IMPACT OF ALTERNATIVE RANGE MANAGEMENT SYSTEMS ON GRASSLANDS IN THE CENTRAL PLATTE RIVER VALLEY, NEBRASKA

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by

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A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Natural Resources Science

Under the Supervision of Professors Felipe Chavez-Ramirez and James Stubbendieck

Lincoln, Nebraska

August, 2011

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University of Nebraska 2011

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Land management strategies can directly and indirectly affect plant assemblages and their behavior. Little research has been performed in south central Nebraska to quantify the effect of fire and grazing interactions on species composition, vegetation structure, forage quality, and potential cost associated with land management.

I evaluate the effect of season-long continuous, patch-burning, and rotational grazing approaches on vegetation and ranching costs to determine their value as conservation tools. This study includes data collected between 2007 and 2009 from grasslands in south central Nebraska. I found that land management influence plant assemblages by shifting communities when grazing and/or fire are present, but other environmental factors such as water availability can play important roles sustaining specific plant communities.

Vegetation structure has been widely accepted as a predictor of wildlife use, but few practical tools are available to measure structure in grassland vegetation. This study explored the adaptation of several diversity indices for use as vegetation structure descriptors. Differences between time after prescribed burning and management approach were detected proving the need to explore the potential use these indices in conjunction of wildlife habitat use data in order to better understand wildlife-habitat relationships.

Continuous grazing resulted in different plant communities. However, abnormally wet years during the study resulted in no observed advantages in terms of forage quality and management cost from the alternative patch-burning and rotational grazing systems.

DEDICATION

To my parents, Roberto and Tere, and my siblings, Beto, Ale, and Luis for being part of this goal.

MY DREAMS IN YOUR DREAMS

ACKNOWLEDGEMENTS

I would like to acknowledge the assistance and advice of my co-advisors Felipe and Jim, and committee members Drew and Walter, without whom this project would not have been possible. I really appreciate their support and mentorship to help me to reach a better understanding of ecology and conservation. I thank The Crane Trust for providing the funding and an excellent environment to develop my knowledge and experience of field conservation. Thanks to the Woitarzewski, Rickter, Hartman, and Woodman families from south central Nebraska for their contribution to this research.

I am also grateful to Aaron Lotz, Ingrid Barcelo, and Karen Leavelle for the support during all the ups and downs of the last five years. This experience has been much more enjoyable because of their friendship. Thanks to my friends Alvaro, Karina, and Alethia who supported from a distance and helped me to seek the midpoint between agriculture and conservation.

I would like to thank the numerous technicians who helped to collect the data used in this dissertation. Their energy and desire to learn helped to maintain my own energy and desire during long days of field work.

Finally, I thank the School of Natural Resources faculty for their contributions to help me achieve my academic goals during my time in Nebraska.

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Introduction

Grasslands

About 40% of the terrestrial surface of the planet, excluding Greenland and Antarctica, is composed by grass dominated biomes in the form of grasslands and savannas (White et al. 2000). These extensive open areas are mostly dominated by members of the Poaceae family (grasses), but some other plant families as Asteraceae (sunflower) and Fabaceae (bean) are also abundant in North American Prairies (Risser et al. 1981). The appearance of grasses in North America can be traced back to the late Cretaceous (70 Ma), but the initial expansion of grasslands in this continent happened during the Miocene (15 Ma) at the time of the uplift of the two main continental mountain ranges (Rocky and Sierra Madre mountains) (Janis et al. 2002). Only after the last glaciations 10,000 YBP, the Great Plains started to develop its actual range (Ehleringer et al. 1997).

In general, grasslands can be considered areas that are too dry to support a forest and too wet to be a desert. Although a complex combination of soils, topography, weather, and disturbances define specific grassland types, they usually occur on level to gently rolling areas (Anderson 2006). Grasslands can occur in a wide variety of climates ranging from 200 to 1300 mm of annual precipitation and average temperatures of 0-30°C (Risser et al. 1981). Another characteristic of grasslands is frequent periods of drought, a condition that is negatively correlated with the number of woody species observed (Sakaran et al. 2004).

Grasslands are early successional ecosystems that are maintained primary by frequent disturbances. Some of the disturbances come from drought, but additional disturbances come from fire and grazing (Briggs et al. 2005). These disturbances create a complex spatio-temporal distribution of successional states (Collins 1987). North American grassland communities evolved with the combination of fire and grazing acting together to maintain heterogeneity at landscape level. The general pattern is the presence of fire, natural or anthropogenic, followed by grazing animals, formerly bison, looking for fresh nutritious forage re-growth (Janis et al. 2002). These two processes drive the structural (Noy-Meir 1995, Collins 1987) and functional (Johnson and Matchett 2001, Hobbs et al. 1991) attributes of grasslands, as well as biodiversity linked to them. Severe ecosystem changes, such as species composition and susceptibility to exotic species invasion or woody plant encroachment, occur when fire and/or grazing patterns are altered (Vickery et al. 2000). These disturbances are credited as the main processes driving the diversity patterns of grasslands. Most prairie plants show at some degree adaptation to periodic droughts, frequent fire, and grazing animals (Gleason 1922). Recent studies have shown that alteration of natural disturbance patterns, mainly by anthropogenic sources, can be attributed as the source of change in plant communities and, as a consequence, grassland biodiversity (Briggs et al. 2005).

Grassland Degradation

Grasslands, from the conservation point of view, represent an important rangeland ecosystem. Blancher (2003) considered this biome as the largest and most threatened ecosystem in North America. Nearly all (97%) of the land in Nebraska is privately owned, and 53% of that land is classified as rangeland (Brenner et al. 2001). Noss et al. (1995) categorized United States grasslands as critically endangered, and 99% of the former tallgrass prairie has been displaced by agriculture and human development. To a lesser degree, the mixed and short grass prairies also have been affected resulting in many species at risk of local or global extinction (Hooper et al. 2005). Nebraska prairies have been modified by human activities since settlement in the 1800s (Weaver and Hansen 1941). Some estimates are that Nebraska has lost 98% and 75% of its former tallgrass and mixed grass prairie, respectively (White et al. 2000).

White et al. (2000) identified agriculture, human settlements, desertification, fire, domestic livestock, fragmentation, and invasive species as the seven main causes of grassland degradation and lost. Some of the American Great Plains was transformed into cropland starting in the 1850s. The transformation changed the landscape, vegetative cover, and soil (Samson et al. 1998). Later, with the implementation of new equipment, fossil fuels, fertilizers, chemicals, and irrigation, this area became one of the most productive agricultural areas in the world.

Fire is an important component of grassland ecosystems, but ithas been eliminated from most areas. It prevents woody species encroachment, removes dead material, recycles nutrients, and influences grazing patterns. Depending on timing, frequency, and intensity, fire can trigger specific grassland processes and functions (Andreae 1991). Fire has a varied impact on wildlife depending on fire characteristics, such as size and shape of the area burned and cover available to animals during the fire (Morrison et al. 1992). The primary impact of fire on wildlife is the effect on its habitat. If the fire-altered habitat is an enhancement for particular species, then those species may be expected to increase after the fire. Conversely, they would be expected to decrease if fire is removed from the system. Therefore, changes in animal species diversity and population density can be expected following fire. Better knowledge of these changes would allow the manager to attain predetermined objectives (Drawe et al. 1999).

Grassland ecosystems evolved with grazers, from horses and camels to ground sloths and rhinos. North American prairies have had grazing pressure as far back as the mid Miocene, and their biodiversity is at some degree a product of this process (Anderson 2006, Janis et al. 2002). Unfortunately, traditional methods of grazing management simplify structural heterogeneity and plant species diversity and often promote landscape fragmentation.

The main two sources of fragmentation on grasslands come from agriculture and road building, although woody encroachment has become as another major fragmentation source (White et al. 2000). Former extensive grasslands are now characterized by farmland dissected by roads creating a landscape where both animal and plants interactions are reduced.

In all parts of the world, the fight against the encroachment of invasive plant species is ongoing. Invasive species can cause dramatic ecological and economic losses. In the United States, the environmental destruction and loss of crops caused by invasive plants was valued at 138 million dollars in 1999 (Zavaleta et al. 2001). Nearly half of threatened and endangered species listings are related to direct effects of introduced species

(Wilcove et al. 1998). In the United States, invasive plants have displaced desirable native plants in once rich prairies, and they have reduced the amount of wildlife habitat in rangelands and forests. Many of woody species have been encroaching prairies changing former grassland functions. As a consequence of this fragmentation and the reduction of natural biodiversity, many non-native species have colonized the Great Plains. Approximately 17% of plant species in Pawnee National Grasslands in eastern Colorado and 28% of grasses in Badlands National Park in South Dakota are exotic to North America (Licht 1997).

Justification

In prairie habitats, birds have shown greater declines during the last 25 years than any other group of North American birds (Knopf 1995). Grassland birds have been strongly affected by grassland conversion and loss, showing the most pronounced decline within bird groups (Sauer et al. 2005, Murphy 2003, Vickery et al. 2000). Sauer et al. (2005) reported that 32 out of 37 grassland bird species monitored from 1966 to 2004 showed some degree of decline.

In the past, the ultimate objective of livestock enterprises was to maximize profit and optimum use of nutrients in the forage resource. To improve economical productivity, patchy, heterogeneous grazing was eliminated (Burboa-Cabrera 1997), patchiness that formerly allowed greater bird diversity. The conservation of grasslands requires a mosaic approach where several patches of vegetation composition and structure are present (Howe 1994, Renken and Dinsmore 1987, Skinner et al. 1984). Howe (1994) stated that plant species diversity should be promoted to ensure the quality of habitat needed by grassland birds. Skinner et al. (1984) recommend managing for a wide range of cover heights during all seasons to provide the best wildlife habitat in Missouri grasslands. Madden (1996) emphasized the need to manage for all stages of prairie succession to provide good grassland bird diversity. The habitat affinities of grassland bird species are diverse, and species respond to similar conditions in different ways (Herkert 1994, Wiens 1969).

Cattle can dramatically alter vegetation characteristics as composition, cover, biomass production, and structure (Kauffman et al. 1983, Knopf and Cannon 1982). Heterogeneity in both structural and plant species composition is vital for the maintenance of biodiversity. In homogeneous environments, processes such as predation and competition often simplify ecosystems, but periodic disturbance (e.g. grazing and/or burning) provides heterogeneity leading to increased biodiversity through the creation of successional gradients of plant communities (Menge and Sutherland 1987, Connell 1978, Menge and Sutherland 1976). Continuous and intensive grazing pressure influences the amount of disturbed ground and the spatial plant distribution creating an opportunity for invasive species to establish (Belgelson et al. 1993). No grazing could be used as an effective system to protect some sensitive rangelands, particularly those with riparian vegetation, common around the central Platte River. New grazing and range management strategies have been created to increase animal production while range health and wildlife habitat are maintained.

Grasslands are important from both agronomic and ecological perspectives (Briggs et al. 2005). The Great Plains have an important role in food production. These extensive landscapes are heavily used as pasture to raise livestock or cultivated for cereal production. Production and conservation activities are not always fully compatible, and in some instances they are opposite. However, the compatibility of those two objectives can be achieved when management practices are focused in maintaining diverse prairie plant communities (Fuhlendorf and Engle 2004, Coppedge et al. 2001, Collins et al. 1998, Hartnett et al. 1996). Beef cattle producers not only face challenges with pasture production and range health, but also many decisions related to economics and profit. A cow-calf budget is a management tool used to support these decisions (Gadberry and Troxel 2002). When trying to express ecological and conservation points of views, managers should be able to support recommendations with economic data. Rancher and cattle producer enterprises are linked to economic factors, and conservation activity should be supported by potential profit or reduction of long term inputs. Low profitability in the beef industry has increased awareness of the needs of diversification and the use of other rangeland resources linked to biodiversity (Hanselka 1998).

In summary, climate, topography, fire, and grazing are the primary factors influencing the development and maintenance of prairie ecosystems. The interaction of these factors creates a mosaic of habitat conditions along vegetation continuity of height, density, and amount of woody plant growth (Ryan 1986). If historic levels of heterogeneity can be restored, rangelands have tremendous potential of maintaining or enhancing biodiversity. Grazing can be considered a source of disturbance on grasslands, but this kind of ecosystem also evolved in close relationship with fire. Therefore, both sources of disturbance have to be present at some level. If large scale grazing disturbance continues with high frequency, the resulting plant community composition will differ qualitatively from the original, creating a landscape mosaic not capable of sustaining local and migrant wildlife populations (Turner et al. 1998).

