Northern Great Plains rangelands, and **2)** Determine the effect of heterogeneity-based management on livestock production.

Methods: General Design

This study is conducted at the North Dakota State University Central Grassland Research Extension Center (CGREC) in south-central North Dakota (lat 46°46'N, long 99°28'W). As part of the North Dakota State Agriculture Experiment Station, CGREC's mission is to extend scientific research and Extension programming to the surrounding rural communities. It consists of 2,160 ha of native grassland and annual crops. The study area is representative of much of the Great Plains ecoregion with large tracts of native grassland used for livestock production intermixed with annual small grain and row-crop agriculture. The CGREC is situated in the Missouri Coteau ecoregion of the northern Great Plains which occupies 125 million hectares, of which approximately 40% is perennial rangeland grazed by livestock. The Missouri Coteau ecoregion is characterized by irregular, rolling, rocky plains, and depressional wetlands. The climate is characterized as temperate and experiences an average yearly rainfall of 40.3 cm. (Limb et al. 2018).

Vegetation at CGREC has been sampled recently and in the past (Limb et al. 2018). It is typical of a Northern mixed grass prairie that has been invaded by Kentucky bluegrass, which includes a diverse forb community that could support a diverse pollinator community. Agroecosystem management strategies that promote sustainable production and ecosystem services are dependent on practical solutions based on sound ecological principles. In rangelands, this research is complicated by the need for large scale replication that is allowed to take place over multiple years. We have the unique situation of being able to take advantage of a tremendous amount of work (and financial cost) that has already been used to create four management treatments that have each been replicated four times, each at a relatively large spatial scale (65 ha replicates).

Within this design framework we compare four management treatments in their ability to optimize livestock production while promoting plant-pollinator interactions. Treatments are based on current management frameworks, but use a combination of well-established and novel designs. The three treatments are *(a) patch-burn grazing, (b) modified twice-over rest rotation grazing (MTRG), and (c) season-long grazing (SLG)*.

(a) Patch-burn grazing (PBG) - spring season of burn is a management framework that is intended to mimic historic disturbance regimes where focal grazing occurs on recently burned areas while lightly grazed areas allow for accumulation of plant biomass (i.e., fuel) for future fires (Fuhlendorf and Engle 2001). Fires will occur in the spring of each year when fuel moisture levels have decreased sufficiently for fire to carry. Patch-burn pastures (appx. 65 ha each) are divided into four relatively equal-size patches (appx. 16 ha each) with one of the four patches being burned each spring. These fire return intervals are designed to mimic the historical disturbance regime of mixed-grass prairie.

(b) Modified twice-over rest rotation grazing (MTRG). Our third treatment is similar to the PGB treatments in that it is designed to produce structural heterogeneity across a grazing unit. However, unlike the PBG treatments our modified twice-over rest-rotation grazing treatment utilized fencing to dictate cattle distribution and influence grazing. The grazing unit is divided into four relative equal patches and cross fenced to create four discrete sub-pastures that cattle cannot move between (without being purposefully moved) and grazed from mid-May to late

October. Across the sub-pastures, cattle are rotated through twice and allowed to graze for a total 74, 54, 27 and zero days (total 155-day grazing season) in each rotation of the heavy use (60-80 percent disappearance), full use (40-60 percent disappearance), moderate use (20-40 percent disappearance), and rested sub-pastures, respectively. The first rotation uses 40 percent of the grazing days, second rotation 60 percent of the available grazing days. In subsequent years, grazing intensity will be rotated to different patches such that the full-use pasture will become the heavy use pasture, the heavy use pasture will transition to the rested pasture, the full-use to the moderate use and rested to moderate grazing. This rotation will create annual heavy disturbance in one sub-pasture, and reduce annual heavy disturbance in the same location in which could result in changes to forage quality and loss of plant species (Fuhlendorf et al. 2017).

(c) Season-long grazing (SLG) is intended to reflect "status quo" management for the region and will serve as a controlled comparison for the other treatments. This is a fairly typical management approach for this region and it serves as an important comparison because it homogeneously applies the disturbance (grazing) throughout the entire patch. Thus, it is expected to lack the heterogeneity and structure of other treatments, and therefore not benefit livestock.

Common among the PBG and SLG treatments, cow/calf pairs grazed within pastures from mid-May to late October each year at a full-use stocking rate (1.01 animal unit months-acre) in all treatments designed to achieve an average 40 to 50 percent degree of disappearance across the pasture. The MTRG was also stocked at an average 1.01 animal unit months-acre across a four cycle, 1.27 animal unit months-acre-year. Stocking rates were determined using a 25 and 30 percent harvest efficiency on the season-long and managed treatments, respectively. All treatments provide fresh water access and mineral supplements for cattle.

With the exception of MTRG, all treatment units (pastures) have exterior fencing only with no interior fences to separate individual patches. The MTRG used interior fencing to separate patches and maintains livestock at a particular stocking rate throughout the year. Soil type and vegetation communities are similar among replicates, as defined by NRCS ecological site descriptions and equivalent land-use histories (USDA-NRCS 2018).

Vegetation quadrat samples were used $0.25m^2$ to determine the cover of native and introduced grasses and forbs. We also measured heights of vegetation, litter, and thatch layers using 10 quadrats per survey set. To determine herbage production and degree of disappearance, three $0.25\ m^2$ plots were caged and paired with three uncaged plots at each monitoring location (6 total plots/monitoring site, 24 total plots per pasture) prior to the onset of grazing. At the peak of forage production for the year, in late-July, two new plots were picked to match each of the original uncaged plots and the original plots and clipped using the $0.25m^2$ quadrats. One of each pair of new plots was caged and at the end of the grazing period the herbage from each remaining plot were clipped. Herbage production clipped from inside caged plots at peak growing season provided an estimate of peak biomass. The difference between biomass in the caged plots at the end of the grazing period and uncaged plots from the peak sampling represent the growth (or disappearance) from peak. Samples were oven-dried to a constant weight and weighed to determine the amount of herbaceous production and percent utilization of the forage.

All cattle were weighed before they go on the pastures and again when the cattle were removed using an average of two-day body weights. We quantified cow and calf performance by management treatment by measuring daily weight gain of both calf and cow through taking the subtracting the average two-day weight at the beginning of the grazing season from the two-day weight from end of the grazing season, then dividing by grazing days (~155 days).

Results:

(a) Vegetation Degree of Disappearance

Degree of disappearance on the PBG treatments varies across the pasture based on timing of fire. Degree of disappearance ranged from 30.2 percent on the burn patches that were three-years post-fire to 75.3 percent on the new burns (Figure 1). There were also pretty high levels of disappearance on the one-year post fire sites at 59.5 percent. If all burn patches were similar in size, the average degree of disappearance on the PBG treatments would be 49.5 percent.

The average degree of disappearance on the SLG across the four years was 37.2 percent. The overall goal is to achieve an average degree of disappearance on the PBG, SLG and full-use pasture of the MTRG at 40 to 60 percent. We did meet this objective on the PBG and two-years of the MTRG treatments, but slightly below the objective on SLG treatment.

Degree of disappearance of graminoid (grasses and sedges) on the modified twice-over rotation rest rotation treatment was 21, 32 and 61 percent in the moderate, full and heavy use pastures in 2018, respectively (Figure 2). The degree of disappearance of graminoids was 32, 40 and 59 percent in the moderate, full and heavy use pastures in 2019, respectively (Figure 2). The degree of disappearance of graminoids was 26, 49 and 56 percent in the moderate, full and heavy use pastures in 2020, respectively (Figure 2). Our full use pasture was stocked to create a similar degree of disappearance as the SLG treatment, which average 33, 27 and 39 percent in 2018, 2019 and 2020; respectively.

The goal is to achieve a degree of disappearance on the SLG treatment and full use pasture of 40 to 50 percent. However, the 2018 and 2019 growing season precipitation was 127 and 136 percent of average; respectively (NDAWN 2020). This additional precipitation creating higher than expected vegetation growth, thus, degree of disappearance was below the targeted level. We were closest to achieving the desired degree on disappearance in 2020. We increased animal numbers on the SLG treatment, adjusted grazing days on the MTRG, and had a drought during the growing season (58 percent of average).

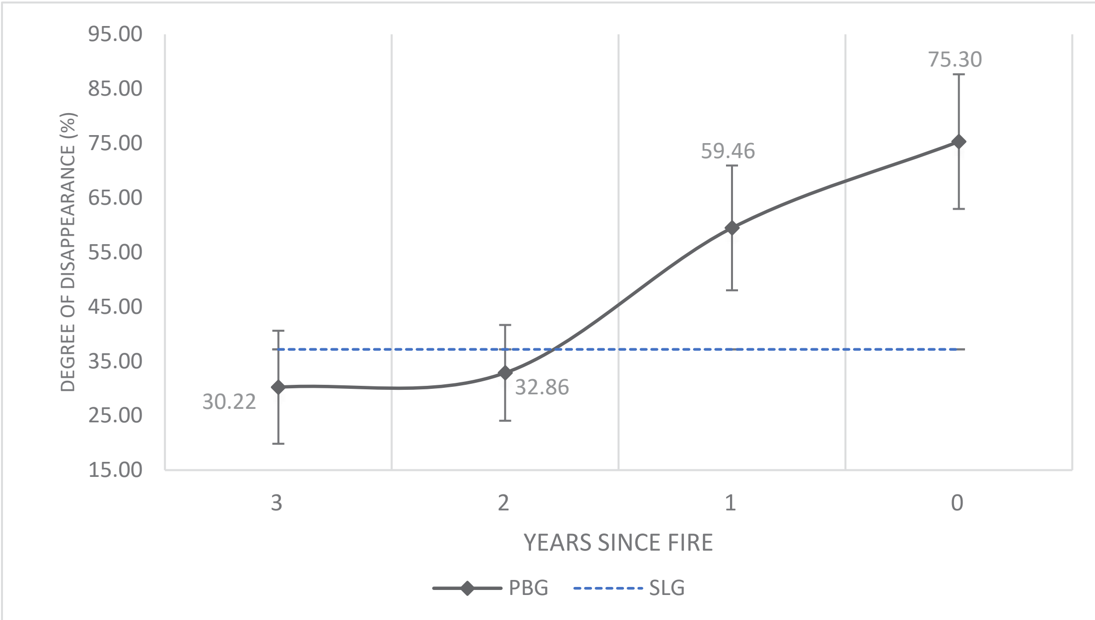


Figure 1. Average degree of disappearance of patches within patch-burn grazing treatments (PBG) arranged by time since fire, with season-long grazing (SLG) degree of disappearance shown as a baseline, at the Central Grasslands Research Extension Center near Streeter, N.D. in 2020.

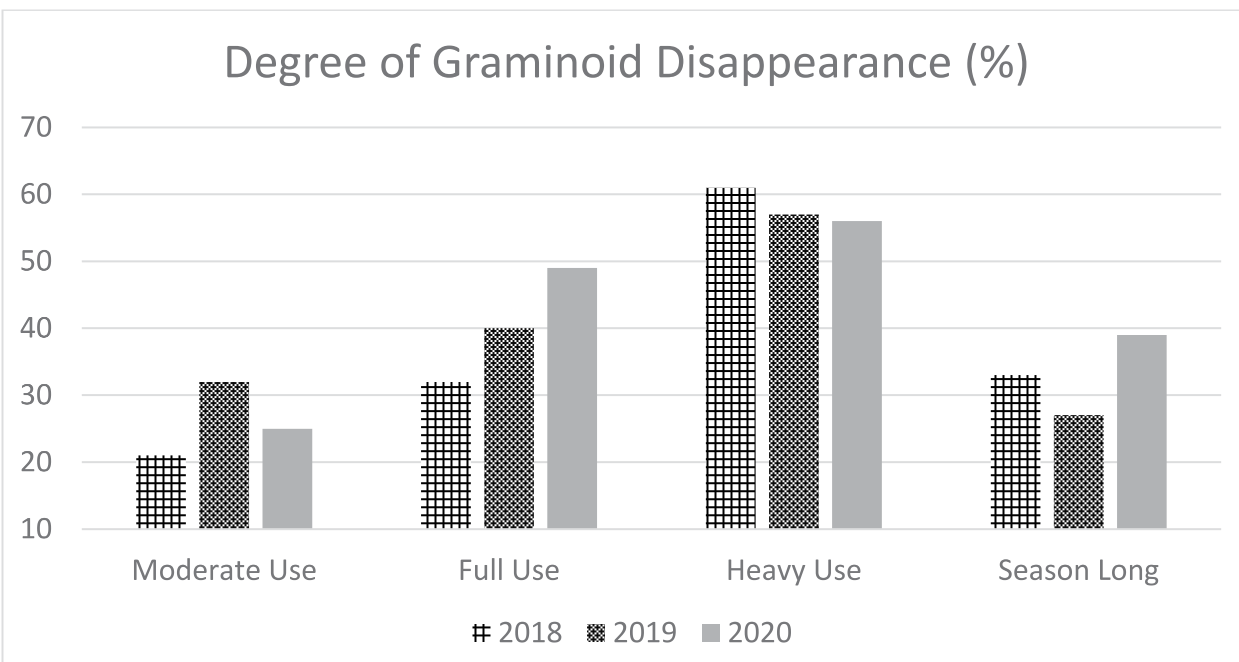


Figure 2. Degree of disappearance on the modified twice-over rotation rest rotation treatment at the Central Grasslands Research Extension Center near Streeter, ND.

(b) Livestock Reproductive and Performance

Percent bred cows was similar (P > 0.05) among treatment in all years of the study, ranging from 88 to 95 percent in 2017, 93 to 95 percent in 2018, 96 to 98 percent in 2019, and 94 to 99 percent in 2020, and 90 to 99 percent in 2021 (Figure 3). On average, conception rates were 94, 95 and 95 percent for the PBG, MTRR, and continuous SL; respectively.

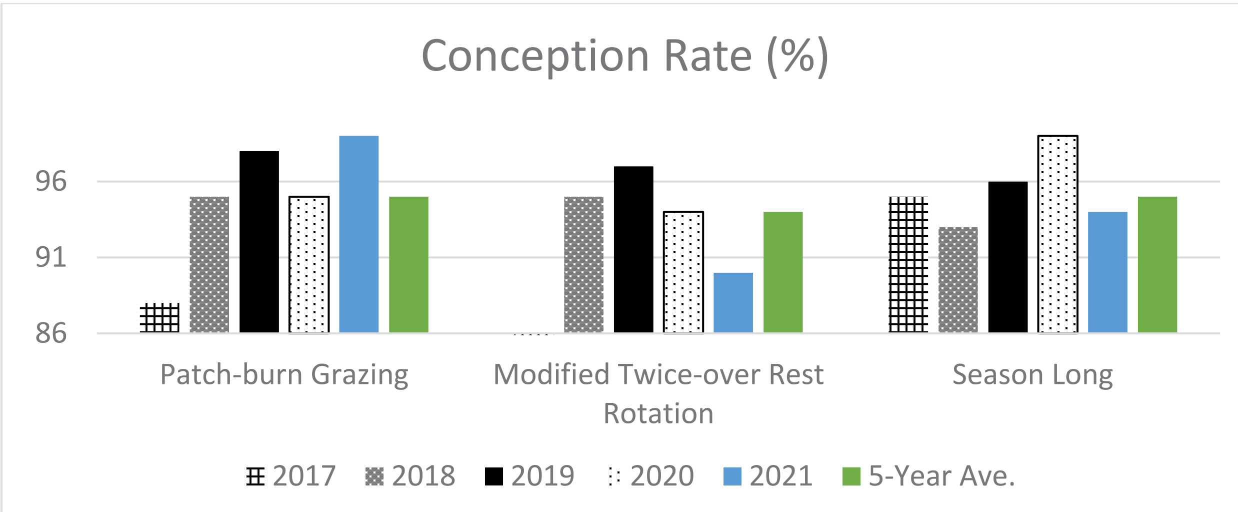


Figure 3. Conception rates of cows bred on pasture by treatment at the Central Grasslands Research Extension Center near Streeter, ND in 2017, 2018, 2019, 2020 and 2021.

Calf performance, in terms of average daily gain was similar, was similar (P > 0.05) among treatments in 2017, 2018, 2019, 2020, and 2021 (Figure 4). On average, calf average daily gain (lb/day) was 2.69, 2.44, and 2.56 on the PBG, MTRR, and continuous SL; respectively.

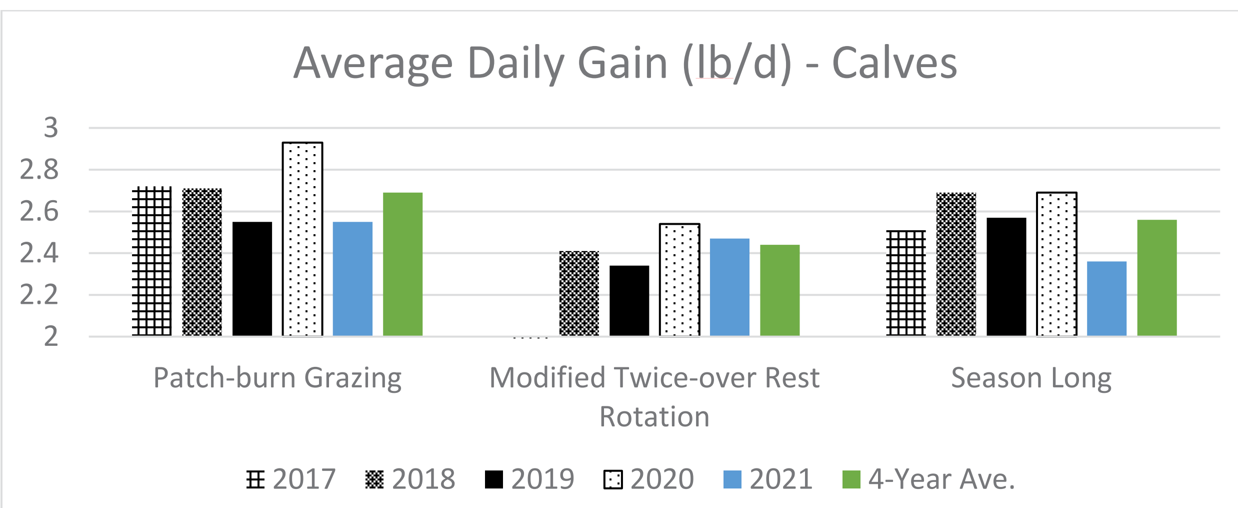


Figure 4. Calf average daily gain (lb/day) by treatment at the Central Grasslands Research Extension Center near Streeter, ND in 2017, 2018, 2019, 2020, and 2021.

Cow performance, in terms of average daily, was greatest ($P \leq 0.05$) on the PBG treatment in 2017 compared to the SLG (Figure 5). The PBG treatment had positive average daily gains (0.72 lb/day) compared to cows losing weight on the SLG treatment (-0.51 lb/day). The PBG was different ($P \leq 0.05$) than the MTRR and SLG in 2018; while the PBG and SLG was different ($P \leq 0.05$) from the MTRR in 2018 and 2019 when compared to zero gain. However, in 2021 the MTRR had higher ($P \leq 0.05$) cow performance than the PBG and SLG. There was no difference between treatments in cow performance in 2020 (Figure 5).

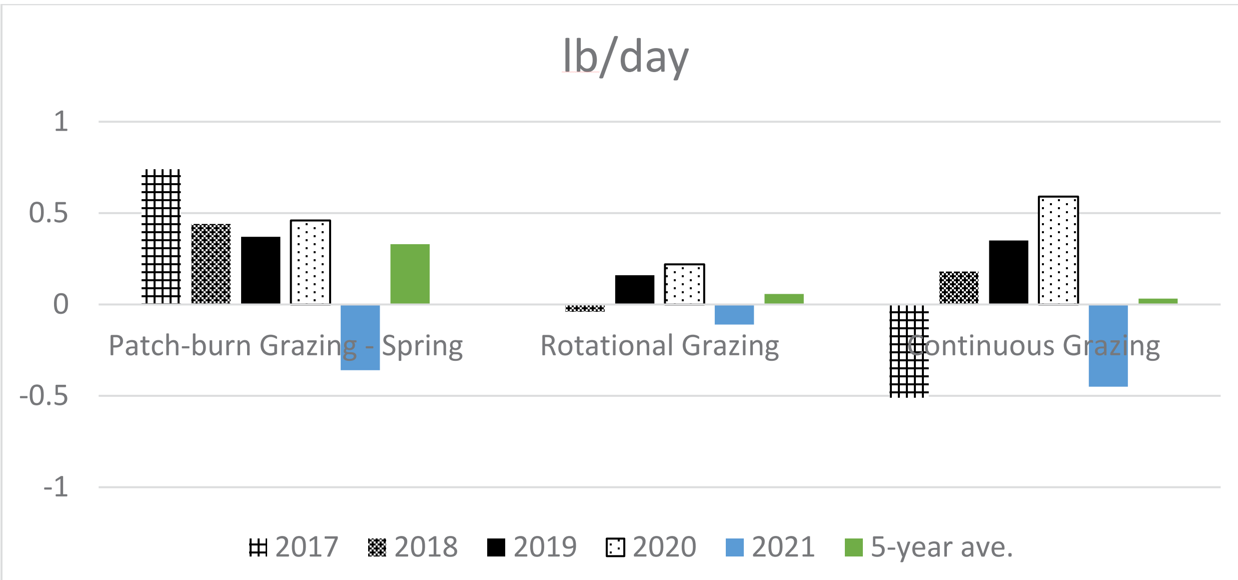


Figure 5. Cow average daily gain (lb/day) by treatment at the Central Grasslands Research Extension Center near Streeter, ND in 2017, 2018, 2019, 2020, and 2021.

Literature Cited

Churchwell, R.T., C.A. Davis, S.D. Fuhlendorf, and D.M. Engle. 2008. Effects of patch-burn management on dickcissel nest success in a tallgrass prairie. *Journal of Wildlife Management* 72:1596-1604.

Coppedge, B.R., S.D. Fuhlendorf, W.C. Harrell, and D.M. Engle. 2008. Avian community response to vegetation and structural features in grasslands managed with fire and grazing. *Biological Conservation* 141:1196-1203.

Dunn, B.H., A.J. Smart, R.N. Gates, P.S. Johnson, M.K. Beutler, M.K. Diersen, and L.L. Janssen. 2010. Long-term production and profitability from grazing cattle in the northern mixed grass prairie. *Rangeland Ecology and Management* 63:233–242.

Engle, D.M., S.D. Fuhlendorf, A. Roper, and D.M. Leslie Jr. 2008. Invertebrate community response to a shifting mosaic of habitat. Rangeland Ecology and Management 61:55-62.

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

Fuhlendorf, S.D., and D.M. Engle. 2004. Application of the fire-grazing interaction to restore a shifting mosaic on tallgrass prairie. *Journal of Applied Ecology* 41:604–614.

Fuhlendorf, S.D., W.C. Harrell, D.M. Engle, R.G. Hamilton, C.A. Davis, and D.M. Leslie Jr. 2006. Should heterogeneity be the basis for conservation? Grassland bird response to fire and grazing. *Ecological Applications* 16:1706–1716.

Fuhlendorf, S.D., D.E. Townsend II, R.D. Elmore, and D.M. Engle. 2010. Pyric–herbivory to promote rangeland heterogeneity: evidence from small mammal communities. *Rangeland Ecology & Management* 6:670–678.

Fuhlendorf, S.D., R.W.S. Fynn, D.A. McGranahan, and D. Twidwell. 2017. Heterogeneity as the basis for rangeland management, in: Briske, D.D. (Ed.), Rangeland Systems: Processes, Management and Challenges, Springer Series on Environmental Management. Springer International Publishing, pp. 169–196.

Kral, K.C., R. Limb, A. Ganguli, T. Hovick, and K. Sedivec. 2018. Seasonal prescribed fire variation decreases inhibitory ability of *Poa pratensis* L. and promotes native plant diversity. *Journal of Environmental Management* 223:908-916.

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 & Environment* 257:113-119.

McGranahan, D. A., T.J. Hovick, R.D. Elmore, D.M. Engle, S.D. Fuhlendorf, S.L. Winter, J.R. Miller, and D.M. Debinski. 2016. Temporal variability in aboveground plant biomass decreases as spatial variability increases. *Ecology* 97:555-560.

NDAWN 2020. North Dakota Agricultural Weather Network. North Dakota State University, Fargo, ND. NDAWN - North Dakota Agricultural Weather Network (nodak.edu). Accessed December 12, 2020.

O'Connor, T.G., P. Kuyler, K.P. Kirkman, and B. Corcoran. 2010. Which grazing management practices are most appropriate for maintaining biodiversity in South African grassland? *African Journal of Range and Forage Science* 27:67–76.

USDA-NRCS. 2018. United States Department of Agriculture-Natural Resource Conservation Service. Web Soil Survey. http://websoilsurvey.nrcs.usda.gov/ . Accessed 29 October 2018.

How does a Grazing System Work: Aboveground Cumulative Production with a Modified Twice-over Rest-rotation Treatment?

Kevin Sedivec[1,2], Erin Gaugler[2], Michael Hamel[1], Ryan Limb[1] and Torre Hovick[1]

[1]*School of Natural Resource Sciences, Range Science Program, North Dakota State University, Fargo, N.D.*
[2]*Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D.*

Summary

Aboveground cumulative production accounts for any additional plant growth that occurs from regrowth following a grazing event plus growth consumed by the animal during the grazing event. We tested a 4-pasture modified rest rotation grazing system (MTRR) to attempt to create heterogeneity in vegetation structure, floral expression, and plant diversity using varying grazing intensities (heavy, full, moderate and rested sub-pastures).

The heavy-use sub-pasture of the MTRR is the first pasture grazed during the grazing season. Rotational grazing created an average recovery period of 33-days from grazing between the first rotation and second rotation. The 4-year average increase of aboveground cumulative production (growth efficiency) was 45.6 and 45.9 percent on the loamy and the shallow loamy ecological site compared to peak production from the nonuse exclosures, respectively. The overall degree of disappearance was at 64.9, 57.2, 56.2, and 68.8 percent, respectively, at the end of the second rotation.

The full-use sub-pasture was the second pasture grazed with a 60-day recovery period between the first and second rotation. We found a 3-year average increase in aboveground cumulative production of 32.8 and 44.1 percent on the loamy and shallow loamy ecological site compared to peak production from the nonuse exclosures, respectively. The overall degree of disappearance was 39.8, 49.7, and 48.0 percent, respectively, at the end of the second rotation.

The moderate-use sub-pasture we the last pasture grazing with a 79-day recovery period between the first and second rotation. We found a 3-year average increased in aboveground cumulative production of 36.2 and 45.1 percent on the loamy, and the shallow loamy ecological site compared to peak production from the nonuse exclosures, respectively. The overall degree of disappearance was 31.7, 24.8 and 44.0 percent at the end of second rotation (end of grazing season).

The recovery period did not appear to be the driving factor in growth efficiency, but the degree of disappearance and uniformity of use, and timing of moisture created greater regrowth across the pasture, thus increasing growth efficiency potential.

Introduction

Grazing systems differ from season-long grazing through stocking rates, stocking density, and timing of grazing and livestock distribution (Holechek et al., 1998; Smart et al., 2010). Typically, season-long and rotational-grazing systems differ in stocking rates and temporal and spatial manipulation of grazing, creating a high stock density.

Rotational grazing is believed to be a superior way to manage resources, especially at the ranching level on private lands (Ranellucci et al. 2012). However, relatively few studies support this concept that rotational grazing systems are superior to other management regimes (Hart et al., 1993; Manley et al., 1997; Briske et al., 2008). Twice-over rotation grazing is promoted widely in the NGP and humid northeastern Great Plains (Sedivec and Barker, 1991; Biondini and Manske, 1996; Shepherd and McGinn, 2003; Limb et al., 2018). Twice-over grazing, like many rotational grazing systems, is a practical application of the grazing optimization hypothesis (McNaughton, 1979).

To assess how a rotational grazing works, in term of growth efficiency, we attempted to quantify how much regrowth and consumption occurs in a rotational grazing system by determining the aboveground cumulative production. We then compared this production parameter to the net primary production and peak production; two parameters most other research studies use when assessing differences (or no differences) in forage production potential and economic return with rotational grazing.

This project will focus on determining the effect of heterogeneity-based management within an exotic perennial cool-season-invaded rangeland on aboveground cumulative production of Kentucky bluegrass invaded rangelands.

Study Area and Design

This study is conducted at the North Dakota State University Central Grasslands Research Extension Center (CGREC) in south-central North Dakota (lat. 46°46’N, long. 99°28’W). The CGREC’s mission is to extend scientific research and Extension programming to the surrounding rural communities. Vegetation at the CGREC has been sampled recently and in the past (Limb et al., 2018). It is typical of a northern mixed-grass prairie that has been invaded by Kentucky bluegrass, and includes a diverse forb community that could support a diverse pollinator community.

The MTRR was designed to be similar to patch-burn grazing (PBG) in that it produces structural heterogeneity across a pasture. However, unlike the PBG treatments, the MTRR utilizes fencing to dictate cattle distribution and influence grazing.

The grazing unit is divided into four relatively equal patches and cross-fenced to create four discrete sub-pastures that cattle cannot freely move between and are grazed from mid-May to late October. Cattle are rotated twice across the sub-pastures, and allowed to graze for a total 74, 54, 27 and zero days (total 155-day grazing season) of the heavy use (60% to 70% disappearance), full use (40% to 60% disappearance), moderate use (20% to 40% disappearance) and rested sub-pastures, respectively.

The first rotation uses 40% of the grazing days and the second rotation uses 60% of the available grazing days. In subsequent years, grazing intensity will be rotated to different patches such that the full-use pasture will become the heavy-use pasture, the heavy-use pasture will transition to the rested pasture, the moderate-use to the heavy-use pasture and rested to moderate grazing. This rotation will create annual heavy disturbance in one sub-pasture and reduce annual heavy disturbance in the same location, which could result in changes to forage quality and loss of plant species (Fuhlendorf et al., 2017).

Cow-calf pairs are grazed within pastures from mid-May to late-October each year. The stocking rate was determined using a 30 percent harvest efficiency. Fresh water access from well water and mineral supplements were provide.

Methodology

Vegetation quadrat samples will be performed using 0.25 m^2 quadrats to determine production of standing crop, graminoids (grasses and sedges) and forbs. To evaluate objectives, five cages were placed on two loamy and two shallow loamy ecological sites in each sub-pasture (heavy, full, moderate, rested) of the MTRR (20 cages total per sub-pasture).

Herbage production was determined during the 1st rotation used the pair-plot clipping technique, with one plot per cage clipped in the cage and its paired plot outside the cage at the end of each grazing period within each sub-pasture during the first rotation. The herbage production inside the cage represents the amount of the growth produced when cattle were moved to a new sub-pasture. The degree of disappearance and herbage production consumed by cattle is determined from the difference between growth in the caged plots and uncaged plot.

Herbage production was collected again prior to cattle grazing the 2nd rotation by clipping inside the cage and from a new paired uncaged plot (grazed) for a second time in each sub-pasture. This growth represents continued growth from the first clipping (first grazing event) without grazing (inside cage) and regrowth with grazing (outside cage).

At the end of each 2nd rotation, herbage production was clipped for the third time inside the cage to represent total herbage production and outside the cage using a new paired plot to determine overall degree of disappearance and herbage production consumed by cattle during the 2nd grazing period.

Aboveground cumulative production was calculated for each grazing intensity level (sub-pastures) by totaling the herbage production at the end of the 2nd grazing period (outside cage) with the amount of production consumed by cattle at the end of the 2nd grazing period (inside cage minus outside cage) plus regrowth (second outside cage clipping minus first outside cage) plus the amount of production consumed by cattle at the end of the 1st grazing period (inside cage minus outside cage) plus senescence (peak production minus net primary production).

Peak production is the greatest production occurred during the growing season. Net primary production is production at the end of the grazing season. If peak production occurred at the end of the grazing season, then peak production and net primary production were the same, meaning no senescence occurred during the grazing season.

<u>Cumulative production</u> = **livestock consumption during 1st rotation** *(production inside exclosure – production outside exclosure)* + **regrowth** *(production outside exclosure prior to 2nd rotation – production outside exclosure after the 1st rotation)* + **livestock consumption during 2nd rotation** *(production inside exclosure – production outside exclosure)* + **senescence**[1] *(peak production – net primary production)*

[1] *If peak production occurred at the end of the grazing period, then it would also be equal to net primary, and senescence = zero.*

Herbage production was clipped monthly (June through October) during the third week of the month in the rested pasture to determine peak herbage production.

Results

In 2018, we only determined aboveground cumulative production for the heavy-use sub-pasture on the loamy and shallow loamy ecological sites. We determined aboveground cumulative herbage production for all sub-pasture grazing use levels on the loamy and shallow loamy ecological sites in 2019 through 2021. **Figures 1 – 6** show net primary production, peak primary production and cumulative production by sub-pastures.

Aboveground cumulative production on the heavy-use sub-pasture had a 4-year average increase in growth efficiency of 45.6 and 45.9 percent on the loamy and shallow loamy ecological sites; respectively, compared to peak production from the non-grazed plots.

Aboveground cumulative production on the full-use sub-pasture had a 3-year average increase in growth efficiency of 32.8 and 44.1 percent on the loamy and shallow loamy ecological sites; respectively.

Aboveground cumulative production on the moderate-use sub-pasture had a 3-year average increase in growth efficiency of 36.2 and 45.1 percent on the loamy and shallow loamy ecological sites; respectively.

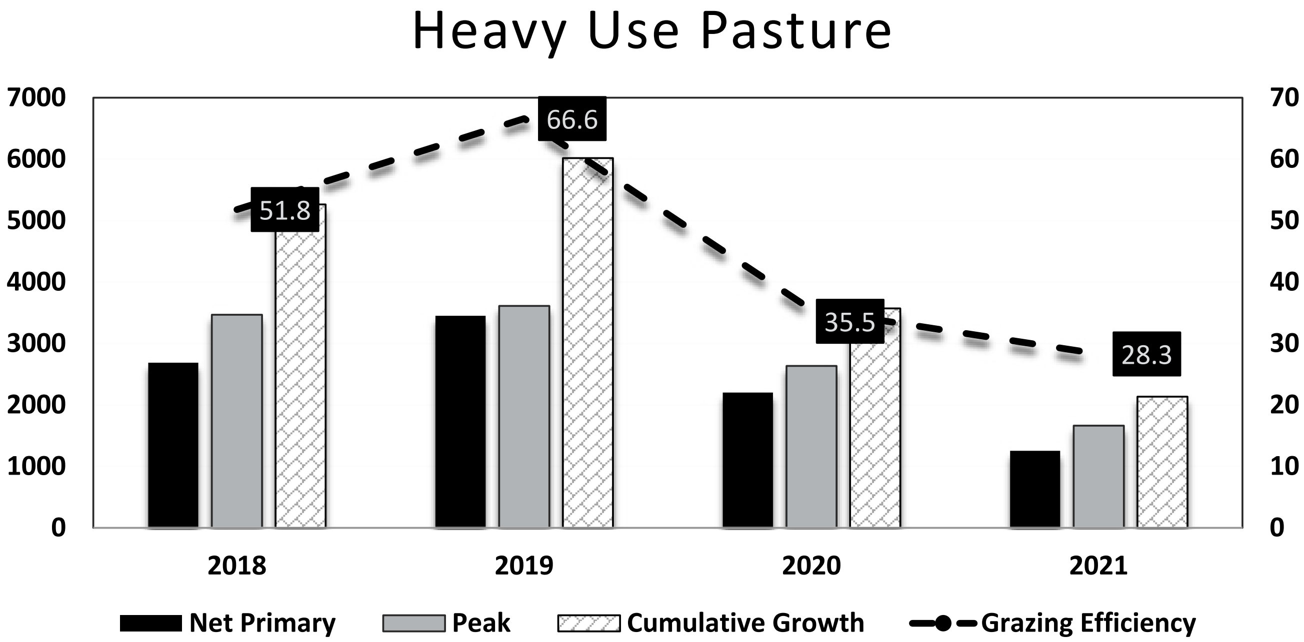


Figure 1. Above-ground net primary, peak and cumulative production on the heavy-use grazing intensity sub-pasture, and growth efficiency from rotational grazing on the loamy ecological site of the modified twice-over rest-rotation grazing treatment at the Central Grasslands Research Extension Center in 2018-2021.

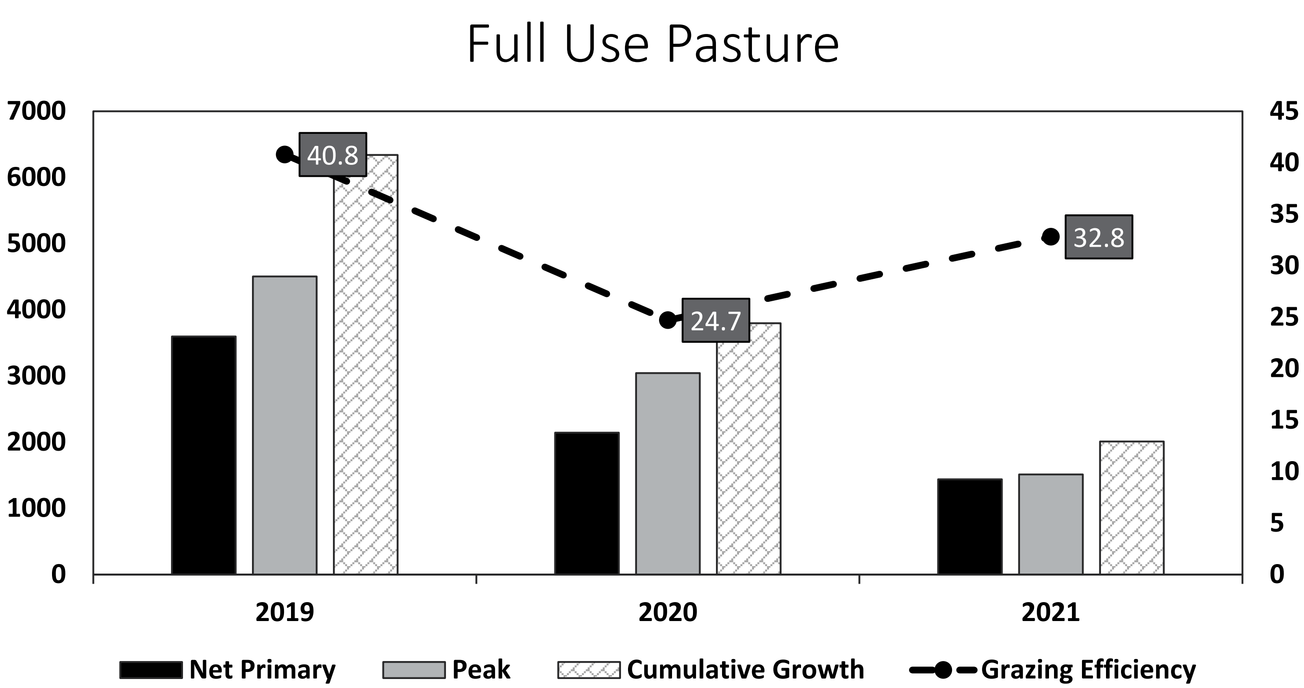


Figure 2. Above-ground net primary, peak and cumulative production on the full-use grazing intensity sub-pasture, and growth efficiency from rotational grazing on the loamy ecological site of the modified twice-over rest-rotation grazing treatment at the Central Grasslands Research Extension Center in 2019-2021.

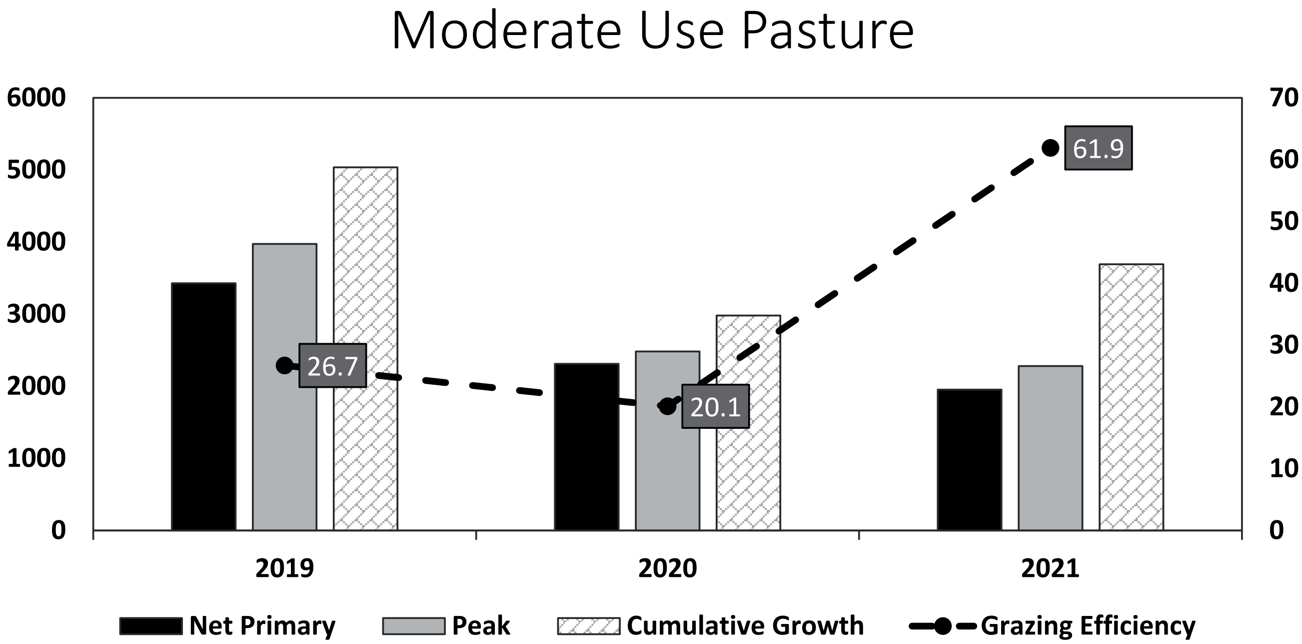


Figure 3. Above-ground net primary, peak and cumulative production on the moderate-use grazing intensity sub-pasture, and growth efficiency from rotational grazing on the loamy ecological site of the modified twice-over rest-rotation grazing treatment at the Central Grasslands Research Extension Center in 2019-2021.

