Plant Community Dynamics Under Multiple Land Management Strategies

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Summary

Fire and grazing are disturbances that interacted with each other to shape grasslands for millennia, creating mosaic landscapes with highly diverse plant communities. Present land management has removed fire from this ecosystem, creating homogenous landscapes that are dominated by invasive grass species, such as Kentucky bluegrass (Poa pratensis) and smooth brome (Bromus inermis).

To determine if reintroduction of the fire-grazing interaction (pyric-herbivory) and other land management strategies could promote more heterogeneous and diverse plant communities, we evaluated the differences in plant communities among a season-long grazing treatment, two patch-burn grazing treatments and a modified twice-over rest rotation treatment starting in 2017. We determined that average plant community composition between the season-long grazing treatment and the patch-burn grazing treatments were different ($P < 0.05$) and became increasingly different with time using nonmetric multidimensional scaling (NMDS) and permutational multivariate analysis of variance (perMANOVA).

We also found the patch-burn grazing treatments had higher diversity indices ($P < 0.05$) than the continuous grazing treatment in all treatment years, with difference in diversity indices between season-long grazing and patch-burn grazing increasing by approximately +.06 in each year. In 2020, diversity in all patch-burn grazing treatments and the modified twice-over rotation treatment was higher than in the season-long grazing treatment and varied by time since fire and pasture use type. This increase in diversity can be beneficial to plant communities because high-diversity plant communities have been found to be more resilient to drought and produce higher-quality forage for livestock.

These more diverse plant communities also can positively influence the diversity of higher trophic levels such as pollinators. Therefore, patch-burn grazing should be considered as a tool for conservation of grasslands and possibly as a replacement for conventional season-long livestock grazing.

Introduction

Fire and grazing are naturally occurring disturbances that, along with climate and topo-edaphic differences, have been shaping plant communities for millions of years (Bowman et al., 2009; Bond and Keeley, 2005; Fuhlendorf and Smeins, 1998, 1999). Fire and grazing historically interacted with each other, otherwise known as pyric-herbivory, in the Great Plains, creating spatial and temporal heterogeneity in plant communities (Fuhlendorf and Engle, 2001; Fuhlendorf et al., 2009).

Pyric-herbivory occurs when large herbivores, such as bison or cattle, preferentially graze recently burned areas due to new growth being more palatable and nutritious (Knapp et al., 1999; Vermeire et al., 2004). Large herbivores focus their grazing efforts on recently burned patches, which allows patches that previously were burned and grazed to recover (Fuhlendorf and Engle, 2001; Gates et al., 2017).

These patches begin accumulating plant litter from a lack of grazing, which leads to increased fuel loads and the probability that this patch will burn again, repeating the cycle of this fire-grazing interaction (Fuhlendorf and Engle, 2001, 2004).

Plant community composition and structure vary significantly in response to pyric-herbivory (Fuhlendorf and Engle, 2004). When fire burns across a grassland, it creates nonuniform, discrete patches of plant communities that vary in successional stages, forming a shifting mosaic of plant communities


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through time and space, which produces an overall diverse landscape (Fuhlendorf et al., 2009).

Pyric-herbivory produces heterogeneous landscapes of various successional stages of plant communities that differ in structure and biomass, and creates an overall diverse plant community (Fuhlendorf and Engle, 2001, 2004). Recently burned and grazed sites see an increase in forbs, annual species and bare ground, with a reduction in litter and graminoid species.

Because large herbivores concentrate grazing in burn patches, this allows for graminoids in past burn patches to recover from the previous fire and grazing (Fuhlendorf and Engle, 2004). The changes in structure and composition of a plant community create heterogeneity on the landscape and in habitat, which in turn supports a diverse system of flora and fauna (Fox and Fox, 2000; Fuhlendorf et al., 2010; Ostfeld et al., 1997; Ricketts and Sandercock, 2016).

Present land management of grassland systems promotes uniform utilization that creates homogenous landscapes (Briske et al., 2003; Fuhlendorf et al., 2009). Due to present land management practices, fire and grazing have been decoupled, which has led to homogenous systems of non-native grasses, such as Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) (Dillemuth et al., 2009; Toledo et al., 2014). Although uniform moderate grazing can be beneficial to ground cover and soil disturbance, it fails to create heterogeneity of habitat structure essential for niche species at extreme ends of the habitat structural gradient (Fuhlendorf et al., 2010; Ricketts and Sandercock, 2016).

A solution to the decoupling of fire and grazing is the restoration of pyric-herbivory as a land management tool (Fuhlendorf and Engle, 2001). One such pyric-herbivory-based land management system is a patch-burn grazing system. It combines the historical elements of pyric-herbivory by creating discrete burned patches in a pasture that vary spatially and temporally, creating patches of recently burned, unburned and transitional areas (Fuhlendorf and Engle, 2001). This system of creating spatial and temporal changes on a landscape produces a shifting mosaic of plant communities, a wide variety of habitat structure and increased biodiversity.