Objectives

The objectives of this study are to investigate the effects of fire-grazing interaction on: (1) forage quality, (2) plant diversity, (3) vegetation structure, and (4) economics. While comparing patch-burning, deferred rotation, and continuous grazing, this study will be approached from four perspectives:

- Vegetation diversity
- Vegetation structure
- Forage quality
- Economic reliability

This project is part of a base study designed to obtain vegetation information to better understand the impact of these management practices on wildlife habitat (arthropods, mammals, reptiles/amphibians, and birds). As a final output, I expect to provide information on alterative grazing strategies for Nebraska ranchers based on both economic and ecological sustainability.

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Impact of Alternative Range Management Systems on Plant Communities in the Central Platte River Valley

INTRODUCTION

Grasslands represent an important component of the rangelands that have been altered since European settlement in the 1800s. Today, nearly all (97%) of the land in Nebraska is privately owned, and 53% of that land is classified as rangeland (Brenner et al. 2001). Farming and ranching have disrupted natural disturbance processes and caused changes in species composition and diversity as introduced and woody species have encroached the grasslands (Vickery et al. 2000). Grassland diversity is highly influenced by several sources of disturbance. Fire, grazing, flooding, drought, and in some rare instances, tornados, and plant diseases directly and indirectly modify resource availability and promote early successional plant assemblages (Pickett and White 1985, Anderson 2006). As a consequence, the maintenance and dynamics of most temperate grasslands will depend on these factors and the frequency and intensity of their occurrence (Huston and Smith 1987). The interaction of these factors creates varied habitat conditions which result in a mosaic of vegetation continuity, height, density, and amount of woody growth (Ryan 1986). Traditional methods of grazing management simplify structural heterogeneity and plant species diversity while promoting landscape fragmentation. Fire has a varied impact on wildlife depending on fire characteristics, size and shape of the area burned, and cover available to animals after the fire (Fuhlendorf and Engle 2004). The primary impact of fire on wildlife is the effect on its habitat. If the fire-altered habitat is enhanced for particular species, then those species may be expected to increase after the fire or decrease in the absence of fire. Therefore, changes in animal species diversity and population density can be expected following fire. Better knowledge of these changes would allow the manager to attain predetermined objectives (Drawe et al. 1999).

If historic levels of heterogeneity can be restored, rangelands have tremendous potential for maintaining or enhancing biodiversity (Christensen 1997, Wiens 1997). The grassland ecosystem evolved in association with both grazing and fire (Anderson 2006). Therefore, both sources of disturbance should be present at some level to maintain ecological function and diversity. Richness increases when both grazing and prescribed burning are used on natural grasslands (Harrison et al. 2003). If large scale grazing disturbance continues with high frequency, the resulting plant community composition will differ from the pre-settlement levels. The landscape mosaic created will not be capable of sustaining native local and migrant wildlife populations (Turner et al. 1998).

In the past, the ultimate objective of livestock enterprises was to maximize profit and make an optimum use of nutrients in the forage resource. Patchy, heterogeneous grazing was avoided to improve economical and forage productivity (Burboa-Cabrera 1997). As a consequence, diverse plant compositions and habitat structure needed by wildlife have not been mantained. In prairie habitats, grassland nesting birds have shown greater declines during the last 25 years than any other group of North American birds (Knopf 1995). The conservation of habitat for grassland birds requires creation of mosaics where several habitat conditions or patches are present (Skinner et al. 1984, Renken and Dinsmore 1987, Howe 1994). Several habitat characteristics, such as plant species heterogeneity and richness, have been identified as being important to increase prairie diversity and ensure grassland bird habitat quality, factors that should be present to increase prairie diversity (Howe 1994). Skinner et al. (1984) recommended managing for a wide range of vegetation heights during all seasons to provide the best wildlife habitat in Missouri grasslands. Madden (1996) emphasized the need to manage for all stages of prairie succession to improve grassland bird diversity. The habitat affinities of individual grassland bird species are diverse, and different species respond to similar conditions in different ways (Wiens 1969, Herkert 1994).

Cattle grazing can dramatically alter vegetation characteristics including species composition, biomass production, and general plant structure (Knopf and Cannon 1982, Kauffman et al. 1983). Heterogeneity in both habitat structure and plant species richness is vital for the maintenance of biodiversity and could be used as an indicator of grassland health (Woodward et al. 1999). The identification of species richness patterns on grasslands can enable land managers and conservationist to assess plant communities and their ability to maintain them (Sluis 2002). In homogeneous environments, processes such as predation and competition often simplify ecosystems, but periodic disturbance (e.g. grazing and/or burning) provides heterogeneity leading to increased biodiversity through the creation of early successional patches (Menge and Sutherland 1976, Connell 1978, Menge and Sutherland 1987).

Continuous grazing pressure influences the amount of disturbed ground and the spatial plant distribution creating an opportunity for establishment of invasive species (Belgelson et al. 1993). The beta diversity of grasslands exposed to intensive grazing could initially increase because of the colonization of species coming from adjacent areas different than the community stressed by cattle (Grace 2001). However, if this intensity is added to high frequency, species pools can be depleted leaving room only for those species adapted to grazing and/or avoided by cattle (Frank 2005). Some have proposed moderate grazing levels (Loeser et al. 2007), rotation (Kauffman and Kruger 1984), and rest periods (Kauffman et al. 1983) as approaches to maintaining range health and heterogeneity, but few studies have considered the interaction of both factors to achieve ecosystem health (Hartnett et al. 1996, Coppedge et al. 2001, Fuhlendorf and Engle 2004, Fynn et al. 2004).

Cattle production and grassland conservation activities are not always fully compatible, and in some instances they are opposite. However, the compatibility of those two objectives can be achieved when management practices are focused on maintaining diverse prairie plant communities (Hartnett et al. 1996, Collins et al. 1998, Coppedge et al. 2001, Fuhlendorf and Engle 2004).

My goal was to evaluate the effect of two alternative rangeland management techniques, patch-burning and deferred rotational grazing, on grassland plant diversity in comparison to traditional continuous seasonal grazing. The objective of this study was to evaluate the response of grassland plant communities to these three range management approaches on three different levels. First, apply diversity analysis to identify richness, relative abundance, and evenness of plant communities. Second, evaluate Floristic Quality Assessment Indices as a tool to evaluate plant community assemblages. Third, use beta diversity analysis to visualize the spatial dynamics of species spatial patterns.

Study site

This study was conducted in the central Platte River Valley of Nebraska on The Crane Trust property during three years starting the summer of 2007. The Crane Trust is comprised of about 4,000 ha of cropland, pastures, and hay meadows along the Platte River in Buffalo, Hall, and Phelps counties, Nebraska. All pastures included in this study are located in Hall County. Climate is continental, with 160 frost free growing days. Mean average temperature is 10°C with the January minimum averaging -11.6°C and the average August maximum temperature of 29.3°C. Average precipitation is 630 mm, occurring mainly from May through September. Soils consist of loamy or sandy alluvial deposits (Henszey et al 2004). Near the Platte River, ecosystems are characteristic of tallgrass prairie with woody encroachment from eastern cottonwood (*Populus deltoides*) forests interspersed with willows (*Salix* spp.) and eastern redcedar (*Juniperus virginiana*). Dominant vegetation includes sedges (*Carex* spp.), rushes (*Eleocharis palustris, Scirpus* spp.*, and Juncus* spp.), and prairie cordgrass (*Spartina pectinata*) in lowland meadows (Currier et al. 1985). Mesic grasslands are characterized by big bluestem (*Andropogan gerardii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutants*), Canada wildrye (*Elymus canadensis*), and switchgrass (*Panicum virgatum*). Common forbs include goldenrods (*Solidago* spp.) and prairie clovers (*Dalea* spp.). Many prairies contain non-native cool season grasses including smooth bromegrass (*Bromus inermis*), Kentucky bluegrass (*Poa pratensis*), red top (*Agrostis stolonifera*), and tall fescue (*Lolium arundinaceum*).

The pastures used for this study are located on the Platte River alluvium with sandy areas created by eolic deposition (sand ridges). The substrate is coarse sand with mixed sand and gravel. These areas are characterized by a high water table, where it is not unusual to observe the depth of soil saturation at 1.2 m (Nagel 1981).

METHODS

Treatment

The first treatment consisting of continuous season-long grazing was considered as a control treatment and representative of the land management scheme most commonly used in this area. Under this system, pastures of variable sizes ranging from 20 to 100 ha were grazed with cow-calf pairs during summer and spring with medium to high stocking rates (>2.5 AUM/ha) without application of fire. The second treatment, patch-burn grazing, used large pastures (>80 ha) divided into four sections or burning units with no fences between them, with stocking rates ranging between 1.5 and 2 AUM/ha. In a 4-year rotation cycle, the whole pasture was burned after applying prescribed fire to each unit. The rationalization behind this system considers that newly burned areas would offer fresh forage regrowth which is preferred by cattle. As a consequence, a concentration of grazing pressure on burned areas and avoidance of previously burned sections create a condition where four different vegetation structure and litter accumulation levels should be present in each treatment pasture.

Finally, the third treatment was a modified rest rotational grazing system, consisting of four pastures of 50 to 250 ha where one was burned each year. In this system only two pastures were grazed each year leaving two pastures without any type of disturbance. Considering a four-year rotation cycle, pasture 1 would be managed with an early spring prescribed burn and grazed during May and June with high stocking rates (>3.5 AUM/ha). After these two initial months, cattle would be moved to pasture 2, which was burned the year before, to be grazed during July and August. Finally, cattle were returned to pasture 1 in September to finish the grazing season in mid-October. Pastures 3 and 4 were not grazed. The following year pasture 4 (after been rested for two years) would be burned in the spring and paired with pasture 1 for grazing.

Experimental design

The experimental design consisted of three treatments with two replicates. All grasslands used in this research were used as pasture or hay meadows for the last 5+ years. Former hay meadows used were conditioned as pastures at least 2 years before data collection. Rotational and patch-burning pastures were under a 3- to 4-year rotational prescribed burning for more than 10 years. Prescribed burning was conducted in March or April.

The null hypothesis to be tested is that alternative management approaches will not result in a greater floral diversity. I define a unit as the area burned every 4 years. For control pastures, no burning was scheduled, so the entire pasture was a unit. For patch-burn pastures, each burned area represented a unit (Coppedge et al. 2001, Fuhlendorf and Engle 2004). For the deferred rotation, the entire pasture was the burn unit, yet four pastures made up the treatment. In order to assess the impacts of each management technique at the scale of the pasture, I sampled all management units equally.

Vegetation Sampling

Modified step-point method (Evans and Love 1957, Owensby 1973) was used to determine species composition and abundance. I defined abundance, following Bonham (1989), as the quantitative estimate, expressed as a percentage, of plentifulness or scarcity of a species. In this procedure, the sampler followed designated transects recording plant bases hit at 1 m intervals. If no basal hit occurred, the species nearest to the point forward was recorded. Five random 100 m transects per burn unit were placed transversal to field gradient (topography). North-south transects were separated by at least 100 m. To improve species richness estimates, each newly encountered species along the transect was recorded whether it was hit or not by the point sample.

Analysis

A floristic quality assessment index was estimated each season (Swink and Wilhelm 1994). This method is based on the concept of species conservatism. Each native plant species occurring in a regional flora is assigned a coefficient of conservatism (C) representing an estimated probability that the species is likely to occur in a relatively unaltered landscape that is in good health. Coefficients range from 0 (highly tolerant of disturbance, little fidelity to any natural community) to 10 (highly intolerant of disturbance, restricted to pre-settlement remnants). Conceptually, this 10-point scale can be subdivided into several ranges.

Floristic quality assessment uses two related, but separate, measures: 1) the average coefficient of conservatism or Mean C, and 2) the Floristic Quality Index or FQI. To use the FQI, the plant community is inventoried or sampled to compile an accurate and complete species list of flora on a site. The choice of sampling methodology is not dictated. The appropriate coefficient of conservatism is applied to each species, and the mean is calculated for the assessment area.

$$\text{Mean C} = \Sigma\ [(C1 + C2 + C3 + \ldots\ Cn)/N\ ]$$

Where C is the coefficient of conservatism for each native species identified on the site and N is the total number of native species inventoried in the assessment area.

The Floristic Quality Index (FQI) is calculated by multiplying the Mean C by the square root of the total number of native species.

$$\text{FQI} = \text{Mean C} \times \sqrt{N} \quad \text{or} \quad \text{FQI} = \Sigma\ [(C1 + C2 + C3 + \ldots\ Cn)/N\ ] \times \sqrt{N}$$

These values can also be calculated with introduced species that are not fully naturalized by counting them as non-native species, but assigning them a value of “0”.