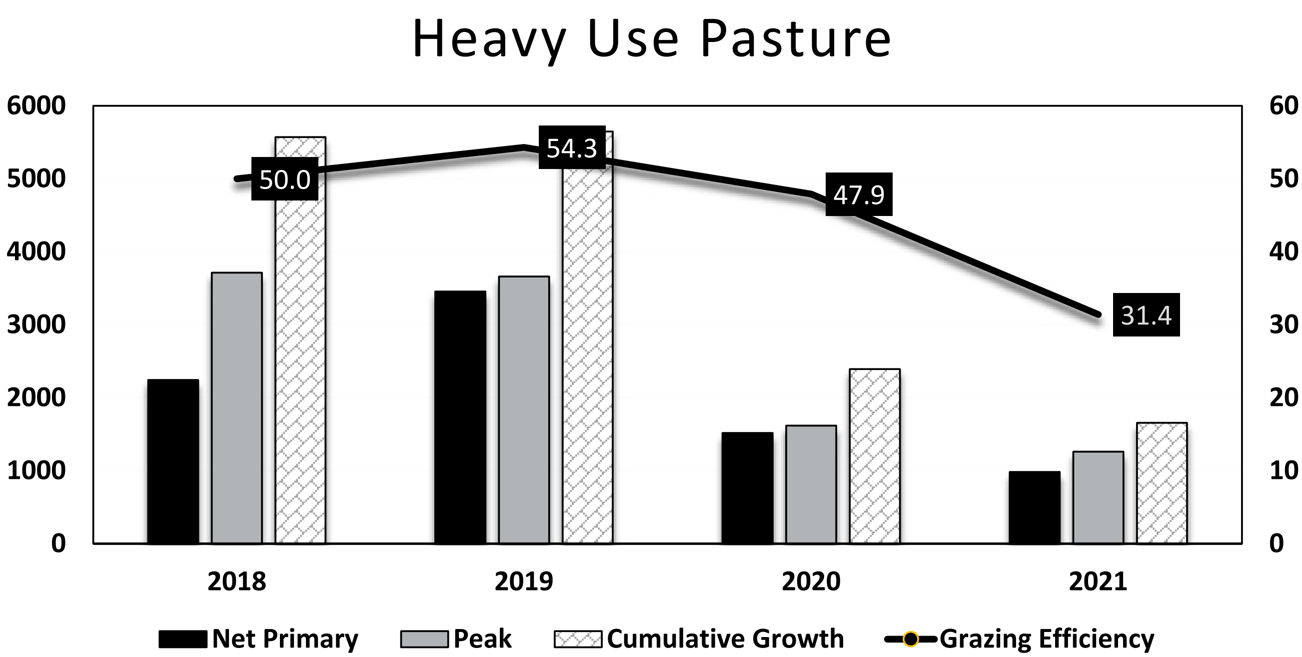


Figure 4. Above-ground net primary, peak and cumulative production on the heavy-use grazing intensity sub-pasture, and growth efficiency from rotational grazing on the shallow loamy ecological site of the modified twice-over rest-rotation grazing treatment at the Central Grasslands Research Extension Center in 2018-2021.

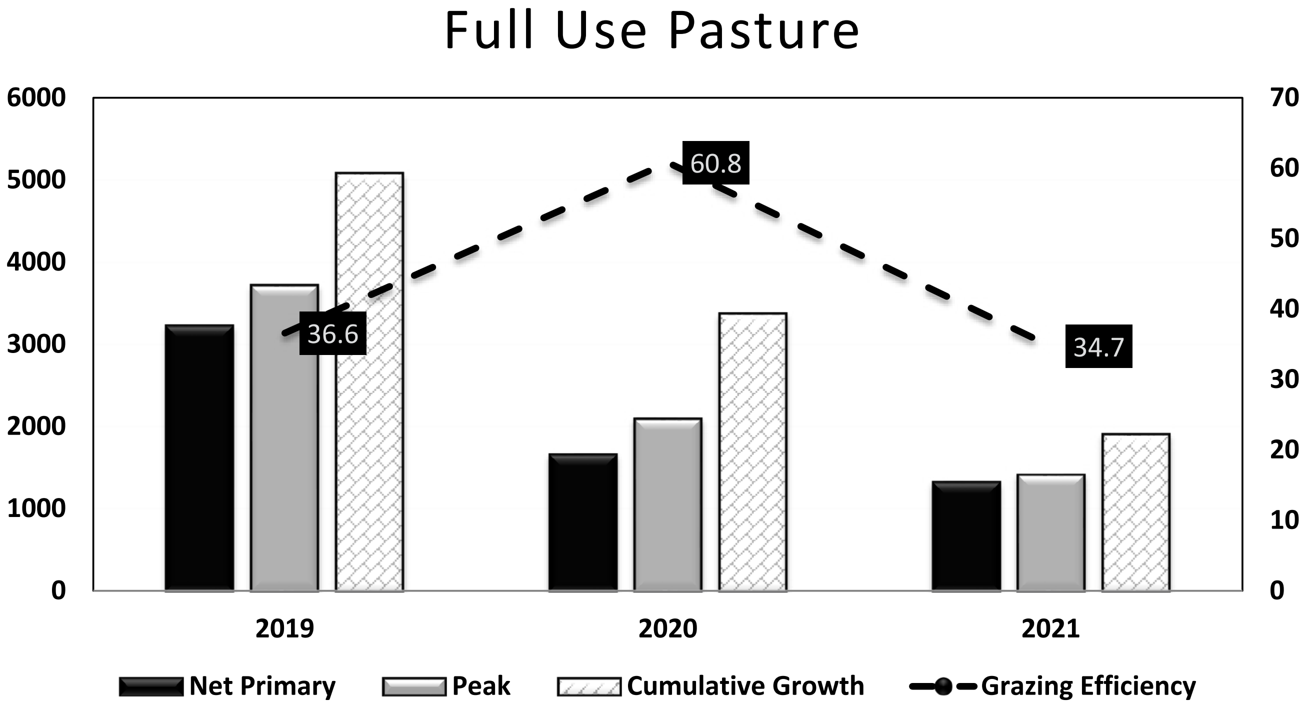


Figure 5. Above-ground net primary, peak and cumulative production on the full-use grazing intensity sub-pasture, and growth efficiency from rotational grazing on the shallow loamy ecological site of the modified twice-over rest-rotation grazing treatment at the Central Grasslands Research Extension Center in 2019-2021.

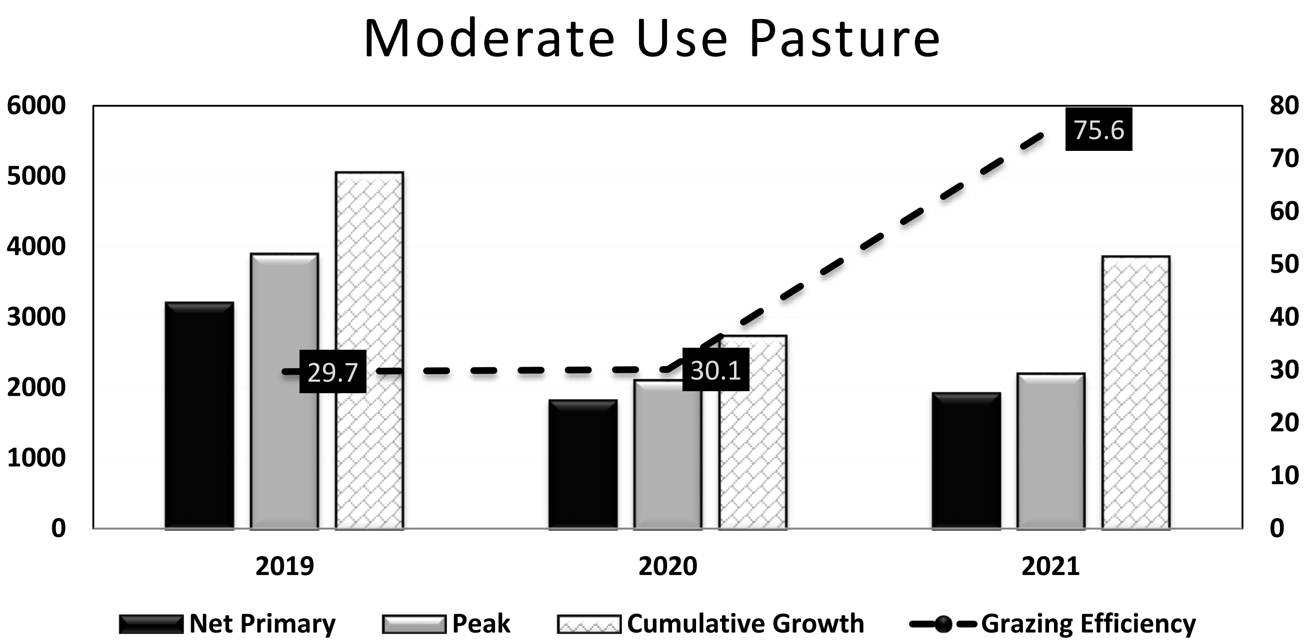


Figure 6. Above-ground net primary, peak and cumulative production on the full-use grazing intensity sub-pasture, and growth efficiency from rotational grazing on the shallow loamy ecological site of the modified twice-over rest-rotation grazing treatment at the Central Grasslands Research Extension Center in 2019-2021.

We achieved our targeted degree of disappearance for all years on the full and moderate-use sub-pasture, except the moderate use sub-pasture in 2021 (44 percent). We achieved the targeted degree of disappearance on the heavy-use sub-pasture (targeted was 60-70 percent) in 2018 and 2021. The degree of disappearance was 57.2 and 56.2 percent in 2019 and 2020, respectively.

Literature Cited

Biondini, M.E., and L.L. Manske. 1996. Grazing frequency and ecosystem processes in a northern mixed prairie, USA. Ecological Applications 5:239–256.

Briske, D.D., J.D. Derner, J.R. Brown, S.D. Fulhendorf, W.R. Teague, R.L. Gillen, A.J. Ash and W.D. Williams. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. Rangeland Ecology and Management 61:3–17.

Fuhlendorf, S.D., R.W.S. Fynn, D.A. McGranahan and D. Twidwell. 2017. Heterogeneity as the basis for rangeland management, in: Briske, D.D. (Ed.), Rangeland Systems: Processes, Management and Challenges, Springer Series on Environmental Management. Springer International Publishing, pp. 169–196.

Hart, R.H., J. Bissio, M.J. Samuel and J.W. Waggoner, JR. 1993. Grazing systems, pasture size, and cattle grazing behavior, distribution and gains. Journal of Range Management 46:81–87.

Holechek, J.L., R.D. Poeper and C.H. Herbel. 1998. Range management: principles and practices. 3rd ed. Upper Saddle River, NJ, USA: Prentice Hall. 542 p.

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 & Environment* 257:113-119.

Manley, W. A., R. H. Hart, M. J. Samuel, M. A. Smith, J. W. Waggoner, JR. and J. T. Manley. 1997. Vegetation, cattle, and economic responses to grazing strategies and pressures. Journal of Range Management 50:638–646.

McNaughton, S.J. 1979. Grazing as an optimization process: grass-ungulate relationships in the Serengeti. Am. Nat. 113:691-703.

Ranellucci, C.L., N. Koper and D.C. Henderson. 2012. Twice-over rotational grazing and its impacts on grassland songbird abundance and habitat structure. Rangeland Ecology and Management 65:109–118.

Sedivec, K. K. and W. T. Barker. 1991. Design and characteristics of the twice-over rotation grazing system. Ext. Publ. R-1006, North Dakota State University Extension, Fargo. 6 pp.

Shepherd, A. and S.M. McGinn. 2003. Climate change on the Canadian prairies from downscaled GCM data. Atmosphere-Ocean 41:301–316.

Smart, A.J., J.D. Derner, J.R. Hendrickson, R.L. Gillen, B.H. Dunn, E.M. Mousel, P.S. Johnson, R.N. Gates, K.K. Sedivec, K.R. Harmoney, J.D. Volesky and K.C. Olson. 2010. Effects of Grazing Pressure on Efficiency of Grazing on North American Great Plains Rangelands. Rangeland Ecology and Management 63:397–406.

Assessing the influence of grazing and fire disturbance regimes on monarch (*Danaus plexippus* L.), milkweed (*Asclepias* spp.), and forb abundances in managed rangelands

Ellysa Johnson[1], Jason Harmon[1], Torre Hovick[1], Kevin Sedivec[1,2] and Ryan Limb[1]

[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
North American monarch butterfly populations have declined by 80% in the last few decades, primarily due to land-use change in the Great Plains region. While row-crop agricultural fields have widely removed food resources in the form of milkweed and forbs, the opportunity for conservation efforts to re-establish such resources remains in rangelands. We monitored North Dakota rangelands for monarch adults, juveniles, milkweed, and flowering forbs in three grazing management practices. Knowing we had extreme drought during the 2021 season, we found that a modified twice-over rest-rotational grazing system, particularly the rested sections, had the most monarchs, milkweed, and flowering forbs. Given that drought events are predicted to increase in both severity and frequency in the future, it may be beneficial for landowners to incorporate rested sections to act as a refuge for wildlife, such as the monarch. By doing so, rangelands will be more readily able to support both production and conservation in the face of climate change. Here we present the preliminary results from the first year of this project.

Introduction
Prairies of the Great Plains region have widely been converted to agriculture (Samson & Knopf, 2004). The prairie fragments that remain are mostly privately owned and managed with livestock grazing (Ribic et al., 2009). Due to this multi-use, these are considered working landscapes, or ecosystems that are managed for both wildlife and economic production. Such working landscapes in the form of livestock-grazed rangelands provide a unique opportunity to not only produce cattle but also serve larger biodiversity goals, including conserving threatened species like the monarch butterfly (*Danaus plexippus* L.). However, rangelands require informed management strategies to maximize conservation and cattle production simultaneously.

The eastern monarch butterfly (hereafter “monarch”) is a migratory species, travelling between central Mexico and Canada. However, in the last twenty years, monarch populations have undergone declines for a variety of reasons including loss of breeding habitat and food resources (Thogmartin et al., 2017; Brower et al., 2006).

Monarch breeding habitat is primarily located in the Great Plains region and Midwestern prairies that include their larval obligate host plant, milkweed (*Asclepias* spp.). Land conversion of these prairies to agriculture led to a decrease in overall availability of both milkweed and nectar resources (Pleasants & Oberhauser, 2013). However, working landscapes, such as livestock-grazed rangelands, still provide the opportunity to support monarchs.

Historically, disturbance regimes, such as fire and bison grazing, maintained rangeland biodiversity and increased resource availability (Mola & Williams, 2018). European settlement, however, led to fire suppression and replacement of bison with domesticated, non-native cattle (Ryan et al., 2013).

To measure if re-introducing disturbance regimes promotes monarchs, we incorporated three different management strategies in North Dakota rangelands in the summer of 2021. We then monitored the abundances of monarchs, milkweed, and flowering forbs.

The results of this project will provide insight into which management strategy on working landscapes most benefit the monarch via establishing necessary resources, further aiding monarch conservation within the Great Plains region.

Procedures

Study Site

The Central Grasslands Research Extension Center (CGREC) is in Stutsman and Kidder counties of North Dakota. This region is primarily mixed-grass prairie consisting of native cool-season grasses such as western wheatgrass (*Pascopyrum smithii*) and green needlegrass (*Nassella viridula*). Invasive plant species on site include Kentucky bluegrass (*Poa pratensis*), smooth brome (*Bromus inermis*), western snowberry (*Symphoricarpos occidentalis*), and Canada thistle (*Cirsium arvense*) (Limb et al., 2018). Common native forbs found at CGREC include prairie coneflower (*Ratibida columnifera*), goldenrod (*Solidago* spp.), yarrow (*Achillea millefolium*), and Flodman's thistle (*Cirsium flodmanii*) (Rogers et al., 2005). The climate at CGREC is classified as temperate and has an average yearly rainfall of 39.9cm (15.7 inches) and an average annual temperature of 4.94°C (40.9°F) (NDAWN 1991-2021). However, we collected data in the summer of 2021 under abnormal weather conditions for the area. The total 2021 precipitation at CGREC was 33.2 cm (13.1 inches) of rainfall, with an average annual temperature of 6.86°C (44.34°F) (NDAWN 2021).

During the field season (June to August), that same region received only 5.08 cm (2 inches) of rainfall (NDAWN 2021). According to the National Integrated Drought Information System, the summer of 2021 was classified as a drought period with 86.27% of Stutsman County in severe drought conditions, 26.7% in extreme drought conditions, and 0.4% in exceptional drought conditions (Fuchs, 2021).

Treatment Structure

Post-European settlement of rangelands, fire suppression and the introduction of privatized livestock grazing (primarily non-native cattle, *Bos taurus*) altered disturbance regimes (Ryan et al., 2013). Historically, rangelands were disturbed by ungulate grazing and fire (Samson &

Knopf, 1994). To re-introduce disturbance, we incorporated cattle grazing, as a surrogate for native herbivores, and fire (Fuhlendorf et al., 2009).

Our treatment structure consists of three treatments, each with four 65-ha replicates each. The treatments consist of: (1) modified twice over rest-rotational grazing (MTORG), (2) patch-burn grazing (PBG), and (3) season-long grazing (SLG). The MTORG treatment is designed to create structural diversity, or heterogeneity, while maximizing cattle gains. Embedded in this system are four paddocks: rested/no-grazing (NG; 0% degree of utilization), moderate grazing (MG; 20-40%), full-use grazing (FG; 40-60%), and heavy grazing (HG; ≥60%). The percentages are estimated by the disappearance of graminoid species. Cattle visit each paddock twice, with the exception of the rested sections. This is a rotational system, so the NG plot will become the MG plot the following year, MG becomes FG, and so on (Figure 1a). The rotational design avoids repeated annual disturbance in any one paddock that may result in a decrease in forage quality or loss in biodiversity (Fuhlendorf et al., 2017).

The PBG treatment is designed to encourage biodiversity while also supporting cattle production. A PBG system uses the fire-grazing interaction, or pyric herbivory, to create contrast among patches within a pasture. Livestock are attracted to the post-fire vegetation growth, and this attraction leads to less grazing in other patches (Vermeire et al., 2004). Consequently, a buildup of vegetation in unburned patches occurs, contributing to heterogeneity (Fuhlendorf et al., 2009). A quarter of the PBG pastures (16-ha total) are burned annually on a 4-year fire-return interval, creating patches that are referred to in time since fire (TSF), ranging from 0-3 years (Figure 1b).

The SLG treatment, like MTORG, does not utilize fire as a disturbance method. Instead, this treatment serves as a control or default management strategy of the area. Each 16ha subsection has no temporal or treatment differences within the pasture. The cattle are allowed to graze the entire 64ha sections throughout the growing season (Figure 1c).

All treatments include cattle grazing as cow-calf pairings with similar 5-year average stocking rates, ranging from 2.15-2.34 animal unit months per hectare (AUMS/ha) for the duration of the growing season (May 1 to October 1) to achieve an average 30% forage utilization with the exception of individual MTORG paddocks.

Transect surveys

From June 16 to August 8, 2021 we surveyed a total of 144 transects three times each (3 transects per plot x 4 plots per replicate x 4 replicates per treatment x 3 treatments). The transects were 150m long and 5m wide (2.5 m to either side). On each transect we conducted a 10-minute butterfly survey down the transect and juvenile, milkweed, and forb surveys on the return.

The butterfly surveys were only conducted between the hours of peak monarch activity (9:00am and 6:30pm; Royer et al., 1998). These same transects were also walked to count milkweed stems and flowering forbs within the transect and identified to species. Milkweed was also noted to be non-flowering, budding, flowering, or bitten-off by cattle. Lastly, on each milkweed stem along the transect we inspected for monarch juveniles (eggs, 1-5 instars, and pupae).

Preliminary Results

We detected a total of 77 juvenile and 96 adult monarchs, 17099 milkweed stems, and 69778 flowering forbs across all treatments, encompassing five milkweed species (in order of most to least relative abundance: *Asclepias syriaca*, *A. speciosa*, *A. ovalifolia*, *A. viridiflora*, and *A. incarnata*) and 74 forb species.

We found the majority of monarch adults (55%), juveniles (57%), milkweed stems (65%), and flowering forbs (65%) in the MTORG treatment (Figure 2). Within the MTORG treatment, most detections were in rested paddocks (58%, 43%, 51%, 43%, respectively; Figure 2).

Discussion

We assessed the influence of three different grazing regimes in North Dakota rangelands on monarchs and their food resources. In our first year of data collection, we detected more monarchs, milkweed, and forbs in the MTORG compared to PBG and SLG treatments. However, 2021 was deemed a drought year (Fuchs, 2021). In drought conditions, perhaps the inclusion of fire or constant grazing adds strain on an already water stressed system. A modified rotational grazing strategy, with the inclusion of rested sections, may offer refuge to plant and animal species.

This project will continue in the summer of 2022. In the event of drought conditions, we expect to find similar results to the summer of 2021. In non-drought conditions, we suspect the PBG system will have the highest abundance of monarchs, milkweed, and forbs. Although floral resource availability immediately decreases following a fire, it quickly rebounds if supplied with water (Mola & Williams 2018). This research, combined with the other studies conducted at CGREC, will inform us what management practices create a holistic benefit in rangelands.

Our current findings give insight into how the re-introduction of disturbance regimes to working landscapes (in this context, rangelands) has the potential to promote the monarch butterfly. With climate change increasing the likelihood of prolonged and extremified drought in the area (Frankson et al., 2017), a management strategy that offers both disturbance and refuge may be of heightened benefit for monarch conservation.

Literature Cited

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.

Fuhlendorf, S.D., R.W.S. Fynn, D.A. McGranahan and D. Twidwell. 2017. Heterogeneity as the basis for rangeland management. In: D.D. Briske (Ed.). Rangeland Systems: Processes, Management and Challenges. p. 169-196.

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.

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.

North Dakota Agricultural Weather Network (NDAWN). 1991-2021. North Dakota State University, Fargo, N.D. https://ndawn.ndsu.nodak.

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.

Ribic, C.A., M.J. Guzy, and D.W. Sample. 2009. Grassland bird use of remnant prairie and Conservation Reserve Program fields in an agricultural landscape in Wisconsin. The American Midland Naturalist 161:110-122.

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.

Royer, R.A., J.E. Austin, and W.E. Newton. 1998. Checklist and “Pollard walk” butterfly survey methods on public lands. American Midland Naturalist. 140: 358-371.

Ryan, K.C., E.E. Knapp, and J.M. Varner. 2013. Prescribed fire in North American forests and woodlands: history, current practice, and challenges. Front Ecol Environ 11(Online Issue 1): e15-e24.

Samson, F. and F. Knopf. 1994. Prairie conservation in North America. BioScience 44(6): 418-421.

Samson, F.B., F.L. Knopf, and W.R. Ostlie. 2004. Great Plains ecosystems: past, present, and future. Wildlife Society Bulletin 32(1):6-15.

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. 2017. Monarch butterfly population decline in North America: identifying the threatening processes. Royal Society Open Science 4(9): 1-9.

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.

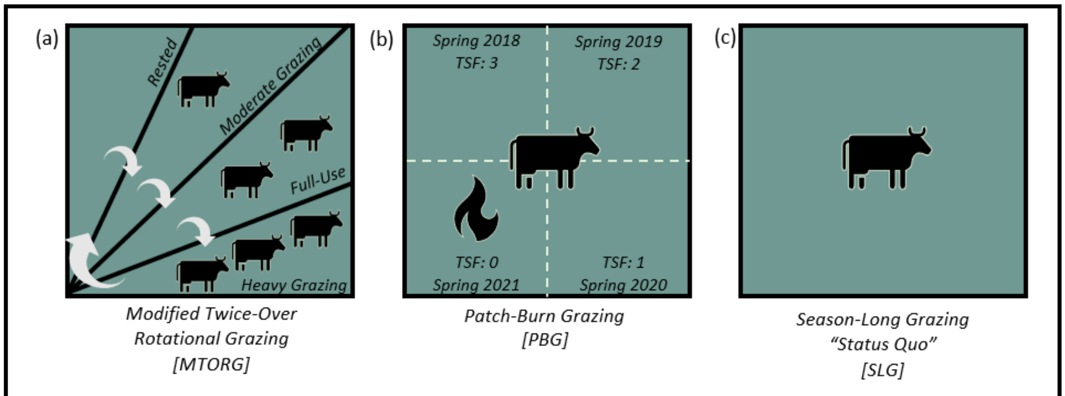


Figure 1. Example layouts of each treatment. Black lines represent fences while dashed white lines represent fire lines (a) MTORG features four paddocks divided in a “pie slice” fashion. These pastures have different degrees of utilization, ranging from rested (or no-grazing) to heavy. These rotate each year, as depicted by grey arrows; (b) PBG is divided into four patches, each burned on a 4-year fire return interval. Time since fire (TSF) equivalents also shown; and (c) SLG represents the “status quo” of the region.

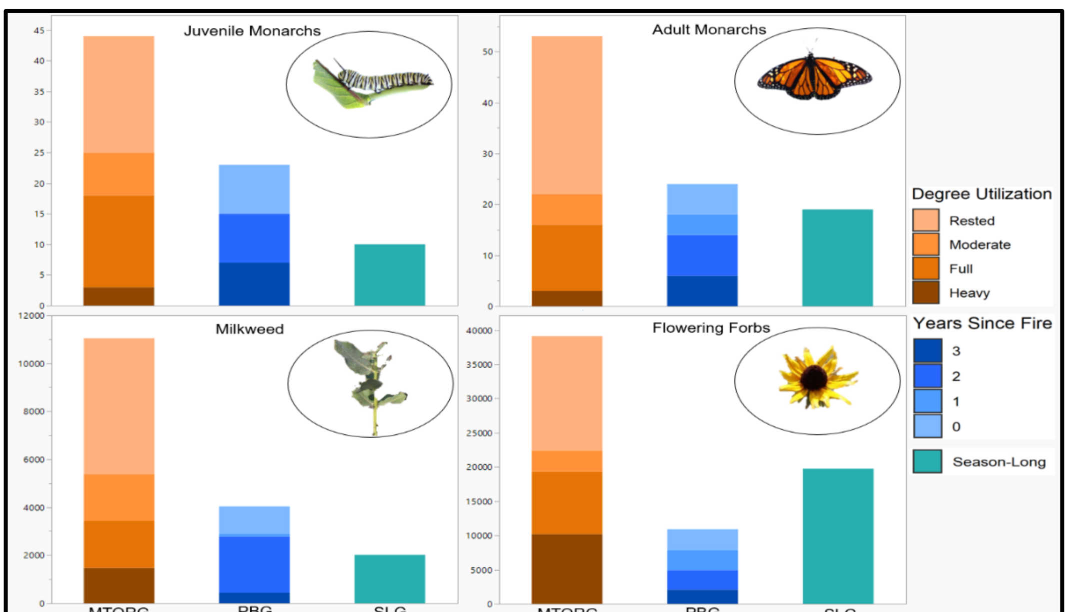


Figure 2. Number of monarch juveniles (77), adults (96), milkweed (17,099), and flowering forbs (69,778) counted in the summer of 2021. Bars represents each treatment (MTORG, PBG, and SLG) and

Preliminary Findings of Bee Community Characteristics under Various Grazing Regimes

Bethany Roberton[1], Torre Hovick[2], and Jason Harmon[1]

[1]Department of Entomology, North Dakota State University, Fargo, N.D.
[2]Department of Natural Resource Management and Range Science, North Dakota State University, Fargo, N.D.

Summary

We are evaluating the effects of three grazing regimes on bee community abundance, diversity, and floral use. Our preliminary results from our first summer of data collection suggest that the rested pastures in the modified twice-rotational grazing treatment had the greatest abundance of bees and flowering plants while the patch-burn grazing treatment had the lowest abundances. There appears to be no difference in the number of bee taxa between treatments. The modified twice-rotational treatment also had the greatest diversity of flowering plants being visited by bees. Different bee taxa were found visiting several plant species, even taxa caught in low abundances. Snowberry (*Symphoricarpos occidentalis* Hook.) was the only plant used by bees across all three treatments indicating a difference in flowering plant composition between the three treatments. Because of the intense drought conditions experienced during this first field season, our preliminary observations suggest that the rested pastures may be a refuge for bees and that snowberry may be a common food source for bees during unfavorable conditions. Although abundances of flowering plants and bees were different between treatments, all three grazing regimes may contribute to supporting bee diversity and floral resource visitation.

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 our ecosystems, but their populations have been facing global declines due to habitat loss, agricultural intensification, and climate change (Brown and Paxton 2009, Potts et al. 2010). Rangelands are therefore becoming increasingly important for bees 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, especially since not all rangeland management is the same.

Rangelands can be managed in different ways including rotational grazing, continuous grazing, and patch-burn grazing (Fuhlendorf and Engle 2001). All types of management may impact bees 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 this field of study, we are examining the effects of three different grazing regimes on bee and floral communities. All three grazing regimes have had little previous study regarding bees, and one, the modified twice-rotational grazing regime, has a unique structure that is of current interest in rangeland management. Our three objectives are to examine 1) bee diversity and abundance, 2) flowering plant diversity and abundance, and 3) floral resource use 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.).

Our first summer of data collection experienced a drought with about 30% less rainfall from a normal year between the months of May and August (NDAWN 2021). 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 2020, 2021).

Treatment Structure

We used three treatments of approximately 260 hectares each (Figure 1): season-long grazing, modified twice-rotational grazing, and patch-burn grazing. Each treatment has four replicates of equal pasture size (65 ha). The season-long grazing acts as a control to reflect common regional management. Within the modified twice-rotational treatment, there are different intensities of grazing including heavy, full, light, and rested. The patch-burn grazing treatment is burned on a four-year rotation with a quarter of each pasture being burned every spring.

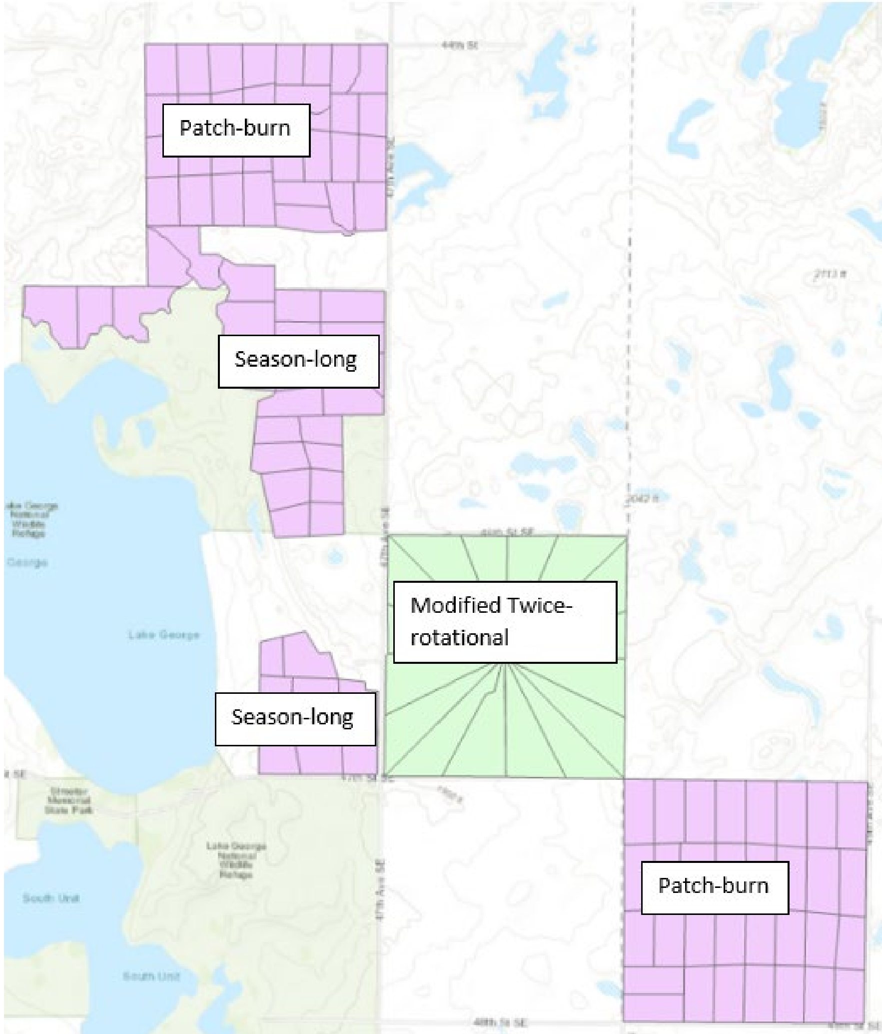


Figure 1. The three grazing treatments used at the CGREC.

Objective 1: Bee diversity and abundance

To sample abundance and diversity of bees, we surveyed a 100-m transect in every 8-ha subplot within each treatment (Figure 2). We caught all bees within reach using a sweep net, photographed for identification, swabbed the bee for a pollen sample, and released it live.

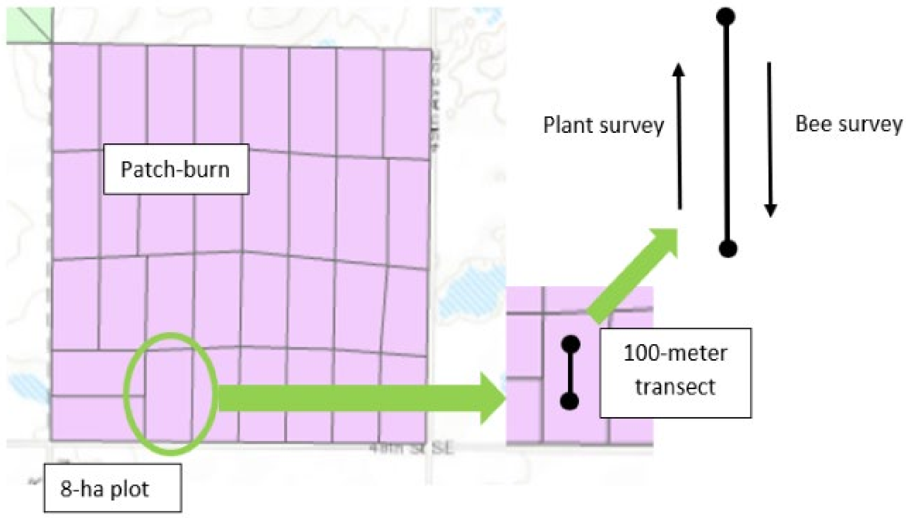


Figure 2. Example of a 100-m transect survey in an 8-ha plot within the patch-burn grazed treatment. Each transect has a bee survey done in one direction and a plant survey done in the opposite direction.

Objective 2: Plant diversity and abundance

After finishing the bee survey, we followed the same 100-m transect in the opposite direction (Figure 2). We counted and identified each individual flowering plant within 2.5 meters on either side of the transect.

Objective 3: Resource use

For each caught bee, we noted the species and height of the flowering plant that the bee was found on. We will use the collected pollen samples to identify pollen grain by plant taxa using a process of acetolysis and microscopy. Finally, we also took 30-minute videos using time-lapse cameras (Brinno TLC200 720p) on native flowering plants within each 8-ha subplot to quantify the visitation rates of bees to native, bee-pollinated plants.

Preliminary Results

Objective 1: Bee diversity and abundance

The greatest number of bees were found in the modified twice-rotational treatment (Figure 3A) and in the rested pastures within that treatment (Figure 3B). The lowest abundances were observed in the patch-burn grazed treatment. Based on a quick identification of the surveyed bees to tribe or genus, we have determined that bee taxa are similar across the treatments, with honey bees (*Apis* spp.) being the most abundant bee detected in each treatment.

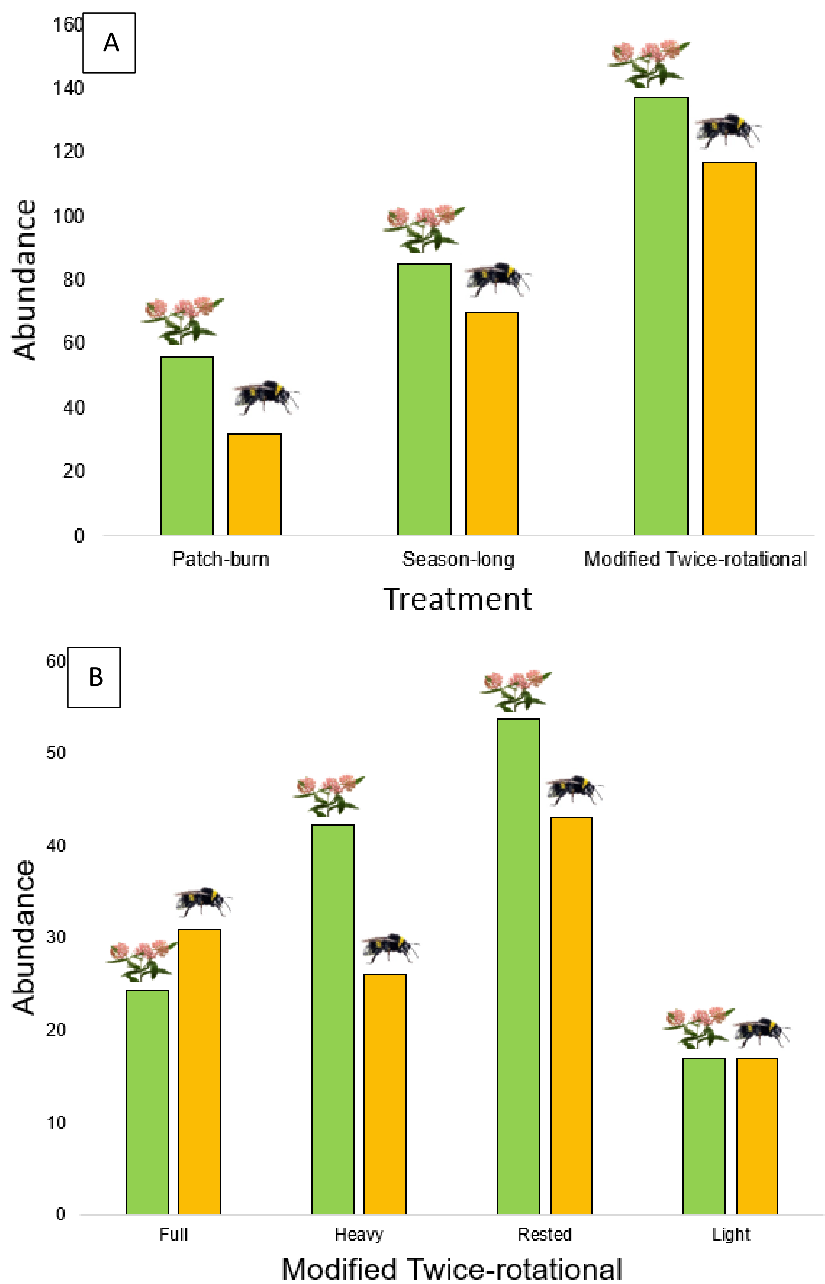


Figure 3. Number of individual flowering plants (divided by 100) and bees within A) each grazing treatment and B) within the pastures of the modified twice-rotational treatment.

Objective 2: Plant diversity and abundance

The greatest number of individual flowering plants were found in the modified twice-rotational grazing treatment overall (Figure 3A) and within the rested pastures specifically (Figure 3B). The lowest abundances were observed in the patch-burn grazing treatment. We have not examined the diversity of the plants between treatments yet.

Objective 3: Resource use

The modified twice-rotational treatment had the highest number of flowering plant species that bees used on our surveys. Snowberry was the only plant that was consistently used between all three treatments. We will be examining our pollen samples and videos in the spring of 2022.

Discussion

Summary of Results

Our preliminary results suggest that the rested pastures in the modified twice-rotational grazing treatment may be beneficial for supporting high abundances of bees and floral resources. However, the diversity of bees appears to be similar between the treatments. Additionally, multiple plant species were used by bees in all treatments despite the differences in abundances.

Honey bees were the most commonly caught bee. This may be because of the proximity of honey bee hives, or perhaps there were fewer native bee taxa due to the drought conditions this summer. The most commonly used plant was snowberry, which appeared to withstand the drought well and was abundant in all treatments. This could highlight the potential usefulness of snowberry during years of unfavorable conditions and also indicates a difference in plant species composition between the three treatments as it was the only plant consistently used in all pastures.

Future Work

We still need to run data analyses to verify the differences that we observed as well as verify the identification of caught bees with multiple identification keys, examine our pollen samples, and finish watching our visitation videos. We plan to continue these surveys for the next three summers.

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 manage rangelands that may best promote bees and their needed resources. 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 2021 summer technicians, Kyle Vernot and Lauren Berman.

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.

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.

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.

Park, M. G., M. C. Orr, and B. N. Danforth. 2010. The rold 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.

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.

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

Avian Nesting Diversity and Nest Success in a Modified Twice-Over Rest-Rotation Grazing System

Justin Clarke[1], Torre Hovick[1], and Kevin Sedivec[1,2]
North Dakota State University School of Natural Resource Sciences, Fargo, N.D.

[2]Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D.

Summary

We are evaluating the impacts of a modified twice-over rest-rotation grazing system on avian nesting diversity and apparent nesting success. The modified twice-over rest-rotation grazing system creates heterogeneity using four different grazing intensities that rotate each year. Our preliminary results suggest that variation in grazing intensity alters vegetation structure, which influences the avian nesting diversity and apparent nesting success. These results provide additional insight into the importance of heterogeneity in rangelands managed for biodiversity.

Introduction

Historically, fire and grazing shaped North American grasslands and avian communities by creating a shifting mosaic of vegetation structure and composition (Fuhlendorf and Engle, 2001). This heterogeneity is missing from current rangelands, which are managed to favor agricultural production resulting in uniform, or homogenous vegetation structure (Becerra et al., 2017; Fuhlendorf et al., 2009). While not the only factor, this change has contributed to declines in grassland bird populations (Rosenberg et al., 2019; Sauer et al., 2013). Since grassland birds evolved in a heterogeneous landscape, restoring heterogeneity is a crucial part of avian conservation on working landscapes (Christensen, 1997; Fuhlendorf and Engle, 2001; Ostfeld et al., 1997; Wiens, 1997).

Altering management to focus on establishing heterogeneity can blend the needs of conservation while simultaneously promoting rangeland productivity (Fuhlendorf et al., 2006). Management practices favoring heterogeneity can increase prey availability, decrease brood parasite abundance, and increase potential habitat for specialist grassland species through changes in vegetation structure (Churchwell et al., 2008; Coppedge et al., 2001; Engle et al., 2008). Increased heterogeneity has been tied to greater temporal stability in avian communities (Hovick et al., 2015) and increased available niche space (Fuhlendorf et al., 2009; Fuhlendorf and Engle, 2004). 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). Other examples include the chestnut-collared longspur and Northern pintail on the sparse end of the vegetation spectrum and Le Conte's Sparrows at the denser end (Beauchamp et al., 1996; Davis et al., 1999; Hovick et al., 2014).