To better understand the impacts of a patch-burn grazing system, we examine whether it can serve as a suitable conservation-based form of livestock management. This study used replicated treatments to examine plant community measurements, such as diversity, richness, evenness and standing crop biomass production, to evaluate what effect focal grazing and fire and rotational grazing with differing levels of grazing intensity have on these areas, and whether these grazing treatments create a shifting mosaic in the plant community and on a landscape level.

Methods

Study Area

This study was conducted at the North Dakota State University Central Grasslands Research Extension Center (CGREC) in south-central North Dakota. The CGREC is in the Missouri Coteau ecoregion in the northern mixed-grass prairie of the Great Plains. This area is characterized by irregular, rolling plains and depressional wetlands.

The climate is characterized as temperate and receives an average of 40.1 centimeters (cm) (15.8 inches) of precipitation per year and has an average temperature of 5 C (41 F) (1991-2020, North Dakota Agricultural Weather Network). The vegetation of this area is typical of a northern mixed-grass prairie invaded by Kentucky bluegrass (Limb et al., 2018).

Treatment Structure

Four treatments were applied to the study area. We compared four intervals of time since fire and nonburned areas of the patch-burn grazing 40-acre treatment (PB40) and the patch-burn grazing 20-acre treatment (PB20); two intervals of four differing grazing intensities of heavy, full, moderate and rested of the modified twice-over rest rotation treatment (MTRR); and a season-long grazing treatment (SLG). Each treatment was replicated using four 160-acre pastures (approximately 65 hectares [ha]) split into eight 20-acre (approximately 8 ha) subpatches (patch = two subpatches) in the PBG and SLG treatments; 16- to 40-acre pastures with four grazed heavily, four grazed at full use, four grazed moderately and four rested; and four SLG pastures in the MTRR treatment. All pastures are stocked with cow-calf pairs to achieve approximately a 40% to 60% degree of disappearance at a harvest efficiency of 30%.

- *Patch-burn grazing 40-acre treatment* (PB40) is a management technique that is used to mimic a historic disturbance regime of pyric-herbivory (Fuhlendorf and Engle, 2001). Prescribed fire was applied to two subpatches (40 acres, 16 ha or one-fourth of the pasture) concurrently within each pasture every year for a total of eight plots being burned in the spring of each year. Data from this treatment was analyzed by zero, one,

two and three years since fire and by nonburned plots.

- *Patch-burn grazing 20-acre treatment* (PB20) is a management technique similar to the previous patch-burn grazing treatment in which two subpatches are burned every year. However, because plant communities can respond differently to season of burn (Kral et al., 2018), we wanted to assess what effect season and size of burn would have on plant communities. One 20-acre subpatch (one-eighth of the pasture) was burned in the spring while the other 20-acre plot was burned in the summer.
- *Season-long grazing treatment* (SLG) is intended to replicate a conventional cow-calf grazing management system and serves as a control treatment.
- *Modified twice-over rest rotation grazing* (MTRR) was designed to be similar to the patch-burn grazing 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 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 subpastures that cattle cannot move among (without being purposefully moved) and are grazed from mid-May to late October. Across the subpastures, cattle are rotated through twice and allowed to graze for approximately 74, 54, 27 and zero days (total 155-day grazing season) in each rotation of the heavy use (60% to 80% disappearance of graminoid species), full use (40% to 60% disappearance of graminoid species), moderate use (20% to 40% disappearance of graminoid species) and rested subpastures, respectively. The first rotation uses 40% of the grazing days and the second rotation 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, heavy-use will become the rested pasture, the rested becomes moderate -use pasture and the moderate-use becomes the full-use pasture. This rotation will create heavy disturbance in one subpasture but will avoid the annual heavy disturbance in the same location that could result in changes to forage quality and loss of plant species (Fuhlendorf et al., 2017).

Data Collection

All vegetation data was measured using ¼-meter $(m)^2$ frames. Species vegetation cover was measured using 60-meter permanent transects per each subpatch and sampling 31 measurements along each transect.

Plant community measurements were assessed using canopy cover. Standing crop biomass (alive and dead plant material) was collected by sampling four randomly located 1-m^2 exclosures per subpatch. Average standing crop biomass was calculated for each subpatch.

Three frames were sampled within each exclosure and outside of each exclosure. By measuring the difference between in- and out-of-exclosure biomass, we calculated the degree of disappearance.

Statistical Analysis

We analyzed differences in plant community composition of treatment pastures across all study years using permutational multivariate analysis of variance (perMANOVA) and nonmetric multidimensional scaling (NMS) procedures in PC-ORD 6.0.