The FQI can be biased by size of the site, especially in communities, such as sedge meadows, in which species richness is strongly influenced by increasing area (Matthews 2003). Higher FQI values can result on sites where disturbance through part of the area allows weedy species to invade, rather than reflecting higher quality, less disturbed habitat (Rooney and Rogers 2002). Francis, et al. (2000) suggest that by combining Mean C and a measure of species richness, the FQI obscures important information, and suggest looking at each component (Mean C and species richness) separately. It appears useful to compute and interpret both the Mean C and the FQI value. FQI values will be sensitive to factors that increase species richness, while Mean C relates directly to aggregate conservatism.

Vegetation data were used to build statistical models to describe plant response to different grazing and fire disturbance patterns. The central idea of these models was to simulate response of vegetation to changes in disturbance, where vegetation succession was represented as sequential changes in species dominance and vegetation structure. Basic premises considered included (Hutson and Smith 1987): 1) competition will occur between all individuals and species, although interactions may change as environmental factors change (fire and grazing); 2) plants may alter their environment in a reaction to new environmental demands and develop new competitive abilities; and 3) physiological and energetic constraints prevent any species from maximizing competitive ability for all circumstances.

Relative species abundances from all treatments were compared using Renyi's generalized diversity and Hill's evenness profiles (Renyi 1970, Hill 1973). For these profiles the value for alpha = infinitum provides information on the proportion of the most abundant species. Profiles with higher values at alpha = infinitum have a larger evenness and thus correspond with lower proportion of dominant species. The profile value for alpha = 0 provides information on species richness, value at alpha = 1 is the Shannon diversity index, and values for alpha = ∞ provide information on the proportion of the most abundant species (Ricotta 2003).

Beta diversity analyses were conducted to develop a better understanding of species patterns between transects within treatments. Following the definition of Koleff et al. (2003), I evaluated beta diversity at four levels: 1) continuity and loss, as a way to evaluate the number of species shared between transects; 2) richness gradients, or change of species richness between transects; 3) continuity, to evaluate species similarity between transects; and 4) gain and loss, to measure species turnover or species shared between transects.

To analyze phytosociological similarities/differences between pastures and treatments, a cluster analysis was performed using BiodiversityR (Kindt and Coe 2005) and vegan (Oksanen et al. 2010) packages from R-Software. This cluster analysis was conducted using the Divisive Analysis method with the Bray-Curtis dissimilarity measure. Added to cluster analysis, unconstrained (Principal Coordinates Analysis, Correspondance Analysis) and constrained by treatment (Canonical Correspondence Analysis) ordination techniques were used to identify general patterns and relationships between plant species and treatments.

RESULTS

A total of 145 species were recorded during this study (Table 1). Species richness was 53 on the continuous grazing areas and 97 and 86 on patch-burn and rotational grazing treatments, respectively. Eighty-nine species were forbs, 38 grasses, 10 grass-like, and 8 shrubs and woody species (Table 1). After 3 years of data collection, average species richness per transect on patch-burning (25.8 species) and rotational grazing (25.4 species) treatments showed greater levels (ANOVA, $p < 0.001$) than continuous grazing (21.0

species) (Table 2). MeanC and FQAI were not significantly different (Table 2). Four diversity measurements including Shannon, Simpson, Inverse Simpson, and Berger-Parker indices were calculated showing no significant difference between treatments (Table 3). The use of mixed models show that neither treatment nor prescribed burning had important effects on species diversity and floristic quality (Table 4).

Time after fire showed significant differences ($P < 0.001$) for richness (Fig. 1) and evenness (Fig. 2). Immediately after the use of prescribed burning (age 0), richness was reduced (23.1 species/transect) relative to pastures time after prescribed burning 1 to 3, but it was still greater than pastures without fire treatment (age ≥ 4, 21.0 species/transect). No significant difference was observed among years 1 to 3. Areas without prescribed burning showed significantly higher evenness ($e = 0.674$, $P = 0.004$) than those under fire pressure, and no significant differences were observed on age class 0 ($e = 0.601$), 1 ($e = 0.621$), 2 ($e = 0.625$), 3($e = 0.614$).

From Ruggeiro's "continuity and loss" (Ruggiero et al. 1998) beta diversity index (Table 5), higher levels of shared species occurred on continuous grazing transects ($p < 0.001$) than on patch-burn and rotational transects. Lennon's (Lennon et al. 2001) "richness gradient" index did not show significant differences between treatments ($p = 0.7065$), implying that transects within treatments maintain similar richness levels. According to Whittaker's (Whittaker 1960) and Cody's (Cody 1975) "species continuity" indices, continuous grazing transects had the lowest average change in species composition among transects within each treatment followed by rotational and patch-burning treatments. Finally, "gain and loss" indices (Routledge 1977, Lennon et al. 2001) indicate a higher percentage of shared species among transects on continuously grazed pastures followed by rotational and patch-burning.

Species ranking showed that 90% of the abundance corresponded to 17 species on the continuous grazing treatment (Table 6), compared with 28 and 21 species on patch-burn (Table 7) and rotational treatments (Table 8), respectively. From this, 90% of total abundance in patch-burn showed the lowest proportion of native species (48.4 %) compared to 63.9% on continuous grazing and 63.6% on rotational grazing treatments (Table 9). Patch-burning had the highest proportion of cool-season species (47.1 %), and rotational grazing showed the highest proportion of warm-season plants (59.2%). These high proportions of cool-season species and low proportion of native species on patch-burn pastures is attributed to 16.7% abundance of Kentucky bluegrass and 10.6% abundance of smooth bromegrass (Table 10). On all treatments, the top 90% abundance was composed mainly of grasses, followed by forbs and shrubs (Table 11).

Renyi (1970) generalized diversity profiles (Fig. 3) revealed higher species richness values on patch-burning and rotational grazing treatments. Hill's evenness profiles (Fig. 4) showed a higher species evenness on continuous grazing treatments. A shallower slope on the rank/abundance plot (Fig. 5) supported the idea of greater evenness on the continuous grazing treatment.

The dendrogram of the cluster analysis (Divisive Analysis, distance: Bray-Curtis, Permutations = 100) demonstrated clear division (DC = 0.613, r = 0.8481) between plant communities on continuously grazed pastures and pastures burned and grazed (Fig. 6).

Two main associations were observed; the first was restricted to areas under continuous grazing (Binfield, Bockman) while the next corresponded to both patch-burning and rotational grazing areas. This last cluster can also be split into a first subcluster including those more upland areas with a higher abundance of short grass prairie species (BNE, BSE, BNW, BSW, and Calving) as blue grama (*Bouteloua gracilis*), prairie larkspur (*Delphinum virescens*), and sensitive briar (*Mimosa quadrivalvis*), and a second subcluster with a higher component of mesic and lowland plant communities.

The Principal Coordinates Analysis (PCoA) generated two vectors that accounted for 53.7% of the variance. One most likely identifies a grazing pressure gradient and a second is related to elevation which also can be correlated to soil water content. Figure 7 separates the plant communities in the studied pastures. Thus, continuously grazed areas have plant communities similar in relation to the rest of the pastures. Similar to the cluster analysis, the Brooks' area pastures (BNE, BNW, BSE and BSW) contain a grater dispersion of species mostly related to a higher elevation and higher abundance of short grass prairie species.

The first two correspondence analysis vectors of the plant communities explain 22.1% and 17.5% of the total variance (Fig. 8). Pastures with lower scores on both vectors tend to show a higher abundance of species adapted to disturbed areas such as dandelion (*Taraxacum officinale*, X131), buckhorn plantain (*Plantago lanceolata*, X107) and wild barley species (*Hordeum* spp., X73, X74). A pattern similar with cluster and PCoA was observed. Excluding pastures with a higher abundance of short grass species, patch-burn and rotational grazing pastures congregate close to the axis where common mixed grass species such as little bluestem, big bluestem and switchgrass and some abundant introduced species as smooth bromegrass and Kentucky bluegrass were located.

The canonical correspondence analysis (CCA) produced two vectors that, together, accounted for 26% of the total variance in the species abundances among sites. Unconstrained factors accounted for the rest 74% of the variance (Fig. 9). The first ordination axis accounted for 17.7% of the variance of the species data, whereas the second axis accounted for 8.3% of this variance. The graphical CCA representation shows two apparent gradients. One followed by those treatments involving prescribed burning and lower stocking rates, and a second following the continuous grazing treatment. Buckhorn plantain, saltgrass (*Distichlis spicata*), foxtail barley (*Hordeum jubatum*), and rushes exhibited higher abundances on continuous grazing treatments. Most uncommon species, those with abundances lower than 1%, were located on the gradient created by patch-burning and rotational treatments. The significance test based on 100 permutations indicated that the observed relationship between treatments and ecological distance is not due to chance ($p < 0.001$).

DISCUSSION

Higher species richness levels were observed on both treatments using prescribed burning, supporting the findings of Leach and Givnish (1996) where periodic fire sustained species richness on grasslands. It is commonly accepted that grazing has a positive influence on plant species richness (Hartnett et al. 1996, Watkinson and Ormerod 2001, Fuhlendorf et al. 2006, Brudvig et al. 2007). Grazing pressure inflicted by season-long continuous grazing and high stocking rates, which is the traditional approach in this part of Nebraska, had a negative effect on the species richness observed in this study, possibly due to the association of lower diversity and richness with uniform distribution of disturbance (Collins and Glenn 1995) and overgrazing stress. The patchiness created by patch-burning and rotational grazing treatments and their associated successional stages was consistent with other studies where species richness increased with the interaction of prescribed burning and moderate grazing levels (Howe 1994, Collins and Glenn 1995, Coppedge et al. 1998). During all 3 years of this study, annual rainfall was higher than average (Fig. 10) possibly affecting species richness and diversity. A study on Arizona grasslands demonstrated the direct influence of climatic variation on plant communities and, indirectly, its effect on grazing patterns and pressure. These effects could easily shift whole plant communities into more or less drought tolerant species (Loeser et al. 2007).

My results did not show significant differences for species diversity or floristic quality assessment indices. Although FQI has been used on grasslands for several years (Allison 2002, Taft et al. 2006), problems with the efficacy to detect changes on species richness on tallgrass prairies have been observed (Bowles and Jones 2006). Diversity and floristic quality indices have been used in central Nebraska for many years as a way to measure grasslands and as an evaluation tool for prairie restoration. The use of floristic quality indices has been criticized by several researchers (Francis et al. 2000, Rooney and Rogers 2002, Cohen et al. 2004) arguing that FQI formula may raise some problems because it combines independent qualitative and quantitative units that ultimately can mislead statistical interpretation. From the results observed on my FQI analysis, I can consider three possible interpretations: 1) FQI are correct and no real species composition quality decrement was observed on areas under continuous grazing pressure and no fire, 2) FQI are correct due to the high abundance of native species, or 3) FQI are misleading floristic quality giving high conservation values to native species without considering relative abundance on more typical species composition assemblages. Jog et al. (2006) showed that, in some scenarios, FQI could lead to the interpretation that some areas posses a higher floristic quality than they actually have (i.e. when there are very low number of species that have average coefficients of conservatism). The results of this research have shown the importance of more detailed evaluation to understand grassland plant communities. However, my analyses did not show significant differences on diversity and floristic quality between pastures under continuous grazing and those including different degrees of prescribed burning and grazing.

The stress on grasslands originated by continuous grazing can produce a shift of botanical composition where native and exotic species alike may change in abundance. In this situation, highly abundant species such as big bluestem with a conservation value of 5, ranked first and third on rotational and patch-burning treatments, respectively. It was 13 on continuous grazing. Likewise, less common native species as swales sedge (*Carex aquatilis*) with conservation value 4 ranked second on continuous grazing pastures and only12 and 9 on patch-burning and rotational grazing, respectively.

This shift in plant composition could be mainly attributed to the joint effects of overgrazing, trampling, and soil compaction (Olff and Ritchie 1998). High stocking rates on continuous grazing pastures can promote and increase pressure on highly palatable warm-season species as big bluestem followed by a reduction on growth due to soil compaction (McNearney et al. 2002). Simultaneously, soil compaction produces a reduction in soil density and water infiltration given the alluvial nature of the soils present in and around the study sites (Nagel 1981). An increase of superficial water retention in sloughs and topographic depressions can affect plant communities. Similar species composition shifts were reported by Currier (1989), were swales sedge and switchgrass increased in abundance after 2 years of sustained high water levels.

A second inspection of richness and evenness levels indicated the presence of different plant communities. Our data support the hypothesis of higher species richness and evenness on areas with prescribed burning management. Although species richness decreased after fire, recently burned areas maintained higher species richness than areas without fire. In this case, an interaction of prescribed burning and subsequent grazing could be the main factor driving these species richness patterns. Turner et al. (1998) identified fire-grazing interactions as the main factor defining grassland distribution and characteristics. Bragg (1982) and McClain and Elzing (1994) estimated a fire return frequency on tallgrass prairie from 2 to 5 years. This fire frequency most likely drives plant succession and species richness changes on these grasslands.