The most commonly recommended management regime to achieve heterogeneity in rangelands is patch-burn grazing (Duchardt et al., 2016; Fuhlendorf and Engle, 2001; McNew et al., 2015). Patch-burn grazing involves the discrete application of fire to manipulate the grazing patterns of cattle (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). This reluctance creates a need for innovative methods to promote grassland heterogeneity for the conservation of declining grassland birds.

We propose that a modified rest-rotation grazing system can achieve heterogeneity in vegetation structure. Conventional rotational grazing is a common cattle management regime in the Northern Plains involving the rotation of cattle through paddocks with the goal of achieving uniform utilization across the pasture, resulting in homogeneity (Campomizzi et al., 2019; Davis et al., 2020). This study utilizes a unique modified twice-over rest-rotation grazing (MTORG) system to create vegetation structural heterogeneity using varying grazing intensities with the goal of maximizing conservation potential and cattle production.

We expect that the MTORG system will alter avian diversity between paddocks with different grazing intensities. Varied grazing intensities should create a vegetation structural gradient which 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 nesting diversity and success will vary between paddocks, with the lowest in the heavily disturbed 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: 1) determine whether varying grazing intensities within paddocks can create a vegetation structural gradient across a pasture, 2) determine whether the resulting structural gradient increases avian nesting diversity within a pasture, and 3) determine whether grazing intensity impacts nest survival.

Methods

Study Area

Central Grasslands Research Extension Center (CGREC) is located in the Missouri Coteau ecoregion, and in 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).

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 invasives 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 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 vegetation structural heterogeneity using varying grazing intensities. 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.

Each year the paddocks rotate, with the rested paddock becoming the moderate paddock, the moderate to full, the full to heavy, and the heavy to rested. Cattle movement within the 65-hectare pasture is constrained to each paddock (approximately 16 hectares) using interior fencing. The system completed one full cycle prior to our study.

Nest Searching/Monitoring

We searched for nests by hand-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 along 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 a total of four times through the breeding season.

When a bird flushed from the rope, we identified the species and began searching for the nest (Hovick et al., 2012). 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 global positioning system (GPS) and searched again within three days (Hovick et al., 2012; Shew et al., 2019). We recorded nest location with a GPS and placed flags approximately 5-m to the north and south of the nest and low in the vegetation to prevent trampling of nests by cattle and to avoid attracting predators (Winter et al., 2003).

We candled two representative eggs to determine the age and subsequently monitored nests every 2-4 days (Johnson and Temple, 1990; Lokemoen and Koford, 1996). We recorded 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 and Temple, 1990).

We continued monitoring until the nest was depredated, fledged, 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.

Vegetation Surveys

We measured vegetation structure of 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 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; Robel et al., 1970). Vegetation measurements were taken at the end of the breeding season during the first two weeks of August 2021.

Analysis

We used a generalized linear model (GLM) with a gamma distribution to determine whether vegetation structure differed between grazing intensities. We used nonmetric multi-dimensional scaling with Bray-Curtis dissimilarity with the VEGAN package in R to evaluate how nesting communities differ between each of the paddocks within the MTORG system (Oksanen et al., 2020; R Core Team, 2021).

We divided avian species 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). We used a PERMANOVA to determine any statistical difference in the nesting communities in each grazing intensity.

Overall avian nest diversity was assessed calculating the Shannon Weaver Index and species richness for each grazing intensity. Apparent nesting success was calculated by dividing the number of successful nests in each grazing intensity by the total number of nests in each grazing intensity.

Results

Visual obstruction readings were significantly higher in the rested and full paddocks than the heavy paddock (p=0.0005, 0.0501, respectively). The moderate paddock did not differ from the heavy, full, or rested paddocks (p=0.1368, 0.9713, 0.2046, respectively). The full paddock was not significantly different from the rested paddock (p=0.4196, Figure 1).

Litter depth was significantly higher in the moderate paddock than in the heavy and rested paddocks (p<0.001, =0.0009, respectively). The full paddock had significantly higher litter depth than the heavy paddock (p=0.0275). The full paddock was not significantly different from the moderate or rested paddocks (p=0.1092, 0.2640, respectively). The heavy paddock was not significantly different from the rested paddock (p=0.7071, Figure 1).

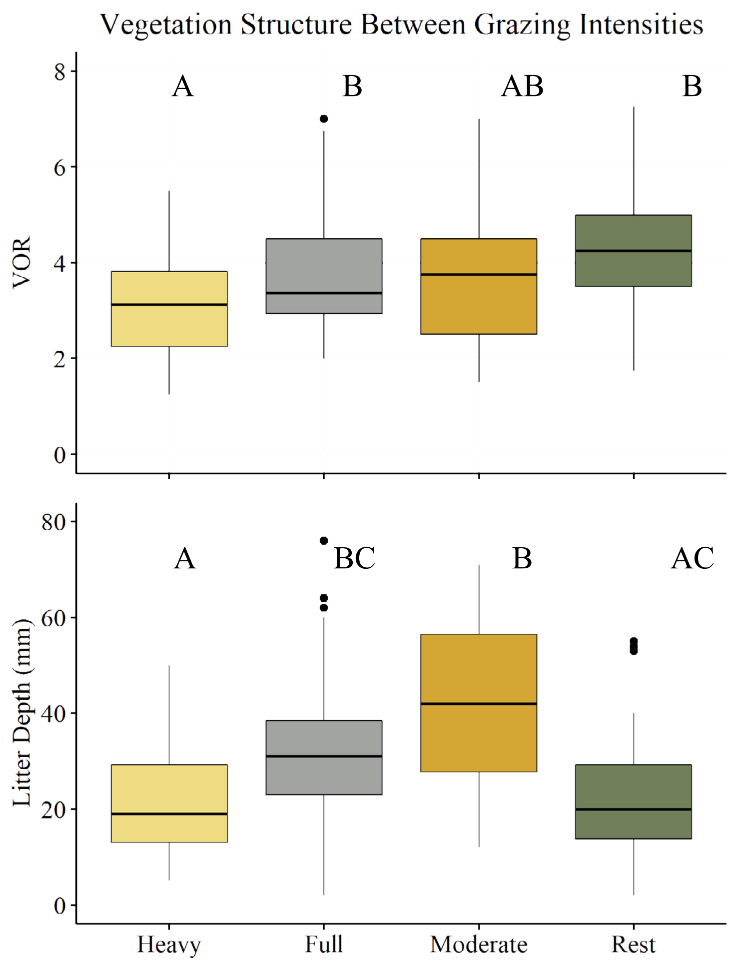


Figure 1. The top figure shows visual obstruction reading for each grazing intensity, measured with a Robel pole. The bottom figure shows litter depth measurements for each grazing intensity. Letters indicate statistical significance between grazing intensities.

We found a total of 437 nests belonging to 24 different species including 16 facultative species and 8 obligate species. These nests were broken down into 393 from facultative species and 44 nests belonging to obligate species. Clay-colored sparrow nests were the most abundant throughout the season with a total of 241 nests. Moderate and full paddocks had the highest number of nests with approximately double the number of nests compared to heavy and rested paddocks (Table 1).

Table 1. Nest abundance by species in each of the grazing intensities. Species were broken down into functional groups (FAC = facultative species, OBL = obligate species) based on Vickery (1999).

Common Name	Latin Name	Group	Heavy	Full	Moderate	Rest
Blue-winged Teal	*Spatula discors*	FAC	2	4	4	1
Northern Shoveler	*Spatula clypeata*	FAC	0	3	2	0
Gadwall	*Mareca strepera*	FAC	4	4	5	2
American Wigeon	*Mareca americana*	FAC	1	1	2	0
Mallard	*Anas platyrhynchos*	FAC	2	3	7	0
Northern Pintail	*Anas acuta*	FAC	3	4	15	2
Mourning Dove	*Zenaida macroura*	FAC	4	6	5	1
Killdeer	*Charadrius vociferus*	FAC	1	0	0	0
Wilson's Snipe	*Gallinago delicata*	FAC	0	1	0	0
Wilson's Phalarope	*Phalaropus tricolor*	FAC	0	2	0	0
Willet	*Tringa semipalmata*	FAC	0	0	1	0
Eastern Kingbird	*Tyrannus tyrannus*	FAC	0	2	2	3
Clay-colored Sparrow	*Spizella pallida*	FAC	46	72	84	39
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	FAC	0	0	1	0
Red-winged Blackbird	*Agelaius phoeniceus*	FAC	0	5	19	0
Brewer's Blackbird	*Euphagus cyanocephalus*	FAC	2	6	12	8
Sharp-tailed Grouse	*Tympanuchus phasianellus*	OBL	0	2	1	0
Upland Sandpiper	*Bartramia longicauda*	OBL	0	0	0	1
Chestnut-collared Longspur	*Calcarius ornatus*	OBL	0	0	4	0
Grasshopper Sparrow	*Ammodramus savannarum*	OBL	0	1	1	1
Savannah Sparrow	*Passerculus sandwichensis*	OBL	0	1	0	1
Bobolink	*Dolichonyx oryzivous*	OBL	0	2	4	1
Western Meadowlark	*Sturnella neglecta*	OBL	3	6	7	6
Dickcissel	*Spiza americana*	OBL	0	0	2	0
Total			**68**	**125**	**178**	**66**

Species richness and the Shannon Diversity Index were also highest in the full and moderate paddocks compared to the heavy and rested paddocks, with the lowest richness and diversity in the heavy paddock (Table 2). Avian nesting communities were not significantly different between grazing intensities (PERMANOVA; p=0.06; Figure 2)

Overall apparent nest success was 27% for all species, with apparent success rates of 22, 26, 30, and 26% for the heavy, full, moderate, and rested grazing intensities, respectively.

Table 2. Nest diversity measures for each grazing intensity.

Grazing Intensity	Shannon Diversity	Nesting Richness
Heavy	1.31	10
Full	1.81	18
Moderate	2.01	19
Rest	1.52	12

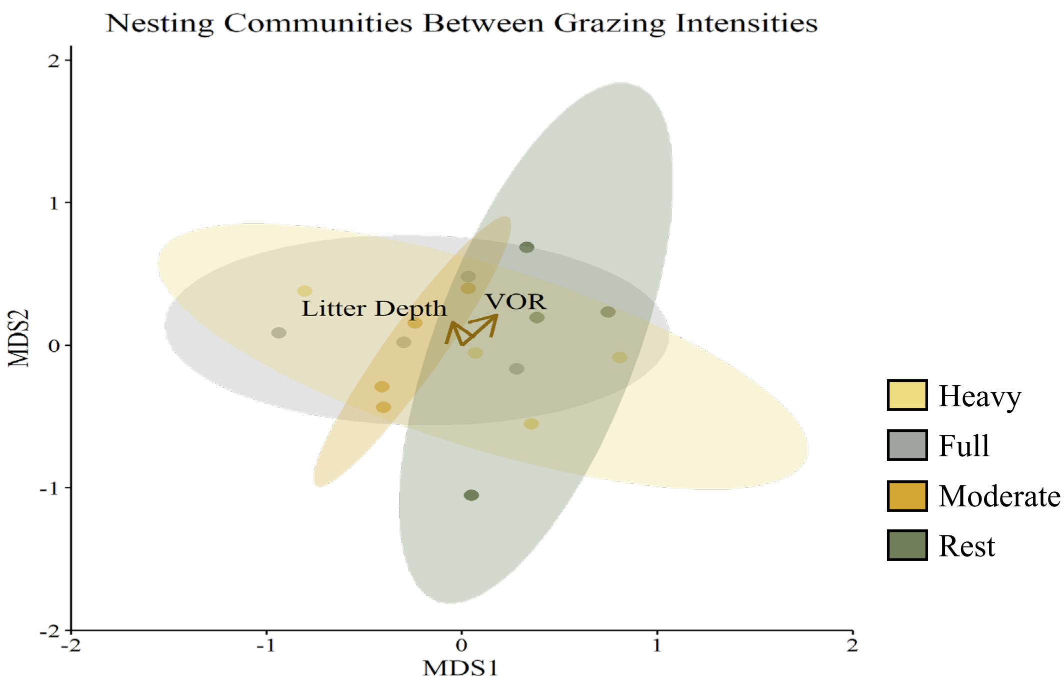


Figure 2. Ordination comparing avian nesting communities between grazing intensities where points represent avian nesting communities in each paddock. The distance between each point represents how similar communities are between paddocks (i.e., points that are close together are similar and points that are far apart are less similar). Vegetation structural measurements are overlaid; longer arrows indicate factors that more strongly differentiate grazing intensities. Ellipses show 95% confidence intervals. No significant difference in avian communities was observed between grazing intensities (PERMANOVA; p=0.06).

Discussion

The preliminary results of this study suggest that heterogeneity can be attained in the absence of fire by varying grazing intensities. Despite differences in vegetation structure, we did not find significant differences in nest diversity or nest success between grazing intensities. While we did not see significant differences in the avian nesting communities between grazing intensities, we did find differences in nesting richness and Shannon diversity.

Lower than average precipitation during the 2021 field season may have impacted the vegetation structural gradient observed between grazing intensities (Derner and Hart, 2007; NDAWN, 2022; Scasta et al., 2016). A reduced structural gradient result in reduced available niche space which is correlated with lower avian diversity (Fuhlendorf et al., 2009; Fuhlendorf and Engle, 2004). We plan to continue this project in future years to further clarify the impacts of grazing intensity on grassland bird nesting diversity and nesting success.

This research will benefit many 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, 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, 601–612. https://doi.org/10.1080/08941920.2016.1239293.

Campomizzi, A.J., Lebrun-Southcott, Z.M., van Vliet, L.D., Morris, G.A., 2019. Rotational grazing of beef cattle to support bobolink breeding success. Avian Conservation and Ecology 14, 1–13. https://doi.org/10.5751/ACE-01420-140213.

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

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, 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, 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.F., 1959. A canopy coverage method of vegetational analysis. Northwest Science 33, 43–64.

Davis, K.P., Augustine, D.J., Monroe, A.P., Derner, J.D., Aldridge, C.L., 2020. Adaptive rangeland management benefits grassland birds utilizing opposing vegetation structure in the shortgrass steppe. Ecological Applications 30, 1–14. https://doi.org/10.1002/eap.2020.

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, 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, 270–276. https://doi.org/10.2111/1551.

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, 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. Dissertation. Fargo, ND. https://doi.org/10.4324/9781315721606-101

Duquette, C.A., Hovick, T.J., Limb, R.F., Mcgranahan, D.A., Sedivec, K.K., 2019. Restored Fire and Grazing Regimes Influence Nest Selection and Survival in Brewer's Blackbirds Euphagus cyanocephalus. Acta Ornithologica 54, 171–180. https://doi.org/10.3161/00016454AO2019.54.2.004.

Dyke, S.R., Johnson, S.K., Isakson, P.T., 2015. North Dakota State Wildlife Action Plan. Bismarck, ND. 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, 55–62. https://doi.org/10.2111/06-149R2.1

Fuhlendorf, S.D., Engle, D.M., 2004. Application of the fire-grazing interaction to restore a shifting mosaic on tallgrass prairie. Journal of Applied Ecology 41, 604–614. https://doi.org/10.1111/j.0021-8901.2004.00937.x.

Fuhlendorf, S.D., Engle, D.M., 2001. Restoring heterogeneity on rangelands: Ecosystem management based on evolutionary grazing patterns. BioScience 51, 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, 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, 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, 848–856. https://doi.org/10.1002/jwmg.723.
Hovick, T.J., Elmore, R.D., Fuhlendorf, S.D., Engle, D.M., Hamilton, R.G., 2015. Spatial heterogeneity increases diversity and stability in grassland bird communities. Ecological Applications 25, 662–672.
Hovick, T.J., Elmore, R.Dwayne., Fuhlendorf, S.D., 2014. Structural heterogeneity increases diversity of non-breeding grassland birds. Ecosphere 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, 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, 106–111.
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, 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, 660–668.
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, 298–304. https://doi.org/10.1016/j.rama.2015.03.009.
NDAWN, 2022. North Dakota Agricultural Weather Network [WWW Document]. URL https://ndawn.ndsu.nodak.edu/ (accessed 2.13.22).
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. R package version 2.5-7. https://CRAN.R-project.org/package=vegan.
Ostfeld, R., Pickett, S., Shachak, M., Lickens, G., 1997. Defining scientific issues, in: Pickett, S.T.A., Ostfeld, R.S., Shachak, M., Likens, G.E. (Eds.), The Ecological Basis for Conservation: Heterogeneity, Ecosystems, and Biodiversity. Chapman and Hall, New York, pp. 3–10.
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, 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, 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, Vienna, Austria. https://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, 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, 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, 325–337. https://doi.org/10.1007/s10980-014-0133-9.

Sauer, J.R., Link, W.A., Fallon, J.E., Pardieck, K.L., Ziolkowski, D.J., 2013. The North American Breeding Bird Survey 1966–2011: Summary Analysis and Species Accounts. North American Fauna 79, 1–32. https://doi.org/10.3996/nafa.79.0001.

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, 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, 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: Pickett, S.T.A., Ostfeld, R.S., Shachak, M., Likens, G.E. (Eds.), The Ecological Basis for Conservation: Heterogeneity, Ecosystems, and Biodiversity. Chapman and Hall, New York, pp. 93–107. 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, 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, 185–197. https://doi.org/10.2193/0022-541x(2005)069<0185:viveod>2.0.co;2

Yield and Quality of Oats Grown for Forage

Justin Leier[1]

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

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 trial is a collaboration between the NDSU oat breeding program and the NDSU Central Grasslands Research Extension Center. A trial was designed that includes 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 2021 forage oats trial.

Variety	Type
Beach	Grain
Goliath (SD)	Dual Purpose
Newburg	Grain
Paul	Grain
ND000461	Grain
Souris	Grain
Jerry	Grain
Everleaf 126	Forage
Mustang 120	Forage

Methods

- Trial consisted of nine varieties, which are listed in Table 1.
- Plots were planted on May 3, 2021 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 lbs/acre.
- Plots were fertilized with 100 lbs/acre of urea and 100 lbs/acre of AMS on May 4.
- Weeds were controlled by a single application of Glyphosate and Sharpen according to product labels on May 4th, and by manual removal of volunteer rye during the growing season.
- 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

There were no significant differences found in the forage yield of the nine varieties tested. This may have been due to the tough growing conditions of 2021, during which we received very little rain. Another contributing factor may have been the infestation of gophers that damaged many of the plots prior to clipping. The highest yielding varieties were Paul and Everleaf 126 at 1.65 and 1.62 tons/acre, respectively. The lowest yielding varieties were Souris and Goliath at 1.21 and 1.16 tons/acre, respectively.

There were, however, significant differences ($P \leq 0.05$) for height among the varieties. The two tallest varieties were Mustang 120 standing 31 inches, and Goliath standing 28 inches tall. These varieties although not significantly different, were also two of the three lowest yielding varieties. The shortest variety was Everleaf 126, which measured in at 20.7 inches. Everleaf 126 has a later heading date than most varieties, which allows it to produce more leaf mass during that time. This delay and increased leaf production are possibly the explanation to why the shortest oat was the second highest yielding.

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--
Paul	55	74	24.3 cd	1.65a[a]
Everleaf 126	71	74	20.7 e	1.62a
Jerry	51	70	23.0 cde	1.37a
Newburg	54	74	23.3 cde	1.28a
ND000461	62	74	23.3 cde	1.26a
Beach	52	67	26.0 bc	1.25a
Mustang 120	55	74	31.0 a	1.22a
Souris	52	66	22.0 de	1.21a
Goliath	55	74	28.0 ab	1.16a
LSD			3.04*	NS

[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.

There are significant varietal differences for all of the feed quality parameter measured. Everleaf 126 proved a suitable forage check variety. This variety was highest in Ash, crude protein, calcium, magnesium and sulfur. The varieties with the next highest crude protein content are Souris, ND000461, and Jerry. When analyzing these varieties for acid detergent fiber content, Souris and ND000461 are the top performers with the lowest ADF. Everleaf was the third best variety in terms of ADF and Newburg had the next lowest ADF value.

These varieties also differed in content of calcium, phosphorus, potassium, magnesium and sulfur content. ND000461 had the second highest calcium content and tied with Souris for the highest phosphorus levels. Mustang 120, Goliath, and Newburg all had the second highest amount of phosphorus. Small but significant differences were also found for potassium, magnesium and sulfur.

Forage Production and Quality for Selected Varieties of Corn Silage

Scott Alm, Justin Leier, Michael Undi and Kevin Sedivec
NDSU Central Grasslands Research Extension Center

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 24 corn silage varieties in this trial ranged in dry matter yield from 3,890 to 7,442 lbs/acre. The highest producing variety was Peterson Farms Seed (PFS) 2LF95. The crude protein levels among all varieties ranged from 8.5 to 9.4 percent dry matter (DM). There were varietal differences ($P \leq 0.05$) for calcium, phosphorus, magnesium, and potassium, but not sulfur. Total digestible nutrients (TDN) ranged from 68.4 to 72.1 percent DM; the two varieties with the highest TDN were PFS 19L95 and REA Hybrids 4B958.

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, N.D. Experimental plots were grown on Williams-Zahl soils, which are classified as gravelly sandy loam soils on 6-9% slopes (USDA, Natural Resource Conservation Service, 2021). Growing conditions were not ideal in 2021. A severe drought struck much of the state including the Center, reducing forage production for all producers and our research trials alike.

Methods

- The trial was planted on May 14, 2021 using a John Deere 1700 MaxEmerge Plus (8 rows, 30 inches spacing). Seeds were planted two inches deep at a population of 26,000/acre.

- Nutrients were supplied based on soil testing and required starter fertilizer (40 lbs of phosphorus and 20 lbs of potassium per acre) and an application of 100 lbs/acre of urea and 100 lbs/acre of ammonium sulfate.
- Plots consisted of two rows, 100 ft in length, which is equal to 0.011 acres. There were 24 varieties; each variety was replicated three times (Table 1).
- 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 August 30, 2021using 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 recorded. A composite sample of each plot was taken as the wagon was unloaded and used to determine forage quality.
- Samples were sent to Dairyland Laboratories, Inc. for nutritional quality testing using near-infrared spectroscopy analysis.
- Data was analyzed as a randomized complete block design using the general linear model in SAS 9.4 (SAS Institute, Cary, N.C.). Significant differences of least square means at the $P \leq 0.05$ level were separated using t-tests.

Results

Corn varieties were analyzed for harvest weight, yield, dry matter, crude protein, acid detergent fiber (ADF), calcium, phosphorus, magnesium, potassium, sulfur, total digestible nutrients (TDN), net energy for growth (NeG), net energy for maintenance (NeM), and net energy for lactation (Nel 3x). There were significant differences among varieties for all tested parameters except crude protein and sulfur.

Table 2 presents all of the harvest and yield data. The top ten varieties ranged in yield from 6,291 – 7,442 lbs/acre dry matter; PFS 2LF95 and Proseed LFY101 were the highest yielding. When moisture is held constant at 65%, LFY101 yielded 10,712 lbs/ac and was not different (P>0.05) from the next ten highest yielding varieties. PFS 2LF95 was the second highest yielding variety and was different (P>0.05) from the six lowest yielding varieties.

Table 3 presents a selection of feed quality parameters tested for each variety. Crude protein (CP) exhibited no significant varietal differences. Acid detergent fiber (ADF) ranged from 22.47 – 27.75% DM, with an LSD of 1.29. The top three varieties with the lowest ADF content were, 19L95, 4B958, and 6B035. The ADF content of these three varieties were lower ($P \leq 0.05$) than the fourteen highest ADF varieties.

The silage varieties were tested for composition of five minerals, of which there are significant varietal differences for all minerals except sulfur. Table 3 shows the mean of each variety for calcium, phosphorus, magnesium, and potassium. Calcium means ranged from 0.29 (LC-3567) to 0.37 (STS102) % DM, with an LSD of 0.039.

Phosphorus, magnesium, and potassium all showed variability between varieties similar to or greater than that of calcium. Varieties 6B035 and E106Q6 had the highest phosphorus levels and were greater (*P*≤0.05) than the lowest twelve varieties. With magnesium, variety STS102 had the highest level and was greater (*P*≤0.05) than nineteen of the 24 varieties; however, the second highest variety was only greater (*P*≤0.05) than the three lowest performing varieties. Potassium levels were highest in variety STP5191, which was different from the eight varieties with the lowest potassium levels. Varieties LFY101 and 9227-3220A, which had the second and third highest potassium levels, were greater than the five lowest varieties.

Table 1. Corn silage trial varieties planted at CGREC in 2021.

Company	Variety	RM[1]
Croplan	CP 3200 S	92
Croplan	CP 3899 VT2P	98
Croplan	CP 4079	100
Croplan	CP 4100 SVT2P	101
Croplan	CP 4188	101
Integra	STP4810	98
Integra	STP5191	101
Legacy	LC-3567	95
Legacy	LC-4545	100
Legacy	LC555-21	100
NK	E095D3	95
NK	E105T1	105
NK	E106Q6	106
NK	9227-3220A	92
Peterson	2LF95	95
Peterson	19L95	95
Peterson	2LF01	101
Proseed	STS102	102
Proseed	LFY101	101
REA	4A301-RHDS	94
REA	4B958	95
REA	5A023	
REA	6B035	
REA	6A633-HDS	106

[1]Relative maturity (days)

Varieties 19L95 and 4B958 had the highest levels of total digestible nutrients (TDN). These varieties were greater (*P*≤0.05) than fourteen of the varieties. TDN values ranged from 68.41 – 72.11% DM with an LSD of 0.94.

Net energy was tested for lactation, growth and maintenance. There are varietal differences with all three measurements of energy, but we decided to report only net energy of growth (NeG). Variety 4B958, 6B035, 19L95 and E095D3 had the highest NeG levels at 46.37, 46.09, 46.08, and 45.86 Mcal/cwt; respectively. The NeG values ranged from 43.72 to- 46.37 Mcal/cwt, with an LSD of 0.74. The top two performing varieties were greater (*P*≤0.05) than sixteen of the varieties, while the next two top varieties were greater (*P*≤0.05) than the fourteen lowest varieties.

Table 2. Means of wet weight yield, 100% dry matter (DM) yield, and yield adjusted to 65% moisture for select silage corn varieties at CGREC, 2021.

Variety	Wet Weight	100% DM	65% Moisture Adjusted DM
	---------------------------------Lbs/acre---------------------------------		
LFY101	30,606	7,417 a[a]	10,712 a
2LF95	28,182	7,442 a	9,864 ab
2LF01	27,576	6,710 ab	9,652 abc
STP5191	27,273	6,576 ab	9,545 abc
E105T1	26,667	6,888 ab	9,333 abcd
6A633-HDS	25,758	6,729 ab	9.015 abcde
STP4810	24,848	6,474 ab	8,697 abcdef
LC555-21	24,848	6,261 ab	8,697 abcdef
CP 4100SVT2P	24,242	6,331 ab	8,485 abcdef
CP 4188	23,030	6,291 ab	8.061 abcdefg
LC-3567	22,727	6,050 abc	7.955 abcdefg
CP 3200S	22,424	6,027 abc	7,848 bcdefg
4A301-RHDS	21,212	5,659 abc	7,424 bcdefg
6B035	21,212	5,747 abc	7,424 bcdefg
LC-4545	20,909	5,423 abc	7,318 bcdefg
CP 4079	20,909	5,765 abc	7,318 bcdefg
9227-3220A	20,606	5,246 abc	7,212 bcdefg
4B958	20,606	5,675 abc	7,212 bcdefg
E095D3	19,455	5,614 abc	6,809 cdefg
E106Q6	18,788	5,284 abc	6,576 defg
CP 3899 VT2P	18,788	5,237 abc	6,576 defg
19L95	18,485	5,070 bc	6,470 efg
5A023	17,576	4,901 bc	6,152 fg
STS102	15,455	3,890 c	5,409 g
LSD	8,176.3*	2326.9*	2861.7*

[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.

References

USDA NRCS. 2021. United States Department of Agriculture, Natural Resources Conservation Service. Web Soil Survey. http://websoilsurvey.sc.egov.usda.gov/. Accessed 12/15/2021.

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

Table 3. Means for crude protein (CP), acid detergent fiber (ADF), calcium, phosphorus, magnesium, potassium, TDN, and NeG for select varieties of corn silage at CGREC, 2021.

Variety	CP	ADF	Calcium	Phosphorus	Magnesium	Potassium	TDN	NeG
	---% Dry Matter---							---Mcal/cwt---
LFY101	9.10	27.32 ab[a]	0.33bcd	0.20 def	0.26 bcd	1.44 ab	68.71 f	43.83 h
2LF95	8.50	25.86 cd	0.33 bcd	0.19 f	0.27 abc	1.24 cdef	69.74 de	44.65 efg
2LF01	9.08	27.46 ab	0.34 ab	0.21 cdef	0.27 bcd	1.41 abc	68.62 f	44.02 gh
STP5191	9.20	27.75 a	0.33 abc	0.21 cdef	0.25 bcd	1.46 a	68.41 f	43.72 h
E105T1	8.91	23.85 ef	0.31 bcd	0.22 abcd	0.26 bcd	1.23 cdef	71.14 bc	45.43 bcd
6A633-HDS	8.97	26.59 abc	0.32 bcd	0.20 ef	0.26 bcd	1.32 abcde	69.23 ef	43.78 h
STP4810	8.65	26.55 abc	0.30 bcd	0.19 f	0.26 bcd	1.26 bcdef	69.26 ef	45.05 gh
LC555-21	9.02	23.67 efg	0.32 bcd	0.21 bcde	0.27 abc	1.26 bcdef	71.27 abc	45.52bcd
CP 4100SVT2P	8.59	25.34 cd	0.30 bcd	0.20 def	0.25 bcd	1.33 abcde	70.10 de	44.62 efg
CP 4188	9.08	23.27 fg	0.33 abc	0.22 abc	0.28 ab	1.27 bcdef	71.55 ab	45.77 abc
LC-3567	8.52	25.54 cd	0.29 d	0.20 ef	0.24 d	1.28 abcdef	69.97 de	44.40 fgh
CP 3200S	8.70	26.45 bc	0.33 abc	0.20 ef	0.27 abc	1.29 abcdef	69.32 df	44.43 fgh
4A301-RHDS	8.64	25.74 cd	0.32 bcd	0.21 cdef	0.27 bcd	1.21 def	69.82 de	44.41 fgh
6B035	9.37	23.16 fg	0.33bcd	0.23 a	0.26 bcd	1.35 abcde	71.63 ab	46.09 ab
LC-4545	9.01	25.50 cd	0.33bcd	0.21 cdef	0.26 bcd	1.39 abcd	69.99 de	44.79 def
CP 4079	9.04	23.71 efg	0.30 cd	0.22 abc	0.24 cd	1.30 abcde	71.58 ab	45.75 abc
9227-3220A	9.36	24.93 de	0.33 abc	0.22 abcd	0.27 bcd	1.44 ab	70.39 cd	45.18 cde
4B958	8.97	22.75 fg	0.32 bcd	0.22 abc	0.27 bcd	1.29 abcdef	71.92 ab	46.37 a
E095D3	8.87	23.82 ef	0.30 bcd	0.21 bcd	0.24 d	1.29 abcdef	71.16 abc	45.86 ab
E106Q6	9.25	23.73 efg	0.32 bcd	0.22 ab	0.25 bcd	1.36 abcde	71.23 abc	45.77 abc
CP 3899 VT2P	8.60	24.63 de	0.32 bcd	0.21 cdef	0.27 bcd	1.19 ef	70.59 cd	45.07 cdef
19L95	8.68	22.47 g	0.31 bcd	0.22 abcd	0.26 bcd	1.11 f	72.11 a	46.08 ab
5A023	9.12	23.82 efg	0.33 abcd	0.22 abc	0.27 bcd	1.31 abcde	71.16 abc	45.82 abc
STS102	9.07	25.89 cd	0.37a	0.21 bcdef	0.31 a	1.34 abcde	69.72 de	44.41 fgh
LSD	NS	1.29*	0.039*	0.014*	0.034*	0.184	0.94*	0.74

[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.

Quality of silage from corn hybrids ensiled at varying moisture contents

Michael Undi, Scott Alm, Justin Leier and Kevin Sedivec
NDSU Central Grasslands Research Extension Center, Streeter, N.D.

The effect of moisture content at ensiling on silage quality was evaluated in 12 early- and late-maturing corn hybrids. The hybrids, with moisture concentrations ranging from 60 to 72%, were ensiled in laboratory silos for 68 days. Generally, ensiling corn hybrids at 60 to 72% moisture produced good-quality silage. However, quality of silage improved with increasing moisture concentration. Moisture content is critical and selecting silage corn hybrids with a narrow range in relative maturity reduces variation in moisture concentration and would lead to more uniform silage quality.

Summary

This study was conducted to evaluate the effect of moisture concentration at ensiling on silage quality. Twelve early- and late-maturing corn hybrids with moisture concentrations ranging from 60 to 72% were ensiled in laboratory silos and stored at 21°C in a temperature-controlled room for 68 days. Silage pH and concentrations of lactic acid, acetic acid and total acids were higher ($P \leq$ **0.05)** in hybrids ensiled at 72% moisture relative to those at 60% moisture. Regression analysis indicated that moisture concentration at ensiling was a significant predictor ($P \leq$ **0.05)** of silage pH, lactic acid, acetic acid and total acids, explaining 84, 55, 65, and 52%, respectively, of the variation in these silage quality attributes. These results suggest that reducing variation in moisture concentration by selecting silage corn hybrids with a narrower range in relative maturity would lead to more uniform silage quality.

Introduction

Corn silage is an important forage source for North Dakota's 1.95 million beef cattle. Annually, 2.45 million tons of corn was harvested for corn silage from 151,000 acres in North Dakota during the last five years (USDA/NASS, 2016-2020). The popularity of corn silage among North Dakota producers is based on high dry matter and nutrient yield of corn silage as well as ease of incorporation into total mixed rations for beef and dairy cattle. Unlike hay, large amounts of corn can be conserved rapidly as silage in a short time period, thus reducing risk of damage from inclement weather.

Seed companies are developing new silage corn hybrids that are better adapted to the climate of northern and western North Dakota (Dahlen and Meehan, 2018). Both early- and late-maturing silage corn hybrids are available in North Dakota. Selection of hybrids with varying maturity may widen the harvest window but can cause considerable variation in moisture concentration at harvest (Coulter, 2018).

Moisture concentration at ensiling has substantial effects on silage fermentation (Muck and Kung, 2007). A recent survey in North Dakota (Dahlen and Meehan, 2018) showed that moisture concentration of silages produced in North Dakota is variable, ranging from 28 to 80%.

This study was conducted to evaluate the quality of silage from new silage corn hybrids ensiled at various moisture concentrations. Early- and late-maturing silage corn hybrids were selected for the study.

Procedures

Twelve silage corn hybrids ranging in relative maturity from 94 to 111 days were planted in experimental plots at Central Grasslands Research Extension Center near Streeter, N.D. on May 28, 2020, using a John Deere 1700 MaxEmerge Plus. Experimental plots were situated on Wabek-Appam soils classified as gravelly sandy loam soils on 6 to 9% slopes. Plots were fertilized with 44.8 kg/ha phosphorus, 22.4 kg/ha potassium and 224 kg/ha urea following North Dakota Soil Testing laboratory recommendations after soil tests. The plots were harvested on Sept. 7, 2020 using a two-row Gehl corn chopper that deposited forage directly into a Knight mixer/feed wagon equipped with a digital scale.

Approximately 500 g of forage sample from three replicates of each hybrid was ensiled in 30- x 22-cm polyethylene bags (Sunbeam Products; foodsaver.com). The bags were vacuum-sealed using a commercial sealer (Maxvac 250, LEM Products, West Chester, OH, lemproducts.com) and stored at 21°C in a temperature-controlled room for 68 days. The silage corn hybrid samples were sent to Dairyland laboratories (Dairyland Laboratories Inc., St. Cloud, Minn., lab) for silage quality (pH, lactic acid, acetic acid, and butyric acid) analysis.

Results and Discussion

Moisture concentration at time of ensilage was higher ($P \leq \mathbf{0.05}$) in late-maturing hybrids relative to early-maturing hybrids (data not shown). Silage pH was lower ($P \leq \mathbf{0.05}$) in late-maturing hybrids relative to early-maturing hybrids. Concentrations of lactic and acetic acid were higher ($P \leq \mathbf{0.05}$) in late-maturing hybrids relative to early-maturing hybrids. Ethanol concentration was low in all silages. Ammonia as a percentage of crude protein was low, ranging from 3.7 to 5.2%, and did not differ among hybrids. Silage pH was lower and concentrations of lactic acid, acetic acid, and total acids were higher ($P \leq \mathbf{0.05}$) in hybrids ensiled at 72% moisture as compared to those with 66% moisture or less (Table 1). Regression analysis indicated that moisture concentration at ensiling was a significant predictor of silage pH, lactic acid, acetic acid and total acids explaining 84, 55, 65, and 52%, respectively, of the variance in these attributes (Figure 1).

Typical corn silage will have pH between 3.7 and 4.2, and contain 4 to 7% lactic acid, 1 to 3% acetic acid, 1 to 3% ethanol, 5 to 7% ammonia-N, and no butyric acid (Kung and Shaver 2001). Based on criteria for typical corn silage, ensiling corn hybrids at 60 to 72% moisture generally produced good quality silages. Reducing variation in moisture concentration by selecting silage corn hybrids with a narrow range in relative maturity would lead to more uniform silage quality.

Acknowledgments

We thank Stephanie Becker, Tim Long and Cody Wieland for technical assistance.

Literature Cited

Coulter, J. 2018. Selecting corn hybrids for silage production. University of Minnesota Extension. https://extension.umn.edu/corn-hybrid-selection/selecting-corn-hybrids-silage-production

Dahlen, C. and Meehan, M. 2018. Corn silage quality program. 2018 Beef and Sheep Report. P.18. https://www.ag.ndsu.edu/publications/livestock/2018-north-dakota-beef-and-sheep-report-1#section-26

Kung, L. and Shaver, R. 2001. Interpretation and use of silage fermentation analysis reports. *Focus on* **Forage. Vol.** 3 (no. 13): pp 1-5. https://fyi.extension.wisc.edu/forage/files/2014/01/Fermentation.pdf

Muck, R.E. and Kung, L. 2007. Silage production. In: Barnes, R.F., Nelson, C. J., Moore, K. J. and Collins, M. (Editors) Forages: The Science of Grassland Agriculture, Volume II. 6th edition. Ames, IA: Blackwell Publishing. p. 617-633.

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

Table 1. Effect of moisture concentration at ensiling on silage pH and concentration of organic acids, ethanol and ammonia.

	Moisture concentration at ensiling, %							
	60	62	64	66	69	72	SE	*P*
pH	3.90[ab]	3.92[a]	3.87[bc]	3.83[c]	3.76[d]	3.73[d]	0.022	<0.001
Lactic acid, %	5.56[c]	5.49[c]	6.04[bc]	5.94[bc]	6.98[ab]	7.83[a]	0.546	0.001
Acetic acid, %	1.28[c]	1.30[c]	1.58[bc]	1.63[bc]	1.88[ab]	2.10[a]	0.204	0.002
Butyric acid	ND[1]	ND	ND	ND	ND	ND		
Propionic acid	ND	ND	ND	ND	ND	ND		
Total acids	6.83[b]	6.78[b]	7.46[b]	7.57[b]	9.20[a]	10.13[a]	0.695	<0.001
Lactic:Acetic[2]	4.39[a]	4.25[a]	4.00[ab]	3.88[ab]	3.56[b]	3.62[b]	0.273	0.027
Lactic, % total	81.4[a]	80.8[a]	79.9[ab]	79.3[ab]	77.9[b]	78.0[b]	1.13	0.019
Ethanol, %	0.48[a]	0.49[a]	0.44[a]	0.38[ab]	0.33[b]	0.42[ab]	0.047	0.020
Ammonia, %CP	4.09	4.62	4.40	4.67	4.69	5.07	0.324	0.080

Means within a row with different superscripts differ ($P \leq 0.05$).

[1]Not detected.
[2]Lactic acid to acetic acid ratio.

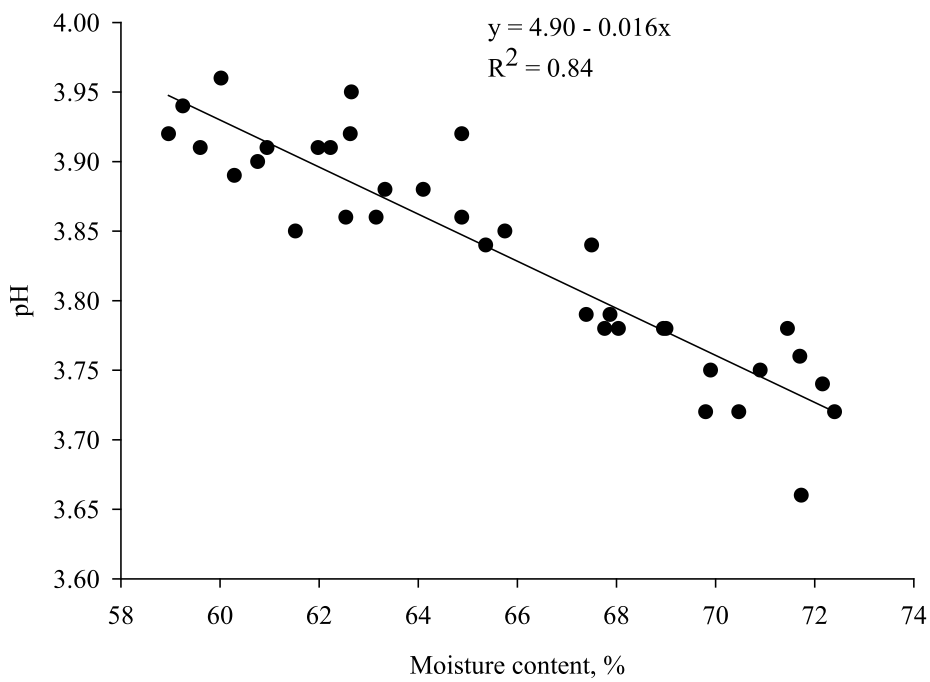


Figure 1. Effect of moisture concentration at ensiling on silage pH.