Results: Update

Plant Community Response

One hundred sixty plant species were recorded during the duration of this study (2017-2020). Common plant species are listed in Table 1. Using NMS ordinations, we observed that average pasture plant community composition of PB treatments shift in size and placement within the ordinations space with time of treatment (Figure 1A & B). This can be seen better when comparing NMS axis 1 to axis 3, where a circular pattern of PB treatments with time can be seen (Figure 1B).

Using perMANOVA analysis, we determined average pasture composition differed in all years between the PB treatments and the SLG treatment, but not between the two PB treatments ($P < 0.05$). Although

average pasture composition did vary with time, changes were not significantly different from 2017 to 2020 in the PB treatments ($P < 0.05$).

Using plant community data from 2020, we constructed an NMS ordination of time since fire in patch-burn grazing treatments (PBG) showing how plant communities vary with time since fire (Figure 2). Plant communities that were burned recently (0 and one year since fire) were more diverse when compared with previously burned plant communities (two and three years since fire), nonburned and SLG communities (Figure 2). Plant communities with increasing time since fire became more similar to SLG plant communities (Figure 2).

In the MTRR treatment, we found plant communities varied slightly with grazing use type, using data from 2020 (Figure 3). Of the four different use types in the MTRR treatment, the moderate use type communities were most similar to the SLG communities (Figure 3).

Diversity, richness and evenness of plant communities were all higher in the PB treatments within each year, compared with the SLG treatment (Figures 4A, 5 and 6). Although plant community measurements did not increase with time of treatment, we saw an increase in the difference between treatments with time (Figure 4B). Unlike diversity and evenness, richness of PBG treatments were slightly higher in 2020, compared with 2017, while SLG richness was similar in both years (Figure 5).

Table 1. USDA plant codes for common species encountered in this study and represented in Figures 1 and 7.

Plant Code	Scientific Name	Common Name
ACMI2	*Achillea millefolium*	common yarrow
AGCR	*Agropyron cristatum*	crested wheatgrass
AMPS	*Ambrosia psilostachya*	western ragweed
ANGE	*Andropogon gerardii*	big bluestem
ARLU	*Artemisia ludoviciana*	cudweed sagewort
ASOV	*Asclepias ovalifolia*	oval-leaf milkweed
ASSP	*Asclepias speciosa*	showy milkweed
ASSY	*Asclepias syriaca*	common milkweed
BOCU	*Bouteloua curtipendula*	sideoats grama
BOGR2	*Bouteloua gracilis*	blue grama
BRIN2	*Bromus inermis*	smooth brome
CALO	*Calamovilfa longifolia*	prairie sandreed
DIOLS	*Dichanthelium oligosanthes*	Scribner's rosette grass
GAAR	*Gaillardia aristata*	blanketflower
HECO8	*Hesperostipa comata*	needle and thread
LIIN2	*Lithospermum incisum*	narrowleaf stoneseed
MEOF	*Melilotus officinalis*	sweetclover
MURI	*Muhlenbergia richardsonis*	mat muhly
NAVI4	*Nassella viridula*	green needlegrass
OENU	*Oenothera nuttallii*	Nuttall's evening primrose
OLRI	*Oligoneuron rigidum*	stiff goldenrod
PASM	*Pascopyrum smithii*	western wheatgrass
POPR	*Poa pratensis*	Kentucky bluegrass
PRVI	*Prunus virginiana*	chokecherry
SCSC	*Schizachyrium scoparium*	little bluestem
SYOC	*Symphoricarpos occidentalis*	western snowberry

Biomass and Degree of Disappearance

In 2020, standing crop biomass for the SLG treatment averaged 4,120 pounds per acre (lbs/ac), while the PBG treatments ranged from 3,080 to 3,760 lbs/ac, increasing with time since fire (Table 2).

The degree of disappearance averaged 37% in the SLG treatment in 2020. The PBG degree of disappearance decreased with time since fire from an average of 75.3% in recently burned subpatches to 30.2% in the three-year post-fire subpatches (Figure 7). Subpatches that were burned two or three years ago experienced a slightly lower degree of disappearance than the average SLG degree of disappearance (Figure 7).

Discussion

The fire-grazing interaction has a dynamic effect on plant communities in grassland ecosystems (Fuhlendorf and Engle, 2004). With patch-burn grazing, we can see patterns developing in our plant communities according to time since fire and time exposed to the PBG treatment.

