The Effects of Patch-Burn Grazing on Vegetation Structural Heterogeneity in the Northern Tallgrass Prairie of South Dakota

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ABSTRACT—Patch-burn grazing was developed as a grazing system to increase vegetation structural heterogeneity in managed grasslands of the central Great Plains. To evaluate this system in northern tallgrass prairie, we compared the structural response of vegetation following patch-burn grazing to that of continuous season-long grazing at two sites in eastern South Dakota. We established two pastures at each site and randomly assigned one pasture at each site to a patch-burn grazing treatment and the other to a continuous season-long grazing treatment. We allotted cow-calf pairs to each pasture during the summers of 2007 through 2009. We burned one patch of the patch-burn grazing pastures each spring for three years, leaving one patch not burned at the end of the study. We measured foliar cover of major plant functional groups, litter cover, and visual obstruction at the end of each grazing season and measured forage quality three times during the final summer. Ordination of principal component patch means showed greater vegetation structural heterogeneity for patch-burn grazing than season-long continuous grazing each year. Our results suggest that patch-burn grazing is a strategy that has potential to increase vegetation structural heterogeneity in northern tallgrass prairies and should be tested at other northern locations.

Key Words: forbs, grasses, grazing, prescribed fire, principal component analysis, tallgrass prairie

Introduction

The tallgrass prairie once was a continuous but heterogeneous natural ecosystem (Knapp and Seastedt 1986) that stretched from southern Manitoba to Texas along the eastern edge of the Great Plains and east across the Prairie Peninsula of Iowa and Illinois (Transeau 1935). At present, this ecosystem has been reduced to 5% of its original extent, is highly fragmented (Samson and Knopf 1994; Reinking 2005), and has lost vegetation structural heterogeneity (Fuhlendorf and Engle 2001). Fuhlendorf and Engle (2001) define vegetation structural heterogeneity as spatial variability in vegetation stature, composition, density, and biomass across the landscape. Vegetation structural heterogeneity is influenced by many factors including physiographic features of geology, topography, and soil and disturbances from climate, fire, animals, and humans (Turner 1989). Concern is growing that vegetation structural heterogeneity on the remaining areas of tallgrass prairie has been reduced by management practices aimed solely at optimizing livestock production (Fuhlendorf and Engle 2001). The decline in grassland bird populations in the North American Great Plains provides evidence of prairie structural diversity loss (Wiens 1974; Askins 2000, Reinking 2005; Fuhlendorf et al. 2006; Coppedge et al. 2008; Powell 2008) due to intensive management.

The relationship between livestock grazing and vegetation structural heterogeneity has been studied from the patch to the landscape level and is one of the reasons alternative grazing systems have been developed (Senft et al. 1987; Coughenour 1991; Bailey et al. 1996; Bailey et al. 1998; Fuhlendorf and Smeins 1999; Fuhlendorf et al. 2006; Derner et al. 2009; Fynn 2012). In an effort to more closely mimic natural systems, researchers have increased vegetation structural heterogeneity

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by recoupling fire and grazing (Fuhlendorf and Engle 2001; Fuhlendorf and Engle 2004; Derner et al. 2009). This management strategy has been given the name "patch-burn grazing" and has gained considerable attention since it was first promoted by Fuhlendorf and Engle (2001).

Patch-burn grazing research has primarily been conducted in the central tallgrass prairie ecoregion of the United States (Fuhlendorf and Engle 2004; Vermeire et al. 2004; Fuhlendorf et al. 2006; Schuler et al. 2006; Engle et al. 2008), and it is unknown if patch-burn grazing will produce similar responses in the northern tallgrass prairie. Both vegetation and fire history are different between these two systems. In the central tallgrass prairie, vegetation is predominately tall warm-season grasses with lesser amounts of forbs in the interstitial spaces (Collins and Gibson 1990). In the northern tallgrass prairie, the vegetation is co-dominated by tall warm-season grasses and native cool-season grasses with perennial forbs and exotic cool-season grasses filling interstitial spaces (Smart et al. 2003). Fire has not been extensively used in land management in the northern tallgrass prairie as compared to the central tallgrass prairie where its use is much more common (Launchbaugh and Owensby 1978). In the central tallgrass prairie, patch-burn grazing systems have been observed to result in increased vegetation structural heterogeneity as evidenced by (1) recently burned patches (<1 year) that are dominated by grasses, have bare ground with an absence of standing dead vegetation, and are less dense; (2) transition patches (1–3 years since burning) that are dominated by forbs, have a high percentage of bare ground, and low cover of litter and standing dead; and (3) older unburned patches (>3 years since burning) that are dominated by litter, standing dead, and mostly grasses (Fuhlendorf and Engle 2004; Leis et al. 2013). Due to the differences between northern and central tallgrass prairies, patch-burn grazing may not produce the same ecosystem benefits in northern prairies as it does in the central prairie. However, if it does, patch-burn grazing may be a viable strategy to increase vegetation structural heterogeneity in the northern tallgrass prairie. To fill this knowledge gap, we examined the effects of patch-burn grazing at two sites in the northern prairie as a pilot study. We hypothesized that vegetation structural heterogeneity would increase with patch-burn grazing as compared to season-long continuous grazing, the more common management practice in the northern tallgrass prairie.

Methods

Study Site Description

We conducted this study from 2007 to 2009 at two sites, Clear Lake and Summit, in northeastern South Dakota (Fig. 1). Vegetation at these sites is typical of the northern tallgrass prairie and includes native and introduced cool-season grasses, native warm-season grasses, native and introduced forbs, and shrubs (Table 1).

Experimental Design and Treatment Application

At both Clear Lake and Summit, we established two pastures and randomly assigned a continuous season-long grazing treatment to one pasture and a patch-burn grazing treatment to the other. We grazed each grazing treatment with cow-calf pairs weighing about 575 kg from mid-May to late August each year (see Table 2 for pasture size and yearly stocking rates). Cattle watered out of several dugouts and small natural pothole lakes, ranging from 0.25–2 ha in size at Clear Lake to 0.25–10 ha at Summit, that were well distributed throughout each pasture. For the patch-burn grazing treatment, we burned approximately one quarter of each pasture each year for three years. Thus at the end of the study, the two pastures that were treated with patch-burning each had three burned patches and one unburned patch. Cattle had access to the entire pasture during the grazing season in both grazing treatments.