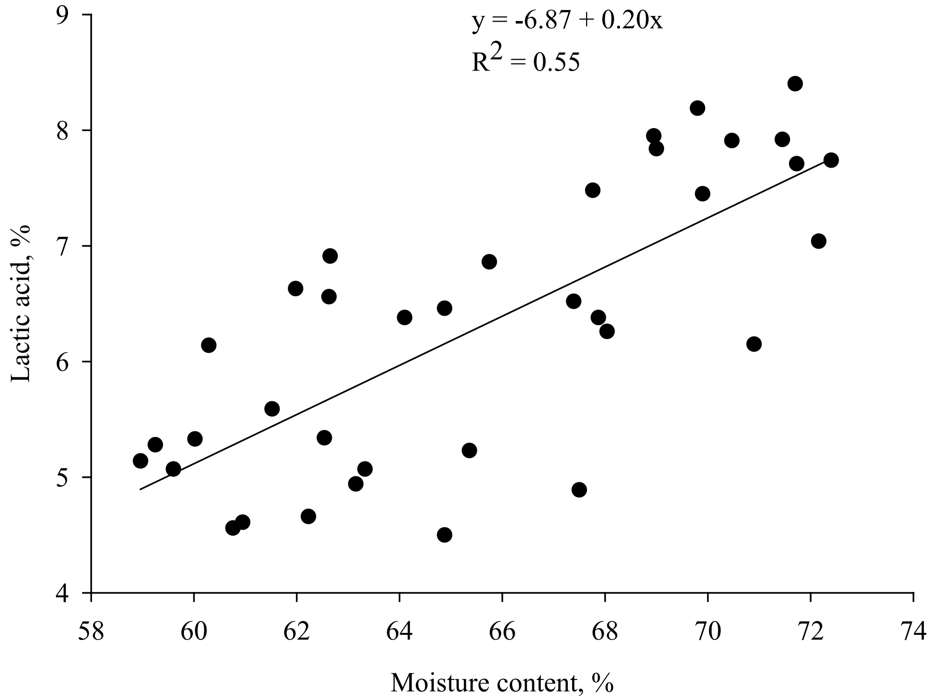


Figure 2. Effect of moisture concentration at ensiling on silage concentration of lactic acid

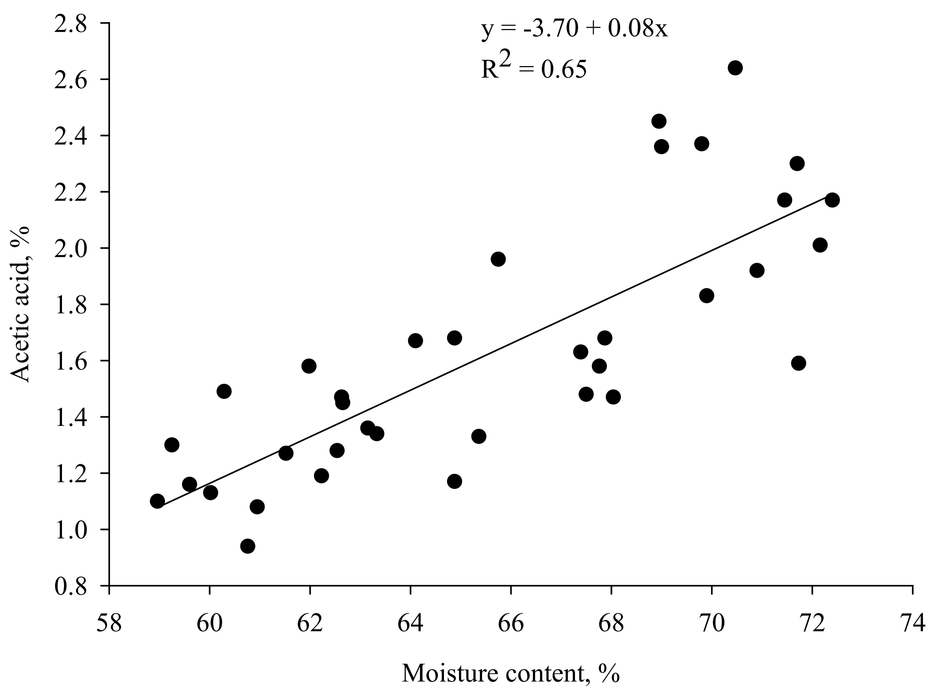


Figure 3. Effect of moisture concentration at ensiling on silage acetic acid.

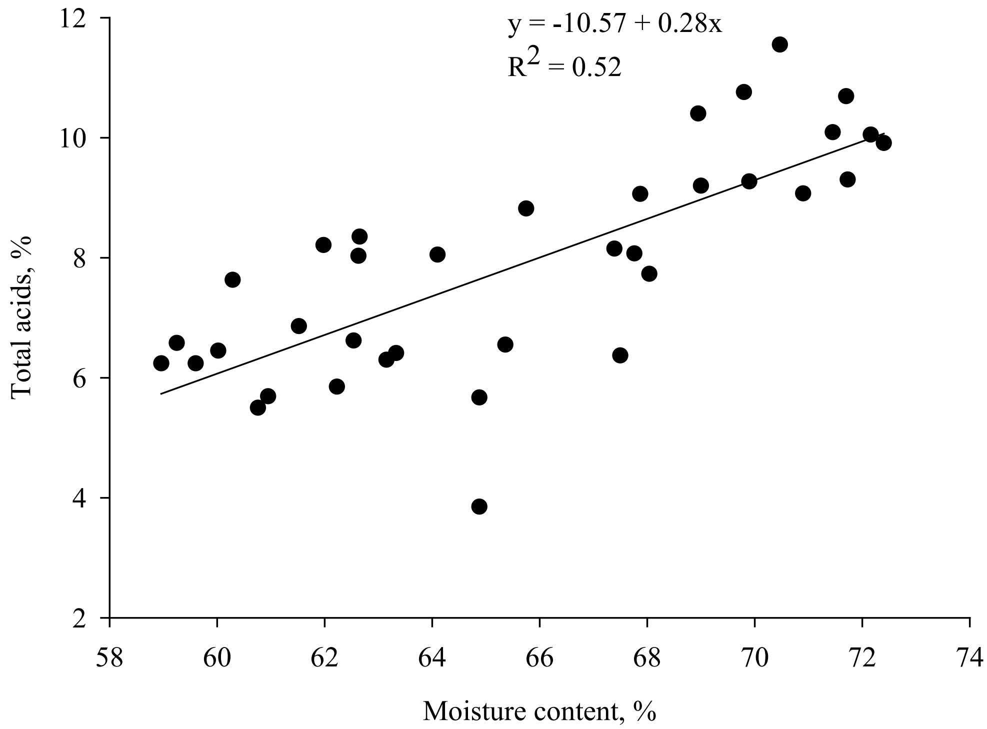


Figure 4. Effect of moisture concentration at ensiling on silage total acids.

Nutritive value and forage yield of annual forage mixes compared with forage sorghum and millet monocrops

Marisol Berti[1], Kenneth Mozea[1] and Kevin Sedivec[2]

[1]Department of Plant Sciences, North Dakota State University, Fargo, N.D.
[2]Central Grasslands Research Extension Center, North Dakota State University, Streeter, N.D.

Plants that develop in a single growing season and are sown on land to be grazed, hayed, or ensiled are known as annual forages. The bulk of these annual forages are summer annuals or spring/winter annuals (Drewnoski and Redfearn, 2017). There are usually more than two annual forage species in an annual forage mix. A mix includes different species with distinct physiological activities that complement one another, such as nutrient scavenging, biological nitrogen fixation, creeping growth, and edible leaves, resulting in increased forage nutritional value and vegetative soil cover (Diaz and Cabido, 2001). At least one grass, legume, and brassica are commonly included in a nutritious annual grazing mix (Sedivec et al., 2020).

Annual forage mixtures, however, can be challenging to establish and manage, especially when species have variable seed sizes, growth rates, herbicide tolerance, and harvest needs, as well as the risk of intraspecific competition (Wortman et al., 2013).

The objective of this research was to evaluate the productivity and nutritive value of forage mixes as compared with forage sorghum and millet monocrops.

Procedure

The research utilized a randomized complete block design and was conducted at the NDSU-Central Grasslands Research Extension Center near Streeter, N.D. The soil is a Hecla-Ulen loamy fine sand with little water storage and a 0% to 6% slope (U.S. Department of Agriculture, Natural Resources Conservation Service, 2020). Except for the end of August and September, rainfall in 2021 was below normal throughout the period of the study.

Twelve treatments were created from the combination of seventeen different species. These treatments consist of seven annual forage mixes (Treatments 1-7) and five monocrops (Treatments 8-12). Treatment 1 was created for frequent high-quality grazing; Treatment 2 was created for fall grazing only; Treatment 3 and 4 were created to maximize the nutritional value of the forage sorghum cultivars in the mix; Treatment 5 and 6 were brassica/warm-season annual grass mixes created to optimize forage quality; and Treatment 7 was created to increase biodiversity (Table 1).

On 25 May 2021, all treatments were seeded using an eight-cone continuous plot drill with a row spacing of 6-inches for combination treatments and 12-inches for monocultures, except Treatment 2, which was a brassica mix and was planted on 30 June 2021. No tillage activities have been in this research site for at least the previous six years. Before sowing, all plots were fertilized with 71 N lb/acre and 89 lb/acre of P_2O_5.

Table 1. Seeding rate of annual forage mixtures at Streeter, N.D.

Treatment	Crops	Cultivar	Seeding rate
			lbs/acre
1	Annual ryegrass	Crusader	12
	Chicory	Choice	2
	Plantain	Tonic	3
	Red clover	Relish/Emarwan	3
2	Hybrid brassica	Winfred	2
	Turnip	New York	2
3	Hybrid brassica	Winfred	2
	Oat	Paul	5
	Forage pea	Arvika	5
	Forage sorghum x sudangrass/ sweet sorghum blend	Pampa Legion BMR-6†	2
	Foxtail millet	Siberian	2
4	Turnip	New York	1
	Forage sorghum x sudangrass/ sweet sorghum blend	Pampa Tribuno XLT‡ BMR-6	2
	Forage pea	Arvika	5
	Hybrid brassica	Winfred	1
	Oat	Paul	2
	Faba bean	Sampo	2
	Forage pearl millet	Pampa Mijo II BMR-6	2
5	Forage pearl millet	Pampa Mijo II BMR-6	5
	Hybrid brassica	Winfred	2
6	Forage sorghum x sudangrass	ADSGS6504 BMR-6, brachytic	2
	Radish	Graza	2
7	Oat	Paul	5
	Phacelia	VNS	1
	Forage pea	Arvika	5
	Faba bean	Sampo	5
	Forage sorghum x sudangrass	AF7101 BMR-6	3
8	Forage sorghum x sudangrass/ sweet sorghum blend	Pampa Legion BMR-6	10
9	Forage pearl millet	Pampa Mijo II BMR-6	10
10	Forage pearl millet	Pampa Mijo Platino	10
11	Forage sorghum x sudangrass	AF7101 BMR-6	10
12	Forage sorghum x sudangrass	ADSGS6504 BMR-6	10

† Pampa Legion is a physical blend that contains 80% of Pampa Verde (BMR-6 trait, photoperiod sensitive) and 20% of Pampa Karamelo (sweet sorghum cultivar).
‡ Pampa Tribuno XLT is a physical blend that contains 80% of Pampa Triunfo XLT (BMR-6 trait) and 20% of Pampa Karamelo (sweet sorghum cultivar).
VNS, Variety not stated

There was just one harvest, which occurred on 15 September 2021. Wet weight was recorded using a flail forage harvester, and a sample was obtained to evaluate moisture. The fresh sample was then dried and used to calculate the dry matter yield of the total plot. The sample dry matter was used to calculate the total plot moisture level. Nutritional values of samples were analyzed at the North Dakota State University Nutrition Lab using AOAC standards (AOAC, 2019). Using near-infrared (NIR) spectroscopic equipment, the wet chemistry data for biomass mixes was calibrated. The method devised by the National Research Council in 2001 (NRC, 2001) was used to estimate total digestible nutrients (TDN).

The experiment used a four-replicate randomized complete block design. Data was analyzed using SAS (SAS version 9.4: SAS Inst. Inc., Cary, N.C.). The means were separated using the least significant difference (LSD) at a 5% significance level.

Results

The weather (rainfall and temperature) had a significant impact on the biomass output of annual forage combinations in Streeter. The rainfall was lower than the 30-year normal, with lengthy durations of no rain between May and July (NDAWN, 2021). During the research, the total rainfall in Streeter was 175 mm, and the average air temperature at sowing was 50.4 °F. The total rainfall during the first week of planting was 4 mm, and the average soil temperature was below 59 °F (15 ºC), the recommended temperature for producing forage sorghum (Thomas and Miller, 1979); as a result, forage development was slow (Fig. 1).

Biomass yield for Treatment 4 (turnip/forage sorghum x sudangrass/sweet sorghum blend/forage pea/hybrid brassicas/oat/faba bean/forage pearl millet) and Treatment 6 (forage sorghum x sudangrass/radish mix) were 1.2 and 1.3 tons/acre, respectively. The maximum biomass output for mixes was similar to the overall average biomass yield of monocrops in a single harvest (Fig. 2). Except for Treatment 4 and 6, monocrops (Treatments 8-12) yielded significantly ($p \leq 0.05$) more than mixes. The brassica mixture of turnip and hybrid brassica (Treatment 2), at 0.2 tons/acre, produced the least biomass yield (Fig. 2)

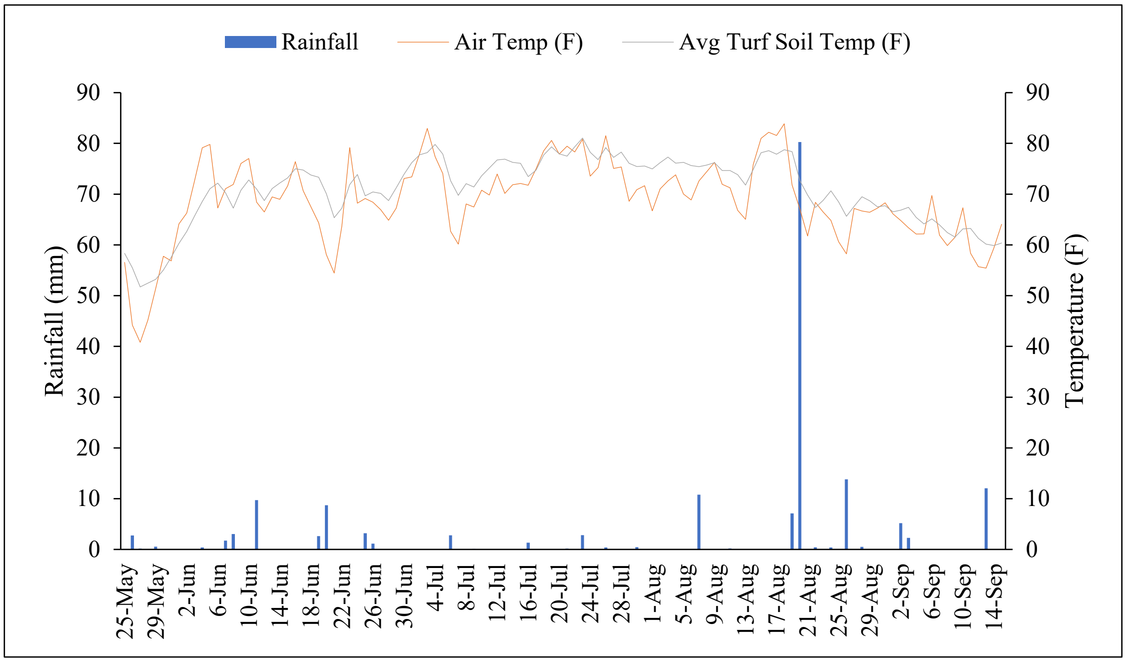


Fig.1 Total daily rainfall, daily average soil and air temperature at the Central Grassland Research Extension Center near Streeter, N.D. (NDAWN, 2021).

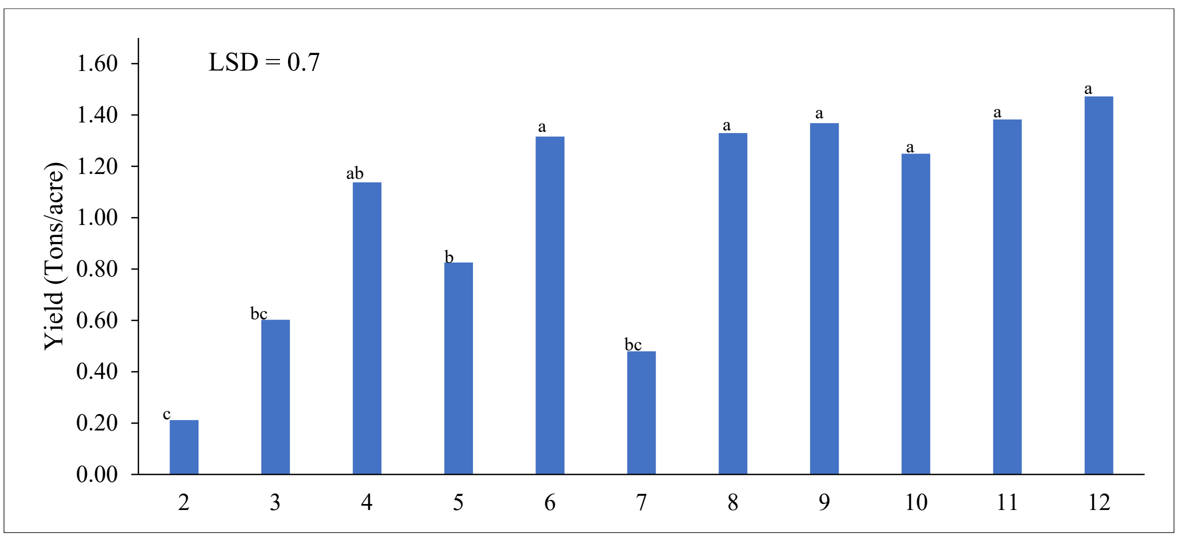


Fig. 2. Biomass yield of annual forage mixtures at the Central Grasslands Research Extension Center in 2021. Forage mixes: 2) hybrid brassica and turnip; 3) hybrid brassica, oat, forage pea, and forage sorghum x sudangrass/sweet sorghum blend and foxtail millet; 4) turnip, forage sorghum x sudangrass/ sweet sorghum blend, forage pea, hybrid brassica, oat, faba bean and forage pearl millet; 5) forage pearl millet and hybrid brassica; 6) forage sorghum x sudangrass and radish; and 7) oat, phacelia, forage pea, faba bean, and forage sorghum. Monocrops: 8) forage sorghum x sudangrass/sweet sorghum blend; 9) forage pearl millet; 10) forage pearl millet; 11) forage sorghum x sudangrass; and 12) forage sorghum x sudangrass. Different letters indicate significant difference ($p \leq 0.05$).

With a seeding rate of 2 lbs/acre in mixes, forage sorghum dominated the annual forage mixes in which it was included. Mixes containing forage sorghum and/or pearl millet yielded significantly more than mixes without it (see Hassan et al., 2015). The annual ryegrass/chicory/plantain/red clover mix (Treatment 1) did not survive, which might be attributed to the cool-season nature of its individual species in the mix. Due to delayed rainfall and primarily high temperatures over the research period, this annual mixture (Treatment 1) may have been stressed, resulting in its incapacity to compete (see Butler at al., 2017).

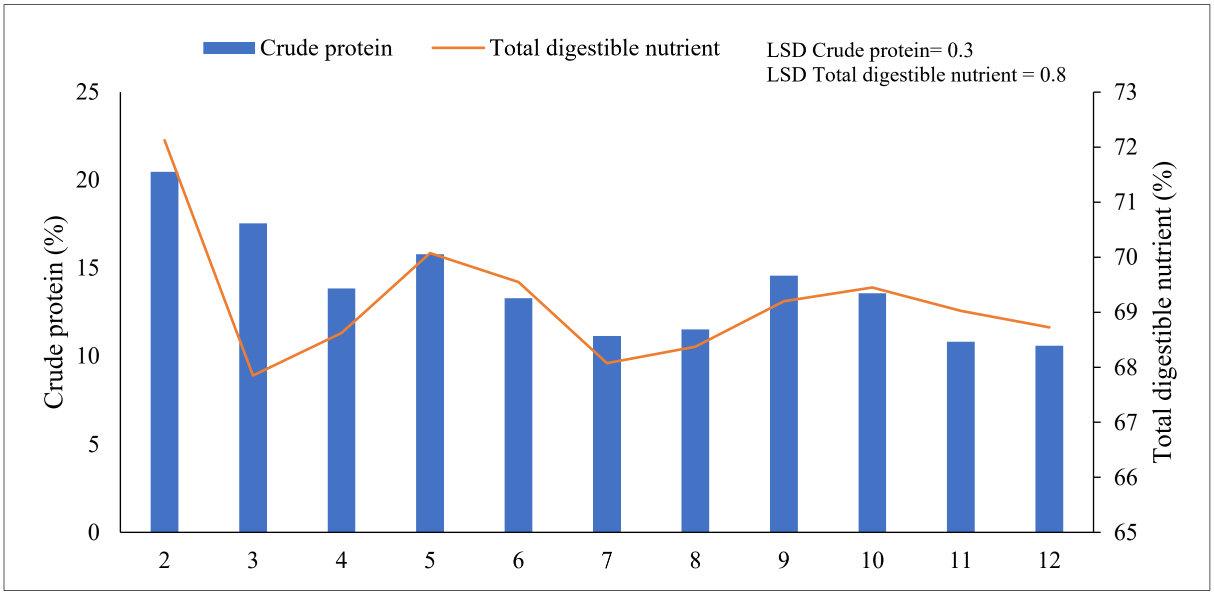


Fig. 3. Crude protein and total digestible nutrients of annual forage mixtures and monocrops in 2021 at the Central Grassland Research Extension Center in 2021. Forage mixes: 2) hybrid brassica and turnip; 3) hybrid brassica, oat, forage pea, and forage sorghum x sudangrass/sweet sorghum blend and foxtail millet; 4) turnip, forage sorghum x sudangrass/ sweet sorghum blend, forage pea, hybrid brassica, oat, faba bean and forage pearl millet; 5) forage pearl millet and hybrid brassica; 6) forage sorghum x sudangrass and radish; and 7) oat, phacelia, forage pea, faba bean, and forage sorghum. Monocrops: 8) forage sorghum x sudangrass/sweet sorghum blend; 9) forage pearl millet; 10) forage pearl millet; 11) forage sorghum x sudangrass; and 12) forage sorghum x sudangrass. Different letters indicate significant difference ($p \leq 0.05$).

The forage brassica mixes of turnip and hybrid brassica (Treatment 2) had significantly ($p \leq 0.05$) the highest crude protein (20.5%) and total digestible nutrients (72.1%) (Fig. 3). Brassicas as feeds for grazing are highly nutritious as they have proven to improve the body weight and average daily gain (ADG) of brassica-fed lambs than oat-fed lambs (Campbell et al., 2021). All mixtures and monocrops met the minimum total digestible nutrient requirements for grazing animals (60%) (NASEM, 2016). There was no difference between the total digestible nutrients of mixes and monocrops. However, this is due to the dominance of forage sorghum in the annual mixes. Forage sorghum brown mid-rib (BMR) and forage pearl millet are high yielding biomass crops, and have proven to increase ADG of finishing cattle by 0.99 kg d^{-1} and 0.85 kg d^{-1}, respectively (Harmon et al., 2019).

Conclusions

Forage yield of monocrops was higher than that of forage mixes with the exception of Treatment 4 (turnip/forage sorghum x sudangrass/sweet sorghum blend/forage pea/hybrid brassicas/oat/faba bean/forage pearl millet) and Treatment 6 (forage sorghum x sudangrass/radish). The seeding rate of forage sorghum x sudangrass in Treatments 4 and 6 was only 2 lbs/acre, but even at that low seeding rate, it dominated the mixes. The nutritive value was highest for the Treatments 2 and 3. Crude protein was highest for Treatment 2, which had turnip and a hybrid forage brassica.

References

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

Butler, T.J., A.E. Celen, S.L. Webb, D.B. Krstic, and S.M. Interrante. 2017. Germination in cool-season forage grasses under a range of temperatures. Crop Sci. 57: 1725-1731. https://doi.org/10.2135/cropsci2015.10.0647

Campbell, B.J., C.H. Gelley, J.S. McCutcheon, F.L. Fluharty, and A.J. Parker. 2021. A comparison of annual forages and stockpiled pasture on the growth and health parameters of grazing fall-born lambs. Small Ruminant Res., 196. http://doi.org/10.1016/j.smallrumres.2021.106335

Díaz, S. and M. Cabido. 2001. Vive la difference: plant functional diversity matters to ecosystem processes. Trends Ecol. Evol. 16: 646-655. http://doi:10.1016/S0169-5347(01)02283-2

Drewnoski, M. and D. Redfearn. 2017. Planting annual forages. Nebraska Extension. University of Nebraska-Lincoln. Lincoln, NE. https://beef.unl.edu/planting-annual-forages#sub1 (accessed 28 July 2021)

Harmon, D.D., D.W. Hancock, R.L. Stewart, J.L. Lacey, R.W. McKee, J.D. Hale, and C.L. Thomas. 2019. Warm-season annual forages in forage-finishing beef systems: I. Forage yield and quality. Transl. Animal Sci. 3(2):911-26. http://doi:10.1093/tas/txz075

Hassan, S.A., M.I. Mohammed, and S.O. Yagoub. 2015. Breeding for dual purpose attributes in sorghum: Effect of harvest option and genotype on fodder and grain yields. J. Plant Breeding Crop Sci. 7:101-106. http://doi:10.5897/JPBCS2015.0498

NASEM, National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient Requirements of Beef Cattle, eighth revised edition. Washington, DC: The National Academies Press. https://doi:10.17226/19014.

NDAWN. 2021. North Dakota Agricultural Weather Network (NDAWN). North Dakota State University. https://ndawn.ndsu.nodak.edu

NRC, 2001. Nutrient requirements of dairy cattle. National Research Council. 7th rev. ed. Natl. Acad. Sci., Washington D.C.

Sedivec, K., M. Meehan, E. Gaugler, M. Berti, and P. Nester. 2020. Annual cover crop options for grazing and haying in the northern plains. North Dakota State Univ. Ext Bull. R1759,

Rev. Ed. Fargo, ND. https://www.ag.ndsu.edu/publications/livestock/annual-cover-crop-options-for-grazing-and-haying-in-the-northern-plains (accessed 22 November, 2021)
Thomas, G. L. and F.R. Miller. 1979. Base temperature for germination for temperature and tropically adapted sorghums. *In*: Proceedings of the 11th Biennial Grain Sorghum Research and Utilization Conference. 1979 Feb. 28–Mar. 02. Grain Sorghum Producers Association, Lubbock, TX. p. 24.
USDA, NRCS. 2020. Web Soil Survey. Natural Resources Conservation Service (NRSC). [Online] Available at https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx (accessed Dec. 27, 2020).
Wortman, S.E., C.A. Francis, M.A. Bernards, E.E. Blankenship, and J.L. Lindquist. 2013. Mechanical termination of diverse cover crop mixtures for improved weed suppression in organic cropping systems. Weed Sci. 61: 162–170.

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

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

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

Summary

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 on the influence of stock density and 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; Franzluebbers 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 western part of the Northern Great Plains is limited (Faust et al., 2018). Livestock management decisions like 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 during the spring of 2020. NDSU Extension partnered with producers to establish six research sites located in central North Dakota, along with a demonstration site near the main campus of NDSU. An annual forage crop was subjected to two grazing density treatments: moderate and high. Additionally, two forage utilization rates were evaluated: 50% and 75%. A non-grazed treatment served as the control. Treatments were imposed for two years and will be followed by a cash crop in 2022.

Each location was developed to test grazing density treatments in a split-plot design. Three producers implemented the high stock density at two utilization rates (50% and 75%), while three producers implemented the moderate stock density at the same two utilization rates. The Fargo location provided a demonstration of all treatments and utilization rates. It should be noted that during the second year of the project, the high stock density treatment at Napoleon was discontinued.

Forage Establishment

The annual forage crop planted by mid-June of 2020 and 2021 included oats, sorghum sudangrass, foxtail millet, sunflower, radish, kale, turnip, flax and forage pea seed seeded at a rate of 18, 3, 2, 1.5, 1, 0.75, 0.75, 2 and 10 lbs/ac, respectively. Following two years of an annual forage crop, corn will be planted during the spring of 2022.

Livestock and Grazing Management

Cattle were randomly assigned to grazing density treatments and carrying capacities were determined based on available forage production and estimated utilization. Stocking rates were determined by dividing the available forage by anticipated dry matter intake per day, then dividing by 30 days of planned grazing to predict the number of cows per plot. The available forage for 50% and 75% utilization treatments was calculated at 35% and 50% 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). The moderate stock density was based on the recommended stocking rate for a 30-day period. The high stock density was set at double the moderate stock density and the grazing period reduced so as to ensure the treatment was not overgrazed. In general, grazing turnout dates ranged from August to early October of each year.

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 at each ICLS site as well as from a nearby field that was managed as part of a traditional cash crop system. 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 sampling.

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 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), carbon (C), 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 C, pH, OM and SO_4-S.

Forage Production and Utilization

Forage production and utilization of the annual crop was estimated by clipping six 59-inch diameter hoops per experimental treatment. Clipping for peak biomass production occurred during the week prior to grazing and turnout dates commonly ranged from August to early October. Clipping to determine forage utilization occurred upon removal of cattle from the grazing treatments.

Livestock Performance

Beef cattle were stratified by a 1-day body weight and body condition score pre- and post-treatment at the Fargo location, whereas cattle at the other research sites were scored for their body condition only. A visual scoring system developed by Wagner et al. (1988) was used to assess body condition.

Project Update

Spring conditions were dry during 2020 and 2021(Table 1). In fact, the only locations that did not start with a major deficit of moisture at the beginning of the project were at Fargo and Lehr. Aside from precipitation, it is important to note that field conditions (soil type, crop history, management, etc.) are variable from site to site and may also be reflected in forage production (Table 2). For example, seeding depth was not consistent during the first year. The annual forage crop at Fargo and Jamestown was seeded to a depth greater than ¾ inch and experienced little to no germination of brassicas, which impacted both forage production and quality. Fargo and Jamestown sites produced the least amount of forage in 2020, averaging 5,600 and 6,800 lbs/acre, while the rest of the sites averaged 6,900 to 12,200 lbs/acre. Though seeding depth was a challenge, strategies for successful field preparation were discussed and the problem did not persist during the 2021 planting season.

Table 1. Average monthly precipitation levels and seasonal totals (inches) by month and year as compared to normal (30-year average) at each project location during the 2020 and 2021 growing season.

		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
	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
	Normal	2.7	3.5	3.3	2.1	2.3	1.7	15.6
McKenzie[1]	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
	Normal	2.4	3.2	2.9	2.3	1.6	1.3	13.7
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
	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
	Normal	2.4	3.2	2.6	2.1	1.6	1.4	13.3
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
	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 (2021).
[2] Data obtained from or near specific locations affiliated with the National Weather Service (2021).

Despite widespread drought in 2021, most locations were able to catch rain during the fall. The late season moisture was especially beneficial for the Fargo, Jamestown, Lehr and Tappen sites, boosting growth and/or re-growth of annual forage species. Even though the rain was helpful, the overwhelming lack of subsoil moisture resulted in limited forage production across all sites except for Fargo. Average forage production at each location ranged from 3,300 to 7,200 lbs/acre with Fargo having the highest production.

Drought conditions in 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. Type and class of cattle varied from site to site and grazing turnout ranged from the end of August to early October. Livestock response to forage quality was variable (Table 3). It should be noted that livestock weight is subject to considerable fluctuation day to day and only 1-day weights were collected in Fargo.

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

	Treatment		2020			2021		
Location	Stock Density	Grazing Utilization (%)	Production (lbs/ac)	Carrying Capacity (AUMs/ac)	Degree of Use (%)	Production (lbs/ac)	Carrying Capacity (AUMs/ac)	Degree of Use (%)
Fargo	No grazing	0	3914			5459		
	High	75	5671	2.32	62	8767	3.59	75
		50	4892	1.40	47	5350	1.53	55
	Moderate	75	6249	2.56	68[1]	5681	2.33	65
		50	6940	1.99	56	7972	2.29	61
Jamestown	No grazing	0	6548			3653		
	High	75	6490	2.66	51[1]	5037	2.07	69
		50	7181	2.06	44[1]	6054	1.74	54
McKenzie	No grazing	0	8079			4022		
	High	75	7714	3.16	71	3177	1.3	72
		50	9333	2.68	58	2392	0.69	51
Lehr	No grazing	0	14437			4903		
	Moderate	75	11017	4.52	60	4381	1.80	49[1]
		50	12725	3.65	52	5015	1.44	50
McClusky	No grazing	0	6375			3605		
	Moderate	75	6893[2]	0.99	44[1]	6187	0.89	63
		50	7164	2.06	32	4733	1.36	57
Tappen	No grazing	0	6444			2659[3]		
	Moderate	75	8782	3.60	61[1]	3485[3]	0.57	75
		50	10536	3.02	43[1]	4228[3]	0.49	49

[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.

Type and class of cattle varied from site to site and grazing turnout ranged from late July to early October of 2021. Producers were encouraged to graze the annual forage cover crop earlier than the previous year, so that forages would offer more grazing quality to livestock. Persistent drought conditions caused concern for nitrate toxicity and prussic acid poisoning. Samples were collected and tested prior to grazing turnout to ensure that forages were safe. The livestock response to forage quality continued to be variable (Table 3). Forage re-growth was substantial enough in Jamestown and McKenzie that treatments were re-grazed to maintain the assigned forage utilization.

Soil samples were collected to characterize physical, chemical and biological properties. Information collected in year one will serve as a baseline for evaluating response to treatments. Soil nutrient data, extracted from 0-6 inches, from year one is reported in Table 4. No other measurements were collected in 2021.

Summary

Rainfall and subsoil moisture influenced forage production and quality during 2020 and 2021. Late season moisture during 2021 was extremely helpful and allowed us to graze sites like Tappen that would have otherwise been abandoned due to poor germination. Other sites like Jamestown and McKenzie had substantial regrowth and were re-grazed to maintain the assigned treatments. Climate conditions like early season frosts were found to be challenging and limited the forage quality available to livestock. Supplementation should be considered when grazing annual forages during the late fall or early winter months.

In general, the integration of crops and livestock resulted in higher annual forage production than the impact of cover cropping alone. Soil nitrogen levels responded positively to both cover crops and livestock integration after just one year. It will be interesting to more thoroughly assess soil physical and chemical properties after two years of cropping and grazing management treatments. Initial calculations indicate a potential fertilizer cost savings can be experiences when livestock are incorporated into the system.

With the exception of locations like Tappen and McClusky, where we ran into challenges due to inclement weather, limited feed or water, livestock of various classes were able to maintain body condition. Management strategies like grazing density and forage utilization should reflect the goals of an operation. The integration of crops and livestock has the potential to impact soil health, crop production, livestock performance and economics. This project will equip producers with information to not only meet their goals but also enhance the sustainability of their operation.

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

	Treatment		2020					2021				
Location	Stock Density	Grazing Utilization (%)	Type of Cattle	Cow ADG (lbs)	Calf ADG (lbs)	Change in BCS	# of Grazing Days	Type of Cattle	Cow ADG (lbs)	Calf ADG (lbs)	Change in BCS	# of Grazing Days
Fargo	High	75	Pairs	-1.8	2.1	1	18	Pairs	-7.0	0.8	0	26
		50		-1.7	1.9	1	11		-5.1	1.4	0	10
	Moderate	75		-4.6	2.0	0	35[1]		-3.0	1.7	-1	34
		50		-4.2	2.4	0	28		-2.7	1.9	0	34
Jamestown	High	75	Pairs and heifers			0	33[1]	Pairs			0	61
		50				0	33[1]				0.5	46
McKenzie	High	75	Heifers			0	41	Heifers			0	17
		50				0	36				0	13
Lehr	Moderate	75	Fall calving cows			0	62	Heifers			0.5	54[1]
		50				0.5	64				0	45
McClusky	Moderate	75	Pairs			-2	24[2]	Pairs			0	25
		50				-1	24[1]				0	20
Tappen	Moderate	75	Pairs and heifers			NA	18[1]	Pairs			0	16[3]
		50				NA	18[1]				0	9[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 nutrient and biological analysis at 0-6 inches (in) sampled within a similar soil series at each project location.

Location	Soil Ecological Type	Grazing Treatment	NO_3-N (lbs/ac)	P (ppm)	K (ppm)	pH	OM (%)	SO_4-S (lbs/ac)	Zn (ppm)	Cu (ppm)
Fargo	Clayey Subsoil	Baseline	7.0	8.5	315.0	7.3	5.3	14.1	0.9	2.2
		No grazing	17.3	3.7	458.3	7.9	6.9	70.2	0.7	1.6
		High, 75%	26.7	6.8	339.2	7.4	7.3	17.0	0.9	1.2
		High, 50%	32.6	4.0	440.0	7.6	6.6	22.0	1.0	1.6
		Moderate, 75%	19.2	9.2	487.0	7.6	6.1	10.6	0.9	1.5
		Moderate, 50%	25.5	5.5	295.8	7.5	7.0	15.7	0.9	1.0
Jamestown	Loam	Baseline	5.0	16.9	248.0	6.6	3.5	59.3	1.3	0.8
		No grazing	12.5	15.0	183.3	6.7	4.3	163.0	1.2	0.5
		High, 75%	14.7	21.3	188.3	7.0	3.4	105.2	1.2	0.3
		High, 50%	18.4	36.2	242.0	6.3	4.1	147.0	1.6	0.3
McKenzie	Loam	Baseline	14.0	4.2	215.0	5.8	2.6	6.1	0.6	0.5
		No grazing[1]	41.3	8.8	299.2	6.5	4.3	163.3	1.9	0.6
		High, 75%	20.8	2.8	174.0	6.2	2.0	5.4	0.3	0.4
		High, 50%	22.3	2.3	218.3	6.0	2.5	6.0	0.4	0.3
Lehr	Loam	Baseline	17.0	7.2	256.0	7.3	4.3	93.8	1.0	1.0
		No grazing	24.5	3	213.3	7.5	4.9	100.2	0.7	0.4
		Moderate, 75%	22.5	2.3	185.8	7.4	3.0	17.0	0.9	0.5
		Moderate, 50%	26.8	4.7	275.8	7.3	4.0	23.8	0.9	0.5
McClusky	Loam	Baseline	31.0	9.7	427.0	7.0	3.9	27.1	1.0	0.6
		No grazing	15	4.2	315.0	7.4	4.7	20	0.4	0.4
		Moderate, 75%	20.6	7.4	280.0	7.2	5.2	11.8	0.6	0.5
		Moderate, 50%	21.3	6.3	431.7	7.0	5.0	10.3	0.8	0.5
Tappen	Very droughty loam	Baseline	20.0	7.5	243.0	7.5	3.9	7.1	1.4	0.5
		No grazing	22.8	7.2	363.3	7.7	5.1	8.2	1.8	0.5
		Moderate, 75%[2]	16.5	4.8	184.2	8.1	3.3	32	0.3	0.5
		Moderate, 50%[2]	15.5	5.5	305.8	8.1	4.3	6.2	0.3	0.7

[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.

Literature Cited

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. Agriculture, Ecosystems and Environment. 190:43-51.

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.

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. Journal of Environmental Quality. 47:1-15.

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? Journal of Soil and Water Conservation. 70:365-373.

Meehan, M., K.K. Sedivec, J. Printz, and F. Brummer. 2018. Determining carrying capacity and stocking rates for range and pasture in North Dakota. NDSU Extension, North Dakota State University, Fargo, N.D. 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. 2021. Accessed February 17, 2022. https://w2.weather.gov/climate

North Dakota Agricultural Weather Network. 2021. North Dakota State University, Fargo, ND. Accessed February 17, 2022. https://ndawn.ndsu.nodak.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. Journal of Animal Science. 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.

Forage Production, Livestock Performance, Soil Nutrients and Cost Comparison for Cover Crops Using a Livestock/Cropping Integrated System

Kevin Sedivec[1], Justin Leier[1], Scott Alm[1], Erin Gaugler[1], Miranda Meehan[2], and Michael Undi[1]

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

Summary

The 2020 drought had a dramatic negative impact on cover crop forage production. Due to low production, hay production and the grazing stocking rate were affected negatively, creating a year when both were not economical options, compared with traditional alternatives. However, both grazing use treatments added nitrogen and organic matter to the soil profile after one season of grazing.

This project will be repeated in 2021 to assess a longer-term economic impact as well as assess soil health benefits, physical and chemical. The final year of the study will assess the impacts of integrated grazing cover crops on farmland and its impact on a cash crop in 2022.

Introduction

Cover crops have gained popularity as a practice implemented by producers across the U.S. According to the U.S. Department of Agriculture's Census of Agriculture, 15.4 million acres were planted to cover crops in 2017, up 50% from the 10.3 million acres in 2012 (UDSA 2019; USDA, 2014).

North Dakota is no exception to this trend, with producers incorporating cover crops to improve soil health and increase crop production (USDA, 2019; Conservation Technology Information Center [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 (ICLS) include enhanced nutrient cycling as well as reduced inputs and livestock feeding costs. Livestock management decisions, such as stocking rates, stock density and utilization, have the potential to impact the environmental and economic sustainability of ICLS.

The majority of research evaluating ICLS has been conducted in regions characterized by humid climates, and little information is available to producers in the northern Great Plains to help make these management decisions. This producer-led demonstration project will aid in the development of best management practices for managing grazing livestock in ICLS to enhance soil health, livestock production, crop production and economic sustainability.

Our study objective is to determine the impact of an ICLS using two years of grazed winter cereal followed by grazed cover crop with two different stocking rates followed by a cash grain crop on soil health, livestock performance and economic return.

Study Area

This study was conducted on the Central Grasslands Research Extension Center (CGREC) in 2020. Experimental plots at the CGREC were on gravelly sandy loam soils (USDA-Natural Resources Conservation Service, 2020). Precipitation was below normal (May and June) prior to seeding the cover crop and below normal while the cover crop grew in July 2020 (Table 1). The average temperature was 3 F cooler than the long-term average in May and above average from June through August (Table 1).

Table 1. Precipitation and average temperature during the growing seasons of the study period September 2019 through October 2021 at the Central Grasslands Research Extension Center near Streeter (North Dakota Agricultural Weather Network, 2021).