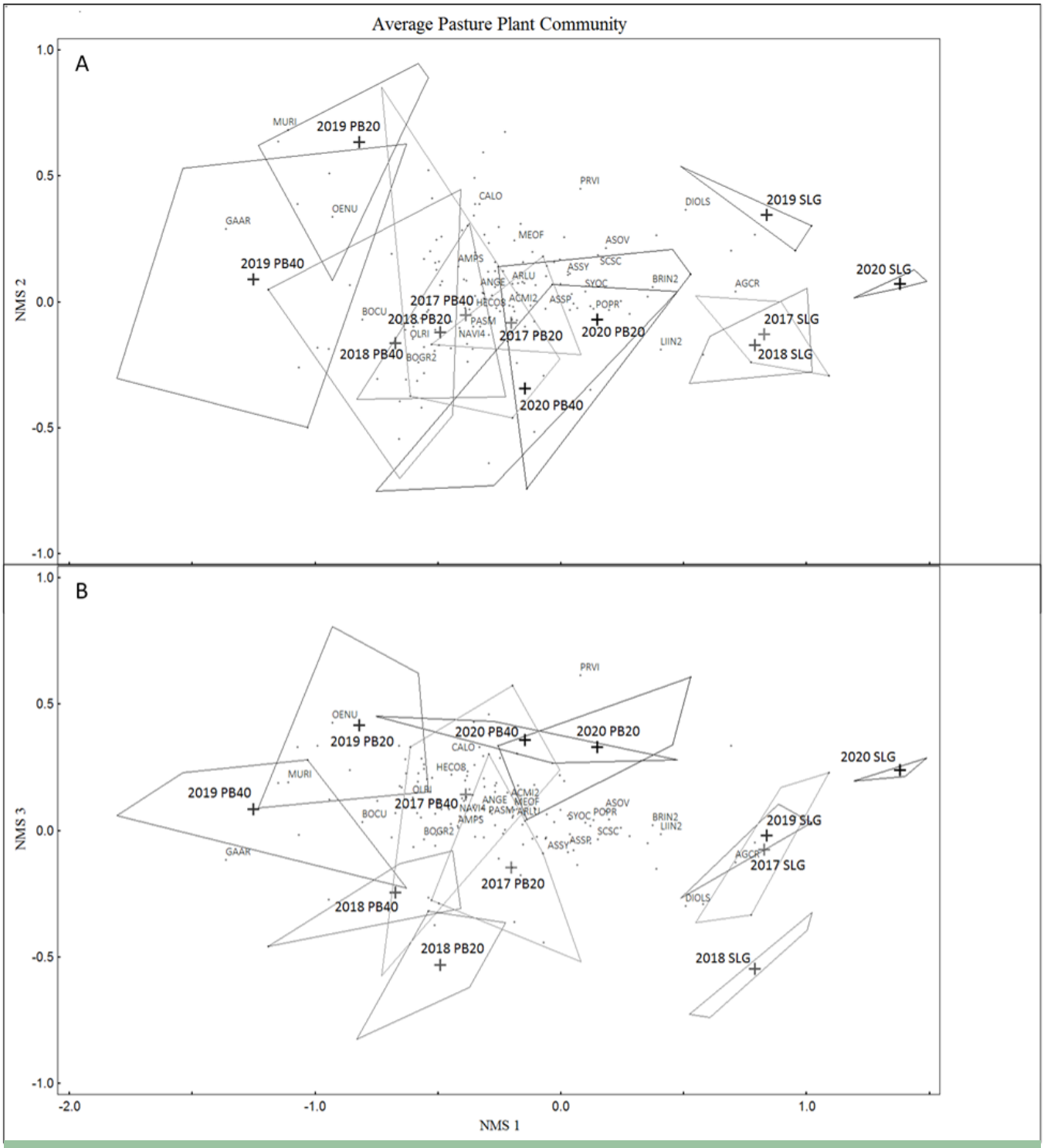

Figure 1. NMS ordination of plant community composition of species found across all years of the study. Polygons represent average pasture composition of patch-burn grazing 40-acre (PB40), patch-burn 20-acre (PB20) and season-long grazing (SLG) treatments from 2017 to 2020. Centroids of each polygon are represented by crosses. Points represent plant species denoted by USDA plant codes listed in Table 1. Axis 1 and 2 (A) and axis 1 and 3 (B) of the 3-dimensional ordination are plotted to visually represent spatial pattern within the ordination space of plant communities at the Central Grasslands Research Extension Center near Streeter, N.D.