Given the nature of pastures in the Platte River Valley, where flooded conditions are possible in a regular basis, the main change in plant communities appears to be toward an assemblage with a higher component of wetland plants. Continuous trampling and the stress coming from elevated grazing rates can affect hydraulic balances increasing the length standing water is maintained in this pasture. This study was able to identify relatively high abundances of several species that, although native, could be interpreted as indicators of high disturbance and grassland degradation. Buckhorn plantain, saltgrass, lanceleaf fogfruit (*Lippia lanceolata*), foxtail barley and several grass-like species are not rare in south central Nebraska, but their abundance indicates a plant assemblage more adapted to saturated soil.

Evenness was higher on those pastures without fire treatment (≥ 4 years post fire), indicating an even proportion of species in these areas. Native mixed-grass prairies are usually dominated by some grasses as big bluestem, switchgrass, indiangrass, and little bluestem, and evenness is reduced as a consequence. Low to moderate disturbance provokes an increase of these productive grass species limiting the abundance of weaker species by direct competition (Prach 1993) leading to a decrease of evenness. High grazing pressure on palatable warm-season species, which tend to be dominant in these areas, can affect abundance creating more balanced plant communities. Foster and Dickson (2004) observed evenness decrease on grasslands exposed to disturbance. When under extended disturbance, some ecological processes such as ecological release or resource availability can change grassland stability making them more susceptible to colonization by native and introduced species changing species composition (Vujnovic et al. 2002).

Similar species richness and evenness on treatments with fire-grazing interactions can be interpreted as similar plant communities. In the other extreme, significant differences between these treatments and the continuous grazing treatment correspond to the presence of two different plant communities where species composition may be arrayed differently. In one way, diversity indices observed on continuous grazing sites are explained by higher species evenness.

I analyzed beta diversity at four different levels: 1) continuity and loss, 2) richness gradients, 3) continuity, and 4) gain and loss. Beta diversity index can be interpreted as a similarity index, in this case between transects, where continuous grazing transects had the highest number of shared species or were more similar to each other. Continuous grazing systems maintain a uniform stress on pastures creating homogeneous plant communities (Vallentine 1990), homogeneity that can be observed on a reduced richness variation between transects. Higher species turnover on patch-burning and rotational grazing transects may be interpreted as an indicator of higher heterogeneity within pastures (Ruggiero and Kitzberger 2004). Continuous grazing treatments produced lower levels of new species detected among transects. This is a similar conclusion to the one achieved from continuity and loss index thru a different approach where average change in species richness is estimated. Although Ruggiero's continuity index showed higher levels of shared species in continuously grazed transects, Lennon's richness gradient index did not detect difference on richness levels on transects within pastures. In other words, richness levels were similar along transects in the same treatment. This lack of variability richness could be mainly explained by scale than any other factor (Lennon et al. 2001).

Many ecologists identify two main causes of species turnover-environmental dissimilarity and geographic distance (Cody 1986, Harrison et al 1992, Simmons and

Cowling 1996, Nekola and White 1999). Given the conditions in this study where geographic distance is minimal, environmental dissimilarity can be identified as the main factor driving not only species composition differences but also the number of species observed and continuity across pastures. Intensive grazing can minimize environmental gradients increasing homogeneity and, as a consequence, only those species adapted to these specific conditions are able to compete and establish.

After analyzing the two main diversity factors (richness and evenness), I can predict different botanical compositions between treatments. The cluster analysis helps to confirm this prediction. Four main clusters can be identified: 1) pastures under continuous grazing; 2) pastures under fire-grazing management and dry conditions; 3) pastures under fire-grazing management, wet conditions and lower abundance of introduced grass species; and 4) pastures under fire-grazing management, low wet meadow conditions, and higher abundance of introduced grass species.

Moderate grazing pressure and fire appear to be the main factors affecting plant communities in the Platte River Valley. Although continuous grazing treatments produced similar diversity and floristic quality indices, pastures under that management approach are clearly different than the rest of the pastures. Topography was the second gradient driving plant communities in pastures under fire and grazing management. Henszey et al. (2004) reported a strong correlation of high surface and groundwater levels to plant communities in these same areas. Water levels had stronger influence on plant communities than management practices. My data show botanical composition is not affected when general grassland processes such as fire and moderate to low grazing pressures are maintained. However, continuous stress to grasslands due to season-long grazing and high stocking rates can surpass the plant community threshold creating new species assemblages.

From 2007 to 2009, higher than average rainfall was recorded, and I observed those areas with higher elevation remained dryer and with less standing water during the growing season. Upland pastures (relative to the rest of the area) contained a higher proportion of native short grasses and were slower to recover after defoliation late in the season (personal observation). Another division between pastures was observed on those areas with higher susceptibility to flooding. The main driver appeared to be spatial conditions as topography and distance to the river bank. The eastern part of the study area was an area with lower levels of introduced grass species. The western part formerly had different management and showed higher proportion of introduced species such as tall fescue, reed canarygrass (*Phalaris arundinacea*), and creeping foxtail (*Alopecurus arundinaceus*).

Statistical models were not able to detect differences on diversity and floristic quality between pastures. This shortcoming is mostly related to the same factors affecting diversity indices and its capacity to detect species composition changes. After analyzing the data collected between 2007 and 2009, I would recommend a different approach to describe plant community patterns in these pastures through modeling. This approach should include a more intensive survey during the complete growing season. This survey should be designed to: 1) detect cool- and warm-season plant patterns within individual years, 2) identify thresholds where plant communities start to shift toward wetland or other plant communities, and 3) determine the flooding effect on grasslands along the Platte River banks.

The ordination records from continuously grazed pastures were distinct from those pastures managed with fire and grazing. The principal coordinates analysis (PCoA) revealed that areas under fire-grazing management and dryer conditions, farther away from the river bank, were separated from those closer to the river. However, there are also floristic affinities between these two groups. The two main gradients considered in this analysis showed: 1) a vegetation response to water availability, and 2) an effect from fire and grazing.

Although all pastures used in this study have similar topography and distance to the river, water availability within these fields can vary due to soil compaction. Less infiltration, thus more standing water, has been attributed to reduced litter and soil compaction and sealing by animal trampling (Naeth et al. 1991). Also, elevated grazing pressure on grasslands can lead to excessive removal of herbage which reduces evapotranspiration (Naeth and Chanasyk 1995). Therefore, standing water levels are maintained for longer periods producing shifts in botanical compositions into more water and grazing tolerant assemblages.

It is widely accepted that fire and grazing are main components of grassland dynamics (Fuhlendorf et al. 2006). The effect of the fire-grazing interaction on the grasslands in this experiment was evident. These disturbances were able to produce higher richness levels and a higher abundance of grasses, giving them an edge as a potential forage resource. The abundance of warm-season native species was also higher in these pastures. Only cool-season species that have been established on the sites for decades were common. For this study, the interaction of fire and grazing was observed as a main component maintaining higher richness levels and a relative dominance of specific species as big bluestem, indiangrass, and switchgrass.

IMPLICATIONS

The impact of season-long grazing with elevated stocking rates appears to be affecting grassland at two levels: 1) affecting individual plants, and 2) affecting general processes as soil water retention and nutrient cycles. Early grazing can deplete plant reserves of palatable species creating stress conditions that under continuous defoliation would be maintained during the whole season reducing species fitness. Once the most palatable species are depleted, cattle shift grazing pressure toward those species initially avoided. These less palatable species, given their evolution under lower grazing stress, are more susceptible and less adapted to continuous defoliation and eventually are replaced by even less palatable species which in many cases are non-native. Parallel to this vegetation composition change, several processes such as water infiltration and retention by soils, litter accumulation, and nutrient cycles are affected by trampling, organic matter removal, and cattle disturbance.

Diversity and floristic quality indices should not be used as an evaluation tool of grasslands in south central Nebraska, but as a monitoring tool to detect species changes and abundances. Added to these surveys, richness and evenness must be considered as the main two factors to evaluate botanical composition. Diversity and floristic indices can lead to several misinterpretations of plant assemblages as described above.

Given the erratic pattern of uncontrollable disturbances such as flooding, the identification of indicator species could be used in these areas. The use of these indicator species should not be interpreted as an indicator of range health or plant composition stability, but as an indicator of plant communities moving toward new assemblages. Grasslands are dynamic ecosystems and no specific condition can be considered optimal. Given that most pastures in south central Nebraska are not large and are usually fragmented or isolated by agriculture and riparian land, the use of beta and gamma diversity could be one future step to recognize how pastures react to management. Invasive species are a constant threat to pastures in Nebraska and a better understanding of movement and dispersion at the landscape level could increase the chances of detecting invasions and our capacity to control them.

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Table 1. Plant species recorded on The Crane Trust grasslands 2007-2009.

Genus	Specific epithet	Common Name	Type
Abutilon	*theophrasti*	Velvetleaf	Forb
Achillea	*millefolium*	Western yarrow	Forb
Agrostis	*stolonifera*	Redtop	Grass
Allium	*canadense*	Wild onion	Forb
Alopecurus	*arundinaceus*	Creeping foxtail	Grass
Ambrosia	*psilostachya*	Western ragweed	Forb
Ambrosia	*trifida*	Giant ragweed	Forb
Amorpha	*fruticosa*	Indigo bush	Shrub
Andropogon	*gerardii*	Big bluestem	Grass
Apocynum	*cannabinum*	Indian hemp	Forb
Artemisia	*ludoviciana*	Prairie sage	Forb
Asclepias	*syriaca*	Common milkweed	Forb
Asclepias	*verticillata*	Whorled milkweed	Forb
Aster	*ericoides*	White aster	Forb
Bouteloua	*curtipendula*	Side-oats grama	Grass
Bouteloua	*gracilis*	Blue grama	Grass
Brassica	*kaber*	Wild mustard	Forb
Bromus	*inermis*	Smooth brome	Grass
Bromus	*tectorum*	Cheatgrass	Grass
Buchloe	*dactyloides*	Buffalo grass	Grass
Calamovilfa	*longifolia*	Prairie sandreed	Grass
Callirhoe	*involucrata*	Purple poppymallow	Forb
Cannabis	*sativa*	Marijuana	Forb
Carduus	*nutans*	Musk thistle	Forb
Carex	*aquatilis*	Swales sedge	Grass-like
Carex	*brevior*	Fescue sedge	Grass-like
Carex	*eleochoris*	Needle sedge	Grass-like
Carex	*lupulina*	Hop sedge	Grass-like
Carex	*tetanica*	rigid sedge	Grass-like
Cenchrus	*longispinus*	Sandbur	Grass
Chamaecrista	*fasciculata*	Partrigepea	Forb
Chloris	*verticillata*	Windmill grass	Grass
Cirsium	*undulatum*	Wavy-leaf thistle	Forb
Conium	*maculatum*	Poison Hemlock	Forb
Convolvulus	*arvensis*	Field bindweed	Forb
Conyza	*canadensis*	Horseweed	Forb
Cornus	*drummondii*	Rough-leaf dogwood	Forb

Croton	*texensis*	Texas croton	Forb
Cuscuta	*pentagona*	Field dodder	Forb
Cyperus	*acuminatus*	Tape-leaf flat-sedge	Sedge
Dactylis	*glomerata*	Orchardgrass	Grass
Dalea	*purpurea*	Purple prairie-clover	Forb
Daucus	*carota*	Wild carrot	Forb
Delphinium	*virescens*	Prairie larkspur	Forb
Desmanthus	*illinoensis*	Illinois bundleflower	Forb
Dichanthelium	*oligosanthes*	Scribner's panicum	Grass
Distichlis	*spicata*	Saltgrass	Grass
Echinochloa	*muricata*	Barnyard grass	Grass
Eleagnus	*angustifolia*	Russian olive	Shrub
Eleocharis	*erythropoda*	Needle sedge	Grass-like
Elymus	*canadensis*	Canada wildrye	Grass
Elymus	*smithii*	Western wheatgrass	Grass
Elymus	*trachycaulus*	Slender wheatgrass	Grass
Equisetum	*arvense*	Field horsetail	Forb
Equisetum	*laevigatum*	Smooth scouringrush	Forb
Eragrostis	*cilianensis*	Stinkgrass	Grass
Eragrostis	*trichodes*	Sand lovegrass	Grass
Erigeron	*strigosus*	Daisy fleabane	Forb
Eupatorium	*altissimum*	Tall joepyeweed	Forb
Eupatorium	*perfoliatum*	Boneset	Forb
Euphorbia	*esula*	Leafy spurge	Forb
Euphorbia	*maculata*	Spoted spurge	Forb
Euphorbia	*marginata*	Snow-on-the-mountain	Forb
Eustoma	*grandiflorum*	Prairie gentian	Forb
Gaura	*mollis*	Velvetweed	Forb
Gleditsia	*triacanthos*	Honeylocust	Forb
Glycyrrhiza	*lepidota*	Wild licorice	Forb
Grindelia	*squarrosa*	Curly-cup gumweed	Forb
Helianthus	*annuus*	Common sunflower	Forb
Helianthus	*maximiliani*	Maximilian sunflower	Forb
Helianthus	*pauciflorus*	Stiff sunflower	Forb
Helianthus	*petiolaris*	Plains sunflower	Forb
Hesperostipa	*comata*	Needle-and-thread	Grass
Hordeum	*jubatum*	Foxtail barley	Grass
Hordeum	*pusillum*	Little barley	Grass
Juncus	*balticus*	Baltic rush	Grass-like