Month	Precipitation (inches)			Percent of Normal			Average Temperature (F)			Departure from Average (F)		
	2019	2020	2021	2019	2020	2021	2019	2020	2021	2019	2020	2021
April		0.64	0.55		59	51		37	40		-5	-2
May		1.81	2.01		74	82		51	53		-3	-1
June		1.35	1.20		39	35		67	69		4	6
July		2.13	0.32		66	10		71	74		2	5
August		2.73	4.47		118	188		69	70		1	3
Sept.	4.44	0.31	1.44	218	15	69	58	57	62	1	0	4
October	2.59	0.22	3.11	136	16	194	36	38	48	-8	-7	5

Procedures

- Three winter cereal crops were tested in 2020 (winter rye, triticale and wheat) and two in 2021 (winter rye and triticale)
    - The winter cereal crops were grazed from May 11-June 8, 2020 and May 11 – June 1, 2021.
- Four treatments were tested on the cover crop, grazing at two stocking rates (50% use and 70% use), haying and non-use
    - Tested a nine-way cover crop mixture seeded after a winter cereal crop
    - The cover crops were grazed with yearling pregnant heifers from Aug. 25 through Sept. 22, 2020, and September 23 through October 14, 2021.
- The study design is a randomized block design, with a split plot design imposed on the non-use treatment, creating an even split for the non-use and hayed treatment.

- The winter cereals were seeded at 90 lb/ac in September, grazed in May or hay in early June, then seeded with a nine-way cover crop mixture was seeded on nine 10-acre fields on June 13 and 10, 2020 and 2021; respectively, with each treatment replicated three times.
- The nine-way cover crop mixture included forage oats (18 pounds/acre), sorghum sudangrass (3 pounds/acre), German millet (2 pounds/acre), sunflowers (1.5 pounds/acre), forage radish (1 pound/acre), kale (0.75 pound/acre), hybrid turnip (0.75 pound/acre), brown flax (2 pounds/acre) and forage peas (10 pounds/acre).
- Each study field has been in a long-term no-till program since 2006 and fertilized with 73.1 pounds/acre of nitrogen (urea, MAP), 19.2 pounds/acre of phosphorus (MAP) and 12 pounds/acre of potassium (potash) in May 2019, then seeded to spring triticale. The spring triticale was harvested for hay in July 2019. No fertilizers were added in 2020 or 2021.
- All fields were sprayed with 1 quart of glyphosate + 1 ounce of Sharpen/acre to kill the winter cereal and any volunteer yellow foxtail (*Setaria pumila*) prior to seeding.
- The stocking rate for each winter cereal type was projected using the estimated forage production from the May 8 and 7, 2020 and 2021, respectively, clippings.
    - Winter rye was stocked at 2.49 heifers per acre, winter triticale at 1.45 heifers per acre and winter wheat at 1.43 heifers per acre in 2020. With the severe drought, the stocking rates in 2021 were 0.55 on the winter rye and 0.4 heifers per acre on the winter triticale.
- The stocking rate for the 50% and 75% use treatments was 0.87 heifer per acre in 2020; and 1.1 and 1.9 heifers per acre in 2021.
- All fields were clipped using six 0.25 meter^2 frames spread evenly across each field (54 frames total) five days prior to grazing to determine forage production and stocking rate for both the winter cereal and cover crop portion of the study.
- Livestock performance was determined by collecting two-day weights prior to turnout and after grazing ended.
- The hayed treatment was cut Sept. 24, 2020 (103 days after planting). The hayed treatment was cut October 1, 2021 (108 days after planting).
- End-of-season residue and degree of use was determined by clipping each grazed field using six 0.25 m^2 frames spread evenly across each field (36 frames total) on Sept. 23, 2020, and October 16, 2021.
- Soils samples were collected: 1) Sept. 6, 2019 – just prior to seeding the winter cereals, 2) May 5, 2020 – prior to cattle grazing the winter cereals, and 3) Nov. 6, 2020 – six weeks after the cattle finished grazing the cover crop and pre-soil freezing, May 8, 2021 and October 25, 2021.
- We analyzed for significance using a general linear model in SAS (SAS version 9.4; SAS Inst. Inc., Cary, N.C.). Means were separated using the post hoc test Duncan's Multiple Range Test (Duncan, 1955).

Results

Winter Cereal Study

Winter rye was the highest-producing cereal on June 1 at 3,610 and 1,436 pounds/acre in 2020 and 2021, respectively (Figures 1 and 2). Winter rye was also the most productive May 8 and

May 22 in 2020 (Figure 1). Crop residue after grazing was lowest in the winter wheat – Willow Creek treatment, mainly due to lower production in May (Figure 1). The percent of crop residue was 49%, 49% and 56% for winter rye, wheat and triticale; respectively in 2020; and 80 and 76 % for winter rye and triticale; respectively, in 2021.

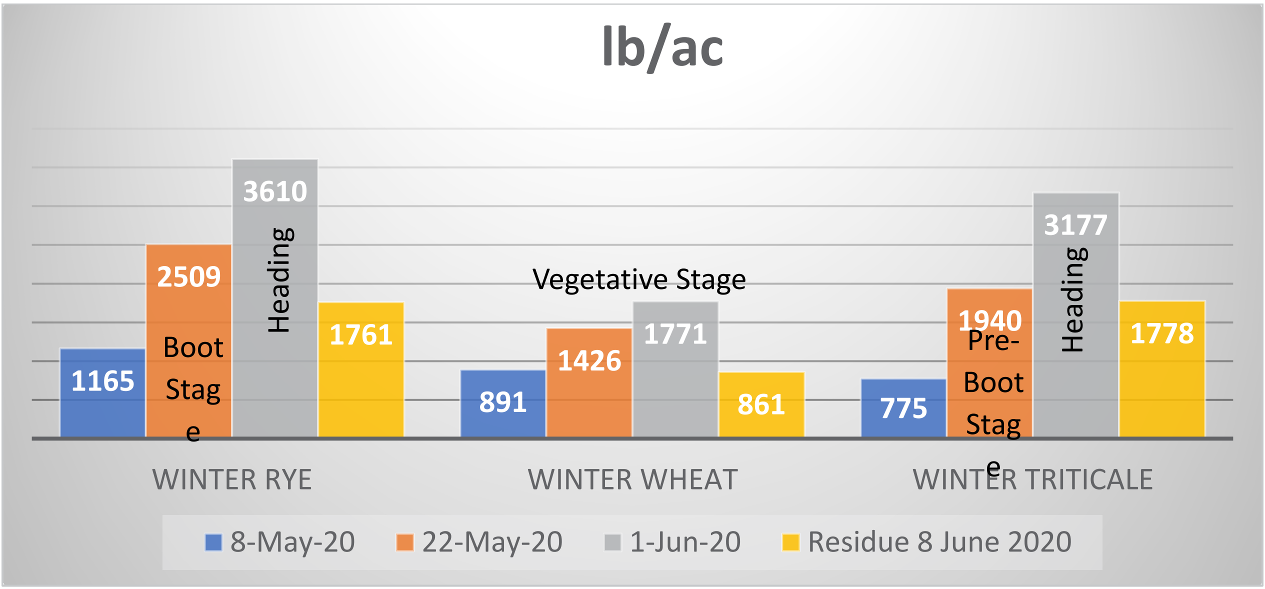


Figure 1. Forage production by winter cereals on May 8, May 22 and June 1, and pounds/acre of residue after grazing at Central Grasslands Research Extension Center near Streeter, N.D., in 2020.

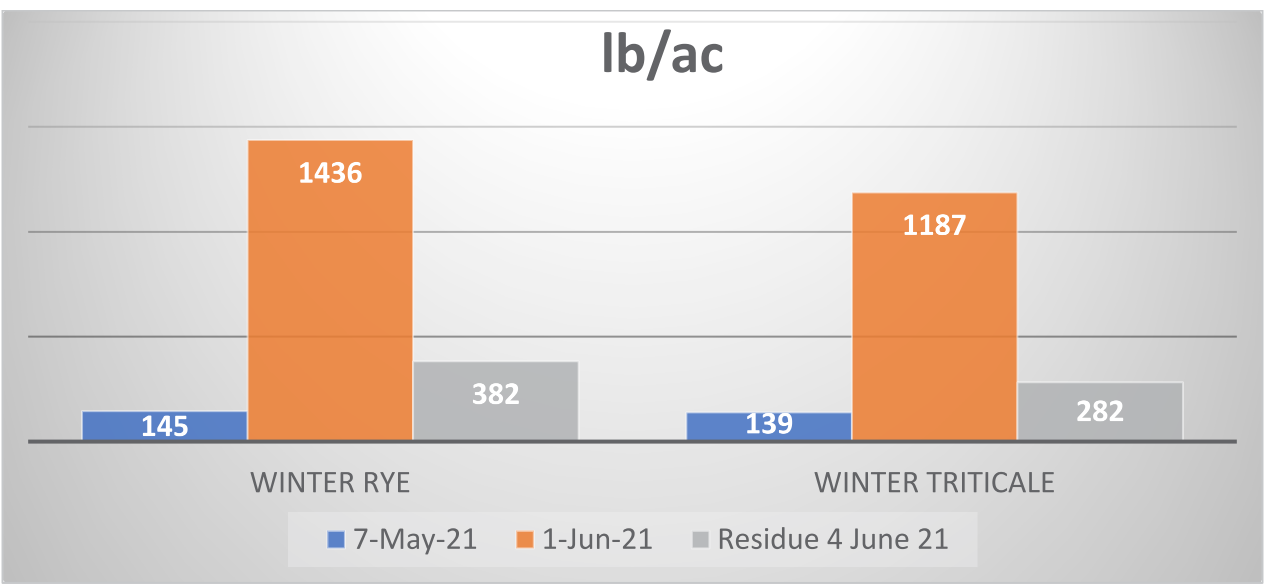


Figure 2. Forage production by winter cereals on May 7 and June 1, and pounds/acre of residue after grazing at Central Grasslands Research Extension Center near Streeter, N.D., in 2021.

Willow Creek winter wheat was highest in crude protein and total digestible nutrients (TDN) throughout May (Table 2). Winter triticale and Willow Creek were below 3% acid detergent lignin (ADL) in May (Table 2). Winter rye and winter triticale were above 5% ADL by June 8, indicating a low palatable hay at this time (Table 2).

Table 2. Forage quality content for winter rye, winter triticale and winter wheat – Willow Creek at Central Grasslands Research Extension Center near Streeter, N.D., in 2020.

Winter Cereal Crop	Crude Protein (%)			Acid Detergent Lignin (%)			Total Digestible Nutrients (%)			Calcium (%)		Phosphorus (%)	
	May 22	June 1	June 8	May 22	June 1	June 8	May 22	June 1	June 8	May 22	June 1	May 22	June 1
Rye	8.7	6.7	6.6	2.4	4.2	5.6	68.6	61.2	58.0	0.20	0.19	0.39	0.28
Triticale	10.4	7.8	7.8	2.3	2.8	5.2	70.8	65.7	59.0	0.25	0.20	0.40	0.27
Wheat, Willow Creek	12.3	9.2	N/A	2.4	2.5	N/A	71.4	69.2	N/A	0.30	0.22	0.46	0.26

The calcium-to-phosphorus ratio ranged from 0.5:1 to 0.65:1 on May 22 for the winter cereals, and ranged from 0.67:1 to 0.85:1 on June 1. All winter cereals were below the minimum recommended threshold of 1.2:1 calcium-to-phosphorus ratio for cows grazing at this period (National Research Council, 2016).

Winter triticale performed best for livestock performance in 2020; however, winter rye outperformed triticale (lost less weight) in 2021 (Table 3). The negative livestock performance in 2021 can be explained by the heavy use (80 and 76 % use), indicating forage intake was probably an issue.

Table 3. Heifer average daily gain (pounds/day) by winter cereal type grazed from May 11 - June 8, 2020, and May 11 – June 1, 2021 at Central Grasslands Research Extension Center near Streeter, N.D**.**

Winter Cereal Crop	2020 Average Daily Gain (lb/day)	2021 Average Daily Gain (lb/day)
Rye	-0.29	-1.75
Triticale	0.01	-2.05
Wheat (Willow Creek)	-0.11	-----

The cost to graze heifers on the winter rye was $1.02 per day and much cheaper than winter triticale and winter wheat – Willow Creek (Figure 3). The cost to graze heifers on the winter triticale was $2.03/head per day, with the higher costs, compared with winter rye, a function of less forage produced and cost of seed. Due to the slow growth rate of Willow Creek in May, the costs to graze heifers on this forage type was also high due to lower forage production.

The cost per day to graze winter cereals was not cost-effective in 2021. Due to the severe drought in 2020 and 2021, forage production was, thus cost to feed a heifer was high. The cost to graze a heifer in 2021 was $6.38 and $10.26 per day for winter rye and triticale, respectively (Figure 4).

The cost to produce hay was $51.27, $65.85 and $110.96 per ton for winter rye, triticale and wheat; respectively, when harvested June 1 (Figure 3). In 2021, the cost to produce hay was $136.51 and $186.76 per ton for winter rye and triticale; respectively, when harvested June 1 (Figure 4).

Due to Willow Creek's slow growth in May, harvesting for hay on June 1 would not be recommended. Willow Creek was still in the vegetative growth stage on June 1 and would be much more economical to harvest in mid to late June.

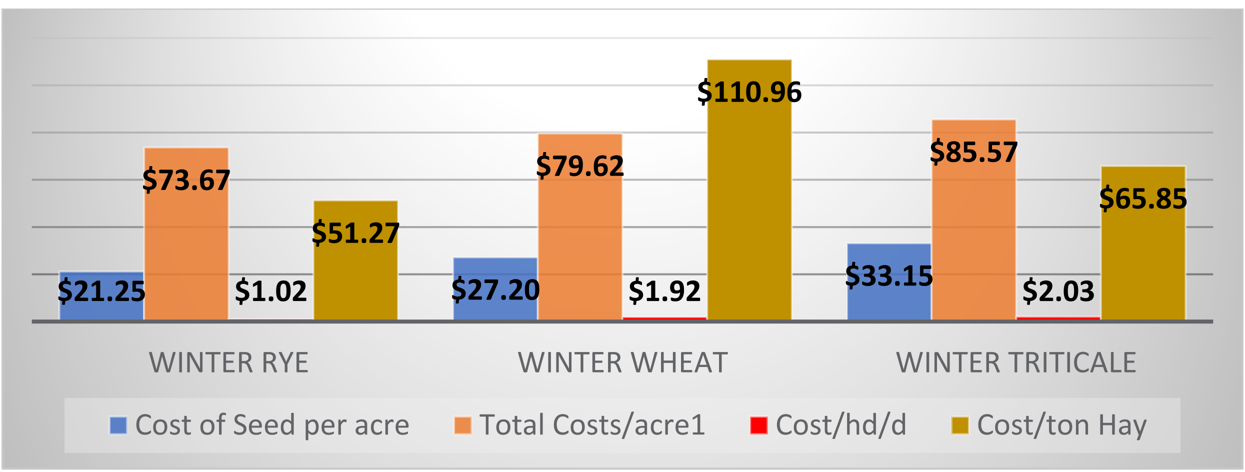


Figure 3. Total costs per acre, cost to graze heifers per day and cost to harvest hay by winter cereal type at Central Grasslands Research Extension Center near Streeter, N.D., in 2021.

[1] Total costs per acre includes custom farm rates (USDA, Agricultural Statistics Service, 2020) for no-till seeding rate ($16.47/acre), custom herbicide application ($6.57/acre), actual cost of herbicide (glyphosate + Sharpen; $5.60/acre), land rent ($22.45/acre) and seed cost (winter rye - $21.25/acre, winter wheat - $27.20/acre, winter triticale - $33.15/acre). Total land rental rate would be $44.90/acre (USDA, Agricultural Statistics Service, 2020); however, we dedicated 50% of the cost toward the winter cereal, 50% for the second crop (cover crop). Grazing period May 11-June 8 (29 days).

[2] Cost per ton of hay includes total costs per acre + cost for swathing ($9.66/acre) and baling ($9.47/acre).

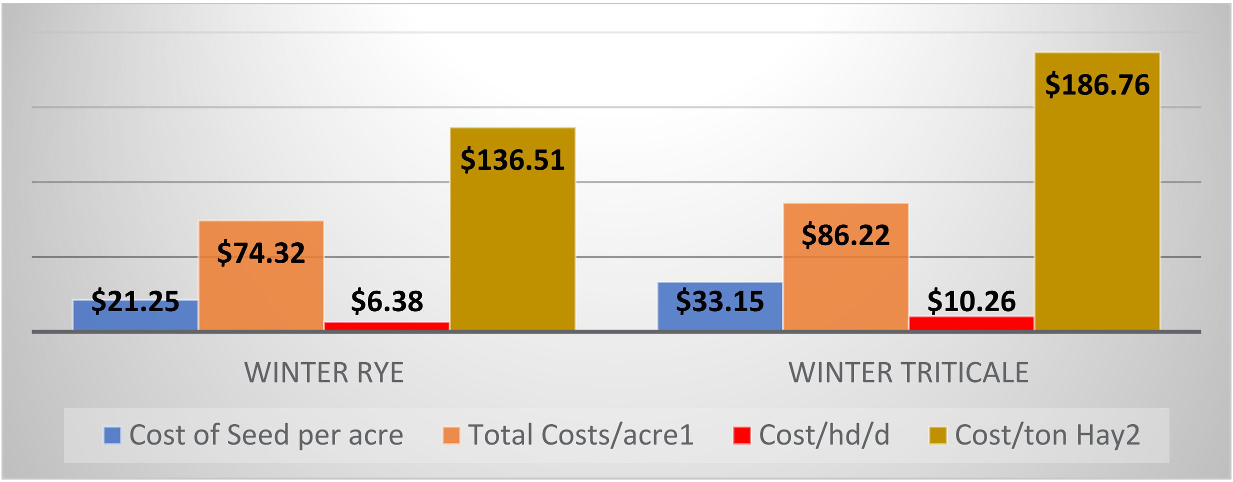


Figure 4. Total costs per acre, cost to graze heifers per day and cost to harvest hay by winter cereal type at Central Grasslands Research Extension Center near Streeter, N.D., in 2021.

[1] Total costs per acre includes custom farm rates (USDA, Agricultural Statistics Service, 2020) for no-till seeding rate ($17.80/acre), custom herbicide application ($7.85/acre), actual cost of herbicide (glyphosate + Sharpen; $5.60/acre), land rent ($23.15/acre) and seed cost (winter rye - $22.50/acre, winter triticale - $33.15/acre). Total land rental rate would be $46.30/acre (USDA, Agricultural Statistics Service, 2020); however, we dedicated 50% of the cost toward the winter cereal, 50% for the second crop (cover crop). Grazing period May 11-June 1 (21 days).

[2] Cost per ton of hay includes total costs per acre + cost for swathing ($12.54/acre) and baling ($11.43/acre).

Cover Crop Study

Average forage production for the cover crop mixture prior to implementing the grazing treatments was 1,617 lb/acre in 2020 and 2,949 lb/acre (2,832 on the 50% use, 3,048 on the 75% use treatments) in 2021 (Figure 5). The degree of use was 38% and 56% in 2020 and 45% and 73% in 2021 on the 50% and 75% degree of use treatments; respectively, (Figure 5). We missed our targeted grazing use levels in 2020, but achieved our objective in 2021.

Yearling heifer performance was surprisingly high for both treatments in 2020, with heifers gaining 1.98 and 1.61 lb/day on the 50% and 75% grazing use treatments, respectively (Figure 6). However, heifer performance on both treatments lost weight, -0.14 and -0.12 lb/day on the 50% and 75% grazing use treatments, respectively (Figure 6). There was no difference ($P > 0.05$) between treatments either year.

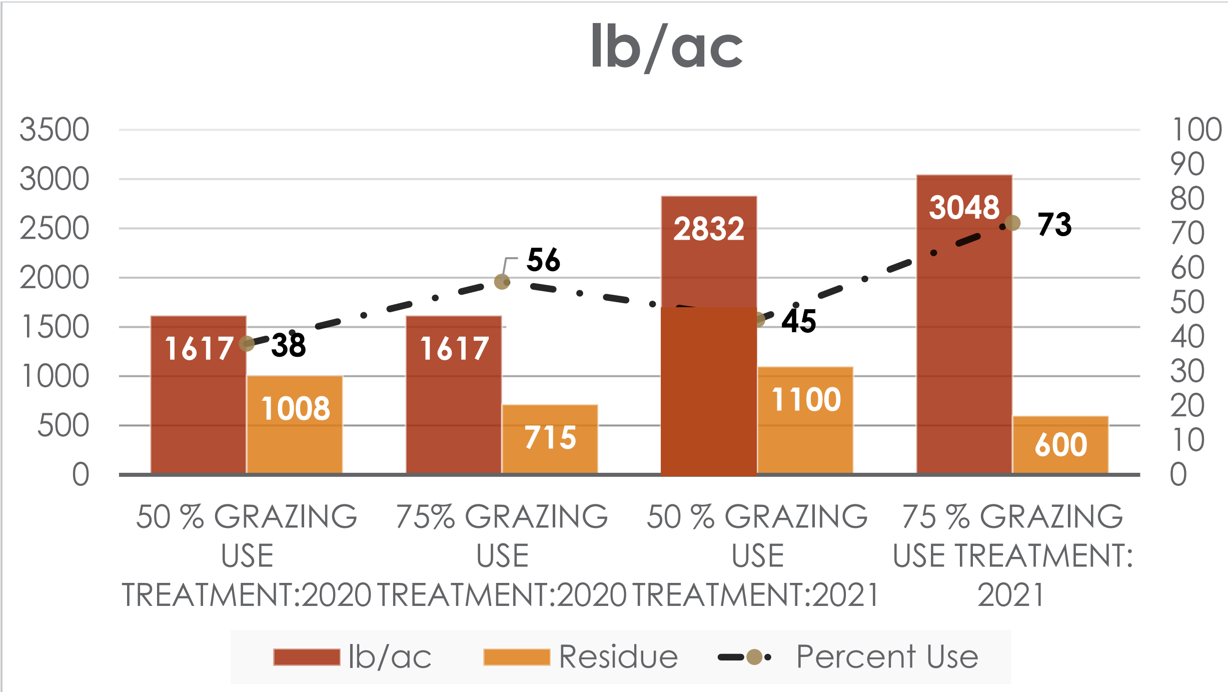


Figure 5. Forage production (lb/ac), residue after grazing (lb/ac) and degree of use (percent) by cover crop grazing treatment at Central Grasslands Research Extension Center near Streeter, N.D., in 2020.

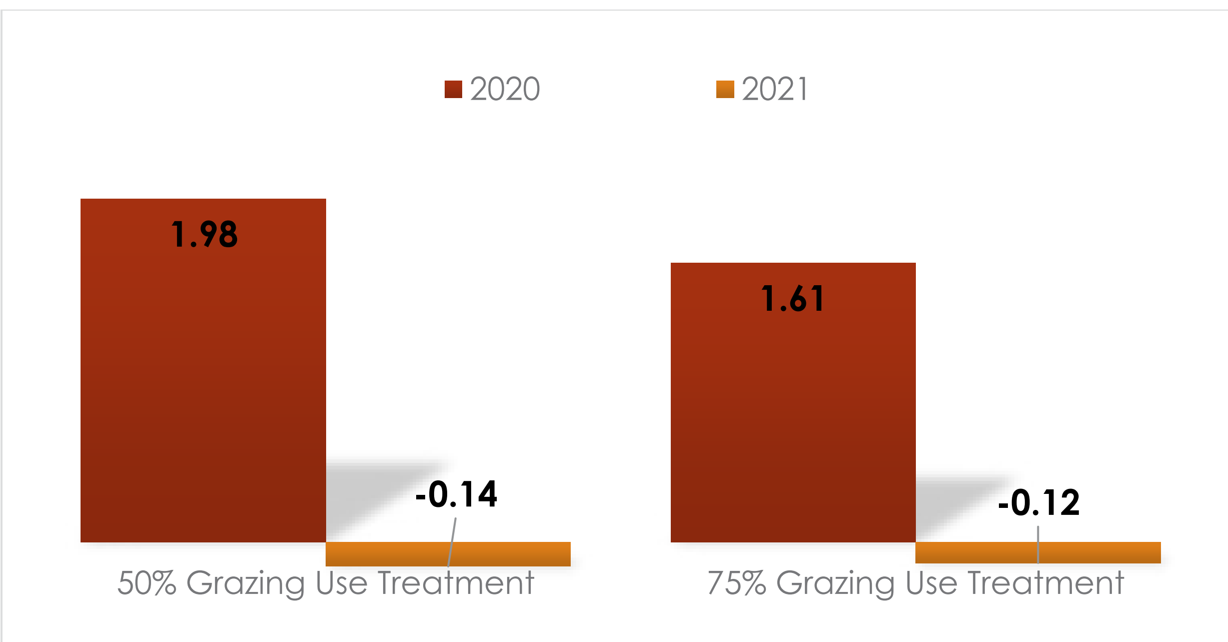


Figure 6. Yearling heifer performance (average daily gain - lb/d) by degree of grazing use treatment (28-day and 21-day grazing period in 2020 and 2021, respectively) at Central Grasslands Research Extension Center near Streeter, N.D., in 2020 and 2021.

There was treatment effect on phosphorus or potassium in the soil 24 months after treatment. We also found no treatment effect in organic matter among treatments in the soil 24 months after treatment.

All treatments, except the 75% degree of use grazing treatment, decline in soil nitrogen content 24 months after treatment (Figure 7). Nitrogen content was greater on the 75% degree of use grazing treatment 24 months post treatment compared to the other treatments, and was the only treatment without a decline after 24 months. There was no different between the non-use, hayed and 50% grazing degree of use treatments at any time of the study (Figure 7).

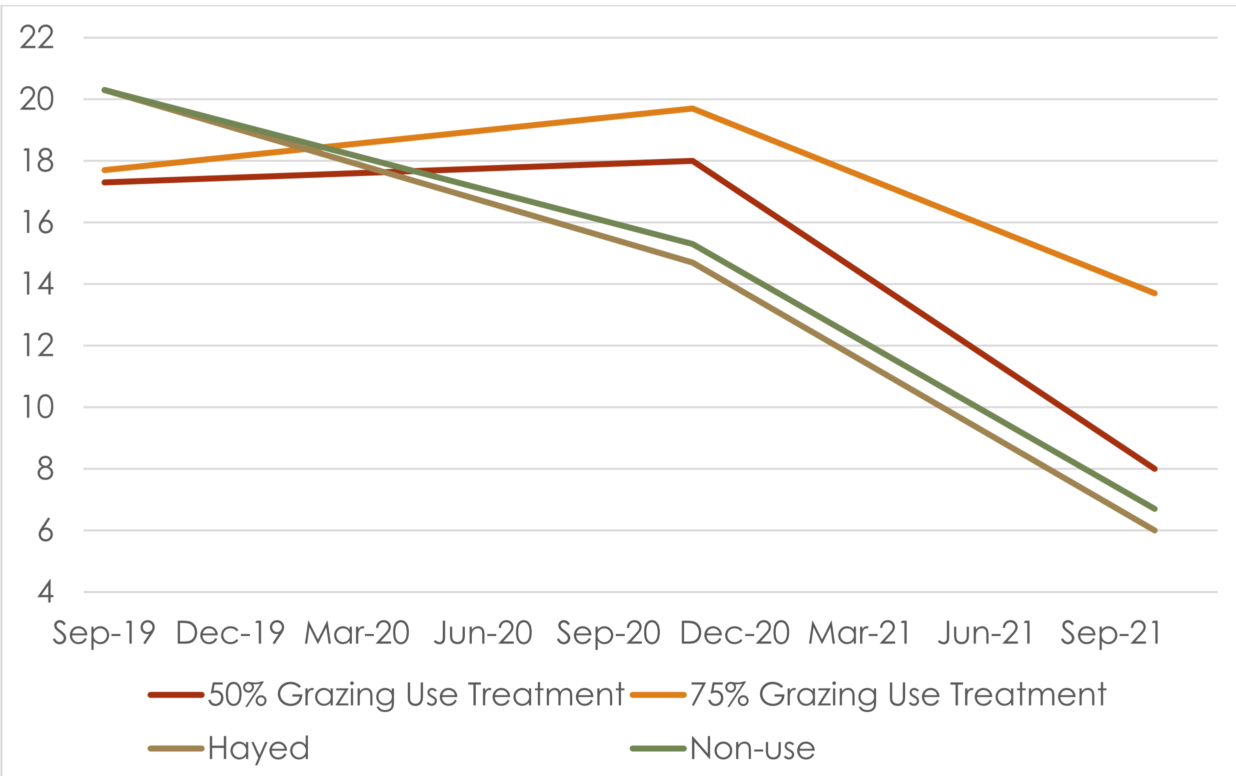


Figure 7. Nitrogen content (pounds/acre) of soil at the 0-6-inch depth pretreatment in September 2019 through the completion of the cover crop grazing in October 2021 by treatment at Central Grasslands Research Extension Center near Streeter, N.D., in 2021.

Based on the soil samples collected at the 0 – 6 inch depth on each treatment in October 2021, the cost for fetrilizing to grow grain corn in 2022 ranged from $214.56 to $232.52 per acre (Table 4). The hay treatment was the least cost efficient in the input cost of fertilzer and $10.32 per acre higher than non-use. Both grazing treatments were more cost-efficent than non-use, with the 75% degree of use most cost efficxient and $7.52 cheaper than non-use and $17.84 cheaper than the hay production system.

Table 4. Estimated cost of fertilizing corn by treatment at the Central Grasslands Research Extension Center near Streeter in 2022.

Fertilizer	Hayed	Non-use	50 % Use	75 % Use
Nitrogen (urea)	199	196	190	188
Phosphorus (DAP)	50	40	40	40
Potassium (Potash)	12	12	12	12
Total Costs (per acre)	$232.52	$222.20	$216.56	$214.68

References

Allhay.com. Hay for sale in North Dakota. Hay for Sale - North Dakota - AllHay.com. Accessed Feb. 17, 2021.

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, Ind.

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. Agriculture, Ecosystems and Environment. 190:43-51.

Franzluebber, 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? Journal of Soil and Water Conservation. 70:365-373.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics. 11: 1–42.

Lardy, G. 2018. A cow-calf producer's guide to custom feeding. AS1162, North Dakota State University Extension, Fargo, N.D. Pp 8.

NDAWN. 2020. North Dakota Agricultural Weather Network. https://ndawn.ndsu.nodak.edu
USDA. 2014. 2012 Census of Agriculture – U.S. Data. USDA, National Agriculture Statistics Service. Washington, D.C.

USDA. 2019. 2017 Census of Agriculture – U.S. Data. USDA. National Agriculture Statistics Service. Washington, D.C.

USDA, National Agricultural Statistics Service. 2020. North Dakota Agricultural Statistics. Ag. Statistics No. 88. North Dakota State University, Fargo. 131 pp.

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

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

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics. 11: 1–42.

National Research Council. 2016. Nutrient Requirements of Beef Cattle, 8th Revised Edition. National Academic Press. 494 pp.

NDAWN. 2020. North Dakota Agricultural Weather Network. https://ndawn.ndsu.nodak.edu

USDA, National Agricultural Statistics Service. 2020. North Dakota Agricultural Statistics. Ag. Statistics No. 88. North Dakota State University, Fargo. 131 pp.

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

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

Annual cool-season cereal forages are excellent feed sources for livestock. Determining which forage type to plant becomes the question. Forage oats were the highest-producing cereal crop in 2019, ranging from 2.6 to 3.7 tons/acre at Central Grasslands Research Extension Center. During the drought years in 2020 and 2021, no differences were found between the forage types (oats, barley, triticale, wheat) at the Wishek Tri-county Agronomy Plots or Central Grasslands Research Extension Center, respectively. 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.

On average, 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 oats, barley and wheat had a crude protein content between 10 and 11% in 2020.

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

The forage oat varieties tended to be the lowest cost forages to produce based on seed cost for all three years. The forage triticale tended to be the costliest type based on seed cost across the years, except Merlin Max was consistently the lowest cost triticale.

Study Area

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

Precipitation was at or above average for all months of the study in May through August in 2019 and well below average for May through July in 2021 at the CGREC (**Table 1**). Precipitation was well below average for May and June in 2020, and June and July in 2021 at the TCAP, but above normal in July in 2020 and May in 2021 (**Table 1**).

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

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	2019	2021	2020	2021	2020	2021
May	2.99	2.01	122	82	1.69	3.38	66	131
June	3.47	1.20	102	35	1.57	1.53	52	51
July	4.15	0.32	130	10	3.10	1.57	113	57

Procedures

- The trial was planted on May 28, 2019, May 12, 2020, and May 19, 2021.
- All varieties were seeded at 90 lb/acre and targeted harvest stage was early dough in 2019.
- All forage oat varieties were seeded at 64 lb/acre except Everleaf 126 (80 lb/ac) in 2020. All forage barley and triticale were seeded at 90 lb/acre except Bunker (100 lb/ac) in 2020.
- All forage oat varieties were seeded at 64 lb/acre except Everleaf 126 (80 lb/ac) in 2020. All forage barley and triticale were seeded at 90 lb/acre except Bunker (100 lb/ac) in 2021.
- All nutritional analysis was conducted at the North Dakota State University Nutrition Lab using AOAC standards (AOAC, 2019).
- Total digestible nutrients were determined using acid detergent fiber and the energy equation for grass (98.625-[1.048*ADF]).
- Study design was a randomized block design with four replications and was analyzed used a general linear model in SAS. Means were separated using the post hoc test Duncan's Multiple Range Test (Duncan, 1955).

Results

Forage oats were the highest-producing cereal forages in 2019 (**Table 2**). Everleaf 126 and Goliath were the highest-producing forage oat. We found no difference in yield between the spring triticale and forage barley varieties (**Table 2**). All forage oat varieties and spring triticale Merlin Max had the best stand establishment, and forage oat varieties Everleaf 126, Goliath and BYS FO were best at suppressing weeds, with yellow foxtail the most common weed (**Table 2**).

We found no difference in yield among all forage types and varieties in 2020, except Haymaker forage barley was greater than Bunker triticale (**Table 2**). Forage barleys Axcel and Haymaker, and spring triticale BYS FT had the highest total digestible nutrient (TDN) levels in 2019 (**Table 3**). Forage wheat had the highest TDN content in 2020 (**Table 3**).

Table 2. Days to early dough, plant height, harvest date, and yield for selected varieties of forage oats, forage barley, spring triticale and forage wheat at Central Grasslands Research Extension Center (CGREC) in 2019 and 2021, and Wishek Tri-county Agronomy Plot (TCAP) in 2020 and 2021.

Cereal Crop[1]	Variety	Harvest Day (early to soft dough)				Yield (100% DM)[2] (ton/ac)			
		CGREC	TCAP	CGREC	TCAP	CGREC	TCAP	CGREC	TCAP
		2019	2020	2021	2021	2019	2020	2021	2021
FO	Everleaf 126	Aug. 8	July 15	July 14	July 15	3.68^{a}	1.99^{ab}	1.82^{a}	1.10^{bcde}
FO	Goliath	July 23	July 8	July 7	July 15	3.24^{ab}	1.71^{ab}	1.61^{a}	1.37^{abc}
FO	Mustang 120	July 23	July 8	July 7	July 15	2.67^{bc}	2.03^{ab}	1.31^{a}	1.29^{abcd}
FO	BYS FO	July 23	July 8	July 14	July 15	2.57^{bcd}	1.65^{ab}	1.90^{a}	1.23^{abcde}
ST	BYS FT	July 23	July 8	July 7	July 15	1.88^{cde}	1.69^{ab}	1.48^{a}	1.42^{ab}
ST	Merlin Max	July 23	July 8	July 14	July 8	1.75^{de}	1.51^{ab}	1.47^{a}	1.44^{a}
ST	Bunker	July 23	July 8	July 7	July 8	1.41^{e}	1.40^{b}	1.96^{a}	1.18^{abcde}
ST	141	July 23	July 8	July 7	July 8	1.31^{e}	------	------	------
FB	Axcel	July 24	July 8	July 7	July 8	1.45^{e}	2.00^{ab}	1.39^{a}	1.02^{de}
FB	Haymaker	July 24	July 8	July 14	July 8	1.34^{e}	2.17^{a}	1.49^{a}	1.07^{cde}
FB	Hayes	---------	July 8	July 7	July 15	-------	1.93^{ab}	1.53^{a}	1.00^{de}
ST	Flex 719	---------	July 15	July 7	July 15	-------	1.46^{ab}	1.55^{a}	0.96^{de}
ST	Surge	---------	July 8	July 14	July 8	-------	1.58^{ab}	1.58^{a}	1.14^{abcde}
ST	Thor	---------	July 8	July 14	July 15	-------	1.44^{ab}	1.69^{a}	1.08^{cde}
ST	Exp. 2063	---------	July 15	July 7	July 8	-------	1.88^{ab}	------	-----
ST	Pronghorn	---------	--------	July 14	July 15	-------	-------	1.87^{a}	1.21^{abcde}
ST	Gunner	---------	--------	July 7	July 8	-------	-------	1.58^{a}	1.08^{cde}
FW	3119A	---------	--------	July 14	July 15	-------	-------	1.57^{a}	0.92^{e}
FW	3099A	---------	July 15	July 14	July 15	-------	1.80^{ab}	1.39^{a}	1.06^{cde}

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

The Everleaf 126 forage oat was the poorest-performing forage in terms of crude protein, with Bunker triticale the superior forage in this trial in 2019. All the triticale varieties except 141 had a crude protein content greater than 11% in 2019 and BYS FT in 2020 (**Table 3**).

The forage barley varieties contained the lowest levels of acid detergent lignin, followed by forage oat BYS FO; all three were less than 4% in 2019 and 2020 (**Table 3**).

All forage cereal varieties provided the minimum requirements of phosphorus for 1,200-pound gestating and early lactating beef cattle in both years (National Research Council, 2016).

All forage cereal varieties were deficient of calcium for the minimum requirements for gestating 1,200-pound beef cattle in 2019 (**Table 3**). However, all the oat and barley varieties, and triticale varieties Merlin Max and Flex 719 provided the minimum levels in 2020 (National Research Council 2016).

Table 3. Forage quality 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[1] (%)		Acid Detergent Fiber[1] (%)		Acid Detergent Lignin[1] (%)		Total Digestible Nutrients[2] (%)		Calcium[3] (%)		Phosphorus[3] (%)	
		2019	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}
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	-----
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}
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}
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.

Because all input costs were the same for planting and harvesting the all forage cereal crops studied in 2019, 2020 and 2021, the only variable would be seed cost. The cost to produce 1 ton/acre of forage was lowest for all four forage oat varieties in 2019, ranging from $9.05 per ton for Everleaf 126 forage oats to $12.61 per ton seed cost for BYS FO forage oats. The seed cost to produce 1 ton/acre of Merlin Max spring triticale was $12.37. All other varieties ranged from $19.15 to $34.35 per ton for seed cost (**Figure 1**).

In 2020, cost associated directly from seed price to produce a ton of forage per acre was lowest for oats and barley (**Figure 2**). The triticale variety Merlin Max was again at similar costs to oats and barley in 2020.

The cost to produce a ton per acre of forage was variable at both study locations in 2021. The forage oat variety BYS FO had the lowest input cost per acre using seed costs at the CGREC, while the forage triticale variety Merlin Max lowest cost at TCAP.

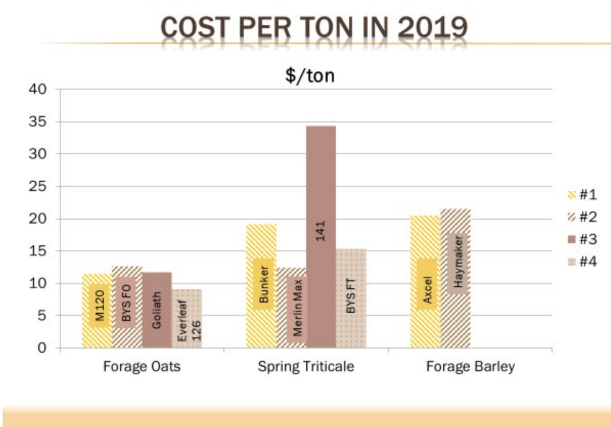


Figure 1. Cost to produce a ton of forage based on seed cost at CGREC in 2019.

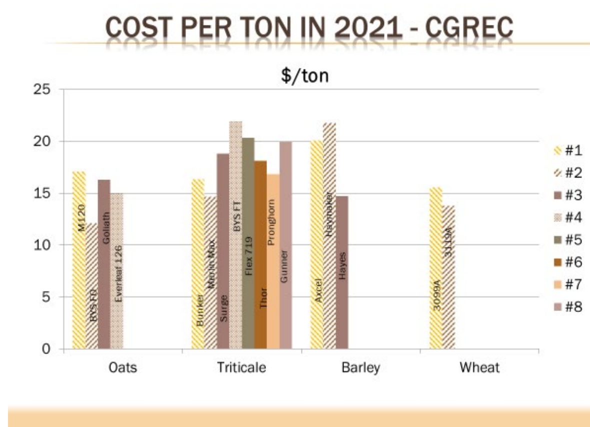


Figure 3. Cost to produce a ton of forage based on seed cost at CGREC in 2021.

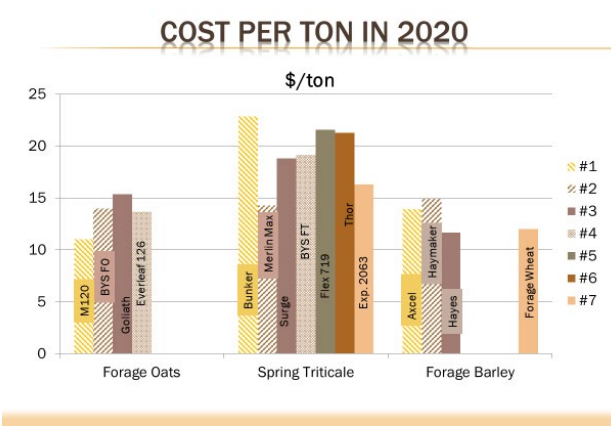


Figure 2. Cost to produce a ton of forage based on seed cost at Tri-county Plots in 2020.

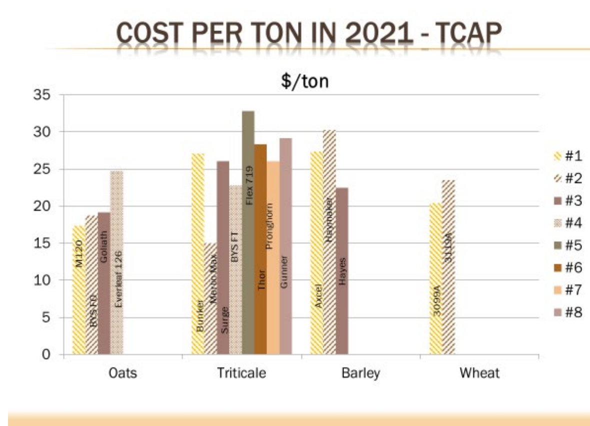


Figure 4. Cost to produce a ton of forage based on seed cost at Tri-county Plots in 2021.

References

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

Block, J. 2020. Nitrate poisoning of livestock. Extension Circular V839, North Dakota State University Extension, Fargo. Pp 1-4.