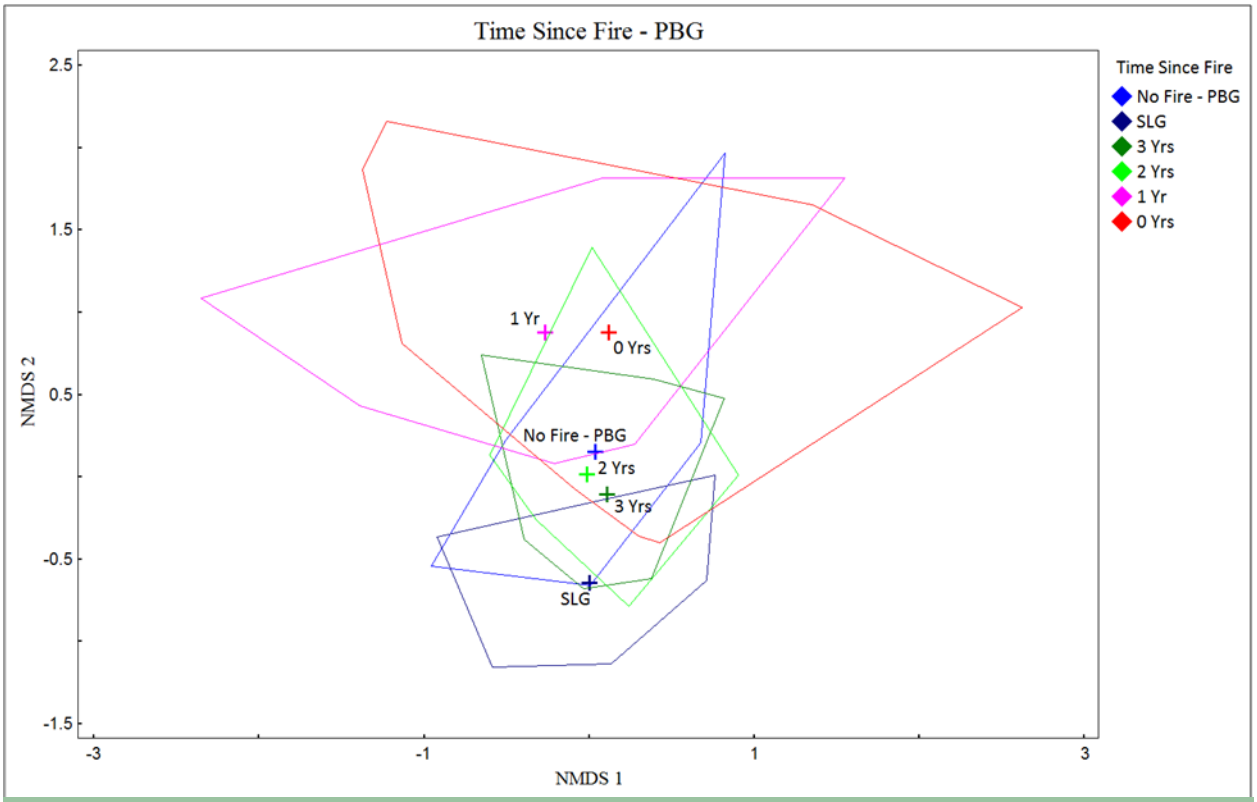

Figure 2. NMS ordination of plant community composition in 2020 arranged by time since fire intervals. Polygons represent average plant community composition of patches treated with season-long grazing (SLG), and patches within the patch-burn grazing system burned in 2017 (three years since fire), 2018 (two years), 2019 (one year) and 2020 (zero years). Patches within the patch-burn grazing treatment not subjected to fire are categorized as No Fire - PBG. Study conducted at the Central Grasslands Research Extension Center near Streeter, N.D. in 2020.

In our NMS ordinations, we observed that exposure to PBG not only shifts plant community compositions with time, but it also expands plant community composition, making them more diverse, while SLG communities contracted with time (Figure 1A and 2). Although SLG communities did shift with time in 2019 and 2020, this likely can be attributed to yearly difference in precipitation (Figure 1A).

In these NMS ordinations that plot treatment through years, average pasture composition of PBG treatments moved in a cycle toward its starting point in 2017. This likely can be attributed to difference in composition within the PBG pastures according time since fire. In two and three years since fire, plant communities will return to similar pre-fire conditions (Fuhlendorf and Engle, 2001).

In the final year of this study (2020), each PBG pasture had a mosaic of four patches with different time-since-fire intervals. Half of each pasture burned two or more years ago, with these patches resembling pre-fire conditions and nonburned plant communities of 2017 (Figure 1A & B).

This dynamic can be observed in data from 2020, where zero- and one-year-since-fire patches had more diverse composition than two- and three-years-since-fire patches, with two- and three-years-since-fire interval plant communities resembling nonburned communities and moving toward SLG communities (Figure 2). Zero- and one-year-since-fire communities also had higher diversity indices (2.32 and 2.40, respectively) than two- and three-years-since-fire communities (2.23 and 2.17, respectively) (Table 2), with two- and three-year indices resembling 2017 treatment indices (Figure 4A).

Although diversity of treatment by year did not show many clear trends, the differences between treatments by year does show a linear increase in diversity from year to year between PBG and SLG. Further study is needed to determine how plant community dynamics are affected by pyric-herbivory, and if these patterns of shifting plant communities continue with time in the northern mixed-grass prairie.