Juncus	*interior*	Inland rush	Grass-like
Juncus	*torreyi*	Torrey's rush	Grass-like
Juniperus	*virginiana*	Estern redcedar	Shrub
Lactuca	*serriola*	Prickly lettuce	Forb
Lepidium	*densiflorum*	Greenflower pepperweed	Forb
Leucanthemum	*vulgare*	Oxeye daisy	Forb
Liatris	*punctata*	Dotted gayfeather	Forb
Lippia	*lanceolata*	Lanceleaf fog-fruit	Forb
Lithospermim	*incisum*	Fringed puccoon	Forb
Lolium	*arundinaceum*	Tall Fescue	Grass
Lotus	*corniculatus*	Bird's-foot trefoil	Forb
Lygodesmia	*juncea*	Rush skeletonplant	Forb
Lythrum	*salicaria*	Purple loosestrife	Forb
Medicago	*lupulina*	Black medic	Forb
Melilotus	*alba*	White sweetclover	Forb
Mentha	*arvensis*	Field mint	Forb
Mimosa	*quadrivalvis*	Sensitive briar	Forb
Mirabilis	*nyctaginea*	umbrellawort	Forb
Monarda	*fistulosa*	Wild bergamont	Forb
Monarda	*pectinata*	Plains beebalm	Forb
Nepeta	*cataria*	Catnip	Forb
Onosmodium	*molle*	Western marbleseed	Forb
Opuntia	*fragilis*	Brittle cactus	Shrub
Oxalis	*stricta*	Wood sorrel	Forb
Panicum	*capillare*	Witchgrass	Grass
Panicum	*virgatum*	Switchgrass	Grass
Paspalum	*setaceum*	Thin paspalum	Grass
Penstemon	*grandiflorus*	Shell-leaf beardtongue	Forb
Phalaris	*arundinacea*	Reed canarygrass	Grass
Physalis	*heterophylla*	Clammy groundcherry	Forb
Physalis	*longifolia*	Common groundcherry	Forb
Plantago	*lanceolata*	Buckhorn plantain	Forb
Plantago	*patagonica*	Woolly plantain	Forb
Poa	*annua*	Annual bluegrass	Grass
Poa	*pratensis*	Kentucky Bluegrass	Grass
Polygonum	*amphibium*	Water smartweed	Forb
Prunella	*vulgaris*	Self-heal	Forb
Ratibida	*columnifera*	Prairie coneflower	Forb
Rhus	*glabra*	Smooth sumac	Shrub

Rosa	*arkansana*	Prairie wildrose	Shrub
Rudbeckia	*hirta*	Black-eyed susan	Forb
Rumex	*crispus*	Curly dock	Forb
Salix	*exigua*	Sandbar willow	Shrub
Salix	*spp*	Willows	Shrub
Schizachyrium	*scoparium*	Little bluestem	Grass
Schoenoplectus	*pungens*	Three-square	Grass-like
Senecio	*plattensis*	Prairie groundsel	Forb
Setaria	*spp*	Bristlegrasses	Grass
Sisymbrium	*loesellii*	Tallhedge mustard	Forb
Sisyrinchium	*campestre*	blue-eyed grass	Forb
Solanum	*rostratum*	buffalo bur	Forb
Solidago	*canadensis*	Canada goldenrod	Forb
Sorghastrum	*nutans*	Indiangrass	Grass
Spartina	*pectinata*	Prairie cordgrass	Grass
Sporobolus	*compositus*	Tall dropseed	Grass
Sporobolus	*cryptandrus*	Sand dropseed	Grass
Symphoricarpos	*occidentalis*	Western snowberry	Forb
Taraxacum	*officinale*	Dandelion	Forb
Toxicodendron	*rydbergii*	Poison ivy	Forb
Tradescantia	*bracteata*	Long-bracted spiderwort	Forb
Tragopogon	*dubius*	Western salsify	Forb
Tribulus	*terrestris*	Puncture vine	Forb
Trifolium	*pratense*	Red Clover	Forb
Triglochin	*maritima*	Arrowgrass	Forb
Verbascum	*thapsus*	Common mullein	Forb
Verbena	*hastata*	Blue Verbena	Forb
Verbena	*stricta*	Wolly verbena	Forb
Vernonia	*baldwinii*	Western Ironweed	Forb
Vulpia	*octoflora*	Sixweeks fescue	Grass

Table 2. Average species richness per transect on pastures under continuous, patch-burning, and rotational grazing (2007-2009).

Treatment	n	Richness	sd	Mean.C	sd	FQAI	sd
Continuous	30	20.967[a]	3.07	2.98	0.36	12.06	1.83
Patch-burning	120	25.808[b]	5.45	2.83	0.48	11.72	2.28
Rotational	120	25.4[b]	5.98	2.86	0.54	11.66	2.27

Table 3. Diversity indices values per transect on pastures under continuous, patch-burning, and rotational grazing (2007-2009).

		Diversity Index							
Treatment	**n**	**Shannon**	**sd**	**Simpson**	**sd**	**InvSimpson**	**sd**	**Berger-Parker**	**sd**
Continuous	30	2.38	0.20	0.88	0.03	8.69	1.91	0.22	0.05
Patch-burning	120	2.31	0.26	0.86	0.05	7.66	2.28	0.26	0.09
Rotational	120	2.32	0.26	0.86	0.05	7.89	2.13	0.25	0.09

Table 4. Results of testing continuous grazing vs. patch-burn and rotational treatments on diversity for fixed effects with random factors PASTURE and PASTURE*YEAR.

			Factor		
		Intercept	**Patch-burning**	**Rotational**	**Fire**
Mean.C	Estimate	2.984	-0.183	-0.153	0.141
	SE	0.181	0.204	0.204	0.115
FQAI	Estimate	12.056	-0.347	-0.412	0.064
	SE	0.991	1.114	1.114	0.452
Richness	Estimate	16.433	1.179	0.688	-1.383
	SE	1.267	1.423	1.422	0.535
Shannon	Estimate	2.384	-0.04	-0.028	-0.125
	SE	0.098	0.111	0.111	0.045
Simpson	Estimate	0.879	-0.017	-0.012	-0.022
	SE	0.018	0.02	0.02	0.009
InvSimpson	Estimate	8.692	-0.762	-0.53	-1.074
	SE	0.822	0.924	0.924	0.384
Berger-Parker	Estimate	0.218	0.033	0.024	0.036
	SE	0.03	0.034	0.034	0.015

MEAN.C = Mean coefficient of conservatism
FQAI = Floristic Quality Assessment Index
Richness = Species richness
Shannon = Shannon diversity index estimated by Vegan package R-Software
Simpson = Simpson diversity index estimated by Vegan package R-Software.
InvSimpson: = Inverse Simpson diversity index estimated by Vegan package R-Software.
Berker-Parker = Berger-Parker diversity index estimate by Vegan package R-Software.

Table 5. Average beta diversity values (2007-2009) for pastures under continuous, patch-burning, and rotation grazing treatments.

	Treatment			
	Continuous	Patch-burning	Rotational	*p*
Continuity & Loss				
Ruggeiro (βrlb)	0.4521	0.316	0.369	< 0.001
Species Richness Gradient				
Lennon (βgl)	0.1405	0.1582	0.1477	0.7065
Continuity				
Whittaker (βw)	0.2578	0.4039	0.3451	< 0.001
Cody (βc)	4.207	6.903	5.736	< 0.001
Gain and Loss				
Routledge (βr)	0.1104	0.246	0.1835	< 0.001
Routledge (βI)	0.1734	0.2731	0.2323	< 0.001
Lennon (βz)	0.3134	0.4569	0.4022	< 0.001

Table 6. Species abundance rank for pastures under continuous grazing treatments.

Rank	Abundance	Species	Origin	Season	Type
1	14.90	*Agrostis stolonifera*	Exotic	Cool	Grass
2	10.60	*Carex aqutilis*	Native	Warm	Grass
3	9.90	*Poa pratensis*	Exotic	Cool	Grass
4	7.83	*Panicum virgantum*	Native	Warm	Grass
5	7.57	*Schoenoplectus pungens*	Native	Warm	Sedge
6	5.77	*Hordeum jubatum*	Native	Cool	Grass
7	5.60	*Distichlis spicata*	Native	Warm	Grass
8	5.27	*Lippia lanceolata*	Native	Warm	Forb
9	4.97	*Eleocharis erythropoda*	Native	Warm	Grass
10	4.37	*Ambrosia psilostachya*	Native	Warm	Forb
11	2.90	*Juncus interior*	Native	Warm	Sedge
12	2.50	*Elymus trachycaulus*	Native	Cool	Grass
13	1.77	*Andropogon gerardii*	Native	Warm	Grass
14	1.77	*Salix spp.*	Native	Warm	Shrub
15	1.70	*Trifolium pratense*	Exotic	Cool	Forb
16	1.53	*Vernonia baldwinii*	Native	Warm	Forb
17	1.47	*Plantago lanceolata*	Native	Warm	Forb

Table 7. Species abundance rank for pastures under patch-burning grazing treatments.

Rank	Abundance	Species	Origin	Season	Type
1	16.73	*Poa pratensis*	Exotic	Cool	Grass
2	10.57	*Bromus inermis*	Exotic	Cool	Grass
3	8.53	*Andropogon gerardii*	Native	Warm	Grass
4	8.32	*Panicum virgantum*	Native	Warm	Grass
5	5.70	*Ambrosia psilostachya*	Native	Warm	Forb
6	5.28	*Lolium arundinaceum*	Native	Cool	Grass
7	3.78	*Spartina pectinata*	Native	Warm	Grass
8	3.67	*Eleocharis erythropoda*	Native	Warm	Sedge
9	3.37	*Bromus tectorum*	Exotic	Cool	Grass
10	2.93	*Agrostis stolonifera*	Exotic	Cool	Grass
11	2.13	*Schoenoplectus pungens*	Native	Warm	Sedge
12	2.06	*Carex aqutilis*	Native	Warm	Sedge
13	1.93	*Schizachyrium scoparium*	Native	Warm	Grass
14	1.90	*Dichanthelium oligosanthes*	Native	Warm	Grass
15	1.75	*Hesperostipa comata*	Native	Cool	Grass
16	1.65	*Medicago lupulina*	Exotic	Warm	Forb
17	1.29	*Poa annua*	Exotic	Cool	Grass
18	1.16	*Sorghastrum nutans*	Native	Warm	Grass
19	1.07	*Phlaris arundinacea*	Exotic	Cool	Grass
20	0.90	*Alopecurus arundinaceus*	Exotic	Cool	Grass
21	0.90	*Equisetum laevigatum*	Native	Cool	Forb
22	0.86	*Symphoricarpos occidentalis*	Native	Warm	Shrub
23	0.83	*Verbena stricta*	Native	Warm	Forb
24	0.73	*Euphorbia esula*	Exotic	Cool	Forb
25	0.62	*Desmanthus illinoensis*	Native	Warm	Forb
26	0.53	*Rosa arkansana*	Native	Cool	Forb
27	0.52	*Callirhoe involucrata*	Exotic	Cool	Forb
28	0.50	*Elymus trachycaulus*	Native	Cool	Grass

Table 8. Species abundance rank for pastures under rotational grazing treatments.