South Dakota Game Fish and Parks Department personnel conducted the prescribed burns at Clear Lake and Summit using a ring fire technique (Higgins et al. 1989). In late April 2007, 16.2 and 21.5 ha were burned at Clear Lake and Summit, respectively. In mid-April 2008, 14.2 and 20.2 ha were burned at Clear Lake and Summit, respectively. In late April 2009, 18.2 and 33.2 ha were burned at Clear Lake and Summit, respectively. We did not assess burns for intensity or severity. We timed the burns to maximize damage to introduced cool-season grasses without harming native warm-season grasses (Smart et al. 2013).

Vegetation Data Collection

We divided each pasture into four equal-sized patches and established permanent sampling locations in each patch and marked them with a fiberglass pole and orange flagging and recorded their locations with a global

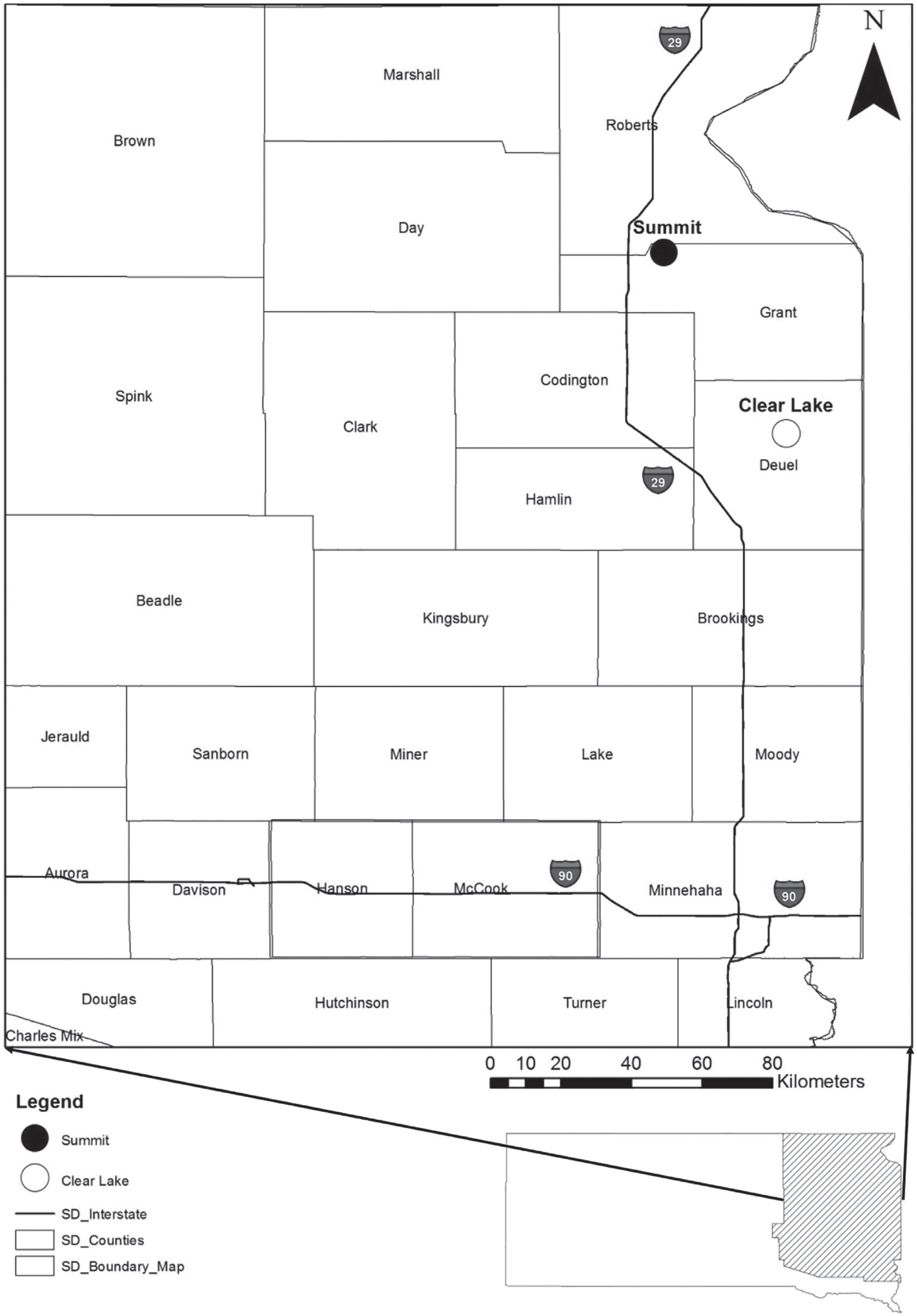

Figure 1. Location of study pastures near Clear Lake and Summit in northeastern South Dakota.

TABLE 1. Frequency of occurrence of plants found in the patch-burn grazing or the continuous season-long grazing treatment at Clear Lake and Summit, South Dakota.