Duncan, D.B. 1955. Multiple range and multiple F tests. Biometrics. **11**: 1–42.

National Research Council. 2016. Nutrient Requirements of Beef Cattle, 8th Revised Edition. National Academic Press. 494 pp.

NDAWN 2020. North Dakota Agricultural Weather Network. https://ndawn.ndsu.nodak.edu Salmon, D.F., M. McLelland, T. Schoff, P.E. Juskiw.

2001. Triticale. Agri-Facts Agdex 118/20-1. V.S. Baron Agriculture and Agri-Food Canada Research Station, Lacombe, Alberta, Canada. 4 pp.

USDA, National Agricultural Statistics Service. 2019.

North Dakota Agricultural Statistics. Ag. Statistics No. 88. North Dakota State University, Fargo. 131 pp.

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

Improving the Success of Fixed-Time Artificial Insemination in Post-partum Beef Cows

Garrett Havelka[1], Friederike Baumgaertner[1], Kerri Bochantin[1], Jennifer Hurlbert[1], Timothy Long[2], Kevin Sedivec[2], and Carl Dahlen[1]

[1]Animal Sciences Department and Center for Nutrition and Pregnancy, NDSU
[2]Central Grasslands Research Extension Center, NDSU

Summary

The purpose of this study was to compare estrus expression and pregnancy rates between two different estrus synchronization protocols. Postpartum beef cows from two different locations were randomly sorted into two treatment groups; 1) 7-day CO-Synch + CIDR (**CO-Synch**), and 2) 7 & 7 Synch (**7&7**). For the CO-Synch treatment, cows received a controlled internal drug release insert (CIDR; 1.38g progesterone) and 100 µg gonadotropin-releasing hormone (GnRH) i.m., followed in 7 d by CIDR removal and 25 mg prostaglandin F2alpha i.m., followed in 60 to 66 hours with AI and 100 µg GnRH i.m. For the 7&7 Synch protocol cows received a controlled internal drug release insert (CIDR; 1.38g progesterone) and 25 mg prostaglandin F2alpha i.m., followed in 7 days by 100 µg gonadotropin-releasing hormone (GnRH) i.m., followed in 7 d by CIDR removal and 25 mg prostaglandin F2alpha i.m., followed in 60 to 66 hours with AI and 100 µg GnRH i.m. Heat detect patches were applied at the time of CIDR removal to determine estrus response by the time of AI, with cows having patches ≥ 50% activated defined as being in estrus and cows with patches < 50% activated defined as not experiencing estrus during our interval of evaluation. Pregnancy status was determined via transrectal ultrasonography 35 days after AI. The 7&7 treatment group expressed estrus at rates 25% greater than those in the CO-Synch treatment ($P < 0.0001$, Table 1). Cows in the 7&7 treatment had pregnancy rates 13% greater than those in the CO-Synch treatment ($P = 0.001$, Table 2). There was also a location effect on pregnancy rates as cows at Location 2 had pregnancy rates 34% greater than Location 1 ($P < 0.0001$, Table 2). Lastly, cows that exhibited estrus prior to FTAI had pregnancy rates 24% greater than those that did not exhibit estrus prior to FTAI (combined rates from both treatments). In this study, a greater proportion of cows expressed estrus and became pregnant after synchronizing with the 7&7 Synch protocol compared with the 7 Day CO-Synch + CIDR protocol.

Introduction

Artificial insemination (AI) is an important tool many beef producers utilize to achieve their reproductive goals. The success of artificial insemination is dependent upon multiple factors including nutrition, environment, and expression of estrus among others. Producers must weigh these factors along with the amount of labor and input costs available when selecting an optimal artificial insemination program.

Fixed-time AI (FTAI) eliminates the need for estrus detection before breeding and allows producers to utilize artificial insemination with fewer labor resources. Certain estrus synchronization protocols for FTAI rely on an initial dose of exogenous gonadotropin-releasing hormone (GnRH) to cause ovulation and begin a new follicular wave. This initial exogenous-controlled ovulation is what begins the synchronization process as all cattle begin a new follicular wave synchronously. Administering this dose at the beginning of a protocol when cows are in random stages of the estrous cycle yields mixed results depending on the presence of a dominant follicle. Research by Ryan *et al.* (1998) has shown cows with dominant follicles ovulate and begin new follicular waves, thus achieving the goal of the GnRH administration. Cows without a dominant follicle fail to ovulate and fail to begin new follicular waves. Cows that do not begin new follicular waves are unlikely to respond to the remainder of the synchronization protocol, thus lowering pregnancy success rate.

Research conducted by the University of Missouri has led to the development of a new estrus synchronization protocol named 7 & 7 Synch. This protocol uses an initial dose of prostaglandin F2alpha and the treatment with sub-luteal levels of progesterone via a CIDR to inhibit follicular atresia and ovulation during the seven days before treatment with GnRH. This inhibition of both atresia and ovulation causes the formation of persistently dominant follicles. These are unviable for fertilization but are able to respond and ovulate due to GnRH. This pretreatment results in a greater proportion of cows with follicles able to respond to GnRH (Bonacker, *et al.,* 2020). Their results found the 7 & 7 Synch increased conception rates by about 10% compared to the 7-day CO-Synch + CIDR protocol (Anderson *et al.,* 2020).

Both NDSU Beef Unit and NDSU Central Grasslands Research Extension Center (CGREC) have utilized the 7-day CoSynch + CIDR protocol in their AI program, which requires cattle to be handled 3 times to facilitate synchronization and AI. The current experiment was conducted to evaluate whether estrus response and pregnancy rates would be enhanced by working cattle through the chute an additional time to employ the 7&7 Synch protocol.

Experimental Procedures

This study took place at the Ekre Grasslands Preserve near Walcott, ND (NDSU Beef Unit, Location 1) and at the Central Grasslands Research Extension Center near Streeter, ND (Location 2) using 568 mixed-breed, post-partum beef cows. Cow age ranged from 2-16 years of age. Cows were randomly sorted into two treatment groups; 1) 7-day CO-Synch + CIDR (CO-Synch), and 2) 7 & 7 Synch (7&7). For the CO-Synch treatment, cows received a controlled internal drug release insert (CIDR; 1.38g progesterone) and 100 µg gonadotropin-releasing hormone (GnRH) i.m., followed in 7 d by CIDR removal and 25 mg prostaglandin F2alpha i.m., followed in 60 to 66 hours with AI and 100 µg GnRH i.m. For the 7&7 Synch protocol cows received a controlled internal drug release insert (CIDR; 1.38g progesterone) and 25 mg prostaglandin F2alpha i.m., followed in 7 days by 100 µg gonadotropin-releasing hormone (GnRH) i.m., followed in 7 d by CIDR removal and 25 mg prostaglandin F2alpha i.m., followed in 60 to 66 hours with AI and 100 µg GnRH i.m. (Figure 1). Heat detect patches were applied at the time of CIDR removal to determine estrus response by the time of AI, with cows having patches ≥ 50% activated or missing patches defined as being in estrus and cows with patches < 50% activated defined as not experiencing estrus during our interval of evaluation. Sire and AI technician data were also recorded. Pregnancy status was determined via transrectal ultrasonography 35 days after AI and at least 40 days after the conclusion of the breeding season.

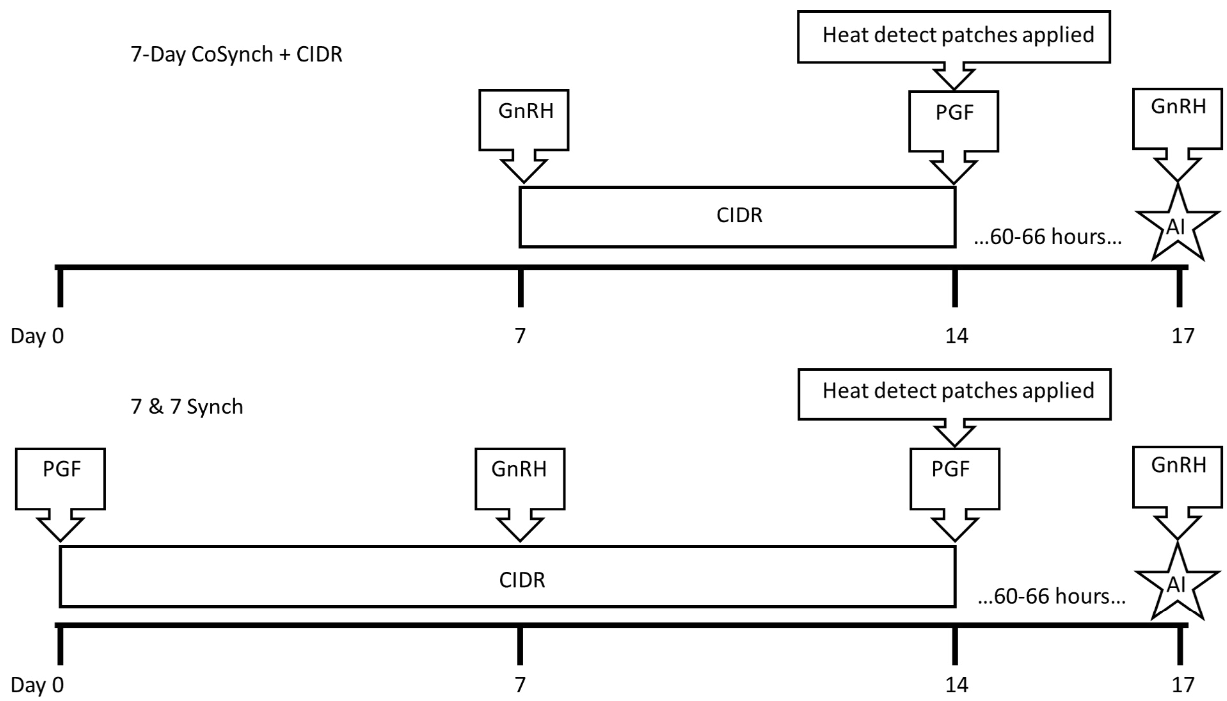


Figure 1. Cows were randomly assigned to two treatments using the following program: 1) 7-day CO-Synch + CIDR (CO-Synch), and 2) 7 & 7 Synch (7&7). For the CO-Synch treatment.

Results and Discussion

Estrus response was based on scores from heat-detect patches (Table 1). Cows with patches of a score 2 (greater than 50% of patch activated) or missing patches were considered to be in estrus before timed AI. Cows in the 7&7 treatment had a 25% greater estrus response than those in the CO-Synch treatment ($P < 0.0001$). This increase in estrus response within the 7&7 Synch group is consistent with results report by Anderson, *et al.*, 2020.

Table 1: Estrus response by location and treatment.				
	Treatment			
	7-day CO-Synch + CIDR		7&7 Synch	
Location	Proportion	%	Proportion	%
1	45/80	56.3	71/82	86.6
2	127/201	63.2	179/206	86.9
Combined	172/281	61.2[x]	250/288	86.8[y]

[x,y]Means within row lacking common superscripts differ (*P* < 0.0001).

Cows in the 7&7 treatment had 13% greater 35-day pregnancy rates than those in the CO-Synch treatment (*P* = 0.001). Overall pregnancy rates in Location 2 (CGREC) were 30% greater than in Location 1 (Beef Unit; *P* < 0.0001). Although pregnancy rates differed between locations, there was no observed interaction between location and treatment. The differences in pregnancy rates between treatments are consistent with results found by Anderson, *et al.*, 2020.

Table 2: 35-Day Pregnancy Results by location and treatment						
	Treatment					
	7-day CO-Synch + CIDR		7&7 Synch		Location Total	
Location	Proportion	%	Proportion	%	Proportion	%
1	19/80	23.8	33/82	40.2	52/162	32.1[a]
2	119/200	59.5	148/206	71.8	267/406	65.8[b]
Combined	138/280	49.3[x]	181/288	62.8[y]		

[x,y]Means within row lacking common superscripts differ (*P* = 0.001).
[a,b] Location means within column lacking common superscript differ (*P* < 0.0001).

Pregnancy rates were examined based on whether or not the cow exhibited estrus prior to fixed-time AI. Cows that exhibited estrus had a pregnancy rate of 62.5% (263/421) while cows that failed to exhibit estrus had a pregnancy rate of 38.1% (56/147). This is consistent with previous research regarding estrus expression prior to fixed-time AI (Richardson, *et al.,* 2016).

Location 1 exhibited much lower pregnancy rates than Location 2. This was attributed to differences in AI date, weather, technician, handling stress due to facilities, or another undetermined variable. Treatment was ruled out as a contributing factoring due to the lack of a treatment by location interaction as described above.

Compared to the results of Anderson *et al.*, 2020, on which the 7&7 Synch protocol was initially reported, the results of this study are consistent. Cows within the 7&7 treatment had greater estrus responses and pregnancy rates. The 7&7 Synch protocol is a viable option for producers to utilize to increase pregnancy rates in post-partum beef cows in situations where an additional time through working facilities is a possibility.

References

Andersen, C.M., R.C. Bonacker, E.G. Smith, K.S. Stoecklein, C.M. Spinka, and J.M. Thomas. 2020. Evaluation of the 7 & 7 Synch and 7-Day CO-Synch + CIDR® protocols for estrus synchronization of beef cows prior to fixed-time artificial insemination with conventional or sex-sorted semen. Society for the Study of Reproduction. Abstract 1717.

Bonacker, R.C., K.S. Stoecklein, J.W.C Locke, J.N. Ketchum, E.R. Knickmeyer, C.M. Spinka, S.E. Poock, and J.M. Thomas. 2020. Treatment with prostaglandin F2alpha and an intravaginal progesterone insert promotes follicular maturity in advance of gonadotropin-releasing hormone among postpartum beef cows. Theriogenology 157:350-359.

Richardson, B.N., S.L. Hill, J.S. Stevenson, G.D. Djira, and G.A. Perry. 2016. Expression of estrus before fixed-time AI affects conception rates and factors that impact expression of estrus and the repeatability of expression of estrus in sequential breeding seasons, Anim. Reprod. Sci. 1661: 33-140.

Ryan, M., M. Mihm, and J.F. Roche. 1998. Effect of GnRH given before or after dominance on gonadotrophin response and the fate of that follicle wave in postpartum dairy cows. J. Reprod. Fertil. 21: 61.

Effects of feeding a vitamin and mineral supplement to cow-calf pairs grazing native range

Jennifer L. Hurlbert[1], Friederike Baumgaertner[1], Timothy Long[2], Cody Wieland[2], Kevin K. Sedivec[2] and Carl R. Dahlen[1]

[1]Animal Sciences Department and Center for Nutrition and Pregnancy, NDSU
[2]Central Grasslands Research Extension Center, NDSU

The objectives of this study were to evaluate the influence of feeding a vitamin and mineral (VTM) supplement to pregnant cows and suckling calves during the summer grazing period on native rangeland. Although performance measures in cows or calves were not affected, concentrations of liver mineral were enhanced in cows and calves that had access to free-choice mineral while grazing summer pastures.

Summary
Our objectives were to evaluate how providing free-choice vitamin and mineral (VTM) supplements to cow-calf pairs during the summer grazing period on native range affects cow and calf performance and liver mineral concentrations. During a two-year period, Angus-based crossbred cow-calf pairs (n = 727; n = 381 in year 1, n = 346 in year 2) from the Central Grasslands Research Extension Center (Streeter, N.D.) were assigned to pastures (16 in year 1, 14 in year 2), which then were assigned to receive a free-choice mineral supplement (Mineral) or no mineral supplement (No Mineral). Prior to treatment assignments, all cow-calf pairs received a common diet as a total mixed ration including a mineral supplement for 120 days before pasture turnout. The grazing periods for year 1 and year 2 were 158 and 156 days, respectively, and treatments began at pasture turnout and concluded at pasture removal. Cows were bred on pasture using artificial insemination followed by natural service cleanup bulls for a 70- to 80-day breeding season. Weights were collected from cows and calves at pasture turnout and removal and liver biopsies were taken from a subset of cows and calves. Additionally, birth weights and calving distribution were evaluated. Cow and calf weights and weight change during the grazing period were not impacted ($P \geq 0.47$) by access to VTM supplement. Furthermore, the pregnancy rate and subsequent birth weight and calving distribution were not affected ($P \geq 0.36$) by treatment. Liver concentrations of selenium, copper and cobalt were greater ($P \leq 0.002$) at pasture removal and weaning for cows and suckling calves that had access to VTM. Although VTM supplementation enhanced concentrations of key minerals in the liver of cows and calves, performance was not impacted.

Introduction
Successful cow-calf herds rely on reproductive efficiency to maintain profitability; thus, maintaining adequate maternal nutritional status, including vitamin and mineral nutrition, is essential to optimal growth, development and programming of the fetus (Kegley et al., 2016).

However, management strategies implemented by producers vary widely, with innumerable programs and intensities of vitamin and mineral supplementation.

Vitamins and minerals are transferred across the placenta to the growing fetus during gestation; however, the long-term implications of the mineral status established at birth in the neonate have yet to be elucidated (Hidiroglou, 1980; Hostetler et al., 2003; Menezes et al., 2021). Therefore, this study evaluated influences of vitamin and mineral supplementation on growth performance and mineral status of the dam and suckling calves throughout the grazing period, reproductive success in the dam, and birthweight and calving distribution of the calf crop.

Experimental Procedures

Animals, Housing and Diet

During a two-year period, 727 Angus-based crossbred cow-calf pairs (n = 381 in year 1, n = 346 in year 2) were used at the Central Grasslands Research Extension Center to evaluate the influence of providing free-choice VTM supplements during the grazing season on cow-calf herd performance. Prior to treatment assignments, all cows and calves were fed a common diet as a total mixed ration including a mineral supplement for 120 days before pasture turnout.

Cow-calf pairs were blocked by cow age, then randomly assigned to one of 16 pastures in year 1 and one of 14 pastures in year 2. Pastures were assigned randomly to one of two treatments: 1) free choice VTM supplement was available in the pasture (Mineral) or 2) no mineral supplement was available in the pasture (No Mineral). Females were blocked by cow age and reassigned to the Mineral or No Mineral treatment group between years 1 and 2. The grazing period for years 1 and 2 were 158 and 156 days, respectively, and treatments began at pasture turnout and concluded at the time the pairs were removed from pasture.

All pastures were stocked at the same stocking rate to achieve 40% to 50% degree of forage disappearance. The vitamin and mineral supplement were offered in free-choice mineral feeders placed in each pasture and consumption was monitored. Mineral feeders were accessible for all cows and calves on pastures receiving the treatment.

The vitamin and mineral supplement offered in year 1 was Stockmen's Supply Repromune MIN YC (Stockmen's Nutrition, West Fargo, N.D.) and in year 2, the supplement offered was Payback Research 12-6+ (CHS Nutrition, Sioux Falls, S.D.). Cows were synchronized using a 7-CoSynch artificial insemination (AI) protocol and bred to multiple sires and natural service cleanup bulls were turned out shortly after AI.

Pregnancy status was determined via transrectal ultrasonography at least 40 days after bull removal to determine overall pregnancy rates. Cows remained on pasture with their suckling calf until the end of the grazing season (weaning).

Cow/calf Performance

Calf weights were recorded at birth, pasture turnout and weaning. Consecutive-day cow weights were recorded at pasture turnout and removal from pasture. Average two-day weights for turnout and removal were used to calculate performance on pasture. Gain during the grazing period and average daily gain were calculated for cows and calves.

Pregnancy ultrasound data were evaluated to assess overall pregnancy rates. Furthermore, calving records were analyzed to determine calving distribution.

Mineral Status

Liver biopsies were taken at pasture turnout and removal from a subset of 16 cows in year 1 and 42 cows in year 2. In addition, samples were collected from a subset of 47 calves in year 1 and 35 calves in year 2 within a week of weaning.

Samples were collected using a Tru-Cut biopsy trochar (14 g; Becton Dickinson Co., Franklin Lakes, N.J.) using techniques outlined by Engle and Spears (2000) and McCarthy et al., (2019). Samples were analyzed for concentrations of selenium, iron, copper, zinc, molybdenum, manganese and cobalt at the Diagnostic Center for Population and Animal Health at Michigan State University using inductively coupled plasma mass spectrometry.

Statistical Analysis

Mean values for individual cows and calves within a pasture were calculated and used to represent the pasture in the final data set. For concentrations of liver mineral, mean pasture values were calculated for each pasture and used for analysis. Data were analyzed for the effect of VTM treatment (Mineral or No Mineral) using the GLM procedure of SAS with pasture as the experimental unit. Differences were considered significant at a P-value ≤ 0.05.

Results

Cow-Calf Performance

Cow weight change and pregnancy attainment were not influenced by VTM supplementation on pasture ($P = 0.99$ and $P = 0.36$, respectively; Table 1). Pregnancy rates in suckled beef cows between both years were not different between treatments, with mineral supplemented cows at 95.3% and non-supplemented cows at 96.4% ($P = 0.36$; Table 1). Overall performance and pregnancy success were adequate for cows in both treatment groups.

Weaning weights of suckling calves were also not different ($P = 0.47$) between treatments, with Mineral calves weaned at an average of 605 pounds and No Mineral calves weaned at an average of 595 pounds (Table 2). Additionally, average daily gain (ADG) was not different between treatments ($P = 0.325$).

The birth weight of the calves conceived during the grazing season did not differ ($P = 0.447$; Table 2) between treatments, with Mineral calves averaging 87 pounds and No Mineral calves averaging 85 pounds at birth. The date of birth in the calving season was also not impacted by treatment ($P = 0.72$).

Mineral Status

Liver selenium, copper and cobalt concentrations were greater ($P \leq 0.002$) in Mineral cows at pasture removal compared with No Mineral cows (Table 3). Additionally, the change in concentrations of liver selenium, copper and cobalt from pasture turn out to pasture removal was greater ($P \leq 0.003$) for Mineral cows than No Mineral cows. At pasture removal, concentrations of iron, zinc, molybdenum and manganese in cows were not influenced ($P \geq 0.222$) by treatment.

Liver biopsies were collected from a subset of 35 calves at weaning, and liver mineral concentrations of selenium, copper and cobalt were greater ($P \leq 0.001$) for calves managed on Mineral pastures compared with calves managed on No Mineral pastures (Table 4). Concentrations of iron, zinc, molybdenum and manganese in calves were not influenced ($P \geq 0.17$) by treatment at weaning.

In the current experiment, providing a mineral supplement to suckled cows did not influence performance of the cows, suckling calves or gestating calves (Tables 1 and 2). However, data provided in Tables 3 and 4 indicate that liver mineral concentrations were enhanced in cows and calves provided with a mineral supplement during the grazing period.

Discussion

The *in-utero* environment experienced by calves during gestation is a product of the dam's environment. Nutrients consumed, weather conditions and stress experienced by dams all can impact the developing fetus.

Vitamins and minerals can serve several key roles in growth and development in the body of the gestating dam as well as the fetus, including structural, physiological, catalytic and regulatory functions, which contribute to effects on hormone production, enzyme activity, tissue growth, oxygen transport and energy production (Menezes et al., 2021). Evaluation of calf crops conceived by dams that received different VTM treatments during the grazing period (the first trimester of gestation) should be continued at later post-natal and post-pubertal time points.

Research by Ahola et al. (2004) supported similar liver mineral status findings, with greater copper liver mineral concentrations in supplemented dams compared with non-supplemented dams over two years, but performance data varied slightly as a result of free-choice mineral supplementation. In that study, overall 60-day pregnancy rates tended to be higher for supplemented cows compared with non-supplemented cows, an effect that was not observed in the current study. Management factors that impact pregnancy attainment or calf growth warrant careful investigation because of their intricate relationship with herd profitability.

When evaluating overall implications of pasture-based mineral supplementation programs, additional evaluations, including assessing immune status of the suckling calves, and post-weaning health implications should be considered. Strategies that enhance immunity and reduce susceptibility to disease in newly weaned calves would be a great benefit to backgrounding and feedlot operations.

Weaning data for calves conceived and gestated in year 2 of this experiment has not yet been incorporated. When completed, this dataset can be used to evaluate the impact of early gestation mineral supplementation on subsequent offspring performance. The effects on the gestating calf receiving the mineral treatment *in utero* should be evaluated further in terms of the potential to program the growing fetus to utilize micronutrients more efficiently. Furthermore, vitamin and mineral deficiencies during stressful events in a calf's life, such as weaning and transport, can become more apparent (Kegley et al., 2016). Decreasing the incidence of morbidity and maintaining calf health may be an outlet to increasing overall calf performance, but further research is necessary to determine the impact vitamin and mineral supplementation may have in scenarios where calf immune status is challenged.

Literature Cited

Ahola, J.K., Baker, D.S., Burns, P.D., Mortimer, R.G., Enns, R.M., Whittier, J.C., Geary, T.W., and Engle, T.E. (2004). Effect of copper, zinc, and manganese supplementation and source on reproduction, mineral status, and performance in grazing beef cattle over a two-year period. *Journal of Animal Science*, 82: 2375–2383. https://academic.oup.com/jas/article/82/8/2375/4790626

Engle, T.E., and Spears, J.W. (2000). Effects of dietary copper concentration and source on performance and copper status of growing and finishing steers 1. *J. Anim. Sci*, 78: 2446–2451. https://academic.oup.com/jas/article/78/9/2446/4670853

Hidiroglou, M. (1980). Trace elements in the fetal and neonate ruminant: a review. *Can. Vet. J.* 21:328-335.

Hostetler, C.E., Kincaid, R.L. and Mirando, M.A. (2003). The role of essential trace elements in embryonic and fetal development in livestock. *Vet. J.* 166:125-139. doi:10.1016/s1090-0233(02)00310-6

Kegley, E., Ball, J. and Beck, P. (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. doi:10.2527/jas2016-0720

McCarthy, K.L., Underdahl, S.R., Undi, M., Becker, S., and Dahlen, C.R. (2019). Utilizing an electronic feeder to measure mineral and energy supplement intake in beef heifers grazing native range. *Translational Animal Science*, 3: 1719–1723. https://doi.org/10.1093/tas/txz065

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.P., Sedivec, K.K., Forcherio, J.C., Scott, R., Caton, J.S., and Dahlen, C.R. (2021). Vitamin and mineral supplementation and rate of gain during the first trimester of gestation affect concentrations of amino acids in maternal serum and allantoic fluid of beef heifers. *Journal of Animal Science*, 99(2). https://doi.org/10.1093/jas/skab024

Table 1. Effect of mineral supplement availability on performance of suckled beef cows.				
	Treatment[1]			
Item	No Mineral	Mineral	SE	*P*-Value
Turnout wt, lbs.	1,325.0	1,330.5	30.6	0.90
Pasture removal wt, lbs.	1,384.5	1,390.3	30.4	0.89
Cow wt change, lbs.	58.0	58.0	7.41	0.99
Pregnancy rate, lbs.	96.4	95.3	0.82	0.36

[1]Treatments were: No Mineral - Cows were grazing pastures with no access to a mineral supplement or Mineral - Cows were grazing pastures with access to a mineral supplement.

Table 2. Effect of mineral supplement availability on performance of calves.				
	Treatment[1]			
Item	No Mineral	Mineral	SE	*P*-Value
Suckling calf				
Turnout wt., lbs.	185.4	183.0	2.92	0.56
Weaning wt. lbs.	595.0	604.8	9.55	0.47
Calf gain, lbs.[2]	410.3	421.9	8.14	0.32
Calf ADG, lbs.	2.61	2.69	0.05	0.32
Gestating calf				
Day of calving	17.75	18.22	0.92	0.72
Birth wt, lbs.	85.26	86.62	1.25	0.45

[1]Treatments were: No Mineral - calves were grazing pastures where they (along with their dams) had no access to a mineral supplement or Mineral - calves were grazing pastures where they (along with their dams) had access to a mineral supplement.
[2]Calf gain is the total gain (lbs) from pasture turnout to weaning.

Table 3. Effects of mineral supplement availability on liver mineral concentrations in suckled cows grazing native range[1]; combined averages of years 1 and 2.

	Sample		Treatment[2] No Mineral	Mineral	SE	*P* – value
			-------µg/g-------			
Selenium, Se	Turnout		1.87	1.78	0.066	0.33
	Removal		2.22	2.87	0.138	0.002
		CHG[3]	0.34	1.08	0.155	0.002
Iron, Fe	Turnout		276.1	263.0	18.46	0.61
	Removal		265.1	252.0	15.73	0.55
		CHG	-11.05	-11.03	16.40	0.99
Copper, Cu	Turnout		204.8	183.1	12.97	0.23
	Removal		183.0	302.4	19.89	0.0002
		CHG	-21.84	119.28	20.40	<0.001
Zinc, Zn	Turnout		139.8	141.1	8.66	0.91
	Removal		149.0	172.2	13.5	0.22
		CHG	9.29	31.09	14.49	0.28
Molybdenum, Mo	Turnout		3.78	3.82	0.121	0.82
	Removal		4.30	4.20	0.092	0.46
		CHG	0.514	0.381	0.127	0.45
Manganese, Mn	Turnout		11.13	11.44	0.326	0.52
	Removal		11.16	11.44	0.316	0.52
		CHG	0.035	0.003	0.344	0.95
Cobalt, Co	Turnout		0.239	0.233	0.0109	0.70
	Removal		0.163	0.300	0.0278	0.001
		CHG	-0.076	0.067	0.0319	0.003

[1]For this analysis, mineral concentration values were averaged between years 1 and 2.
[2]Treatments were: No Mineral - Cows were grazing pastures with no access to a mineral supplement or Mineral - Cows were grazing pastures with access to a mineral supplement.
[3]Change in concentration: reflects the concentration at pasture removal minus the value from pasture turnout.

Table 4. Effects of mineral supplement availability on liver mineral concentrations in suckling calves grazing native range.

	Treatment[1]			
Item, µg/g	No Mineral	Mineral	SE	*P*-Value
Se	1.62	1.93	0.063	0.001
Fe	203.8	179.3	14.93	0.2547
Cu	48.4	103.3	6.88	<0.001
Zn	168.3	169.0	6.50	0.94
Mo	3.45	3.19	0.130	0.17
Mn	8.78	9.06	0.277	0.47
Co	0.114	0.172	0.009	<0.001

[1]Treatments were: No Mineral - Calves were grazing pastures with no access to mineral supplement or Mineral - Calves were grazing pastures with access to mineral supplement.

Bulls managed on a negative plane of nutrition for 112 days have increased abundance of mammalian target of rapamycin (mTOR) in testicular biopsies

Kerri A. Bochantin[1], Pawel P. Borowicz[1], Jordan Flaten[1], Sarah R. Underdahl[1], Matthew S. Crouse[2], Kacie L. McCarthy[3], Cierrah J. Kassetas[1], Friederike Baumgaertner[1,4], Ana Clara B. Menezes[1], James D. Kirsch[1], Sheri T. Dorsam[1], Kevin K. Sedivec[4], Alison K. Ward[1], Joel S. Caton[1], and Carl R. Dahlen[1]

[1]Department of Animal Sciences, North Dakota State University, Fargo ND
[2]USDA, ARS, U.S. Meat Animal Research Center, Clay Center, NE
[3]Department of Animal Science, University of Nebraska, Lincoln, NE
[4] NDSU Central Grasslands Research Extension Center, Streeter, ND

The objective of this study was to determine the effects of divergent planes of nutrition in mature beef bulls on nutrient sensing pathways and androgen receptor abundance in testicular tissue. Abundance of a key regulator in nutrient metabolism pathways, mTOR, was decreased in bulls on a positive plane of nutrition, which could contribute to differences in sire fertility or messages carried in sperm to future offspring.

Summary

The objective of this study was to evaluate the influence of divergent plane of nutrition on nutrient sensing pathways and androgen receptor abundance in testicular tissue of bulls. Angus bulls (n = 15; 4 to 5 years old) were randomly assigned to one of two treatments: 1) a positive plane of nutrition managed to gain 12% body weight (BW) over 112 days (POS, n = 8); or 2) a negative plane of nutrition managed to lose 12% BW over 112 days (NEG, n = 7). On day 113, testicular biopsies were performed on all bulls. Parenchyma tissue samples were fixed in formalin, embedded in paraffin, cut at 5 µm and placed on glass slides. Slides underwent processing followed by incubation with antibodies to mammalian target of rapamycin (mTOR), phosphorylated mTOR (p-mTOR), or androgen receptor (AR), followed by a fluorescent-tagged antibody. Slides were examined for fluorescent intensity of the specific antibody and optical density was quantified for three to five randomly selected images of seminiferous tubules. The number of Sertoli cells and germ cells within each seminiferous tubule were counted and a ratio of germ cells to Sertoli cells was calculated. No differences were observed between treatments for mTOR ($P = 0.89$), ratio of p-mTOR to mTOR ($P = 0.32$), AR abundance ($P = 0.64$), or Sertoli and germ cell counts ($P = 0.78$, $P = 0.35$, respectively) within the seminiferous tubules. Similarly, no differences were observed in the interstitial space for mTOR abundance ($P = 0.86$) or AR abundance ($P = 0.62$). However, p-mTOR abundance tended to be higher in the seminiferous tubules ($P = 0.06$) and in the interstitial space ($P = 0.004$) of NEG bulls compared with POS bulls. These findings suggest that dietary factors influence testicular abundance of signaling proteins involved in metabolic function of the cell, potentially influencing the

developing sperm and ultimately affecting sperm quality, sire fertility, or epigenetic messages carried by sperm to future offspring.

Introduction

Nutritional management of bulls is an important consideration for producers to achieve optimal herd reproductive performance. The consequence of variable nutritional management strategies on sire fertility and subsequent offspring performance remains underexplored. Previous research conducted in livestock species has demonstrated that nutritional status of sires influences scrotal circumference, sperm number and motility, seminal plasma quality, and DNA damage (Guan et al., 2016).

Sperm production occurs within the seminiferous tubules of the testes and requires various molecular signals to allow for this dynamic process. Sertoli cells (SC) serve as nurse cells within the seminiferous tubule, providing support, nourishment, and protection to developing sperm cells. These cells are enclosed within a blood-testes barrier that eliminates direct contact of tubule cells from circulatory blood. Testosterone produced by the Leydig cells of the interstitial space of the testes is also critical to sperm production and supports SC function via the nuclear transcription factor, androgen receptor (Alves et al., 2013). Mammalian target of rapamycin (mTOR) is a protein kinase involved in the cellular signaling pathways of nutrient metabolism and plays a critical role in sperm production in SC. Activation via phosphorylation of mTOR is influenced by factors like insulin and insulin-like growth factor 1 (IGF-1), cellular energy level, and amino acids (Saxton & Sabatini, 2017). A reduction in mTOR abundance in SC is associated with reduced metabolic activity of the cell, ultimately leading to reduced sperm production and motility (Oliveira et al., 2017). Nutritional changes of the sire may act at the level of the testes, influencing the nutrient sensing and metabolic capacity of SC to support germ cells (Alves et al., 2013). More specifically, studies on overnutrition in rodent and human models have demonstrated paternal effects of transgenerational transmission of metabolic dysfunction and reproductive performance in their offspring (Fullston et al., 2015). Whether different circulating nutrients attained via divergent sire nutrition can work across the blood testes barrier to influence testicular mTOR or AR abundance, and potentially impact developing sperm, is unknown.

Experimental Procedures

Fifteen Angus bulls of 4 to 5 years of age from the Central Grasslands Research Extension Center near Streeter, N.D. were utilized for this study. Bulls were randomly assigned to one of two treatments: 1) a positive plane of nutrition managed to gain 12% BW (POS, n = 8); or 2) a negative plane of nutrition managed to lose 12% BW (NEG, n = 7) over a 112-day period prior to the breeding season. Bulls were housed at the Beef Cattle Research Complex in Fargo, N.D. and individually fed using the Insentec Roughage Intake Control System (Markenese, Netherlands) with feed allocations adjusted bi-weekly to achieve targeted growth trajectory. On day 113, testicular biopsies were performed on all bulls using a procedure modified from Heath et al., (2002). Briefly, bulls were restrained in a hydraulic Silencer chute and the scrotal area was scrubbed with iodine and cleaned with alcohol. At the biopsy target site (approximately 5 cm below the head of the epididymis on the lateral aspect of the left testicle), 3mL lidocaine was administered as a local anesthetic. A 14-gauge x 10-cm automatic biopsy needle (AccuCore Single Action Biospy, Inrad, Kentwood, MI) was inserted into the testicle, penetrating the parietal and visceral vaginal tunics and tunica albuginea, with care to avoid the epididymis. Two biopsy cores of parenchyma were collected from the left testicle.

The tissue sample was placed in a 10% formalin fixative solution, embedded in paraffin, cut in 5-µm thick sections using a microtome and placed on a glass slide. Immunohistochemistry on the slides was performed, as previously described (Crouse et al., 2021). Briefly, sections were deparaffinized, rehydrated, and underwent antigen retrieval. Slides were stained with monoclonal antibodies to either mTOR (ab32028; Abcam), p-mTOR (ab109268), or AR (ab74272). This was followed by incubation with IgCF633 fluorescent antibody and counterstaining with DAPI. Images were captured at 40×s magnification with an inverted microscope with laser scanning head attachment.

Testicular parenchyma consists of two distinct regions, the seminiferous tubule containing SC and developing sperm, and the interstitial space, or space between the tubules (Fig. 1). For each bull, three to five seminiferous tubules were randomly selected for image capture. The image was further processed with image analysis software to measure optical density of fluorescence staining within the seminiferous tubule and interstitial space, which is defined as the relative fluorescence intensity of staining divided by the pixel area of the selected field. Sertoli cells were characterized by the presence of AR within the nucleus, with remaining nuclei in the tubule characterized as a germ cell. The number of SC and germ cells per seminiferous tubule were counted and a ratio generated by dividing the number of germ cells by number of SC.

Data were analyzed using the GLM procedure of SAS (Ver.9.4, SAS Inst. In., Cary N.C.) for the effect of plane of nutrition (POS or NEG) with bull as the experimental unit. Significance was set at $P \leq 0.05$ and tendency at $0.05 < P \leq 0.10$. Data are presented as means ± standard error (SE).

Results and Discussion

No differences were observed between treatments for the measurement of optical density fluorescent staining for total mTOR within the seminiferous tubules ($P = 0.89$) or in the interstitial space ($P = 0.86$; Table 1; Fig. 2C – D). However, p-mTOR was higher in the interstitial space ($P = 0.004$) and tended to be higher in the seminiferous tubules ($P = 0.06$) of NEG bulls compared with POS bulls (Table 1; Fig. 2A – B). No differences were observed for AR between treatments within the seminiferous tubules ($P = 0.64$) or interstitial space ($P = 0.62$; Table 1; Fig. 2E – F). The number of Sertoli cells ($P = 0.78$) and germ cells ($P = 0.35$) per seminiferous tubule, as well as the ratio of germ cells to Sertoli cells ($P = 0.21$) did not differ between treatments (Table 2).

In the presence of elevated nutrient levels, mTOR abundance and activity is increased to aid in regulation of these key metabolic pathways (Saxton & Sabatini, 2017). Interestingly, although POS bulls had increased concentrations of key mTOR signals (amino acids and IGF-1) in the blood, the abundance of p-mTOR within the seminiferous tubules and interstitial space was reduced when compared to NEG bulls (Table 1; Fig. 1A – B). While this reduction is contrary to the anticipated elevated abundance, previous research has demonstrated decreases of mTOR abundance in the Sertoli cells of rats fed a high-fat diet (Cui et al., 2017). In this experiment, POS bulls may be experiencing similar dysregulation of mTOR activity as a result of alterations in circulating metabolites in the blood and subsequent weight gain. This may be contributing to dysregulation of these nutrient sensing pathways, which could alter metabolism in the testes.

A lower germ cell to Sertoli cell ratio may be indicative of decreased metabolic capacity of Sertoli cells to provide support to the germ cells. However, in this experiment, no differences were observed between POS and NEG bulls for number of germ cells and SC, as well as the ratio (Table 2). Guan et al. (2016) reported similar findings in sheep models, demonstrating no effects of over- or undernutrition on the number of Sertoli cells in mature rams. While no treatment differences were observed, nutrient availability has been demonstrated to impact sperm quality and cause DNA damage (Guan & Martin, 2017).

No differences were observed in AR abundance in the seminiferous tubules and interstitial space between treatments (Table 1). However, AR localization in the nuclei has been demonstrated to be specific to certain spermatogenic stages, indicating a role in germ cell development (Bremner et al., 1994). Further characterization of the stages of the tubules in models of divergent nutrition may provide insight on the interaction of nutrient levels and hormonal signals and subsequent effects on spermatogenesis.

In summary, abundance of the activated form of nutrient sensing regulator, phosphorylated mTOR, was higher in the testicular tissue of bulls on a negative plane of nutrition. This may be the result of the altered nutrient availability to the SC in response to excess or reduction of circulating metabolites, such as amino acids. Future research will evaluate the expression of glucose and amino acid transporters in the seminiferous tubules to further elucidate the contributions of nutrition on SC function and sperm production. While there were no differences in the abundance of AR or germ cell to SC ratio, metabolic differences within the SC may have lasting effects on sperm quality, sire fertility, and epigenetic messages carried to offspring.

Literature Cited

Alves, M. G., Rato, L., Carvalho, R. A., Moreira, P. I., Socorro, S., & Oliveira, P. F. (2013). Hormonal control of Sertoli cell metabolism regulates spermatogenesis. *Cellular and Molecular Life Sciences*, *70*(5), 777–793.

Bremner, W.J., Millar M.R., Sharpe R.M., & Saunders P.T. (1994). Immunohistochemical localization of androgen receptors in the rat testis: Evidence for stage-dependent expression and regulation by androgens. *Endocrinology* 135: 1227– 1234.

Crouse, M. S., K. J. McLean, J. Dwamena, T. L. Neville, A. C. B. Menezes, L. P. Reynolds, C. R. Dahlen, B. W. Neville, P. P. Borowicz, & J. S. Caton. (2021). The effects of maternal nutrition during the first 50 days of gestation on the location and abundance of hexose and cationic amino acid transporters in beef heifer utero-placental tissues. *J. Anim. Sci., 99* (1), 1-12.

Cui, X., Long, C., Zhu, J., & Tian, J. (2017). Protective effects of fluvastatin on reproductive function in obese male rats induced by high-fat diet through enhanced signaling of mTOR. *Cellular Physiology and Biochemistry*, *41*(2), 598–608.

Fullston, T. Shehadeh H, Sandeman L.Y., Kang W.X., Wu L.L., Robker R.L., McPherson N.O., Lane M. (2015). Female offspring sired by diet induced obese male mice display impaired blastocyst development with molecular alterations to their ovaries, oocytes and cumulus cells. *J. Assist. Reprod. Genet.* 32(5):725–735.