Rank	Abundance	Species	Origin	Season	Type
1	16.78	*Andropogon gerardii*	Native	Warm	Grass
2	11.33	*Panicum virgantum*	Native	Warm	Grass
3	9.48	*Poa pratensis*	Exotic	Cool	Grass
4	7.32	*Agrostis stolonifera*	Exotic	Cool	Grass
5	5.83	*Bromus inermis*	Exotic	Cool	Grass
6	4.88	*Spartina pectinata*	Native	Warm	Grass
7	4.70	*Lolium arundinaceum*	Native	Cool	Grass
8	3.69	*Ambrosia psilostachya*	Native	Warm	Forb
9	3.09	*Carex aqutilis*	Native	Warm	Sedge
10	3.00	*Helianthus peliolaris*	Native	Warm	Forb
11	2.90	*Solidago canadensis*	Native	Warm	Forb
12	2.76	*Sorghastrum nutans*	Native	Warm	Grass
13	2.74	*Medicago lupulina*	Exotic	Warm	Forb
14	2.10	*Schoenoplectus pungens*	Native	Warm	Sedge
15	2.01	*Phlaris arundinacea*	Exotic	Cool	Grass
16	1.61	*Eleocharis erythropoda*	Native	Warm	Sedge
17	1.61	*Equisetum laevigatum*	Native	Cool	Forb
18	1.27	*Melilotus alba*	Exotic	Warm	Forb
19	1.21	*Symphoricarpos occidentalis*	Native	Warm	Shrub
20	1.05	*Desmanthus illinoensis*	Native	Warm	Forb
21	0.80	*Dichanthelium oligosanthes*	Native	Warm	Grass

Table 9. Native and introduce species abundance (2007-2009) as part of the top species covering 90% of total abundance on pastures under continuous, patch-burning, and rotational grazing treatment.

Treatment	Native	Introduced
Continuous	63.9	26.5
Patch-burning	48.4	39.8
Rotational	63.6	28.6

Table 10. Cool and warm season species abundance (2007-2009) as part of the top species covering 90% of total abundance on pastures under continuous, patch-burning and rotational grazing treatment.

Treatment	**Cool-Season**	**Warm-Season**
Continuous	34.8	55.6
Patch-burning	47.1	43.1
Rotational	30.9	59.2

Table 11. Abundance (2007-2009) distribution between plant functional groups (Forbs, Grass, Grass-like, Shrubs and trace species) on pastures under continuous, patch-burning and rotational grazing treatment.

	Top dominant species				
Treatment	**Forb**	**Grass**	**Grass-like**	**Shrub**	**Trace Species**
Continuous	14.3	63.8	10.5	1.8	9.6
Patch-burning	11.5	70	7.9	0.9	9.7
Rotational	16.3	65.9	6.8	1.2	9.8

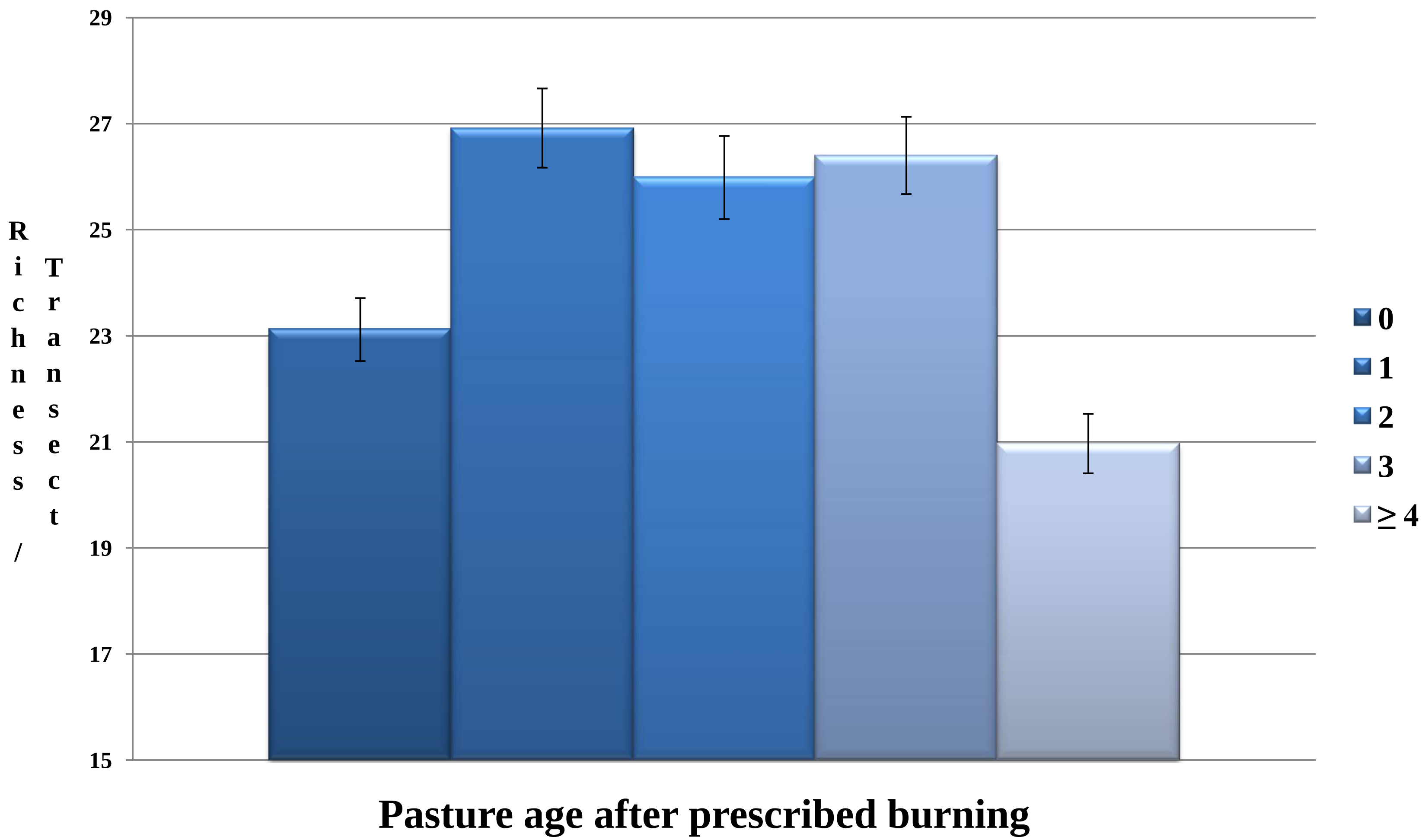

Figure 1. Average species richness (2007-2009) per transect 0, 1, 2, 3, ≥4 years after prescribed burning. Pastures 0-3 years after fire are treated with a combination of prescribed burning and grazing; ≥4 refer to pastures under grazing pressure and no recent fire treatment.

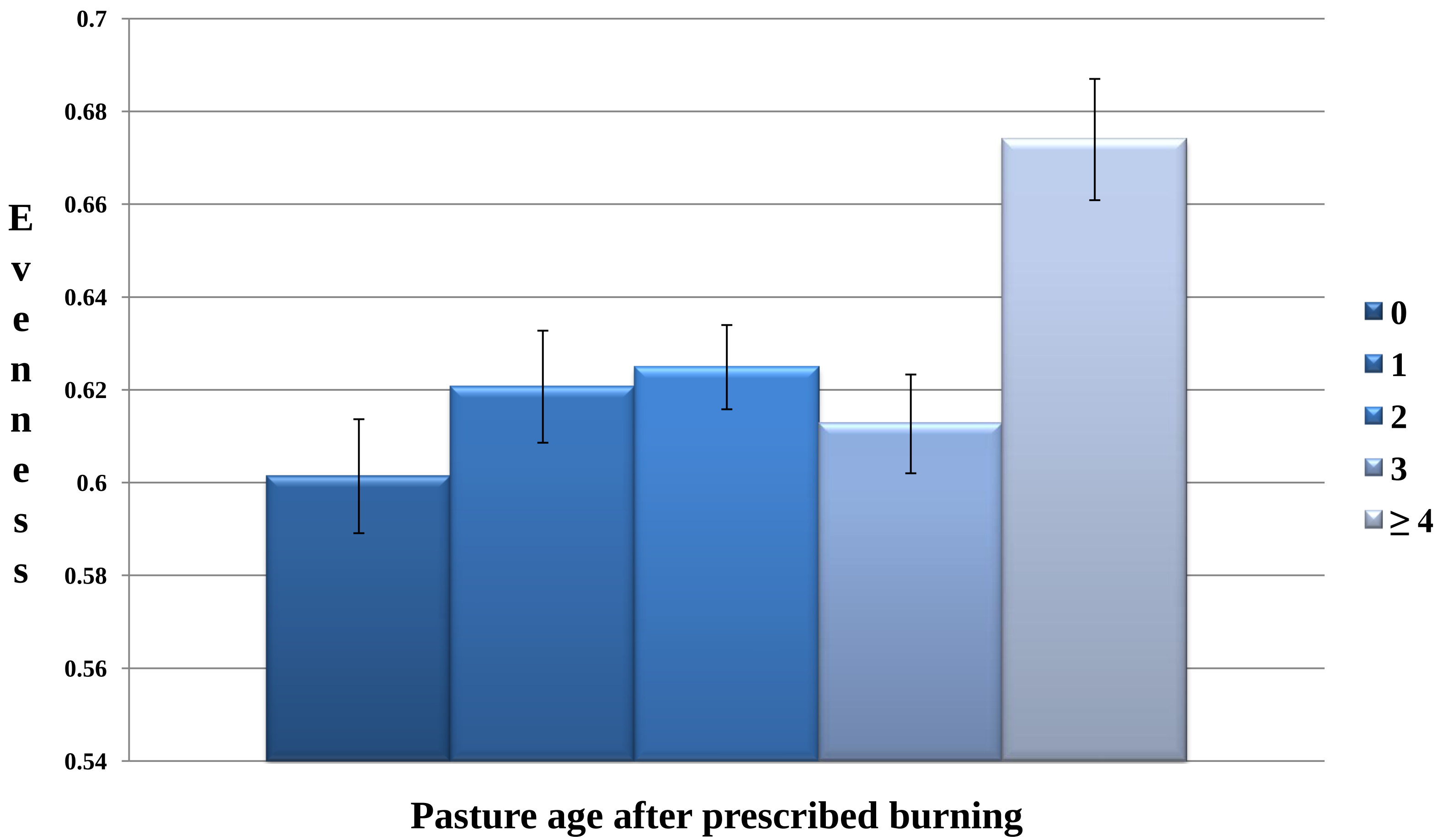

Figure 2. Average species evenness (2007-2009) per transect 0, 1, 2, 3, ≥4 years after prescribed burning. Pastures 0-3 years after fire are treated with a combination of prescribed burning and grazing; ≥4 refer to pastures under grazing pressure and no recent fire treatment.

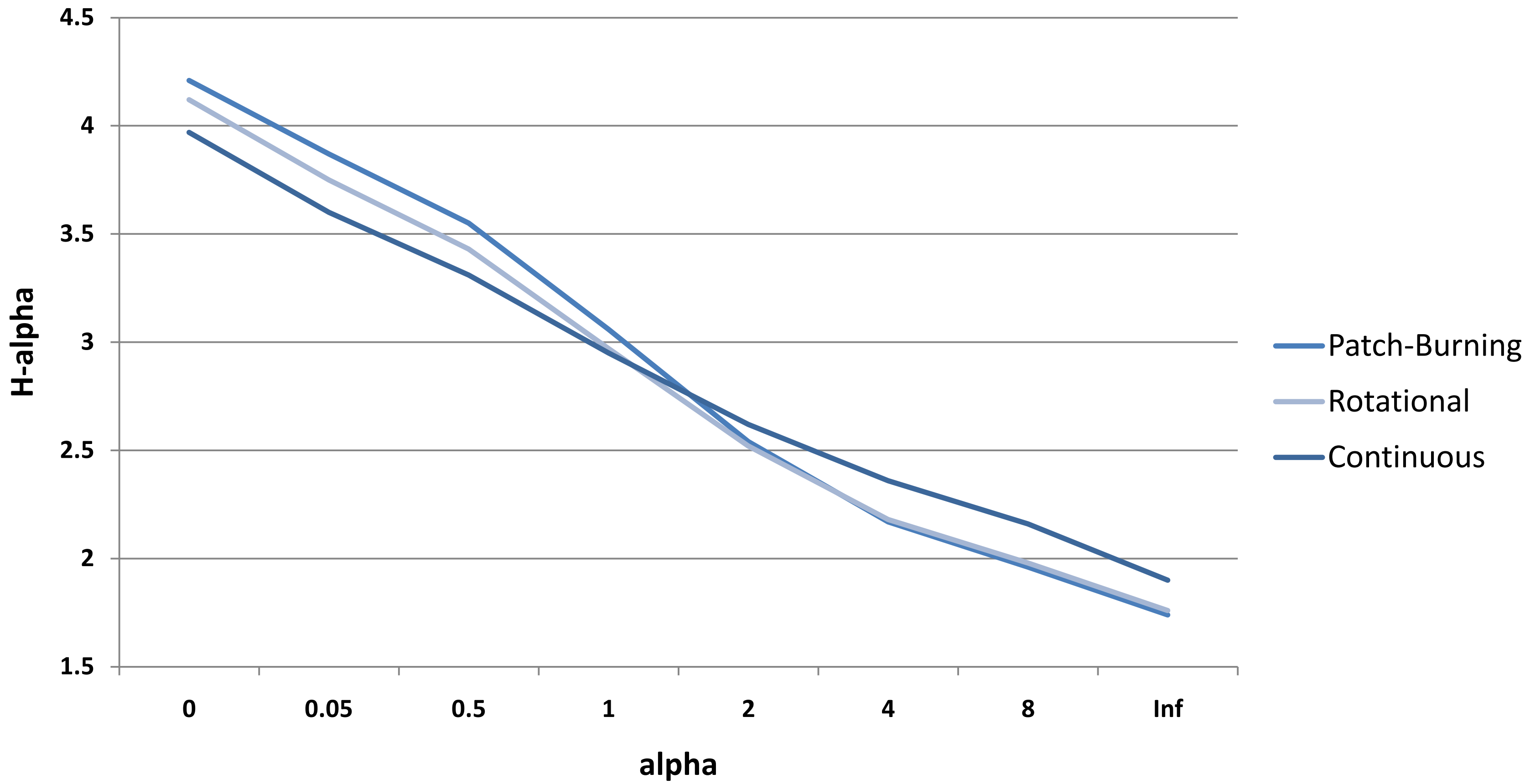

Figure 3. Renyi's generalized diversity profiles on pastures under patch-burning, rotational, and continuous grazing treatment (2007-2009).