		Clear Lake		Summit	
Scientific name	Common name[a]	Patch-burn grazing (%)	Continuous season-long grazing (%)	Patch-burn (%)	Continuous season-long (%)
		Grasses and grasslikes			
Agrostis stolonifera	Redtop (P, I)	0.00	1.19	0.50	0.00
Andropogon gerardii	Big bluestem (P, N)	2.94	3.25	1.60	7.69
Bouteloua curtipendula	Sideoats grama (P, N)	10.63	7.13	2.40	4.75
Bouteloua dactyloides	Buffalograss (P, N)	0.00	0.00	0.00	0.19
Bouteloua gracilis	Blue grama (P, N)	0.06	0.00	0.00	0.00
Bromus inermis	Smooth bromegrass (P, I)	13.19	8.56	15.70	4.56
Calamagrostis canadensis	Canada bluejoint (P, N)	0.38	0.25	0.00	0.00
Calamovilfa longifolia	Prairie sandreed (P, N)	0.00	0.00	0.00	0.00
Carex spp.	Sedge species (P, N)	1.25	2.06	1.50	2.56
Dactylis glomerata	Orchardgrass (P, I)	0.00	0.00	0.00	0.00
Dichanthelium oligosanthes	Scribner's panicum (P, N)	4.75	2.44	0.60	0.06
Dichanthelium wilcoxianum	Wilcox panicum (P, N)	0.00	0.13	0.00	0.00
Elymus canadensis	Canada wildrye (P, N)	0.00	0.00	0.00	0.00
Elymus repens	Quackgrass (P, I)	0.00	1.19	2.30	0.31
Elymus smithii	Western wheatgrass (P, N)	0.44	0.00	0.00	1.69
Elymus trachycaulus	Slender wheatgrass (P, N)	0.50	0.81	1.20	1.13
Hordeum jubatum	Foxtail barley (P, N)	0.00	0.00	0.00	0.13
Koeleria macrantha	Prairie junegrass (P, N)	0.00	0.00	0.00	0.06
Muhlenbergia spp.	Muhly species (P, N)	0.00	0.06	0.00	0.00
Panicum virgatum	Switchgrass (P, N)	0.06	0.31	0.00	0.06
Phalaris arundinacea	Reed canarygrass (P, N)	0.38	0.06	0.20	0.38
Phleum pretense	Timothy (P, I)	0.06	1.25	0.40	0.06
Poa pratensis	Kentucky bluegrass (P, I)	28.50	50.38	44.00	46.00
Schizachyrium scoparium	Little bluestem (P, N)	0.19	0.69	4.30	0.00
Setaria pumila	Yellow foxtail (A, I)	0.00	0.31	4.10	0.00
Sorghastrum nutans	Indiangrass (P, N)	0.75	1.19	1.20	0.00
Spartina pectinata	Prairie cordgrass (P, N)	1.06	0.13	2.40	0.75
Sporobolus heterolepis	Prairie dropseed (P, N)	1.38	0.56	0.10	0.13
Stipa spp.	Needlegrasses (P, N)	4.25	2.25	2.20	6.19
Total		**70.75**	**84.19**	**84.70**	**76.69**
		Forbs and shrubs			
Achillea millefolium	Common yarrow (P, N)	0.25	0.19	0.00	0.38
Ambrosia psilostachya	Western ragweed (P, N)	1.44	0.63	0.10	3.63
Amorpha canescens	Leadplant (P, N)	4.56	2.69	0.60	0.88
Anemone canadensis	Canada anemone (P, N)	0.69	0.31	0.10	0.69
Anemone patens	Prairie smoke (P, N)	0.06	0.25	0.10	0.00
Anemone virginianna	Thimbleweed (P, N)	0.19	0.06	0.00	0.13
Antennaria neglecta	Field pussytoes (P, N)	0.13	0.13	0.00	0.00
Artemisia absinthium	Wormwood sage (P, I)	0.13	0.25	0.00	0.06
Artemisia frigida	Fringed sagewort (P, N)	0.00	0.00	0.00	0.06

		Clear Lake		Summit	
Scientific name	Common name[a]	Patch-burn grazing (%)	Continuous season-long grazing (%)	Patch-burn (%)	Continuous season-long (%)
Artemisia ludoviciana	Cudweed sagewort (P, N)	0.69	0.38	0.10	0.88
Asclepias speciosa	Showy milkweed (P, N)	0.13	0.00	0.10	0.00
Asclepias syriaca	Common milkweed (P, N)	1.00	0.00	0.20	0.13
Asclepias verticillata	Whorled milkweed (P, N)	0.00	0.00	0.00	0.06
Aster ericoides	Heath aster (P, N)	1.88	1.13	0.30	0.69
Astragalus crassicarpus	Ground plum milkvetch (P, N)	0.06	0.00	0.00	0.06
Brickellia eupatorioides	False boneset (P, N)	0.00	0.00	0.00	0.19
Cirsium arvense	Canada thistle (P, I)	1.50	0.56	2.00	0.25
Cirsium flodmanii	Flodman's thistle (P, N)	0.06	0.19	0.20	0.25
Cirsium undulatum	Wavyleaf thistle (P, N)	0.00	0.06	0.00	0.00
Cirsium vulgare	Bull thistle (B, I)	0.00	0.00	0.00	0.13
Convolulus arvensis	Field bindweed (P, I)	0.00	0.13	0.00	1.44
Dalea purpurea	Purple prairie clover (P, N)	0.25	0.13	0.20	0.25
Echinacea angustifolia	Purple coneflower (P, N)	0.06	0.00	0.00	0.06
Equisetum laevigatum	Smooth horsetail (P, N)	0.00	0.00	0.10	0.31
Erigeron canadensis	Horesweed (A, N)	0.06	0.00	0.00	0.00
Erigeron strigosus	Daisy fleabane (A, N)	0.13	0.00	0.00	0.00
Euphorbia esula	Leafy spurge (P, I)	0.50	0.00	1.10	0.00
Fragaria virginiana	Virginia strawberry (P, N)	0.38	0.38	0.00	0.00
Galium boreale	Northern bedstraw (P, N)	0.25	0.06	1.70	0.00
Gaura coccinea	Scarlet gaura (P, N)	0.00	0.00	0.00	0.06
Glycyrrhiza lepidota	American licorice (P, N)	0.31	0.13	0.00	0.00
Helianthus maximiliani	Maximilian sunflower (P, N)	0.44	0.19	0.00	0.00
Helianthus pauciflorus	Stiff sunflower (P, N)	1.75	0.38	0.30	0.13
Liatris punctata	Dotted gayfeather (P, N)	0.06	0.06	0.00	0.06
Linaria vulgaris	Yellow toadflax (P, I)	0.19	0.06	0.30	0.06
Lithospermum canescens	Hoary puccoon (P, N)	0.00	0.06	0.00	0.06
Lycopus spp.	Bugleweed species (P, N)	0.06	0.13	0.00	0.06
Lygodesmia juncea	Rush skeletonplant (P, N)	0.00	0.00	0.00	0.06
Medicago lupulina	Alfalfa (P, I)	0.06	0.00	0.00	0.13
Medicago lupulina	Black medic (A, I)	0.00	0.00	0.00	2.38
Melilotus officinalis	Yellow sweetclover (B, I)	0.00	0.38	2.50	2.81
Mentha arvensis	Wild mint (P, N)	0.00	0.00	0.00	0.06
Monarda fistulosa	Wild bergamot (P, N)	1.06	0.00	0.00	0.00
Onosmodium spp.	Gromwell species (P, N)	0.13	0.00	0.10	0.31
Oxalis spp.	Woodsorrel species (P, N)	0.13	0.00	0.20	0.00
Physalis virginiana	Virginia ground cherry (P, N)	0.00	0.06	0.20	0.25
Plantago major	Common plantain (P, I)	0.00	0.06	0.00	0.00
Polygonum spp.	Smartweed species (P, N)	0.00	0.00	0.40	0.00
Potentilla spp.	Cinquefoil species (P, N)	0.06	0.06	0.10	0.13
Psoralea argophylla	Silverleaf scurfpea (P, N)	0.44	0.31	0.00	0.69