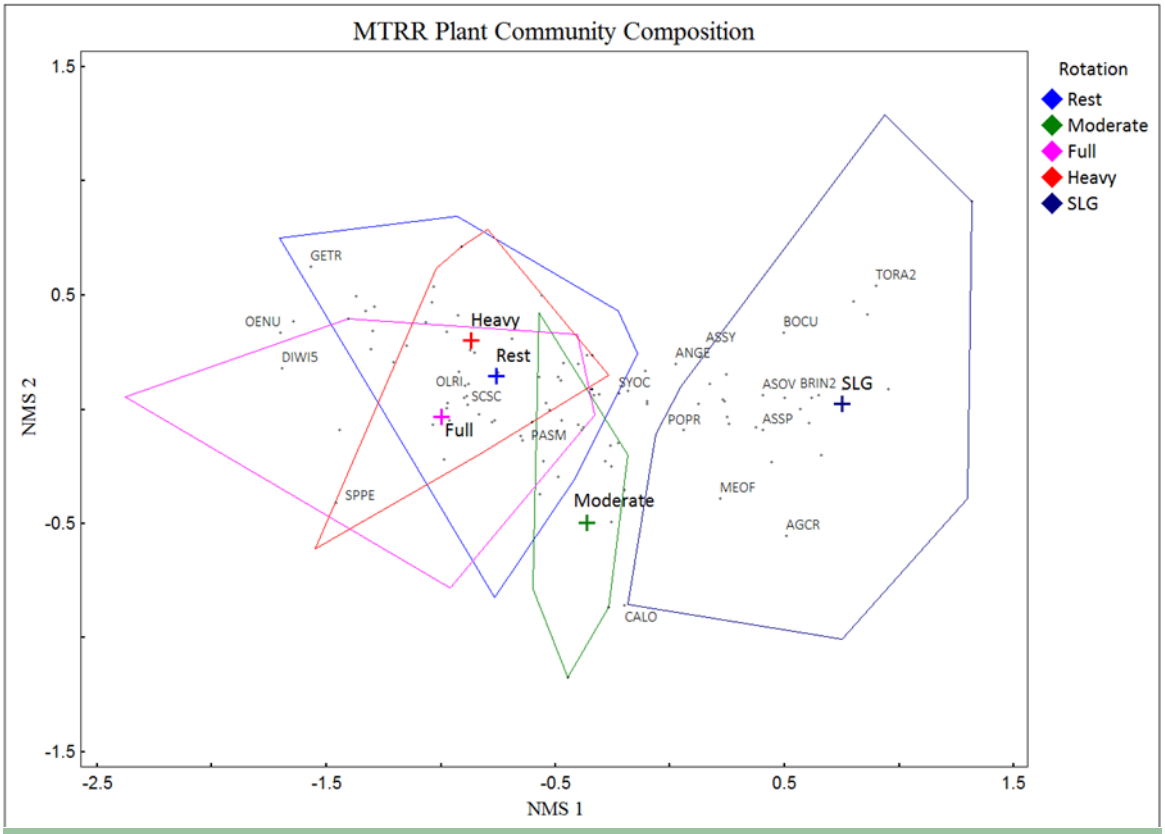

Figure 3. NMS ordination of plant community composition in 2020 of the modified twice-over rest rotation grazing treatment (MTRR) arranged by pasture use. Polygons represent average plant community composition of heavy-use pastures (Heavy), full-use pastures (Full), moderate-use pastures (Moderate) and rested pastures (Rest) within the MTRR treatment, compared to season-long grazing (SLG). Points represent different plant species, denoted by USDA plant codes listed in Table 1. Study conducted at the Central Grasslands Research Extension Center near Streeter, N.D. in 2020.