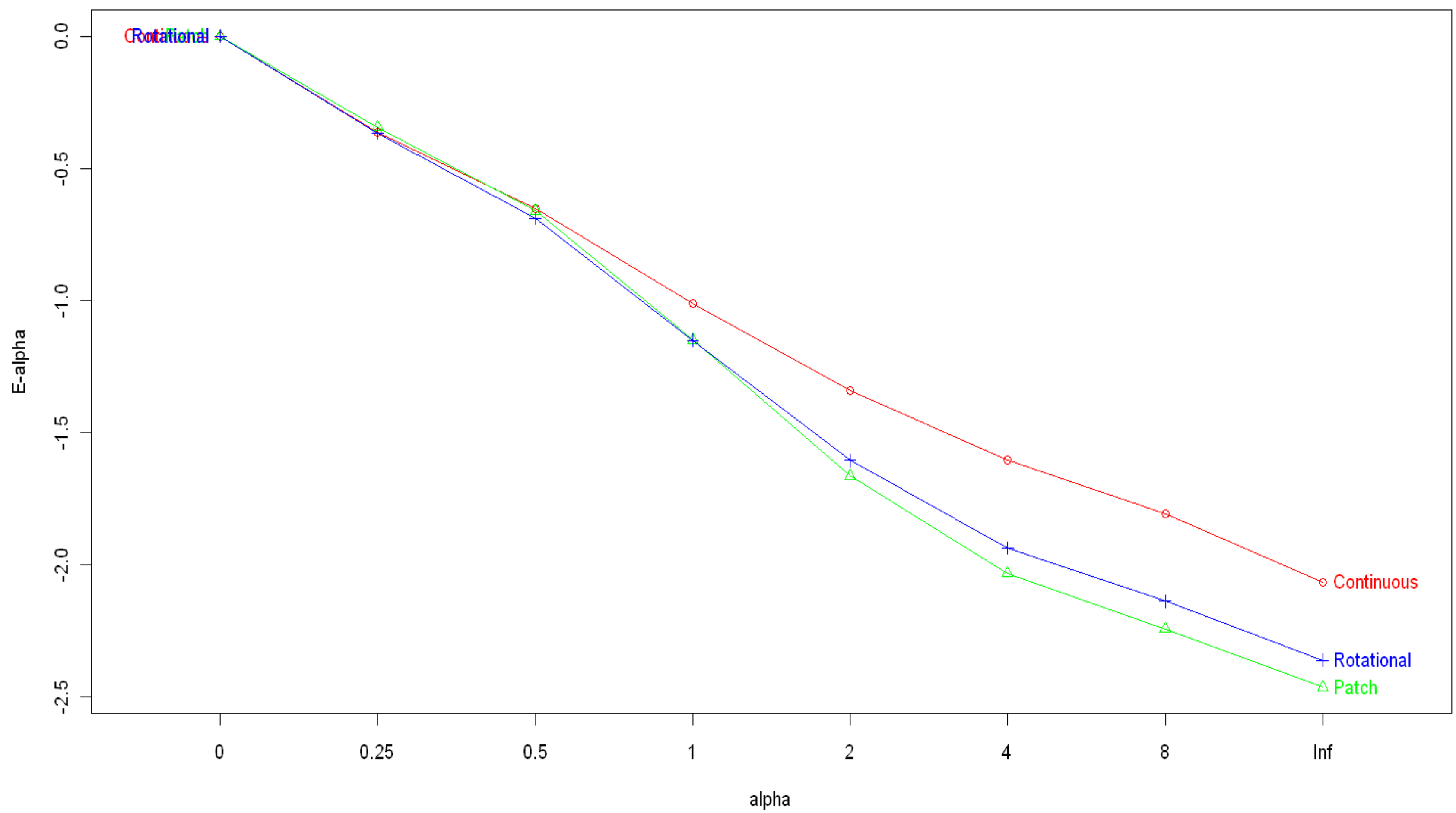

Figure 4. Hill's evenness profile on pastures under patch-burning, rotational, and continuous grazing treatment (2007-2009).

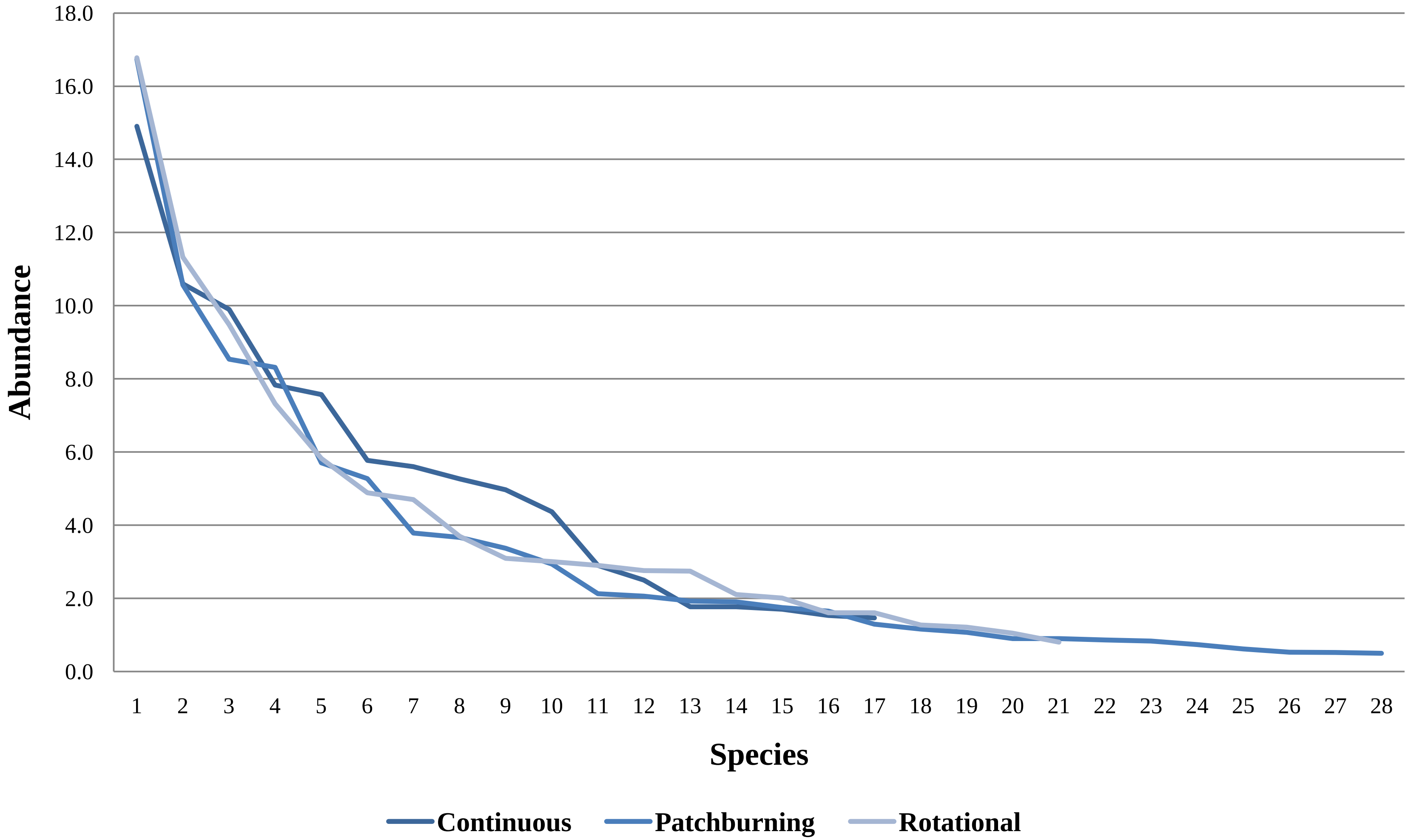

Figure 5. Rank abundance curve for species covering 90% of the total observed abundance per treatment (2007-2009).

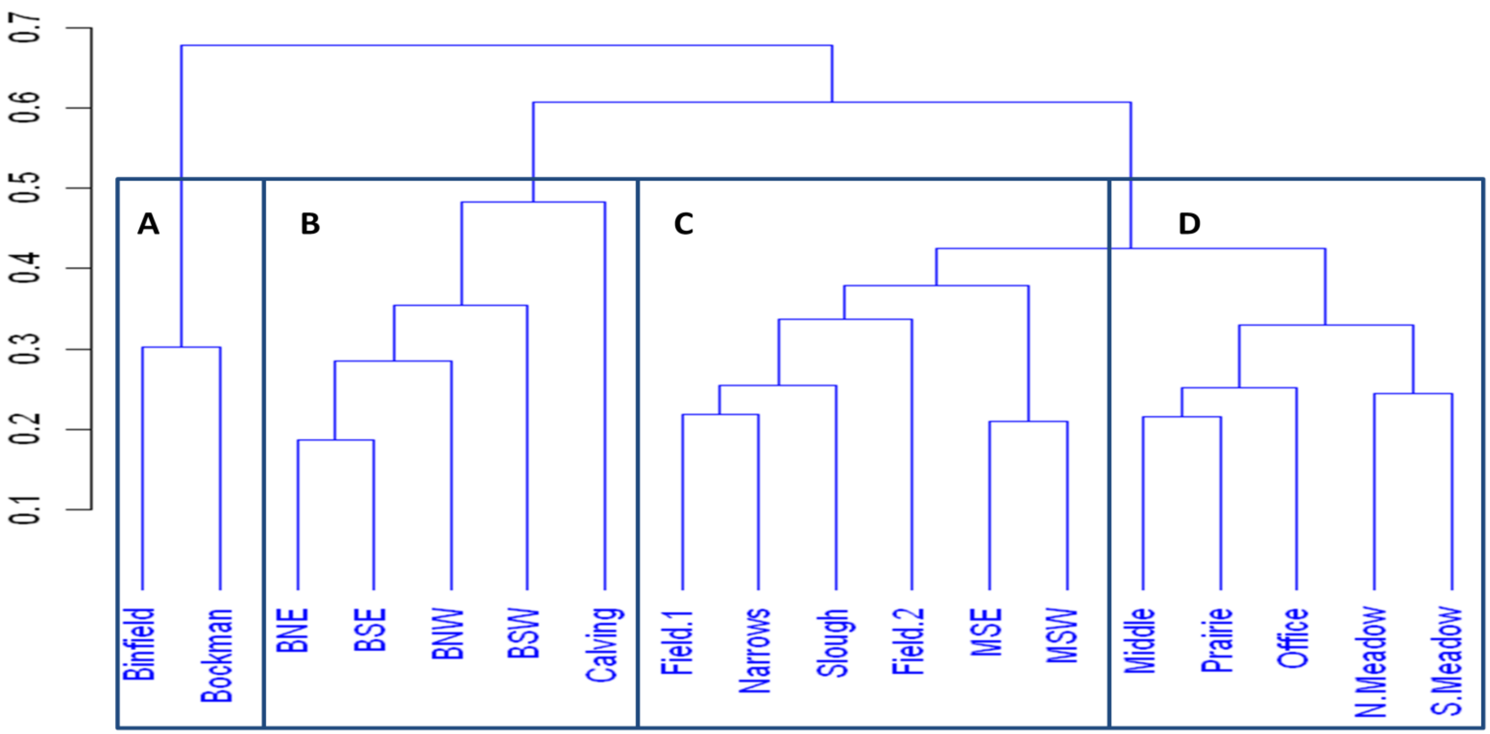

Figure 6. Bray-Curtis dendogram displaying similarity of plant communities on pastures under rotational, patch-burning, and continuous grazing from 2007 to 2009. A) pastures under continuous grazing; B) pastures under fire-grazing management and dry conditions; C) pastures under fire-grazing management, wet conditions and lower abundance of introduced grass species; and D) pastures under fire-grazing management, low wet meadow conditions, and higher abundance of introduced grass species.