TABLE 1, *continued*

Scientific name	Common name[a]	Clear Lake		Summit	
		Patch-burn grazing (%)	Continuous season-long grazing (%)	Patch-burn (%)	Continuous season-long (%)
Psoralea esculenta	Breadroot scurfpea (P, N)	0.06	0.00	0.00	0.00
Pulsatilla patens	Pasque flower (P, N)	0.00	0.00	0.00	0.06
Ratibida columnifera	Prairie coneflower (P, N)	0.13	0.06	0.10	1.00
Rosa arkansana	Prairie rose (P, N)	1.94	0.75	1.30	0.31
Rudbeckia hirta	Black-eyed susan (P, N)	0.06	0.13	0.00	0.00
Rumex crispus	Curly dock (P, I)	0.00	0.00	0.00	0.06
Senecio spp.	Ragwort species (P, N)	0.00	0.00	0.00	0.00
Solidago canadensis	Canada goldenrod (P, N)	3.19	0.81	0.30	0.38
Solidago missouriensis	Missouri goldenrod (P, N)	1.19	1.44	0.00	0.25
Solidago rigida	Stiff goldenrod (P, N)	1.50	2.06	0.00	0.06
Sonchus arvensis	Field sow thistle (P, I)	0.00	0.00	0.10	0.13
Stachys tenuifolia	Smooth hedgenettle (P, N)	0.06	0.00	0.00	0.00
Symphoricarpos occidentalis	Western snowberry (P, N)	0.19	0.00	0.20	0.00
Symphyotrichum sericeum	Silky aster (P, N)	0.25	0.56	0.10	0.00
Taraxacum officinale	Common dandelion (P, I)	0.00	0.13	0.20	0.19
Thalictrum dasycarpum	Purple meadowrue (P, N)	0.00	0.06	0.00	0.00
Tragopogon dubius	Goats beard (B, I)	0.00	0.00	0.00	0.06
Trifolium repens	White clover (P, I)	0.06	0.00	0.80	2.44
Verbena spp.	Verbena species (P, N)	0.06	0.00	0.10	0.06
Viola pedatifida	Prairie violet (P, N)	0.00	0.13	0.20	0.38
Zizia aurea	Golden alexanders (P, N)	0.25	0.19	0.00	0.00
Total		**28.00**	**15.69**	**14.40**	**23.13**

Note: Frequencies were measured in August 2008 using the modified step-point technique (n = 1,600 for each treatment).
[a]Parenthetical abbreviations: A = annual, B = biennial, P = perennial, I = introduced, and N = native.

TABLE 2. Pasture size and stocking rates of season-long continuous and patch-burn grazing treatments during 2007–2009 in northeastern South Dakota.

Site	Ownership	Latitude and longitude	Grazing treatment	Size (ha)	Stocking rate by year (AUM ha^{-1})		
					2007	2008	2009
Clear Lake	Public	44.813 N, 96.649 W	Continuous season-long	72.8	1.4	1.3	1.3
	Public	44.807 N, 96.649 W	Patch-burn	72.8	1.4	1.3	1.3
Summit	Private	45.304 N, 97.004 W	Continuous season-long	64.0	2.5	4.3	4.3
	Public	45.304 N, 97.016 W	Patch-burn	132.7	2.1	2.1	2.1

Note: AUM = Animal Unit Month.

positioning system. We used these sampling locations for the duration of the study. We established four 25 m transects that radiated from the sampling locations in the four cardinal directions and took vegetation measurements every 5 m for a total of 5 sampling points along each transect. We measured visual obstruction at each sampling point using the Robel pole method (Robel et al. 1970). We estimated foliar cover of plant functional groups (native grass, introduced grass, native forbs, introduced forbs, and shrubs) and litter cover at each sampling point using a 50 cm by 50 cm (0.25 m^2) frame. We took all measurements at the end of the grazing season, in late August of each study year, except litter, which we did not estimate in the first year.

Forage Quality

In 2009 we clipped vegetation for forage quality analysis in mid-June, mid-July, and mid-August from two randomly located 0.25 m^2 plots at each permanent sampling location (within a patch) in each pasture. We put the clipped vegetation into paper bags and dried them in a forced-air oven at 60°C for 72 hours. We ground the forage samples in a mill so that the plant material would pass through a 1 mm screen and stored it in plastic bags prior to wet chemistry analysis. We analyzed crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) following Official Methods of Analysis of AOAC International (2000).