Guan, Y. & Martin, G.B. (2017). Cellular and molecular responses of adult testis to changes in nutrition: novel insights from the sheep model. *Reproduction* 154 (5), R133-R141

Guan, Y., Liang, G., Hawken, P. A. R., Meachem, S. J., Malecki, I. A., Ham, S., Stewart, T., Guan, L. L., & Martin, G. B. (2016). Nutrition affects Sertoli cell function but not Sertoli cell numbers in sexually mature male sheep. *Reproduction, Fertility and Development*, *28*(8), 1152–1163.

Heath, A. M., Carson, R. L., Purohit, R. C., Sartin, E. M., & Wenzel, J. G. W. (2002). Effects of testicular biopsy in clinically normal bulls. *Journal of the American Veterinary Medical Association*, *220*(4), 507–512.

Oliveira, P. F., Cheng, C. Y., & Alves, M. G. (2017). Emerging role for mammalian target of rapamycin in male fertility. *Trends in Endocrinology and Metabolism*, *28*(3), 165–167.

Saxton, R. A., & Sabatini, D. M. (2017). mTOR Signaling in growth, metabolism, and disease. *Cell*, *169*(2), 361–371.

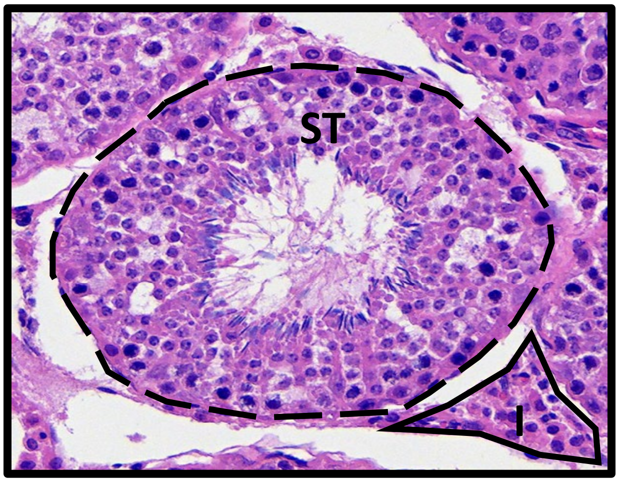


Figure 3. Histology of the testicle. The seminiferous tubule (ST; dashed black line) is the circular structure in the middle of the image, within which Sertoli cells nourish the developing sperm. The interstitial space (IS; solid black line) is the space between Sertoli cells where testosterone is produced by Leydig cells. The contents of the seminiferous tubules are protected from blood circulation though a mechanism called the blood-testis-barrier.

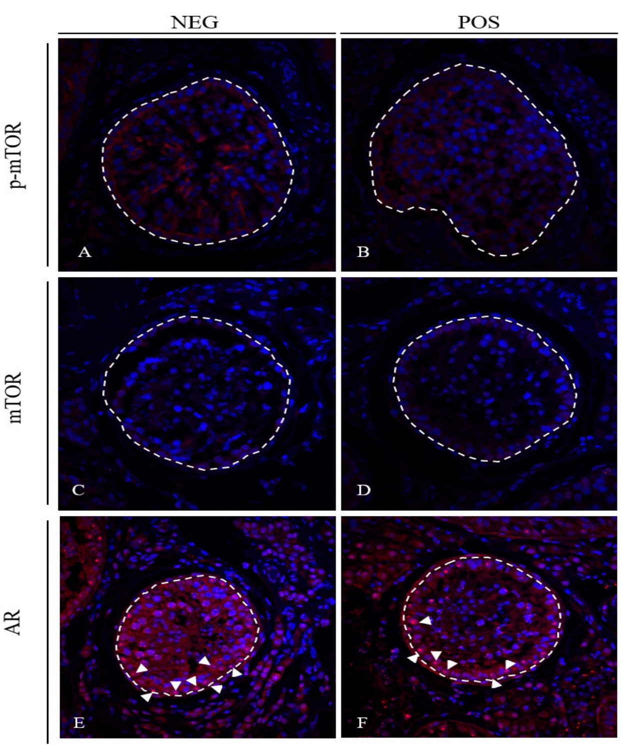


Figure 2. Immunohistochemistry staining of testicular biopsies of bulls on divergent planes of nutrition. Respective antibody staining is represented in red. DAPI staining of nuclei is represented in blue. Seminiferous tubules are outlined by the dashed white line and remaining space outside of tubule is the interstitial space. Arrowheads point to Sertoli cells, characterized by localized androgen receptor (AR) abundance. Fig. A & B: p-mTOR abundance in NEG and POS bulls. Fig. C & D: mTOR in NEG and POS bulls. Fig. E & F: AR abundance in NEG and POS bulls.

Table 1. Optical density of fluorescent staining for mTOR, p-mTOR, ratio of p-mTOR to mTOR, and AR abundance in testicular parenchyma of bulls managed on divergent planes of nutrition.

	NEG		POS		
Item	**Mean**	**SE**	**Mean**	**SE**	***P*-value**
Seminiferous tubule					
mTOR	362.6	69.6	348.8	69.6	0.89
p-mTOR	1256.5	167.4	759.4	178.9	0.06
Ratio (p-mTOR/mTOR)	4.0	0.9	2.8	0.9	0.32
AR	2588.2	626.4	3028.2	669.7	0.64
Interstitial space					
mTOR	107.5	14.8	111.2	14.7	0.86
p-mTOR	179.9	19.3	80.1	20.6	0.004
Ratio (p-mTOR/mTOR)	1.8	0.2	0.8	0.2	0.009
AR	896.5	144.3	1003.0	154.3	0.62

[1]Treatments were: POS = bulls managed on a positive plane of nutrition over 112 days; NEG = bulls managed on a negative plane of nutrition over 112 days. AR = androgen receptor; mTOR = mammalian target of rapamycin; p-mTOR = phosphorylated mTOR; SE = standard error.

Table 2. Number of Sertoli cells, germ cells, and ratio of germ cells to Sertoli cells in the seminiferous tubules of bulls managed on divergent planes of nutrition.

	NEG		POS		
Item	**Mean**	**SE**	**Mean**	**SE**	***P*-value**
Cell counts					
Sertoli cells / ST	21.1	1.9	21.9	2.1	0.78
Germ cells / ST	170.5	8.3	158.9	8.8	0.35
Ratio (germ cells / Sertoli cells)	9.3	0.7	8.1	0.7	0.21

[1]Treatments were: POS = bulls managed on a positive plane of nutrition over 112 days; NEG = bulls managed on a negative plane of nutrition over 112 days. SE = standard error; ST = seminiferous tubule.

Managing mature beef bulls on divergent planes of nutrition alters scrotal circumference and concentrations of hormones and metabolites

Carl R. Dahlen[1], Sarah R. Underdahl[1], Matthew S. Crouse[2], Kacie L. McCarthy[3], Cierrah J. Kassetas[1], Friederike Baumgaertner[1], James D. Kirsch[1], Sheri T. Dorsam[1], Kevin K. Sedivec[4], Alison K. Ward[1] and Joel S. Caton[1]

[1]Department of Animal Sciences, North Dakota State University, Fargo ND
[2]USDA, ARS, U.S. Meat Animal Research Center, Clay Center, NE
[3]Department of Animal Science, University of Nebraska, Lincoln, NE
[4] NDSU Central Grasslands Research Extension Center, Streeter, ND

Plane of nutrition in mature bulls fluctuates over the course of a year due to the demands of the breeding season and as a result of strategies implemented to regain weight and prepare for the subsequent breeding season. We developed a model to evaluate the impacts of divergent planes of nutrition that resulted in bulls managed on a positive plane of nutrition having enhanced concentrations of hormones and metabolites compared with bulls managed on a negative plane of nutrition. Further investigation into the fertility and offspring outcomes resulting from our model of divergent bull nutrition is ongoing.

Summary

Fifteen mature beef bulls [4 and 5 years old; body weight (BW) = 1,816 ± 38.3 lb] were used in each of two years to evaluate effects of divergent planes of nutrition on concentrations of hormones and metabolites. In Year 1, bulls were ranked by BW and randomly assigned to one of two treatments for a 112-day evaluation period; 1) managed on a positive plane of nutrition (POS), or 2) managed on a negative plane of nutrition (NEG). In Year 2, bulls were assigned to the opposite treatment they received in Year 1 (i.e. POS in Year 1 were assigned to NEG in Year 2, and vice versa). Bulls were fed a common diet with deliveries into Insentec feeders adjusted biweekly to achieve targeted weight loss or gain (~12.5% of original BW). Blood samples were collected on day 0, 56, and 112 and analyzed for concentrations of amino acids (AA) in Year 1 and for glucose, non-esterified fatty acids (NEFA), testosterone (T), triiodothyronine (T3), thyroxine (T4), and insulin-like growth factor-1 (IGF-1) in Year 1 and Year 2. By design, bull BW was influenced by a treatment × day interaction ($P < 0.001$), with POS bulls being heavier ($P < 0.01$) than NEG bulls by day 28. Over the course of the experiment, POS bulls gained 2.74 ± 0.10 lb/d while NEG lost 2.35 ± 0.10 lb/d. Body condition score and scrotal circumference were also impacted by treatment × day interactions ($P < 0.001$), both starting similar among treatments, then greater for POS than NEG thereafter. To achieve targeted weight divergence POS bulls ate more (30.4 ± 0.99 lb/d) ($P < 0.0001$) than NEG bulls (11.2 ± 0.99 lb/d). Concentrations of glucose, NEFA, T3, T4, and IGF-1 were influenced by treatment × day interactions ($P < 0.001$). Concentrations of glucose, T3, T4, and IGF-1 were greater ($P < 0.01$) for POS bulls on day 112 compared with NEG bulls on the same day. Concentrations of NEFA, however, were greater ($P < 0.001$) for NEG than POS on day 56 and 112. Total amino acids

present in serum were impacted by a treatment × day interaction ($P < 0.001$), with POS bulls having more ($P \leq 0.001$) AA present in serum than NEG bulls on day 56 and 112. Our model resulted in altered body composition and profiles of hormones and metabolites, which could have effects on testicular tissue and semen at functional, morphological, and molecular levels. Further investigation into the fertility and offspring outcomes resulting from our model of divergent bull nutrition is ongoing.

Introduction

Dramatic and dynamic changes in body weight and plane of nutrition occur within a year in the life of breeding bulls. Factors contributing to weight loss in mature bulls may be due to work load and nutritional management. A survey of producers revealed that stocking rates varied from 4 cows per bull up to 80 cows per bull (Dahlen and Stoltenow, 2015), and bulls can experience dramatic weight loss; between 100 and 400 lb (Walker et al., 2009; Hersom and Thrift, 2008). Bulls losing weight during the breeding season must subsequently be managed to regain lost weight (Barth, 2013).

Producer decisions determine the point at which bulls begin losing and gaining weight relative to the breeding season. In some scenarios, bulls begin losing weight only at the beginning of breeding season, and are then managed to gain weight thereafter, reaching targeted optimal weight just before the subsequent breeding season. Bulls in this scenario are in a positive energy balance over the time course of spermatogenesis. In other scenarios, bulls may start losing weight before the breeding season. Perhaps these bulls experienced a recent change in environment and diet after purchase, or perhaps they were managed to gain weight over winter and needed to be cut back to get into "breeding shape" or placed on pastures to graze ahead of the breeding season. In either instance, these bulls would be on a negative plane of nutrition leading up to the breeding season. When we evaluate the two respective scenarios together we see a major and common divergence in plane of nutrition leading up to the breeding season.

Spermatogenesis is a continual process that takes roughly 61 days for sperm development, followed by up to 14 days residence in the epididymis prior to ejaculation (Senger, 2012). The net result is that sperm used to inseminate a cow today likely began the process of development up to 75 days before breeding. Thus, divergence in plane of nutrition likely exposes sperm to different hormonal profiles and metabolic substrates during the time of spermatogenesis, residence in the epididymis, and upon combination with seminal plasma at ejaculation. The consequences of these differing environments remain underexplored. Therefore, our objectives were to evaluate divergent planes of nutrition on body composition and concentrations of hormones and metabolites in mature beef bulls.

Experimental Procedures

All procedures were approved by the North Dakota State Institution for Animal Care and Use Committee.

Fifteen mature beef bulls (4 and 5 years old; BW = 1,816 ± 38.3 lb) were used in each of two years to evaluate effects of divergent planes of nutrition on body composition and concentrations of hormones and metabolites. In Year 1 bulls were ranked by BW and randomly assigned to one of two treatments for a 112-day evaluation period; 1) managed on a positive plane of nutrition (POS), or 2) managed on a negative plane of nutrition (NEG). In Year 2 bulls were assigned to the opposite treatment they received in Year 1 (i.e. POS in Year 1 were assigned to NEG in Year 2, and vice versa). In each year bulls were fed a common diet containing corn silage, triticale hay, cracked corn, dried distiller's grains plus solubles (DDGS), and a vitamin/mineral premix (Table 1). Diets were placed in Insentec feeders with deliveries adjusted based on biweekly body weight to achieve targeted weight loss or gain (~12.5% of original BW). Scrotal circumference and body condition score were determined every 28 days.

Table 1. Dietary ingredients and nutrient profile of diet fed to bulls on divergent planes of nutrition.

Item	Percent in diet
Ingredient	%, dry matter basis
Corn silage	44.6
Triticale hay	27.4
Cracked corn	8.0
DDGS	15.6
Vitamin/mineral premix	4.4
Nutrient Composition	
Ash	9.16
Crude protein	12.32
Acid detergent fiber	27.34
Neutral detergent fiber	49.96
Fat	2.91
Calcium	0.56
Phosphorus	0.39

Blood samples were collected from the tail vein on day 0, 56, and 112. Samples were allowed to clot for 30 minutes and centrifuged at 1,500 × g at 4°C for 20 minutes. Serum samples were separated and stored in plastic vials at -20°C until further analysis. Samples were analyzed using the Synergy H1 Microplate Reader (Biotek, Winooski, VT) with the Infinity Glucose Hexokinase Kit (Thermo Scientific, Waltham, MA) and NEFA-C Kit (WAKO Chemicals, Inc., Richmond, VA). Serum samples were analyzed for concentrations of testosterone (T), triiodothyronine (T3), thyroxine (T4), and insulin-like growth factor-1 (IGF-1) by competitive chemiluminescent immunoassay using the Immulite 1000 (Siemens, Los Angeles, CA). Concentrations of total amino acids were determined in serum samples from Year

1 only using the ACQUITY Ultra-Performance Liquid Chromatography System (Waters Corporation, Milford, MA).

Data were analyzed using the MIXED procedures of SAS for effects of treatment, collection day, year, and their respective interactions with bull as the experimental unit. Differences were considered significant at a $P \leq 0.05$.

Results and Discussion

By design, BW of bulls on the respective treatments diverged over the course of the experiment. Bulls on the POS treatment tended ($P = 0.08$) to be heavier than NEG bulls by day 14 of the experiment, with differences significant by day 28 ($P < 0.01$; Figure 1, Panel A) and continuing through the evaluation period. Over the course of the experiment, POS bulls gained 2.74 ± 0.10 lb/d while NEG lost 2.35 ± 0.10 lb/d. To achieve targeted weight divergence, POS bulls ate more (30.4 ± 0.99 lb/d) ($P < 0.000$) than NEG bulls (11.2 ± 0.99 lb/d).

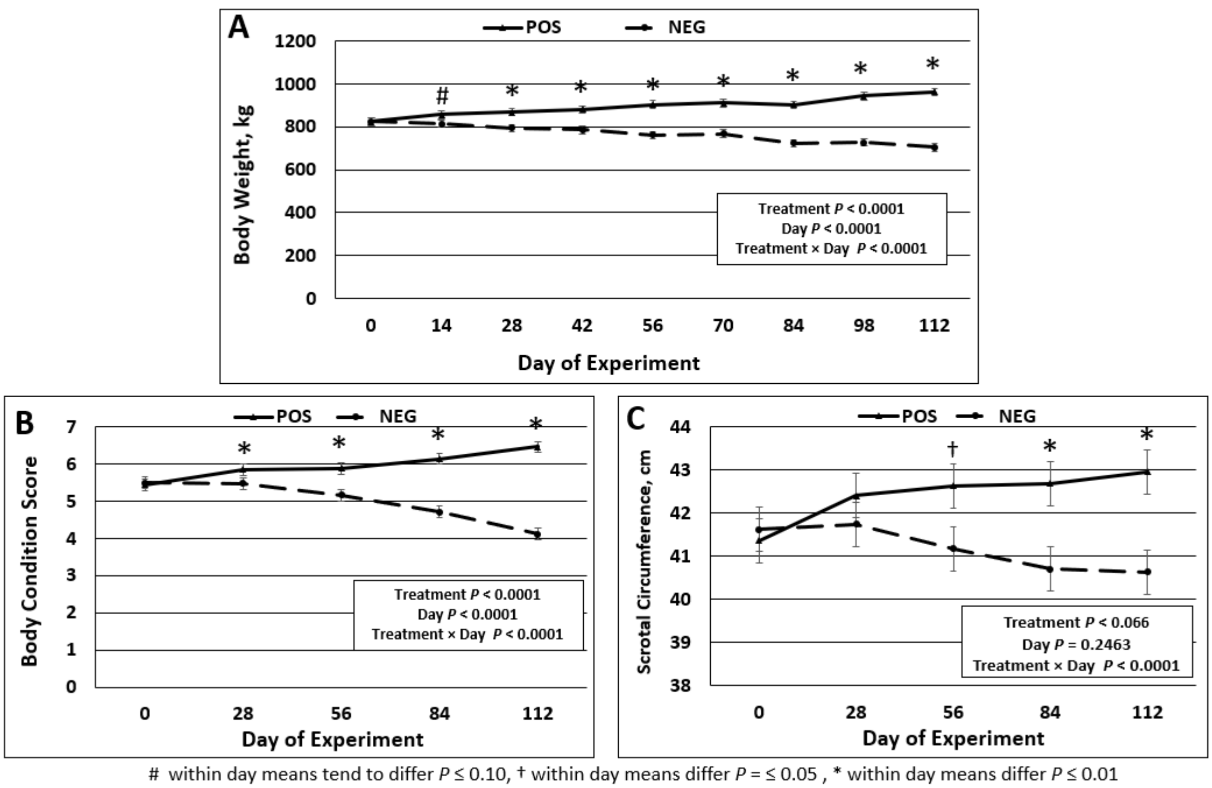


Figure 1. Body weight (Panel A), body condition score (Panel B) and scrotal circumference (Panel C) of beef bulls managed on divergent planes of nutrition. Bulls on POS were targeted to gain 12.5% of BW over 112 days, whereas bulls on NEG were targeted to lose 12.5% of initial BW over 112 days.

Body condition score was also impacted by a treatment × day interaction ($P < 0.001$), with BCS starting similar among treatments, then being greater ($P < 0.01$) for POS than NEG from day 28 to 112 (Figure 1, Panel B). By the end of the evaluation period, there was a 2.3 BCS unit difference between treatments. Additionally, scrotal circumference was impacted by a treatment × day interaction ($P < 0.001$), with no difference present at the beginning of the experiment, but divergence between treatments was observed beginning on day 56 and continuing through the end of the evaluation period (Figure 1, Panel C).

Concentrations of glucose, NEFA, T3, T4, and IGF-1 were influenced by treatment × time interactions ($P < 0.001$; Table 2). Concentrations of glucose, T3, T4, and IGF-1 were greater ($P < 0.01$) for POS bulls on day 112 compared with NEG bulls on the same day. However, concentrations of NEFA were greater ($P < 0.001$) for NEG than POS on day 56 and 112. Concentrations of testosterone evaluated from a single blood sample before feeding were not impacted by the treatment × day interaction ($P = 0.44$) or by the main effect of treatment ($P = 0.40$). Concentrations of testosterone did increase ($P < 0.001$) through the evaluation period as days lengthened and the traditional breeding season approached. As testosterone is released episodically from Leydig cells in respond to pulses of LH from the pituitary, future work should include serial sampling or GnRH challenges to more precisely evaluate the impact of bull nutrition on concentrations of testosterone.

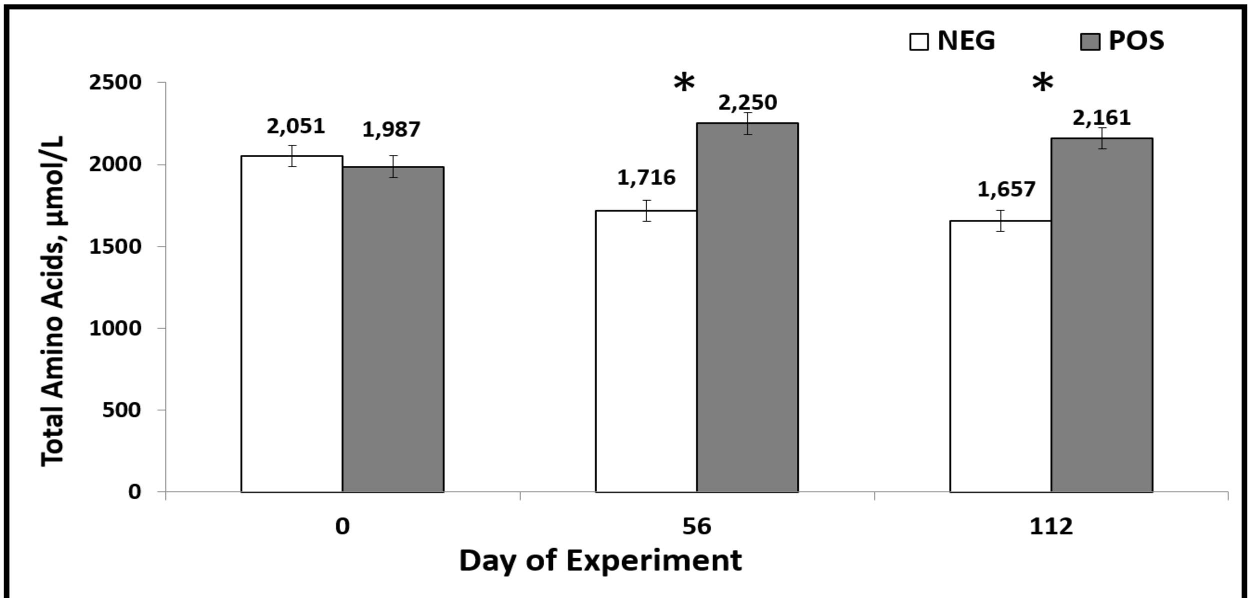
Table 2. Effects of divergent planes of nutrition on serum concentrations of hormones and metabolites in mature beef bulls

	Treatment[1]									
	NEG			POS				*P*-Values		
Collection day	0	56	112	0	56	112	SE	TRT	Time	TRT × Time
Glucose, mg/dl	74.7^{xy}	63.2^{z}	65.2^{z}	70.2^{y}	72.0^{xy}	75.6^{x}	1.812	0.01	0.012	<0.001
NEFA, µmol/L	309.7^{y}	810.9^{x}	816.5^{x}	254.8^{y}	148.0^{z}	211.1^{yz}	42.36	<0.001	<0.001	<0.001
Testosterone, ng/dl	1358	1750	3485	1423	3109	4427	772	0.40	<0.001	0.44
T3, ng/dl	98.2^{x}	56.9^{y}	50.8^{y}	93.0^{x}	64.3^{y}	104.7^{x}	9.11	0.12	<0.001	<0.001
T4, µg/dl	6.53^{x}	4.08^{y}	3.99^{y}	5.81^{x}	4.40^{y}	5.80^{x}	0.293	0.21	<0.001	<0.001
IGF-1	282.9^{x}	190.8^{y}	162.4^{z}	277.1^{x}	295.8^{x}	291.3^{x}	17.06	0.002	<0.001	<0.001

[1] Bulls on POS were targeted to gain 12.5% of BW over 112 days, whereas bulls on NEG were targeted to lose 12.5% of initial BW over 112 days.
[x,y,z] Means within row lacking common superscript differ ($P \le 0.05$).

Total amino acids present in serum were impacted by a treatment × day interaction ($P < 0.001$), with POS bulls having more ($P \le 0.001$) AA present in serum than NEG bulls on day 56 and 112 of the evaluation period (Figure 2).

Under the common production scenarios evaluated in this experiment, fluctuations in body weight and plane of nutrition of breeding bulls lead to changes in blood hormone and metabolite profiles. Increased hormone and metabolite concentrations in POS bulls were a product of enhanced plane of nutrition, and elevated NEFA in NEG bulls was indicative of bulls mobilizing body reserves as a source of energy. The observed alterations in blood profiles likely resulted in alterations of nutrients available for developing sperm. Whether and how these different blood nutrient profiles influence cellular function in the testis and in sperm produced should be evaluated further. Specific efforts being undertaken with our model of divergent planes of nutrition include evaluating novel measures of fertility via flow cytometry, evaluating the mRNA and miRNA of resultant sperm, and evaluating *in vitro* fertility and embryo development, with the ultimate goal of evaluating offspring outcomes.



Treatment *P* = 0.0004; Day *P* < 0.099; Treatment × Day *P* < 0.0001
* Within day mean differ (P < 0.001)

Figure 2. Total amino acids present in serum of bulls managed on divergent planes of nutrition. Bulls on POS were targeted to gain 12.5% of BW over 112 days, whereas bulls on NEG were targeted to lose 12.5% of initial BW over 112 days.

Literature Cited

Barth, A. D. 2013. Bull Breeding Soundness. 3rd Ed. Western Canadian Association of Bovine Practitioners.

Dahlen, C. R. and C. L. Stoltenow. 2015. The PregCard study; assessing the impact of routine management strategies on reproductive performance of beef herds in the upper Great Plains. Bov. Pract. 49(2): 152-155.

Hersom, M and T. Thrift. 2008. Nutritional Management of Bulls. University of Florida AN211. Available at: AN21100.pdf (ufl.edu)

Senger, P. L. 2012. Pathways to Pregnancy and Parturition. 3rd ed. Current Conceptions Inc., Redmond, OR.

Walker, J., G. Perry, R. Daly and K. Olson. 2009. Bull management and nutrition. Range Beef Cow Symposium XXI.

Vitamin and mineral supplementation during gestation does not influence milk yield or composition during early lactation in beef heifers

Friederike Baumgaertner[1,2], Jennifer Hurlbert[1], Kerri Bochantin[1], Ana Clara B. Menezes[1], Kevin K. Sedivec[2], James D. Kirsch[1], Sarah R. Underdahl[1], Carl R. Dahlen[1]

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

We conducted two experiments to 1) evaluate whether feeding a vitamin and mineral supplement to replacement heifers throughout gestation affects milk yield and composition in grazing beef heifers at a single point in time and to 2) establish a lactation curve of parlor-milked beef heifers by milking them twice daily for the first 78 days of lactation. For grazing heifers, milk yield and components were not affected by vitamin and mineral supplementation during gestation. For parlor-milked heifers, feeding a vitamin mineral supplement during gestation did not influence milk yield. However, our results show that while milk yield did not increase after day 10 of lactation, urea content in milk varied between sampling days.

Summary

We conducted two experiments to test our hypothesis that vitamin and mineral supplementation during gestation has a positive impact on milk yield and composition at a single point in time in grazing heifers and on daily milk production during early lactation in parlor-milked beef heifers. A total of 41 Angus-based heifers received either a basal ration (**CON**) or the basal diet plus vitamin mineral supplementation (**VTM**, 4 ounces per head per day) from breeding until parturition. For Exp. 1, 29 heifers (12 CON and 17 VTM) were managed as one pasture group after parturition. Using a portable milking machine, heifers were milked at d 56 postpartum between 7 and 10.5 hours after calf removal. For experiment 2, 12 heifers (6 CON and 6 VTM) were acclimated to a free stall barn and milked twice daily for 78 d following parturition. We recorded milk yield twice daily and collected milk samples at days 32, 58, and 78 of lactation for component analysis. For Exp. 1, milk yield and components ($P \leq 0.91$) were similar between treatments. Mean yield was 21.9 ± 0.75 pounds/day with 4.1 ± 0.11% fat and 2.8 ± 0.04% protein. For Exp. 2, mean milk yield was 18.1 ± 0.18 pounds/day with 3.4 ± 0.14 % fat and 3.2 ± 0.03 % protein. Furthermore, milk production was not increased beyond day 10 of lactation ($P \geq$ 0.271and concentrations of milk urea were reduced ($P < 0.0001$) at day 78 compared with days 32 and 58 (11.24 ± 0.55 vs. 18.84 ± 0.55 and 19.10 ± 0.55 mg/dL, respectively). This study clearly demonstrated that we can successfully manage beef heifers in a dairy facility and consequently lays the platform for future work that will establish energy requirements during early lactation for primiparous beef cows.

Introduction

In cow-calf operations, milk production of the dam is a major determinant of pre-weaning calf growth and impacts weaning weight, as calves rely on milk for nutrients especially during early lactation (Sapkota et al., 2020). As calves grow, their forage intake increases and they become less reliant on their dam's milk production (Lancaster et al., 2021), coinciding with the amount of milk produced by the dam over the course of their lactation. Because the dam's lactational performance directly impacts weaning weights, milk production could be an indicator of cow and herd profitability. However, increasing milk yield also leads to greater energy requirements in order to sustain this milk, which in return is associated with increased cost for feed (Mulliniks et al., 2020). Therefore, providing producers with milk production estimates can be a potential tool to balance input costs while maximizing calf crop and ranch profitability. Different approaches to obtain milk yield estimates include single time point measurements of milk yield over the duration of lactation to use in prediction models for lactation curves and using a meta-analytical approach that evaluates studies across the literature to provide more robust estimates across varying management conditions and breed. Nonetheless, both approaches rely on prediction models. We are not aware of any studies establishing lactation curves for beef cattle as it is routinely reported in dairy cattle based on twice-daily milking in a parlor, which raises the question of what actual recorded daily milk production values are.

While in grazing systems, cow-calf performance is mainly influenced by the amount of energy and protein content available in forages, micronutrients such as minerals are essential for reproduction, lactation, energy metabolism, and immune health (Harvey et al., 2021). If no additional source of mineral is provided, grazing cattle have to rely on the content provided by forages, which varies greatly between geographical regions (Arthington and Ranches, 2021). Furthermore, mineral status of the herd and supplementation strategies vary widely among producers (Davy et al., 2019) and extensive grazing systems can make supplementation on range challenging (Brummer et al., 2019).

Previous research demonstrates that providing cows with supplemental trace mineral sources during gestation can affect milk yield and milk components. Injecting Holstein heifers with a selenium and vitamin E supplement during late gestation increased milk yield and decreased somatic cell score (**SCC**; Moeini et al., 2009). Others reported that providing a trace mineral supplement from late gestation throughout lactation to extensive grazing dairy cows increased milk yield but did not affect milk composition (Griffiths et al., 2007). Furthermore, administration of an injectable trace mineral during heifer development and gestation increased milk yield in Angus heifers (Stokes et al., 2019). These studies raise the question if mineral supplementation when provided during gestation affects milk yield and composition of beef heifers.

Therefore, our objectives were to evaluate the effect of mineral supplementation during gestation on milk yield and composition and to establish a lactation curve for the first third of lactation.

Experimental Design

All animal procedures were approved by the Institutional Animal Care and Use Committee at North Dakota State University.

Forty-one crossbred Angus heifers were randomly assigned to either a basal diet targeting a gain of 1 pound/day (**CON**) or the basal diet plus a vitamin mineral supplement (**VTM;** Purina Wind & Rain Storm All-Season 7.5 Complete Mineral, Land O'Lakes Inc., Arden Hills, Minn.) fed at a rate of 4 ounces per heifer per day. Briefly, for Exp. 1 (CON, n = 12; VTM, n = 17) treatments were assigned at breeding via artificial insemination, whereas for Exp. 2 (CON, n = 6; VTM, n = 6) the VTM supplement was initiated 70 days before artificial insemination.

Heifers were individually fed using Calan gates or using the Insentec Feeding System. For the Calan gate system, supplements were top dressed over the total mixed ration (**TMR**; Tables 1 and 2), whereas the supplement was mixed into the TMR for feeding in the Insentec system.

For Exp. 1, heifers calved at the Beef Cattle Research Complex (**BCRC**) in Fargo and then were transported to the Central Grasslands Research Extension Center (**CGREC**), where heifer dams and calves were managed as a single group grazing native mixed-grass prairie. At day 56 postpartum, dams were milked using a portable milking machine. Briefly, dams and calves were assigned to one of four groups with 3 groups of 7 pairs and one with 8 pairs. Beginning at midnight, calves were separated from their dams in 30-minute intervals per groups to stagger milking times and allows for continuous milking. Six hours after calf removal, calves were allowed to nurse their dams until satiety (approximately 30 minutes) to allow for similar milking status across the dams. Then pairs were separated again and dams were milked out approximately 7 to 10.5 hours after calf removal. As part of the protocol, 1 mL of oxytocin was administered i.m. to each dam, the udder was prepped, and the milking machine was attached. To calculate 24-hour milk production, the measured milk yield was multiplied by 24 and divided by the average number of hours that each group was separated from their calves. Furthermore, a milk sample for analysis of composition, including SCC, concentrations of urea, and percent fat, protein, lactose, and solids, was collected for each dam.

For Exp. 2, heifers were trained and halter broken. Immediately following calving, heifers and calves were separated and heifers were completely milked out using a portable milking machine to determine composition of colostrum. Within the first ten days of lactation, heifers were acclimated to a free stall barn at the NDSU Dairy Unit, where they were then milked twice daily for 78 days. Milk yield was recorded at each milking using the milk meters installed in the parlor. At days 32, 58, and 78 of lactation, milk samples were collected from each heifer for analysis of components. At day 58, milk samples were also collected from a contemporary group of 12 primiparous Holstein heifers (84 ± 10 DIM). Milk samples were thoroughly mixed and stored at 4°C until further analysis of components, i.e. SCC, concentrations of urea, and percent fat, protein, lactose, and solids, by a DHIA laboratory.

Statistical Analysis

For Exp. 1, milk yield and composition were analyzed using the GLM procedure of SAS for effect of treatment. For Exp. 2, milk yield was analyzed as repeated measures in time using the MIXED procedure and composition was analyzed using the GLM procedure to test for effects of treatment, day of lactation (DIM), and treatment × DIM interaction. For the comparison of the beef and Holstein heifers at day 58 of lactation, milk yield and composition were analyzed using the GLM procedure for effect of breed. In all analyses, heifer was considered the experimental unit and significance was determined at $P \leq 0.05$.

Results and Discussion

Experiment 1

At day 56 of lactation, milk yield of grazing heifers was not affected by mineral supplementation during gestation ($P = 0.57$; Table 3). Providing dairy cows in New Zealand with a trace mineral supplement from late gestation to day 230 of lactation increased milk production by 1.98 pounds/day (Griffiths et al., 2007). Similarly, Stokes et al. (2019) reported that milk production at day 71 of lactation estimated via weigh-suckle-weigh procedure was 3.46 pounds/day greater for beef heifers that were administered trace mineral injections during heifer development and gestation. Machine milking is a direct methods to measure milk production, whereas weigh-suckle-weigh is an indirect approach, because it measures calf weight change as a result of suckling (Sapkota et al., 2020). Consequently, milk production may vary based on the method used.

Milk composition and SCC were not affected by mineral supplementation during gestation ($P \geq 0.13$; Table 3). Our findings contrast from others, who reported that dairy heifers supplemented with selenium and vitamin E during late gestation had reduced SCC (Moeini et al., 2009) and that administering a sustained release trace mineral bolus to dairy cows during late gestation increased percentage of fat, protein and solids non-fat in milk (Khorsandi et al., 2016). Moreover, milk fat values reported here are greater than reported for sample collection using hand-stripping or hand milking with and without administration of oxytocin (Shee et al., 2016; Williams et al., 2018; Schubach et al., 2019; Baumgaertner at al., 2021). For instance, Baumgaertner et al. (2021) found that percent milk fat in hand-stripped samples ranged from 0.34 ± 0.078 % without oxytocin to 1.03 ± 0.078 % after oxytocin injection. Similarly, Shee et al. (2016) reported percentages for milk fat ranging from 0.49 ± 0.13 % to 1.50 ± 0.13 % when hand milking a complete quarter. However, when a milking machine was used for estimating milk yield and composition of multiparous cows, milk fat content was 4.11 ± 0.33% for control and 4.21 ± 0.33% for basal diet plus distiller's grains with solubles treatments (Kennedy et al., 2019). These results demonstrate that sampling technique has a large influence on the proportion of milk fat in a sample and needs to be carefully considered when designing and interpreting research efforts and deciding whether results can be assumed to represent actual calf consumption.

Experiment 2

Colostrum composition (Table 4) was similar between CON and VTM heifers for all components ($P \geq 0.33$). Further, milk yield (Figure 2) was not affected by mineral supplementation during gestation ($P = 0.43$), but was influenced by DIM ($P < 0.01$). The average milk yield measured during early lactation was 18.1 ± 0.18 pounds/day with 3.4 ± 0.14 % fat and 3.2 ± 0.03 % protein and daily milk production did not increase beyond day 10 of lactation ($P \geq 0.271$). Additionally, milk composition during early lactation (Table 5) was similar ($P \geq 0.07$) between CON and VTM heifers. However, concentrations of urea were reduced on day 78 compared with days 32 and 58 ($P < 0.01$).

Lactation curves vary based on the method of milk yield estimation, e.g. weigh-suckle-weigh technique or a milking machine, and the prediction model used (Espasandin et al., 2016). Across the literature, milk yield is mainly determined via the weigh-suckle-weigh technique (Sapkota et al., 2020). However, milk production estimates using weigh-suckle-weigh may vary depending on calf losses, i.e. feces and urine, and accuracy of scales used. To our knowledge no other experiments measured twice daily milk production in beef heifers to establish lactation curves without the use of prediction models. While we were only able to use a small set of animals for Exp. 2 with inherent individual animal variation, we clearly demonstrated that it is possible to train beef heifers to a free stall dairy barn and milking in a parlor, which will allow us to record milk production throughout lactation and determine energy requirements for first parity beef females in future experiments.

When comparing milk yield and composition of the Holstein heifers and beef heifers (Table 6), as expected Holstein heifers had greater milk production ($P < 0.01$). Percent of protein and concentrations of urea were greater in beef heifers ($P < 0.01$), whereas SCC tended to be increased in Holstein heifers ($P = 0.08$). Percent fat was similar between the two breeds ($P = 0.25$). It is important to note that this is not an optimal comparison as the beef and Holstein heifers were not exactly managed the same, i.e. they were not exactly at the same stage of lactation and did not receive the same diets; however, it provides some insight at a single point in time in regards to milk characteristics in primiparous beef and dairy heifers.

The SCC for the Holstein heifers reported here fall above the bulk tank average of 237,000 cells/mL for the dairy unit and may be a result of individual variation rather than breed.

Acknowledgements

The authors express their gratitude for the many personnel involved in this project including staff and students at the Central Grasslands Research Extension Center, the Animal Nutrition and Physiology Center, the Beef Cattle Research Complex, and the NDSU Dairy Unit for assisting with animal handling and data collection.

Literature Cited

Baumgaertner, F., A. C. B. Menezes, W. J. S. Diniz, K. K. Sedivec, J. D. Kirsch, S. R. Underdahl, S. T. Dorsam, A. K. Ward, K. L. McCarthy, J. S. Caton and C. R. Dahlen. 2021. Effect of rate of gain during early gestation on colostrum and milk composition in beef heifers. 2021 North Dakota Livestock Research Report. p. 20.

Arthington, J. D., and J. Ranches. 2021. Trace Mineral Nutrition of Grazing Beef Cattle. Animals. 11:2767. doi:10.3390/ani11102767.

Brummer, F. A., L. Gow-Hogge, C. Mueller, G. Pirelli, and G. Bobe. 2019. Short Communication: Mineral assessment of rangeland-managed beef cows in the high desert region of Oregon. Appl. Anim. Sci. 35:577–585. doi:10.15232/aas.2019-01871.

Davy, J. S., L. C. Forero, M. W. K. Shapero, D. R. Rao, T. A. Becchetti, C. Koopman Rivers, J. W. Stackhouse, K. L. DeAtley, and B. R. McNabb. 2019. Mineral status of California beef cattle1. Transl. Anim. Sci. 3:66–73. doi:10.1093/tas/txy114.

Doska, M. C., D. F. F. da Silva, J. A. Horst, A. A. Valloto, P. Rossi Junior, and R. de Almeida. 2012. Sources of variation in milk urea nitrogen in Paraná dairy cows. Rev. Bras. Zootec. 41:692–697. doi:10.1590/S1516-35982012000300032.

Espasandin, A. C., V. Gutierrez, A. Casal, A. Graña, O. Bentancur, and M. Carriquiry. 2016. Modeling Lactation Curve in Primiparous Beef Cattle. J. Agric. Sci. 8:10.

Griffiths, L. M., S. H. Loeffler, M. T. Socha, D. J. Tomlinson, and A. B. Johnson. 2007. Effects of supplementing complexed zinc, manganese, copper and cobalt on lactation and reproductive performance of intensively grazed lactating dairy cattle on the South Island of New Zealand. Anim. Feed Sci. Technol. 137:69–83. doi:10.1016/j.anifeedsci.2006.10.006.

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

Kennedy, V. C., J. J. Gaspers, B. R. Mordhorst, G. L. Stokka, K. C. Swanson, M. L. Bauer, and K. A. Vonnahme. 2019. Late gestation supplementation of corn dried distiller's grains plus solubles to beef cows fed a low-quality forage: III. effects on mammary gland blood flow, colostrum and milk production, and calf body weights. J. Anim. Sci. 97:3337–3347. doi:10.1093/jas/skz201.

Khorsandi, S., A. Riasi, M. Khorvash, S. A. Mahyari, F. Mohammadpanah, and F. Ahmadi. 2016. Lactation and reproductive performance of high producing dairy cows given sustained-release multi-trace element/vitamin ruminal bolus under heat stress condition. Livest. Sci. 187:146–150. doi:10.1016/j.livsci.2016.03.008.

Lancaster, P. A., L. O. Tedeschi, Z. Buessing, and M. E. Davis. 2021. Assessment of milk yield and nursing calf feed intake equations in predicting calf feed intake and weaning weight among breeds. J. Anim. Sci. 99:skaa406. doi:10.1093/jas/skaa406.

Moeini, M. M., H. Karami, and E. Mikaeili. 2009. Effect of selenium and vitamin E supplementation during the late pregnancy on reproductive indices and milk production in heifers. Anim. Reprod. Sci. 114:109–114. doi:10.1016/j.anireprosci.2008.09.012.

Mulliniks, J. T., J. K. Beard, and T. M. King. 2020. Invited Review: Effects of selection for milk production on cow-calf productivity and profitability in beef production systems. Appl. Anim. Sci. 36:70–77. doi:10.15232/aas.2019-01883.