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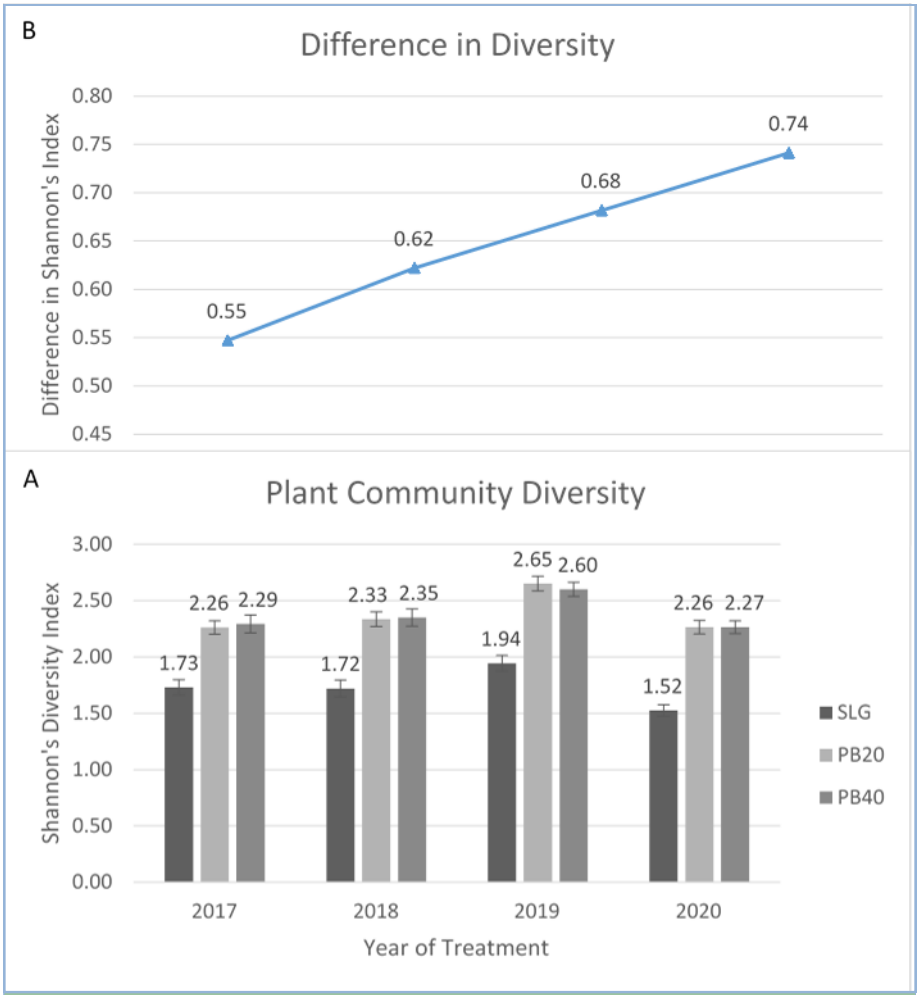

Figure 4 (A). Shannon-Weiner Diversity Index of treatments arranged by year (SLG = season-long grazing, PB20 = patch-burn grazing 20-acre and PB40 = patch-burn 40-acre). **(B)** Difference of Shannon Index between the average of patch-burn grazing treatments and the season-long grazing treatment in each year at the Central Grasslands Research Extension Center near Streeter, N.D. from 2017-2020.

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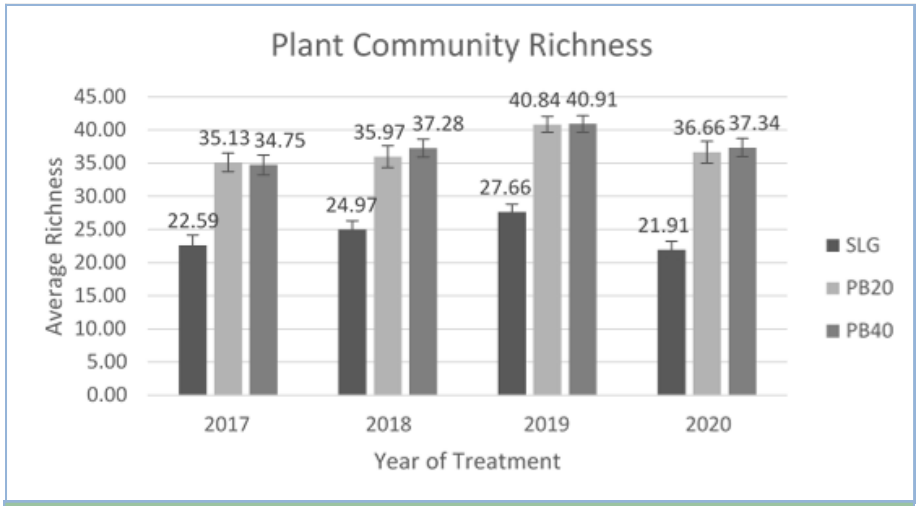

Figure 5. Plant community richness of each treatment arranged by year (SLG = season-long grazing, PB20 = patch-burn grazing 20-acre and PB40 = patch-burn grazing 40-acre) at the Central Grasslands Research Extension Center near Streeter, N.D. from 2017-2020.