Statistical Analysis

We used principal component analysis (PCA) to assess vegetation structural heterogeneity of the two grazing treatments (Fuhlendorf and Engle 2004). We analyzed patch means for visual obstruction, foliar cover of plant functional groups, and litter cover using PROC PRINCOMP (SAS Institute 2009). We used the first two eigenvalues and associated eigenvectors of principal component 1 and 2 to ordinate these data in two dimensions. We used analysis of variance (ANOVA) of the patch means for visual obstruction, foliar cover of plant functional groups, litter cover, and forage quality samples to assess patch differences between grazing treatments using a randomized complete block design in PROC MIXED (SAS Institute 2009). Grazing treatment (patch-burn or continuous season-long grazing), patch, and the grazing treatment by patch interaction were the independent variables and site was the blocking effect. We analyzed forage quality parameters, CP, ADF, and NDF using ANOVA by month in a randomized complete block design in PROC MIXED (SAS Institute 2009). We separated least squares means using the PDIFF option in SAS Institute (2009). We considered means significantly different at alpha = 0.10. We checked residuals for normality using the Shapiro-Wilk W test in PROC UNINVARIATE (SAS Institute 2009). All variables indicated normality with a nonsignificant $P > 0.01$.

Results

Patch Ordination

CLEAR LAKE SITE

In 2007 the first and second eigenvalues explained 39% and 32% of the variation, respectively, in the PCA of foliar cover of the major functional groups and visual obstruction. The x-axis eigenvector loadings were positively weighted by native forb cover and shrub cover and negatively weighted by introduced grass cover and visual obstruction (Fig. 2). The y-axis eigenvector loadings were positively weighted by native grass cover and introduced forb cover. The Year 1 burned patch was clearly separated from the unburned patches based on PCA scores (Fig. 3). The continuous season-long grazing patches were grouped more closely than the patch-burn grazing patches and orientated along the x-axis.

In 2008 the first and second eigenvalues explained 45% and 27% of these data, respectively. The x-axis eigenvector loadings were positively weighted by litter cover, visual obstruction, and introduced grass cover and negatively weighted by native forb cover and introduced forb cover (Fig. 2). The y-axis eigenvector loadings were positively weighted by shrub cover and native grass cover and negatively weighted by introduced forb cover and introduced grass cover. The Year 2 burned patch and the unburned patches were widely separated with the Year 1 burned patch in between (Fig. 3). Data from the continuous season-long grazing patches were grouped closely together and orientated near the x-axis but with some overlap with the patch-burn patches.

In 2009 the first and second eigenvalues explained 52% and 24% of the variation in foliar cover, litter cover, and visual obstruction, respectively. The x-axis eigenvector loadings were positively weighted by introduced grass cover, litter cover, and visual obstruction and negatively weighted by native grass cover and native forb cover (Fig. 2). The y-axis eigenvectors loadings were

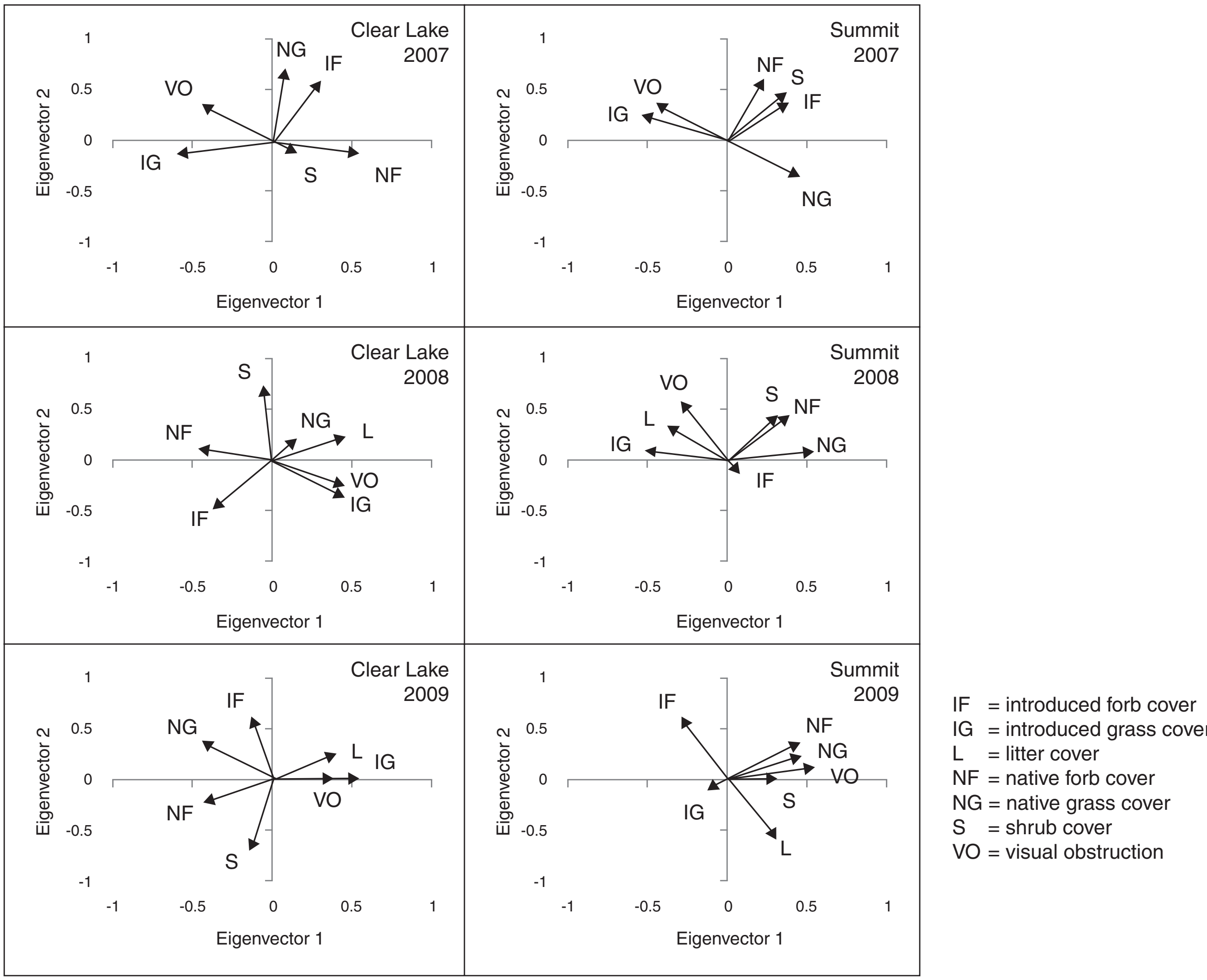

Figure 2. Eigenvector loadings (arrows) for introduced forb cover, introduced grass cover, litter cover, native forb cover, native grass cover, shrub cover, and visual obstruction at Clear Lake and Summit, South Dakota (2007–2009).

positively weighted by introduced forb cover and native grass cover and negatively weighted by shrub cover and native forb cover. The continuous season-long grazing patches were closely grouped on the positive side of the x-axis and were separated from the patch-burn grazing treatment's Year 3 burn and Year 2 burn, but were located near the unburned and Year 1 burn patches (Fig. 3).