Sapkota, D., A. K. Kelly, P. Crosson, R. R. White, and M. McGee. 2020. Quantification of cow milk yield and pre-weaning calf growth response in temperate pasture-based beef suckler systems: A meta-analysis. Livest. Sci. 241:104222. doi:10.1016/j.livsci.2020.104222.

Schubach, K. M., R. F. Cooke, A. P. Brandão, T. F. Schumaher, K. G. Pohler, D. W. Bohnert, and R. S. Marques. 2019. Impacts of postweaning growth rate of replacement beef heifers on their reproductive development and productivity as primiparous cows1. J. Anim. Sci. 97:4171–4181. doi:10.1093/jas/skz262.

Shee, C. N., R. P. Lemenager, and J. P. Schoonmaker. 2016. Feeding dried distillers grains with solubles to lactating beef cows: impact of excess protein and fat on cow performance, milk production and pre-weaning progeny growth. Animal. 10:55–63. doi:10.1017/S1751731115001755.

Stokes, R. S., F. A. Ireland, and D. W. Shike. 2019. Influence of repeated trace mineral injections during gestation on beef heifer and subsequent calf performance. Transl. Anim. Sci. 3:493–503. doi:10.1093/tas/txy105.

Williams, A. R., C. T. Parsons, J. M. Dafoe, D. L. Boss, J. G. P. Bowman, and T. DelCurto. 2018. The influence of beef cow weaning weight ratio and cow size on feed intake behavior, milk production, and milk composition1. Transl. Anim. Sci. 2:S79–S83. doi:10.1093/tas/txy044.

Table 1. Dietary ingredients and nutrient profile of the diet fed to replacement heifers during gestation.

Item	Basal TMR at ANPC[1,2]
Ingredient, % of DM	
Corn silage	37
Prairie hay	53
DDGS	10
Nutrient Composition, % [3]	
Dry Matter	51.57
Ash	11.58
Crude protein	10.63
Acid Detergent Fiber	33.67
Neutral Detergent Fiber	56.40
Fat	2.16
Ca	0.59
P	0.31

[1]Both control (CON) and vitamin mineral supplement (VTM) groups received the same basal diet targeting a gain of 1 pound/day, but VTM heifers also received a commercially available vitamin mineral supplement (Purina® Wind & Rain® Storm® All-Season 7.5 Complete Mineral, Land O'Lakes Inc., Arden Hills, Minn.) fed at a rate of 4 ounces per head per day. The supplement was top-dressed.
[2]First feed ration after breeding.
[3]Chemical composition of TMR sample collected at ANPC at the beginning of the experiment.

Table 2. Micronutrient composition of vitamin and mineral (VTM) supplement provided to beef heifers during gestation; 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	1,200.0	-
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	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 D3 supplement, natural and artificial flavors, and sodium selenite.

Table 3. Milk yield and composition of grazing beef heifers as influenced by vitamin mineral supplementation during gestation collected at single point in time during lactation.

	Treatment[1]			
Item	CON	VTM	SEM[2]	*P*-value
Milk yield, lbs.	21.41	22.30	1.191	0.574
Fat, %	4.30	3.94	0.173	0.128
Protein, %	2.83	2.82	0.060	0.883
SCC, cells x 10^3/mL	31.6	36.0	14.47	0.781
MUN, mg/dL	11.01	10.46	0.521	0.421
Lactose, %	5.09	5.08	0.031	0.905
Other Solids, %	5.96	5.97	0.038	0.832

[1]Treatment: Control (CON) and vitamin mineral supplement (VTM) groups received the same basal diet targeting a gain of 1 pound/day, but VTM heifers also received a commercially available vitamin mineral supplement (Purina® Wind & Rain® Storm® All-Season 7.5 Complete Mineral, Land O'Lakes Inc., Arden Hills, Minn.) fed at a rate of 4 ounces per head per day.
[2]SEM=Standard error of the mean (CON, n = 12; VTM, n = 17).

Table 4. Colostrum composition of beef heifers later milked in a parlor as influenced by vitamin mineral supplementation during gestation.

	Treatment[1]			
Item	CON	VTM	SEM[2]	*P*-value
Fat, %	7.39	8.84	0.997	0.326
Protein, %	12.16	10.90	1.166	0.460
SCC, cells x 10^3/mL	5,160	3,457	1341.21	0.390
MUN, mg/dL	13.60	12.28	3.010	0.762
Lactose, %	3.11	3.25	0.191	0.601
Other Solids, %	4.03	4.13	0.178	0.717

[1]Treatment: Control (CON) and vitamin mineral supplement (VTM) groups received the same basal diet targeting a gain of 1 pound/day, but VTM heifers also received a commercially available vitamin mineral supplement (Purina® Wind & Rain® Storm® All-Season 7.5 Complete Mineral, Land O'Lakes Inc., Arden Hills, Minn.) fed at a rate of 4 ounces per head per day.
[2]SEM=Standard error of the mean (CON, n = 6; VTM, n = 6).

Table 5. Milk composition of parlor-milked beef heifers at days 32, 58, and 78 of lactation as influenced by vitamin mineral supplementation during gestation.

			Days in milk[1]					*P*-value[2]	
Components[3]	Trt[4]		32	58	78	Trt Avg[5]	SEM[6]	Trt	Day	Trt × Day
Fat, %	CON		3.20	3.27	3.96	3.47	0.355	0.7701	0.9540	0.1341
	VTM		3.64	3.50	3.03	3.39				
		Day[7]	3.42	3.39	3.49					
Protein, %	CON		3.19	3.30	3.18	3.22	0.067	0.0733	0.0704	0.5810
	VTM		3.01	3.22	3.13	3.12				
		Day	3.10	3.26	3.16					
SCC, cells $x10^3$/mL	CON		126.17	153.67	141.50	140.44	54.306	0.8202	0.7809	0.9588
	VTM		100.50	143.00	147.33	130.28				
		Day	113.33	148.33	144.42					
MUN, mg/dL	CON		18.27	18.93	10.18	15.79	0.781	0.0685	<0.0001	0.5289
	VTM		19.42	19.28	12.30	17.00				
		Day	18.84[a]	19.10[a]	11.24[b]					
Lactose, %	CON		4.83	4.90	4.88	4.87	0.089	0.1425	0.8301	0.9774
	VTM		4.96	5.00	4.98	4.98				
		Day	4.89	4.95	4.93					
Total Solids[8], %	CON		12.12	12.37	12.93	12.47	0.381	0.8028	0.8700	0.2022
	VTM		12.52	12.63	12.05	12.40				
		Day	12.32	12.50	12.49					

[1]Days in milk = days after calving.
[2]Probability values for the effects of treatment, day, and treatment × day.
[3]Components = components analyzed in milk.
[4]Trt = treatment; CON heifers received a basal total mixed ration to gain 1 pound/day; VTM heifers received the basal diet plus a vitamin mineral supplement (4 ounces per head per day) from first time breeding until parturition.
[5]Mean component values of treatment groups across days 32, 58, and 78 in milk.
[6]Average SEM for the treatment × day interaction (for all days CON n = 6, VTM n = 6).
[7]Mean component values across treatments within days in milk.
[8]Total solids calculated based on the formula: fat + protein + lactose + ash, with 0.91 as the constant for ash.
[a,b]Means within row with different superscripts differ significantly ($P \leq 0.05$).

Table 6. Comparison of milk yield and composition between beef and dairy heifers.*

Item	Breed[1]		SEM[2]	*P*-value
	Beef	Dairy		
Milk yield, lbs.	16.34	64.37	2.852	<0.001
Fat, %	3.39	3.70	0.195	0.253
Protein, %	3.26	2.84	0.074	<0.001
SCC, cells x 10^3/mL	148.3	574.7	163.59	0.079
MUN, mg/dL	19.1	11.25	0.568	<0.001

[1]Breed: Beef are Angus-crossbred heifers and dairy are Holstein heifers from the NDSU dairy unit.
[2]SEM=Standard error of the mean (Beef, n = 12; Dairy, n = 12).
*Beef heifers were at day 58 of lactation and where compared to a contemporary group of Holstein heifers housed in the same facility.

Figure 4. Beef heifer from experiment 2 being milked in the parlor at the NDSU dairy unit.

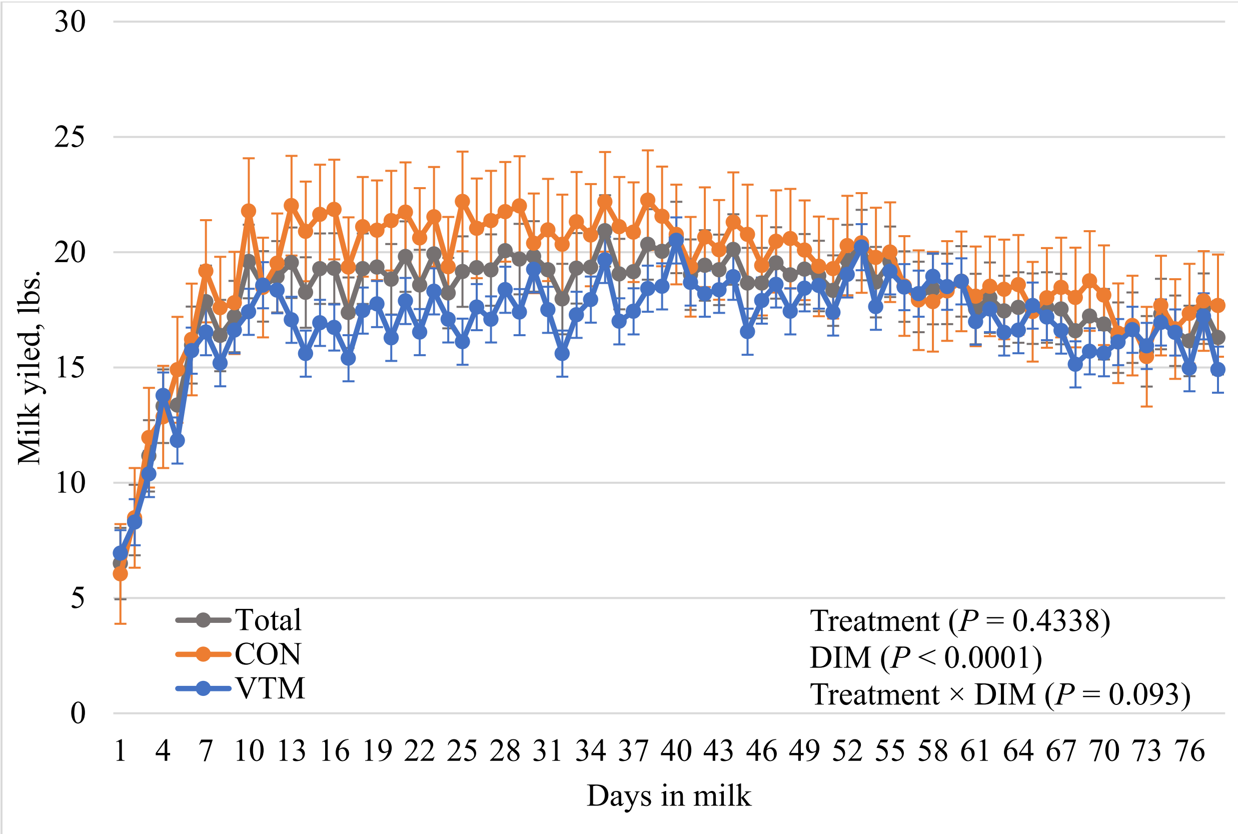


Figure 5. Milk yield of parlor-milked beef heifers during the first 78 days of lactation.

Rate of Gain During Early Gestation in Beef Heifers Does Not Influence Development, Feed Intake and Behavior, Puberty Attainment, and Concentrations of Hormones and Metabolites in Female Offspring

Friederike Baumgaertner[1,2], Ana Clara B. Menezes[1], Wellison J. S. Diniz[3], Jennifer L. Hurlbert[1], Kerri A. Bochantin[1], James D. Kirsch[1], Sheri T. Dorsam[1], Sarah R. Underdahl[1], Kevin K. Sedivec[2], Carl R. Dahlen[1]

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

The objectives of this study were to evaluate whether feeding an energy/protein supplement to replacement heifers to achieve a moderate rate of gain during early gestation affects offspring growth and development, feed intake and behavior, body size and composition, puberty attainment, and concentrations of hormones and metabolites. Our results show that while calves born to moderate gain heifers were heavier at birth, offspring post-natal growth, performance, and metabolic indicators were not impacted by maternal nutritional treatment.

Summary

We hypothesized that a moderate rate of gain during the first 84 days of gestation would positively affect heifer offspring growth and development, feed intake and behavior, body size and composition, puberty attainment, and metabolic and hormonal profiles. Starting at breeding, we fed 45 Angus-based heifers either a basal total mix ration for gains of 0.63 pounds/d (low gain [LG], n = 23) or the basal diet plus an energy/protein supplement allowing for 1.75 pounds/d gain (moderate gain [MG], n = 20) for 84 days. For the remainder of gestation, heifer dams were managed as a single group grazing rangeland at the Central Grasslands Research Extension Center (Streeter, ND), where they calved in early March 2020. Dams and their calves grazed native mixed-grass prairie until weaning, at which point they were managed at BCRC (Fargo, ND) to record individual feed intake, where offspring then received a common hay-based diet.

Heifer offspring were weighed at key timepoints between calving and day 84 of gestation. Blood samples were collected at calving, turnout, weaning, breeding, d 42 and d 84 of gestation and analyzed for concentrations of IGF-1, insulin, NEFA, and glucose. Additional blood samples were collected throughout development and analyzed for progesterone concentration to determine puberty attainment. Carcass characteristics and body measurements were recorded at a single point in time during the development period.

Our results show that calves from MG were heavier at birth ($P = 0.02$) than calves from LG dams; however, weights, feed intake and behavior, carcass characteristics and body measurements, hormones and metabolites, and puberty attainment did not differ between female

offspring from LG or MG dams ($P > 0.12$). We conclude that while early gestation maternal nutrition affected offspring birth weights, no long-term effects throughout offspring development and breeding were observed.

Introduction

Nutrient availability often varies for grazing cattle because energy and protein content in forages declines throughout the grazing season. Providing supplemental sources of energy and/or protein when available forage cannot meet nutrient demands during gestation can positively affect growth rates and reproductive performance (Cappellozza et al., 2014), and therefore, improve productivity of the cow herd. While the majority of fetal growth occurs during the last trimester of gestation, the first trimester is a critical period as key events for gestation take place. For instance, during early gestation the placenta is established and vascularized to allow for optimal transfer of nutrients to the fetus, and vital fetal organs are developed (Funston et al., 2010; Wu et al. 2004).

During early gestation, fetal growth is vulnerable to maternal dietary nutrient supply, which may affect post-natal offspring characteristics. Reports across the literature vary regarding the impact of maternal nutrition on offspring birth weights and appear to depend on the timing and type of nutritional strategy. For instance, research from Nebraska on protein supplementation during late gestation demonstrated that offspring weaning weights, reproductive performance, and carcass characteristics can be positively altered in the absence of birth weight differences (Funston et al., 2012). Similarly, others reported that while early gestation nutrient restriction to 65% of the requirements did not alter birth weights (Noya et al., 2019a) or body weights during the development period, weaning weights were reduced in calves from restricted cows (Noya et al., 2019b).

Despite the importance of maternal nutritional management of grazing cattle, little is known about how rate of gain during early gestation in beef heifers affects offspring development and performance. Some of our previous work demonstrates that providing mineral supplements and feeding beef heifers to different rates of gain achieved via energy/protein supplements during early gestation altered the nutrient environment experienced by the fetus *in utero* (Menezes et al., 2021) and affected fetal growth (McCarthy et al., 2020). However, the long-term effects of different rates of gain during early gestation on offspring performance need to be evaluated. Therefore, the primary aim of this study was to test the hypothesis that a moderate rate of gain during the first 84 days of gestation would positively affect heifer offspring growth and development, feed intake and behavior, body measurements and composition, puberty attainment, and metabolic and hormonal profiles.

Experimental Procedures

All animal procedures were approved by the Institutional Animal Care and Use Committee at North Dakota State University.

To generate offspring, 100 Angus-based heifers were estrus synchronized and bred to female sexed semen from a single sire via artificial insemination. At breeding, heifers were either assigned to one of two treatments: 1) a basal total mixed ration (TMR; low gain [LG]) to achieve 0.63 pound/d gain or 2) the basal TMR diet plus an energy/protein supplement mixed into the ration (moderate gain [MG] to achieve 1.75 pounds/d gain). The supplement was included in the ration at a rate reflective of what we would expect to see consumed on pasture. We would expect gains similar to our LG treatment when heifers are grazing mixed grass-prairie, and gains similar to our MG treatment if supplementation was provided. After the 84-day feeding period, heifers gestating female calves were managed as a single group grazing native mixed grass prairie at the Central Grasslands REC.

Female offspring weights were recorded at calving before calves suckled their dams for the first time, at pasture turnout (2-day), mid-summer, weaning (2-day), upon the arrival at BCRC in Fargo, once a month during the development period, at the initiation of estrus synchronization, and d 42 of gestation.

Following weaning, 43 offspring (LG, n = 23; MG, n =20) were transported from CGREC to BCRC for the development period and trained to the Insentec Feeding System (Hokofarm B.V., Marknesse, The Netherlands). Offspring were managed as one group and had *ad libitum* access to a forage-based diet including a mineral supplement (Purina® Wind & Rain® Storm® All-Season 7.5 Complete Mineral, Land O'Lakes Inc., Arden Hills, Minn.). Individual feed intake was monitored daily using the Insentec Feeding System to determine feed intake and behavior. Individual feeding events were summarized by heifer and day for each day of the experimental period. The parameters evaluated were events (number of daily visits and meals to the feed bunk), time eating (per visit, per meal, and per day), dry-matter intake (per day, per visit, and per meal), and eating rate. A visit was defined as each time the Insentec system detected a heifer at a feed bunk, and a meal was defined as eating periods that might include short breaks separated by intervals no longer than seven minutes (Montanholi et al., 2010; Sitorski et al., 2019).

We evaluated body composition and morphometric measurements of offspring when they were approximately 10 months of age. Body composition was assessed via carcass ultrasonography (500 V Aloka with 3.5-MHz transducer, Wallingford, CT) for the specific measurements of rump fat, rib fat, rib-eye area, and percent of intramuscular fat. Body measurements included shoulder-hip length (distance between the middle of the shoulder blades to the middle of the hip), chest circumference (circumference around the chest right behind the shoulder blades), abdominal girth (circumference around the abdominal cavity at the umbilicus behind the last rib), hip circumference (circumference right before the hips), hip width (distance between the highest points of the hip protrusions), and hip height (from the highest part of the hip bone to the floor).

We collected blood samples at calving before first suckling, pasture turnout, weaning, initiation of first estrus synchronization, d 42, and d 84 of gestation for analysis of insulin, IGF-1, glucose, and NEFA. Additional blood samples were collected for assessment of puberty attainment at four timepoints throughout development with two samples per timepoint spaced ten days apart. Heifers were considered pubertal once serum P4 concentration were ≥ 1.0 ng/mL at any of the sampling points.

Statistical Analysis

Offspring body weights, feed intake and behavior, concentrations of hormones and metabolites were analyzed as repeated measures in time using the MIXED procedure of SAS for effects of maternal treatment, day, and a maternal treatment × day interaction. Puberty attainment, carcass characteristics, and body measurements were analyzed using the GLM procedure for effects of maternal treatment. In all analyses, offspring were considered the experimental unit and significance was determined at $P \leq 0.05$.

Results and Discussion

The present data does not support our hypothesis that rate of gain during the first 84 days of gestation alters heifer offspring growth and development, feed intake and behavior, body size and composition, puberty attainment, and metabolic and hormonal profiles. While offspring from MG heifers were 4.8 pounds heavier at calving (Baumgaertner et al., 2020), this divergence did not persist postnatally (Figure 1).

Maternal rate of gain during early gestation did not affect dry-matter intake or behavior as both LG and MG offspring had a similar number of visits to the feed bunks and spend similar times eating throughout the development period ($P \geq 0.15$; Table 1). Furthermore, neither body composition (Table 2) nor morphologic measurements (Table 3) differed between offspring from LG and MG dams ($P \geq 0.31$ and $P \geq 0.53$, respectively). A study evaluating the effect of feeding mature cows either 100% or 65% of the nutrient requirements during the first 82 days of gestation found that offspring body measurements were greater for calves from dams fed 100% of the nutrient requirements at 4 months postpartum (Noya et al., 2019a; Noya et al., 2019b). However, at 12 months of age body size was not different between offspring from dams fed 100% or 65% of the nutrient requirement during early gestation (Noya et al., 2019b). While their window of nutritional intervention coincides with our timeline, our study had positive gain targets that are well within the range observed in production scenarios instead of restricting nutrient availability. Furthermore, we took body measurements later during the development period, when potential effects of maternal treatment may no longer have been present, which is supported by the observation by Noya et al. (2019b) at 12 months of age.

While we did not observe an effect of maternal treatment on circulating concentrations of serum IGF-1 ($P = 0.23$), insulin ($P = 0.78$), glucose ($P = 0.12$) or NEFA ($P = 0.17$) in female offspring (Figure 3), concentrations of IGF-1, insulin, glucose, and NEFA were influenced by the main effect of day ($P < 0.01$). Concentrations of IGF-1 changed over time, with the lowest values present at calving ($P < 0.01$). Contrarily, concentrations for insulin, glucose, and NEFA were greatest at calving and decreased over time ($P < 0.01$) in female offspring. Despite other studies evaluating effects of age at first calving (López Valiente et al., 2021) and effects of maternal nutrient restriction during early (Noya et al., 2019a) and late (López Valiente et al., 2022) gestation on offspring growth and performance, they reported similar trends to what we found for offspring hormone and metabolite profiles.

The timing of puberty onset, i.e. start of cyclicity, was similar between heifers from LG and MG dams ($P \geq 0.39$; Figure 2). While onset of puberty in female offspring did not differ between maternal treatments, the percent of heifers that were cyclic increased over time. Just prior to the first estrus synchronization and breeding, at which point in time female offspring were between 14 to 15 months of age, more than 80% of the heifer offspring were cyclic. It has been shown that heifers that have at least three estrous cycles prior to breeding have improved fertility compared to heifers undergoing their first estrous cycle (Byerley et al., 1987). This is important as heifers becoming pubertal younger can go through several estrous cycles prior to breeding, and therefore, have a greater possibility of conceiving early in the breeding season.

Overall, these results clearly indicate areas necessary for future evaluation. This includes looking at different windows of maternal supplementation, e.g. mid gestation, late gestation, and gestation in its entirety. While differences based on maternal treatment were not present at the sampling timepoints described for this research effort, we need to determine whether differences may develop later in an offspring's life, e.g. after their third, fourth, etc. calf. Lastly, effects of maternal treatment during early gestation may not be present in female offspring but could show up in future generations. Therefore, future research needs to extend to grand- and great-grand offspring.

Acknowledgements

The authors express their gratitude for the many personnel involved in this project including staff and students at the Central Grasslands Research Extension Center, and the Beef Cattle Research Complex, and undergraduate students for assisting with animal handling and data collection.

Literature Cited

Baumgaertner, F., S. R. Underdahl, K. K. Sedivec, J. D. Kirsch, S. T. Dorsam, A. C. B. Menezes, W. J. S. Diniz, A. K. Ward, K. L. McCarthy, J. S. Caton, and C. R. Dahlen. 2020. Effects of two different rates of gain during early gestation in beef heifers on body weight, concentrations of IGF-1, and calf characteristics. 2020 North Dakota Beef and Sheep Report. p. 32.

Byerley, D. J., R. B. Staigmiller, J. G. Berardinelli, and R. E. Short. 1987. Pregnancy Rates of Beef Heifers Bred Either on Puberal or Third Estrus. J. Anim. Sci. 65:645–650. doi:10.2527/jas1987.653645x.

Cappellozza, B. I., R. F. Cooke, T. A. Guarnieri Filho, and D. W. Bohnert. 2014. Supplementation based on protein or energy ingredients to beef cattle consuming low-quality cool-season forages: I. Forage disappearance parameters in rumen-fistulated steers and physiological responses in pregnant heifers1. J. Anim. Sci. 92:2716–2724. doi:10.2527/jas.2013-7441.

Funston, R. N., D. M. Larson, and K. A. Vonnahme. 2010. Effects of maternal nutrition on conceptus growth and offspring performance: Implications for beef cattle production1. J. Anim. Sci. 88:E205–E215. doi:10.2527/jas.2009-2351.

López Valiente, S., A. M. Rodriguez, N. M. Long, I. M. Lacau-Mengido, and S. Maresca. 2022. The degree of maternal nutrient restriction during late gestation influences the growth and endocrine profiles of offspring from beef cows. Anim. Prod. Sci. 62:163. doi:10.1071/AN20527.

López Valiente, S., A. M. Rodríguez, N. M. Long, G. Quintans, F. E. Miccoli, I. M. Lacau-Mengido, and S. Maresca. 2021. Age at First Gestation in Beef Heifers Affects Fetal and Postnatal Growth, Glucose Metabolism and IGF1 Concentration. Animals. 11:3393. doi:10.3390/ani11123393.

McCarthy, K. L., J. Nestande, C. J. Kassetas, A. C. B. Menezes, F. Baumgaertner, J. D. Kirsch, S. T. Dorsam, T. L. Neville, A. K. Ward, P. P. Borowicz, L. P. Reynolds, K. K. Sedivec, J. C. Forcherio, R. Scott, J. S. Caton and C. R. Dahlen. 2020. Effects of feeding vitamin and mineral supplement and rate of gain during the first 83 days of pregnancy on beef heifer performance, concentrations of progesterone, and corpus luteum size and fetal body measurements. 2020 North Dakota Beef and Sheep Report. p. 27.

Menezes, A. C. B., K. L. McCarthy, C. J. Kassetas, F. Baumgaertner, J. D. Kirsch, S. Dorsam, T. L. Neville, A. K. Ward, P. P. Borowicz, L. P. Reynolds, K. K. Sedivec, J. C. Forcherio, R. Scott, J. S. Caton, and C. R. Dahlen. 2021. Vitamin and mineral supplementation and rate of gain during the first trimester of gestation affect concentrations of amino acids in maternal serum and allantoic fluid of beef heifers. J. Anim. Sci. 99:skab024. doi:10.1093/jas/skab024.

Montanholi, Y. R., K. C. Swanson, R. Palme, F. S. Schenkel, B. W. McBride, D. Lu, and S. P. Miller. 2010. Assessing feed efficiency in beef steers through feeding behavior, infrared thermography and glucocorticoids. Animal. 4:692–701. doi:10.1017/S1751731109991522.

Noya, A., I. Casasús, J. Ferrer, and A. Sanz. 2019a. Long-Term Effects of Maternal Subnutrition in Early Pregnancy on Cow-Calf Performance, Immunological and Physiological Profiles during the Next Lactation. Animals. 9:936. doi:10.3390/ani9110936.

Noya, A., I. Casasús, J. Ferrer, and A. Sanz. 2019b. Effects of Developmental Programming Caused by Maternal Nutrient Intake on Postnatal Performance of Beef Heifers and Their Calves. Animals. 9:1072. doi:10.3390/ani9121072.

Sitorski, L. G., M. L. Bauer, and K. C. Swanson. 2019. Effect of metabolizable protein intake on growth performance, carcass characteristics, and feeding behavior in finishing steers. Transl. Anim. Sci. 3:1173–1181. doi:10.1093/tas/txz124.

Wu, G., F. W. Bazer, T. A. Cudd, C. J. Meininger, and T. E. Spencer. Maternal Nutrition and Fetal Development. 2004. 134:2169–2172.

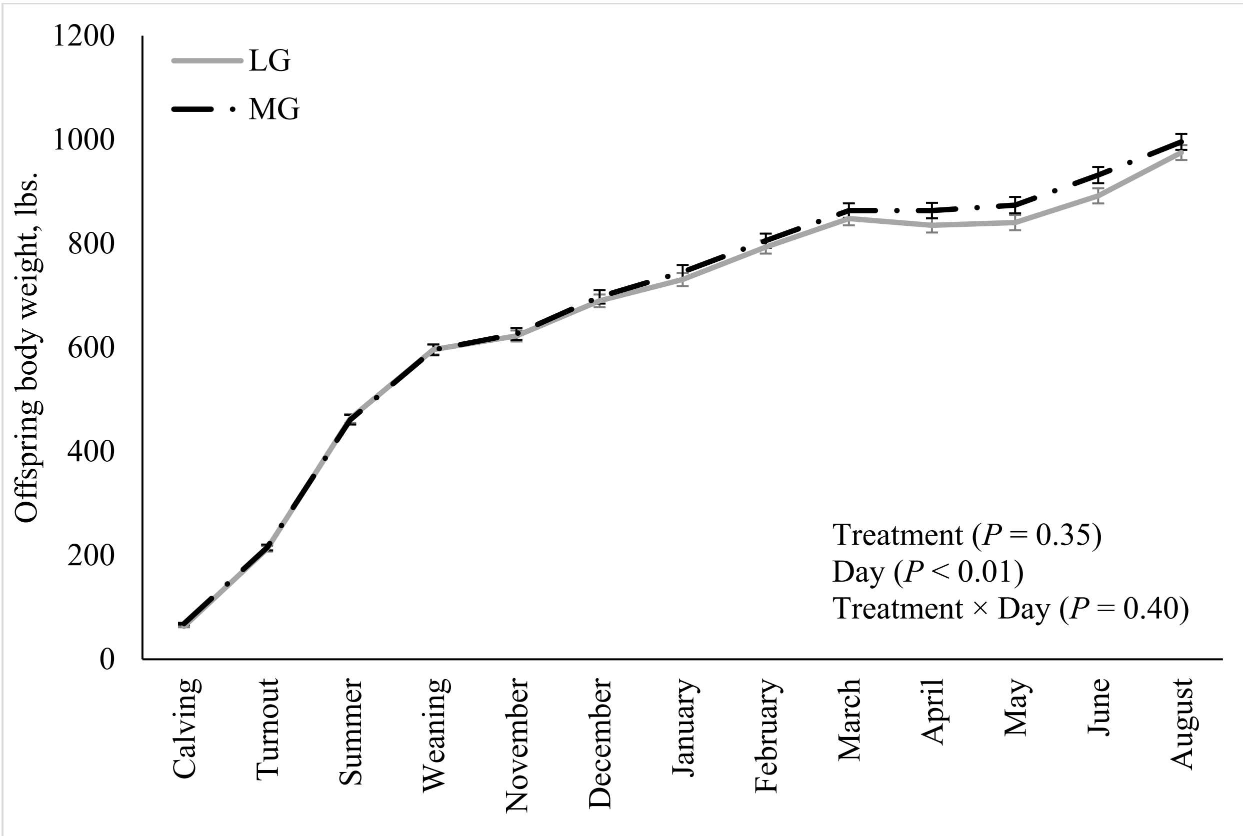


Figure 6. Impact of maternal rate of gain during the first 84 days of gestation (low gain [LG], 0.63 pound/day; moderate gain [MG], 1.75 pounds/day) on female offspring body weight from calving to early gestation.

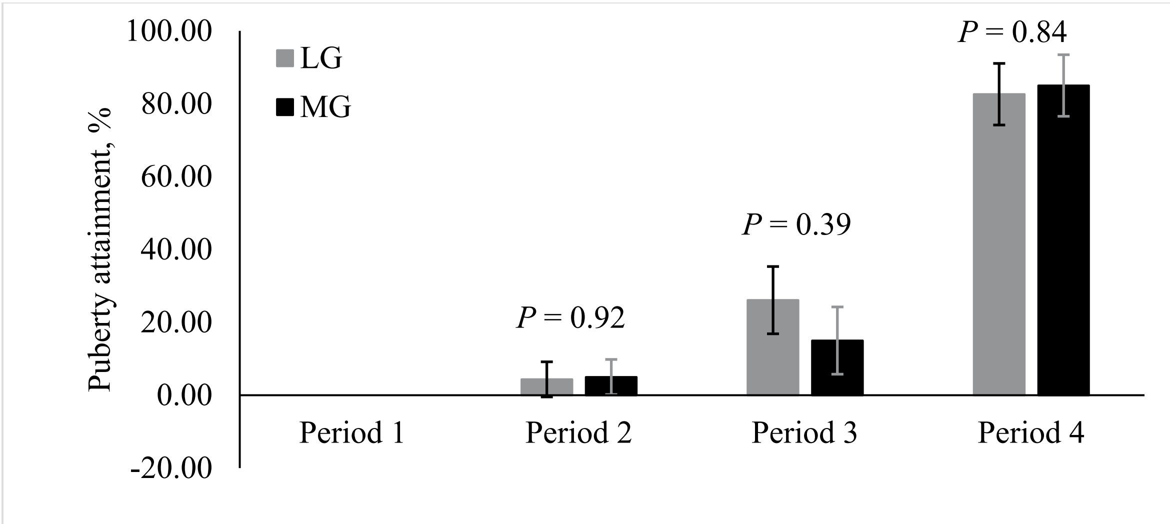


Figure 7. Impact of maternal rate of gain during the first 84 days of gestation (low gain [LG], 0.63 pound/day; moderate gain [MG], 1.75 pounds/day) on female offspring puberty attainment rate. Heifers age from period 1 to 4 was approximately 8.5 to 14.5 months.

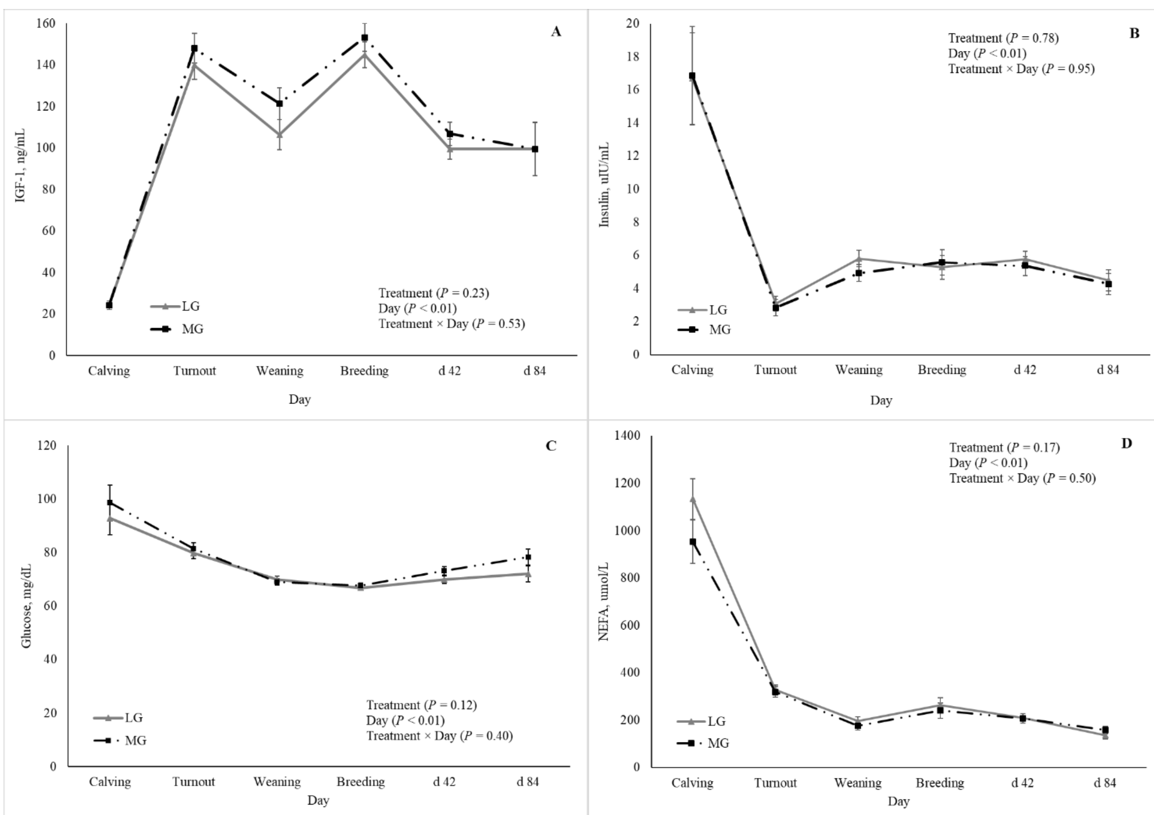


Figure 8. Impact of maternal rate of gain during the first 84 days of gestation (low gain [LG], 0.63 pound/day; moderate gain [MG], 1.75 pounds/day) on female offspring metabolic and endocrine profile. Panel A = IGF-1; Panel B = Insulin; Panel C = Glucose; and Panel D = NEFA.

Table 1. Feed intake and feeding behavior of female offspring during the development period.

	Treatment[1]			
Item	LG	MG	SEM[2]	*P*-value
Events, per day				
Visits[3]	50.5	49.3	0.75	0.283
Meals[4]	9.2	9.0	0.20	0.473
Time eating, min				
Per visit	5.8	5.8	0.08	0.718
Per meal	24.7	25.1	0.78	0.673
Per day	208.2	209.8	4.14	0.777
Dry-matter intake				
Per day, lbs.	17.2	17.6	0.29	0.153
Per visit, oz.	6.9	7.1	0.38	0.730
Per meal, oz.	31.8	33.5	0.91	0.179

[1]Maternal treatment: LG, basal diet; MG, basal diet plus an energy/protein supplement formulated with a blend of ground corn, DDGS, wheat midds, fish oil and urea, targeting gain of 1.75 pounds/day for moderate gain and 0.63 pound/day for low gain heifers.
[2]SEM = Standard Error of the mean (n = 43).
[3]A visit was defined as each time the Insentec system detected a heifer at a feed bunk.
[4]A meal was defined as eating periods that might include short breaks separated by intervals no longer than seven minutes (Montanholi et al., 2010; Sitorski et al., 2019).

Table 2. Impact of maternal nutritional treatment on carcass ultrasonography measurements in female offspring during the development period.

	Treatment[1]			
Item	LG	MG	SEM[2]	*P*-value
No. of offspring	23	20		
Rump fat, in	0.19	0.19	0.015	0.728
Rib fat[3], in	0.20	0.20	0.013	0.741
Rib-eye area[4], in^2	7.63	7.80	0.199	0.527
Intramuscular fat[5], %	4.36	4.42	0.184	0.814

[1]Treatment = Nutritional treatments of dams during the first 84 d of gestation: LG, basal diet; MG, basal diet plus an energy/protein supplement formulated with a blend of ground corn, DDGS, wheat midds, fish oil and urea, targeting gain of 1.75 pounds/day for moderate gain and 0.63 pound/day for low gain heifers.
[2]SEM = Standard error of the mean (n = 43).
[3]Rib fat (measured at 12th rib).
[4]Rib-eye area (measured at 12th rib).
[5]% intramuscular fat (measured at 12th rib).

Table 3. Impact of maternal nutritional treatment on body measurements of female offspring during the development period.

Item	Treatment[1] LG	MG	SEM[2]	P-value
No. of offspring	23	20		
Shoulder-hip length[3], in	28.85	29.38	0.375	0.310
Chest circumference[4], in	64.72	64.58	0.537	0.847
Abdominal circumference[5], in	76.98	78.00	0.904	0.413
Hip circumference[6], in	67.89	67.93	0.740	0.974
Hip width[7], in	14.35	14.48	0.191	0.629
Hip height[8], in	45.26	45.30	0.231	0.902

[1]Treatment: LG, basal diet; MG, basal diet plus an energy/protein supplement formulated with a blend of ground corn, DDGS, wheat midds, fish oil and urea, targeting gain of 1.75 pounds/day for moderate gain and 0.63 pound/day for low gain heifers.
[2]SEM = Standard error of the mean (n = 43).
[3]Shoulder-hip length (from shoulders to hips).
[4]Chest circumference (circumference around the chest at the shoulder).
[5]Abdominal circumference (circumference behind the last rib).
[6]Hip circumference (circumference before the hips).
[7]Hip width (distance between protrusion of hip bones).
[8]Hip height (distance from the hip to the floor).

CGREC Staff and Advisory Board

Current Staff – 2022

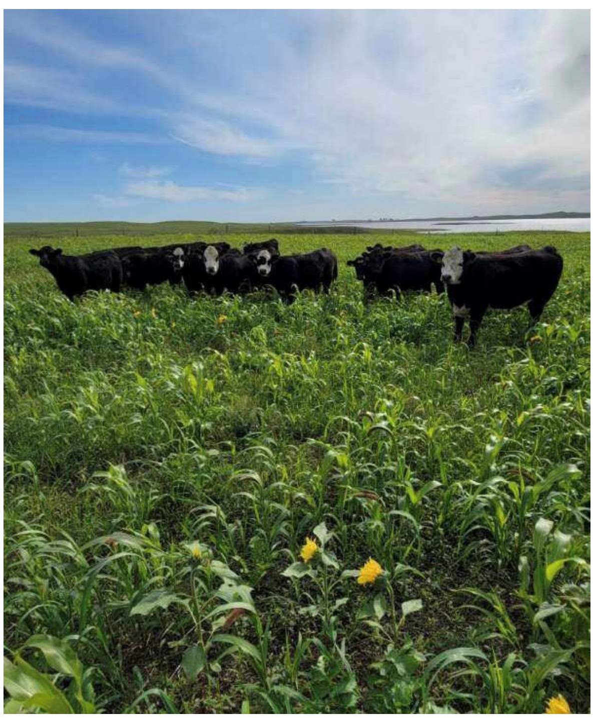
Kevin Sedivec	Interim Director
Michael Undi	Animal Scientist
Sandi Dewald	Administrative Assistant
Justin Leier	Forage Research Specialist
Timothy Long	Beef Herdsman
Lisa Pederson	Extension Livestock – Beef Quality Assurance Specialist
Erin Gaugler	Range Research Specialist
Cody Wieland	Livestock Technician
Rick Bohn	Range Technician
Janet Patton	Research Technician
Tanya Metz	Office Maintenance

Advisory Board - 2021

Gary Aichele, Steele
Jayce Doan, Hazelton
Charlotte Heim, Bismarck
Richie Heinrich, Medina
Gerald Horner, Medina
Christof Just, Berlin
Cody Kreft, Streeter
Krista Reiser, Washburn
Arlyn Scherbenske, Steele
David Toledo, Mandan
Robert Weigel, Kintyre
Jeff Williams, Streeter
Greg Lardy, Fargo

The CGREC Annual Field Day will be held in July 11, 2022 and is open to the public.
The Advisory Board meets in July and the second Thursday of November.



NDSU Central Grasslands Research Extension Center

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