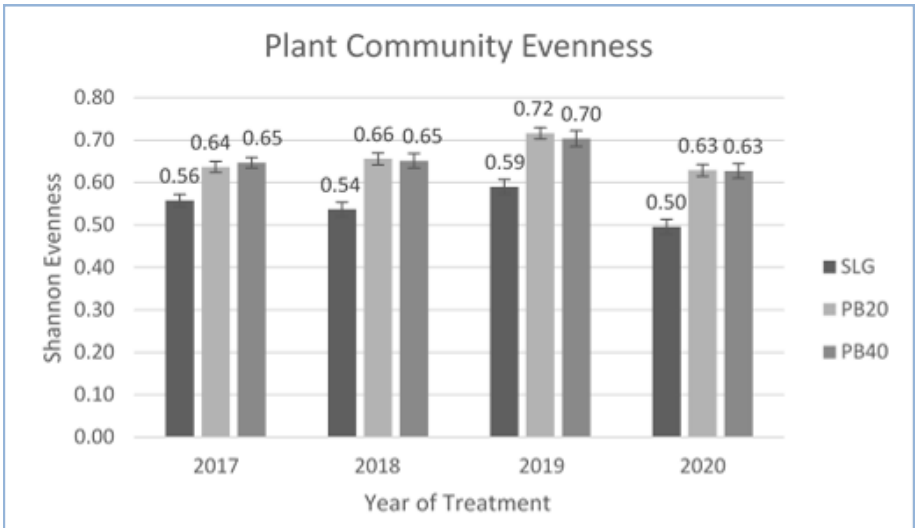

Figure 6. Plant community evenness of each treatment arranged by year (SLG = season-long grazing, PB20 = patch-burn grazing 20-acre and PB40 = patch-burn grazing 40-acre) at the Central Grasslands Research Extension Center near Streeter, N.D. from 2017-2020.

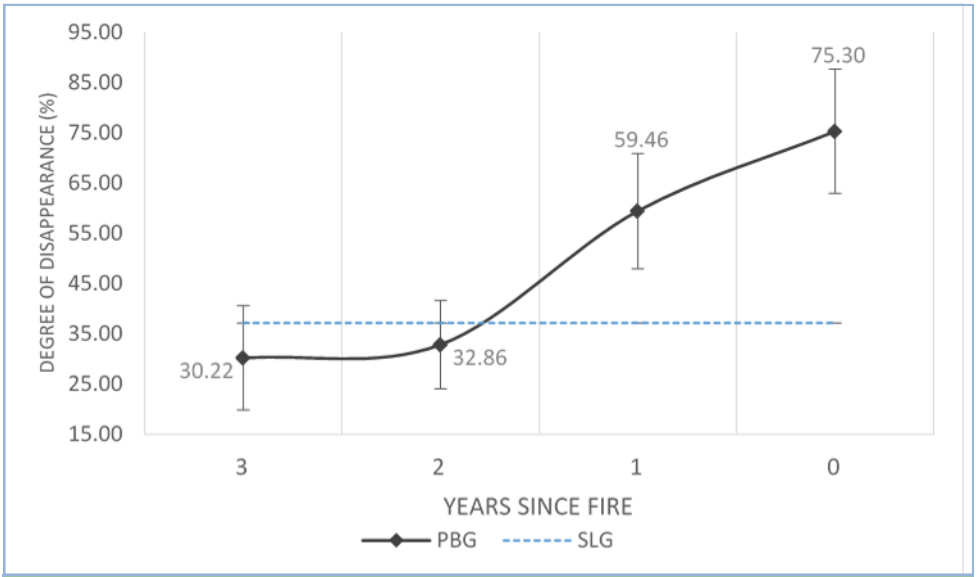

Figure 7. Average degree of disappearance of patches within patch-burn grazing treatments (PBG) arranged by time since fire with season-long grazing (SLG) degree of disappearance shown as a baseline. Study conducted at the Central Grasslands Research Extension Center near Streeter, N.D. in 2020.

Table 2. Mean effect of treatment on four plant community measurements, with patch-burn grazing and modified twice-over rest-rotation grazing split by years since fire and pasture use, respectively, at the Central Grasslands Research Extension Center near Streeter, N.D., in 2020 (mean ± SE).

2020 Plant Community Measurements				
Treatment	**Diversity[1]**	**Richness**	**Evenness**	**Standing Crop Biomass (lbs/ac)**
Season Long Grazing	1.52 ± .52	21.9 ± 1.0	0.50 ± .01	4,120 ± 110
Patch-Burn Grazing Years Since Fire:				
0	2.32 ± 0.1	37.0 ± 2.1	0.64 ± .02	3,080 ± 140
1	2.40 ± .08	38.9 ± 1.8	0.66 ± .02	3,520 ± 180
2	2.23 ± .08	37.1 ± 1.2	0.62 ± .02	3,580 ± 150
3	2.17 ± .09	36.2 ± 2.2	0.61 ± .02	3,760 ± 140
Modified Twice-over Rest-rotation Grazing Pasture Use:				
Heavy	2.40 ± 0.07	38.4 ± 1.9	0.66 ± 0.01	n/a
Full	2.24 ± 0.12	37.6 ± 2.8	0.62 ± 0.02	n/a
Moderate	1.97 ± 0.08	34.0 ± 1.6	0.56 ± 0.02	n/a
Rest	2.31 ± 0.11	36.5 ± 3.1	0.65 ± 0.01	n/a

[1] Shannon-Wiener Diversity Index