SUMMIT SITE

In 2007 first and second eigenvalues explained 48% and 37% of the variation of the Summit data, respectively. The x-axis eigenvector loadings were positively weighted by native grass cover, introduced forb cover, shrub cover, and native forb cover and negatively weighted by introduced grass cover and visual obstruction (Fig. 2). The y-axis eigenvector loadings were positively weighted by native forb cover, shrub cover, introduced forb cover, introduced grass cover, and visual obstruction and negatively weighted by native grass cover. The patches within the patch-burn grazing treatment were separated from one another with only the Year 1 burned patch negative along the y-axis (Fig. 3). The patches in the continuous season-long grazing treatment were closely grouped together along the x-axis.

In 2008 the first and second eigenvalues explained 52% and 27% of the variation in these data. The x-axis corresponding eigenvector loadings were positively weighted by native grass cover, native forb cover, and shrub cover and negatively weighted by introduced grass cover, litter cover, and visual obstruction (Fig. 2). The y-axis eigenvector loadings were positively weighted by litter cover, visual obstruction, shrub cover, and

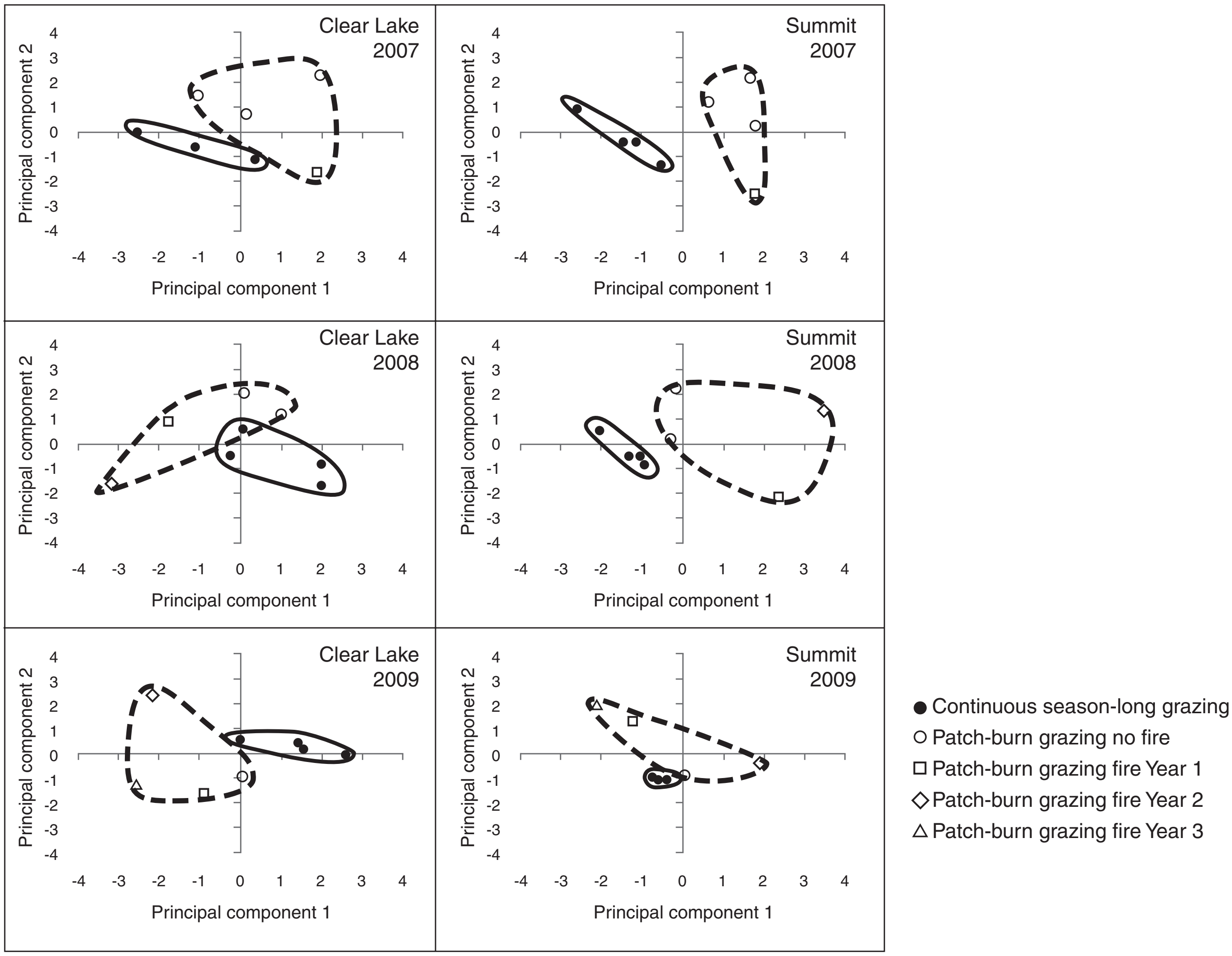

Figure 3. Principal component scores for principal component 1 (x-axis) and principal component 2 (y-axis) for four patches within patch-burn grazing with no fire, areas burned in Years 1, 2, and 3, and continuous season-long grazing at Clear Lake and Summit, South Dakota (2007–2009). Polygons represent tightness of clustering: the dashed polygon is the patch-burn treatment and the solid polygon is the continuous season-long grazing treatment.

native forb cover. The Year 1 burned patch and Year 2 burned patch were widely separated from the unburned patches and positive along the x-axis (Fig. 3). The patches of the continuous season-long grazed treatment were closely clustered along the x-axis.

In 2009 the first and second eigenvalues explained 49% and 23% of these data, respectively. The x-axis eigenvector loadings were positively weighted by shrub cover, visual obstruction, native grass cover, and native forb cover and negatively weighted by introduced grass cover and introduced forb cover (Fig. 2). The y-axis eigenvector loadings were positively weighted by introduced forb cover, native forb cover, and native grass cover and negatively weighted by litter cover. The Year 3 burned patch was widely separated from the unburned patch and the Year 2 burned patch (Fig. 3). The patches of the continuous season-long grazed treatment were very tightly grouped near the origin of both axis.

In general, sampling sites within the continuous season-long grazing sites were more similar to each other than to the patch-burn sites as indicated by the polygon size in Figure 3. Burning combined with grazing reduced litter cover, reduced visual obstruction, and usually increased native forb cover. Unburned and continuous season-long grazing patches usually had greater introduced grass cover, litter cover, and visual obstruction (Fig. 2).

Patch Structural Characteristics

Visual obstruction varied among patches, with burned patches tending to have lower visual obstruction the

TABLE 3. Grazing treatment patch means and *P*-values, in the first year of burning, for foliar cover of major functional plant groups, measured in late August and averaged across two sites in northwestern South Dakota.

Grazing treatment	Patch	Years since burn	Visual obstruction (cm)	Native grass (%)	Introduced grass (%)	Native forb (%)	Introduced forb (%)	Shrub (%)
Patch-burn	1	–	7	14	36	10	4	4
	2	–	11	16	28	12	3	7
	3	–	8	21	25	14	4	3
	4	0.33	3	15	20	10	1	4
Continuous season-long	1	–	8	8	40	7	1	1
	2	–	13	9	52	9	1	0
	3	–	8	15	34	10	0	4
	4	–	9	10	36	13	0	2
Source of variation					***P*-value**			
Grazing treatment			0.40	0.29	0.11	0.59	0.30	0.26
Patch			**<0.01**	0.41	**0.02**	0.80	0.39	0.94
Grazing treatment × Patch			**0.08**	0.98	**0.08**	0.81	0.56	0.21
Standard error			1.3	5.8	3.0	5.7	1.7	2.3

TABLE 4. Grazing treatment patch means and *P*-values, in the second year of burning, for foliar cover of major functional plants groups, measured in late August and averaged across two sites in northwestern South Dakota.

Grazing treatment	Patch	Years since burn	Visual obstruction (cm)	Native grass (%)	Introduced grass (%)	Native forb (%)	Introduced forb (%)	Shrub (%)	Litter cover (%)
Patch-burn	1	–	10	15	35	8	6	6	94
	2	–	12	14	40	7	2	7	93
	3	0.33	6	17	26	12	6	5	76
	4	1.33	7	14	25	11	4	4	74
Continuous season-long	1	–	11	14	44	4	2	1	89
	2	–	15	11	48	5	3	1	96
	3	–	8	8	42	8	2	2	93
	4	–	7	15	36	5	1	2	91
Source of variation					***P*-value**				
Grazing treatment			0.58	0.36	0.18	0.27	0.40	0.25	0.20
Patch			**0.05**	0.85	**0.09**	0.36	0.82	0.98	**0.06**
Grazing treatment × Patch			0.84	0.44	0.86	0.87	0.72	0.83	**0.07**
Standard error			2.7	4.2	6.3	3.4	3.6	3.6	5.4

TABLE 5. Grazing treatment patch means and *P*-values, in the third year of burning, for foliar cover of major functional plant groups, measured in late August and averaged across two sites in northwestern South Dakota.

Grazing treatment	Patch	Years since burn	Visual obstruction (cm)	Native grass (%)	Introduced grass (%)	Native forb (%)	Introduced forb (%)	Shrub (%)	Litter cover (%)
Patch-burn	1	–	11	11	31	8	1	1	88
	2	0.33	3	6	41	11	3	1	36
	3	1.33	7	13	35	9	2	3	81
	4	2.33	7	8	24	11	2	1	64
Continuous season-long	1	–	6	4	33	2	0	0	92
	2	–	9	2	56	2	1	1	94
	3	–	7	5	40	5	0	0	92
	4	–	6	8	43	7	1	0	94
Source of variation					***P*-value**				
Grazing treatment			0.96	0.29	0.35	0.25	0.41	0.35	0.16
Patch			0.14	0.65	0.68	0.73	0.93	0.77	**0.10**
Grazing treatment × Patch			0.73	0.50	0.27	0.86	0.63	0.72	0.11
Standard error			3.1	4.5	11.5	4.7	1.9	1.4	9.3

TABLE 6. Grazing treatment patch means and *P*-values, in the third year of burning, for percentage of crude protein, acid detergent fiber, and neutral detergent fiber from whole plant samples, averaged across two sites in northwestern South Dakota.

Grazing treatment	Patch	Years since burn	Crude protein (%)			Acid detergent fiber (%)			Neutral detergent fiber (%)		
			June	July	August	June	July	August	June	July	August
Patch-burn	1	–	12	10	10	38	39	40	67	71	72
	2	0.33	15	15	15	35	38	38	66	64	68
	3	1.33	11	12	12	39	37	41	67	67	69
	4	2.33	13	12	11	37	39	40	67	67	68
Continuous season-long	1	–	10	10	12	38	38	39	68	65	67
	2	–	11	11	13	40	38	40	67	66	66
	3	–	10	15	13	40	36	39	68	65	65
	4	–	10	14	13	38	37	41	68	66	66
Source of variation						***P*-value**					
Grazing treatment			0.20	0.91	0.45	**0.02**	0.17	0.98	0.63	**0.03**	**0.03**
Patch			0.58	0.17	0.77	**0.08**	0.12	0.22	0.99	**0.02**	0.74
Grazing treatment × Patch			0.24	**0.07**	0.49	0.68	0.70	0.26	0.99	**0.05**	0.48
Standard error			1.5	1.7	2.1	1.3	1.2	1.0	3.2	1.1	2.4

Note: Samples were collected in mid-June, mid-July, and mid-August of 2009.

year they were burned. This pattern was especially apparent in Year 1 and Year 3 (Tables 3, 4, 5). Invasive grass cover significantly varied by patch, with invasive grass cover being lower in the burned patches than in other patches in Years 1 and 2 (Tables 3 and 4). Litter cover was significantly influenced by patch, with lower litter cover in the burned patches in Years 2 and 3 (Table 4 and 5). Other response variables were similar among patches and grazing treatments.

Forage Quality

Forage quality differed between the patch-burn and continuous season-long grazing treatments. Crude protein was not significantly affected by grazing treatment or patch, but was significantly affected by the interaction of grazing treatment and patch in July (Table 6). Crude protein was higher in the recently burned patch than the older burned patches, whereas it was not significantly different among patches in the continuous season-long grazing treatment (Table 6). Acid detergent fiber was lower in the recently burned patch in June, and no significant effects of patch or grazing treatment were found for July or August (Table 6). Neutral detergent fiber was lower in the recently burned patch than in the other patches within the patch-burn grazing treatment in July, and there were no difference in neutral detergent fiber among patches in the continuous season-long grazing treatment (Table 6).

Discussion

The results of our pilot study suggest that patch-burn grazing in northern tallgrass prairie increased vegetation structural heterogeneity among patches within a pasture when compared to continuous season-long grazing. This difference in vegetation structural heterogeneity between the two grazing treatments was evident both in the results of the ordination and in visual obstruction, litter cover, and cover of invasive grasses (Tables 3, 4, and 5). Our results were consistent with those found in the central tallgrass prairie (Fuhlendorf and Engle 2004; Vermeire et al. 2004; Fuhlendorf et al. 2006; Schuler et al. 2006; Engle et al. 2008; McGranahan et al. 2012).

However, we found the vegetation structural components in patches following burning did not respond in the same way as those observed by Fuhlendorf and Engle (2004). In the central tallgrass prairie, patch-burn grazing resulted in an increase in forbs and a decrease in litter and tallgrasses that lasted for two years (Fuhlendorf and Engle 2004; Engle et al. 2008). Their sites were dominated by C4 tallgrasses which when mature are lower in forage quality compared with C3 grasses (Mitchell et al. 1997). Allred et al. (2011) reported that the decline in crude protein occurred (0–150 days) from patches that were recently burned and leveled off after 150 days since burning. Our crude protein data did not show this decline over three months (Table 6). It is possible that with more time, our data may agree with Allred et al. (2011), or it is possible that the northern tallgrass prairie and the central tallgrass prairie respond differently. The species composition of our pastures included a mixture of introduced cool-season, native cool-season, and native warm-season grasses (Tables 2–5). It is possible that cattle in the patch-burn grazing treatment in our study did not focus their grazing on the most recently burned patch to the same extent as was found by others (Fuhlendorf and Engle 2004; Vermeire et al. 2004) because our species composition produced high-quality forage throughout the growing season (Table 6). Secondly, our experimental pasture size was relatively small (<150 ha), meaning the distance livestock traveled to reach either end of the pasture was at most 0.8 km and was similar to the pasture scale (45–65 ha) of Fuhlendorf and Engle (2004). In comparison, Vermeire et al. (2004) had pastures of 635 ha and Allred et al. (2011) had units ranging from 430 ha to 980 ha, so that once in an area, cattle would tend to stay and focus on grazing the site. Thirdly, our pastures contained several dugouts and small pothole lakes that were well distributed across the landscape such that cattle only had to travel 400 m at most to water. Vermeire et al. (2004) reported that cattle traveled up to 1,600 m to preferentially graze burn patches. Thus the more plausible explanations for less differences among patches include: (1) our plant composition was dominated by cool-season rather than warm-season grass species (Tables 2–5), which usually do not grow as tall, are less fibrous, and produce less biomass than warm-season grasses (Wilson et al. 1983; Masters et al. 1992; Mitchell et al. 1997; Barbehenn et al. 2004a, 2004b), and (2) water was well distributed across the study pastures.

We did not find differences in native forb cover between the patch-burn and continuous season-long grazing treatments. The native forb cover in our study ranged between 2% and 15% of the total canopy cover in pastures for both grazing treatments. This range was much smaller than those Fuhlendorf and Engle (2004), Vermeire et al. (2004), and Engle et al. (2008) encountered at study sites in the central tallgrass region. This may result from prior use of herbicides to control invasive weeds (Smart et al. 2011) in the pastures we studied. Also, only six of the 71 species of forbs and shrubs we found in our botanical assessment were annuals or biennials (Table 1). Of these, four are classified as invaders (Johnson and Larson 1999). Only yellow sweetclover and black medic (*Medicago lupulina* L.), both introduced forbs, had 2%–3% occurrence frequency, whereas the other annuals or biennials had frequencies of <0.15% (Table 2). The invasive perennial forbs Canada thistle, leafy spurge, wormwood sage (*Artemisia absinthium* L.), and yellow toadflax (*Linaria vulgaris* Mill.) had frequencies of occurrence of 2% or less (Table 1).

Management Implications

We found patch-burn grazing resulted in greater vegetation structural heterogeneity as compared to traditional continuous season-long grazing in the northern tallgrass prairie. However, some effects of patch-burn grazing were not as long-lasting as those observed from this grazing system in the central tallgrass prairie. Because of the nature of our pilot study, we could not determine precisely why some effects of patch-burn grazing that we observed in the northern tallgrass prairie were not more concordant with those reported in the central tallgrass prairie. The differences could be due to our limited experimental design (small number of study sites and short duration of study) or that patch-burn grazing produces somewhat different results in the northern and central tallgrass prairies. Nevertheless, based on our pilot study, we recommend patch-burn grazing be given more consideration as a system to increase vegetation structural heterogeneity in northern tallgrass prairie. Our recommendation could be strengthened by the results of longer studies conducted in other areas.

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