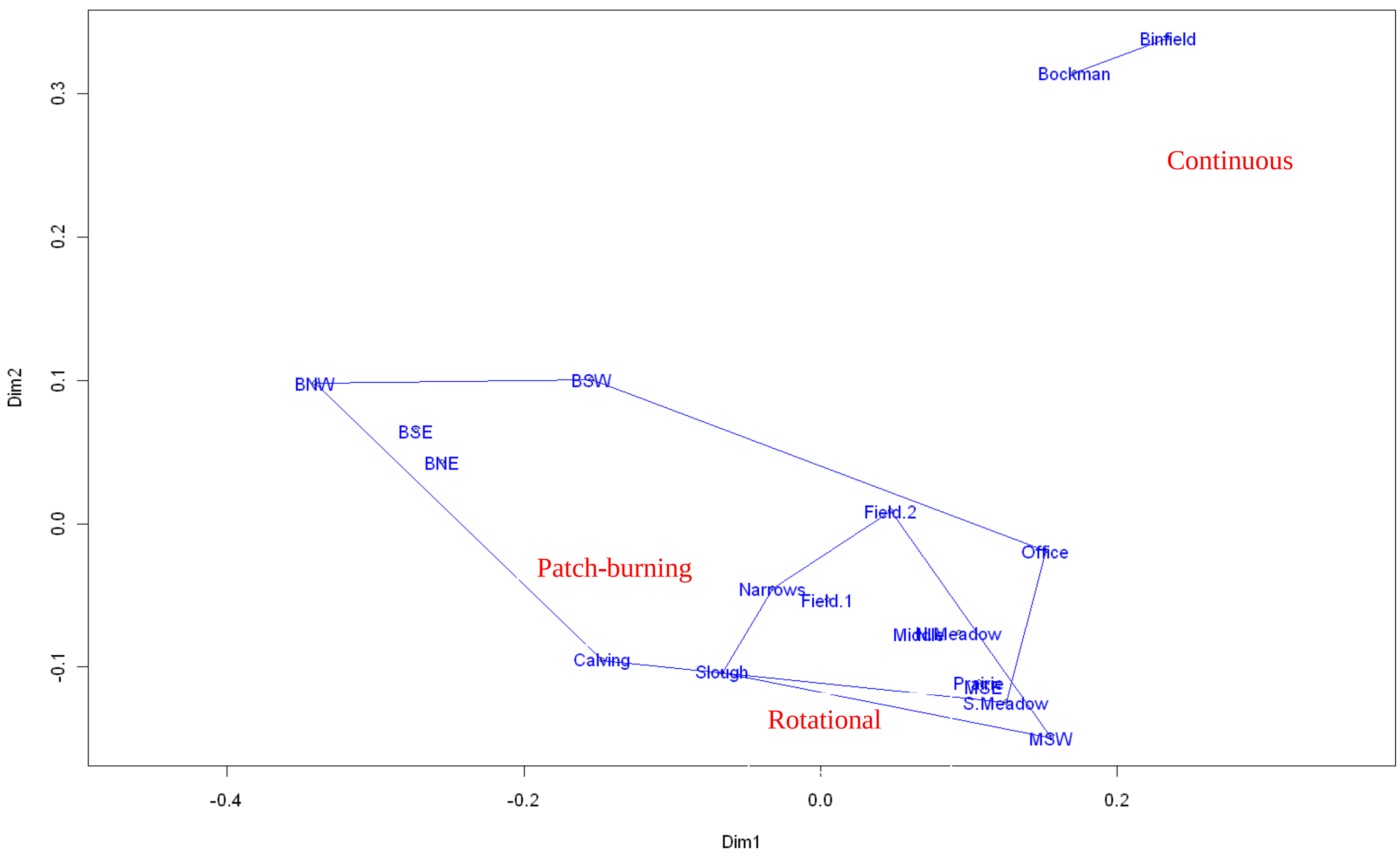

Figure 7. Principal Coordinates Analysis ordination diagram with pastures under continuous, patch-burning, and rotational grazing treatments between 2007 and 2009.

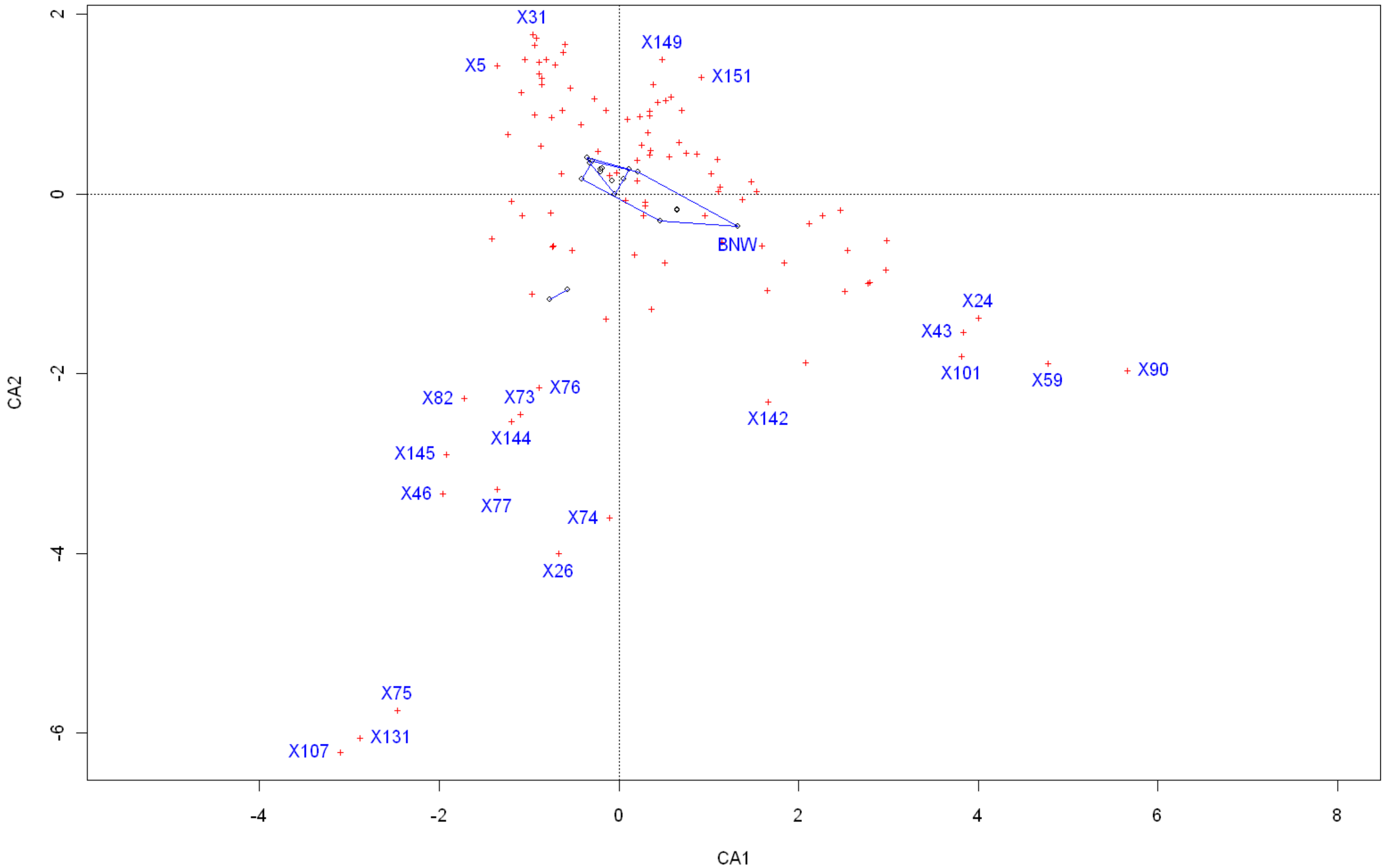

Figure 8. Correspondance analysis ordination diagram with plant species (X), and treatments (polygons).

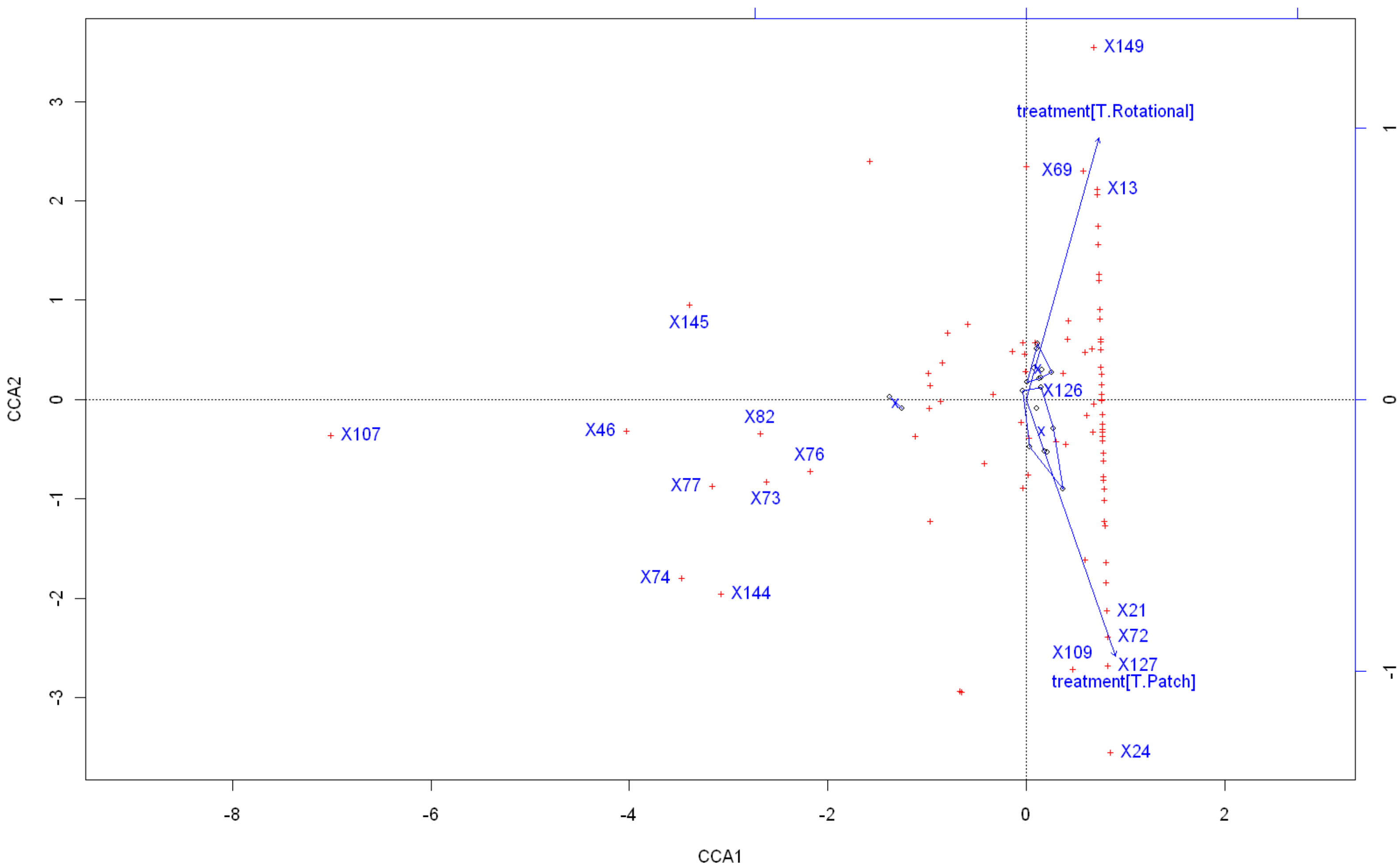

Figure 9. Canonical correspondance analysis ordination diagram with plant species (X), and treatments (polygons).

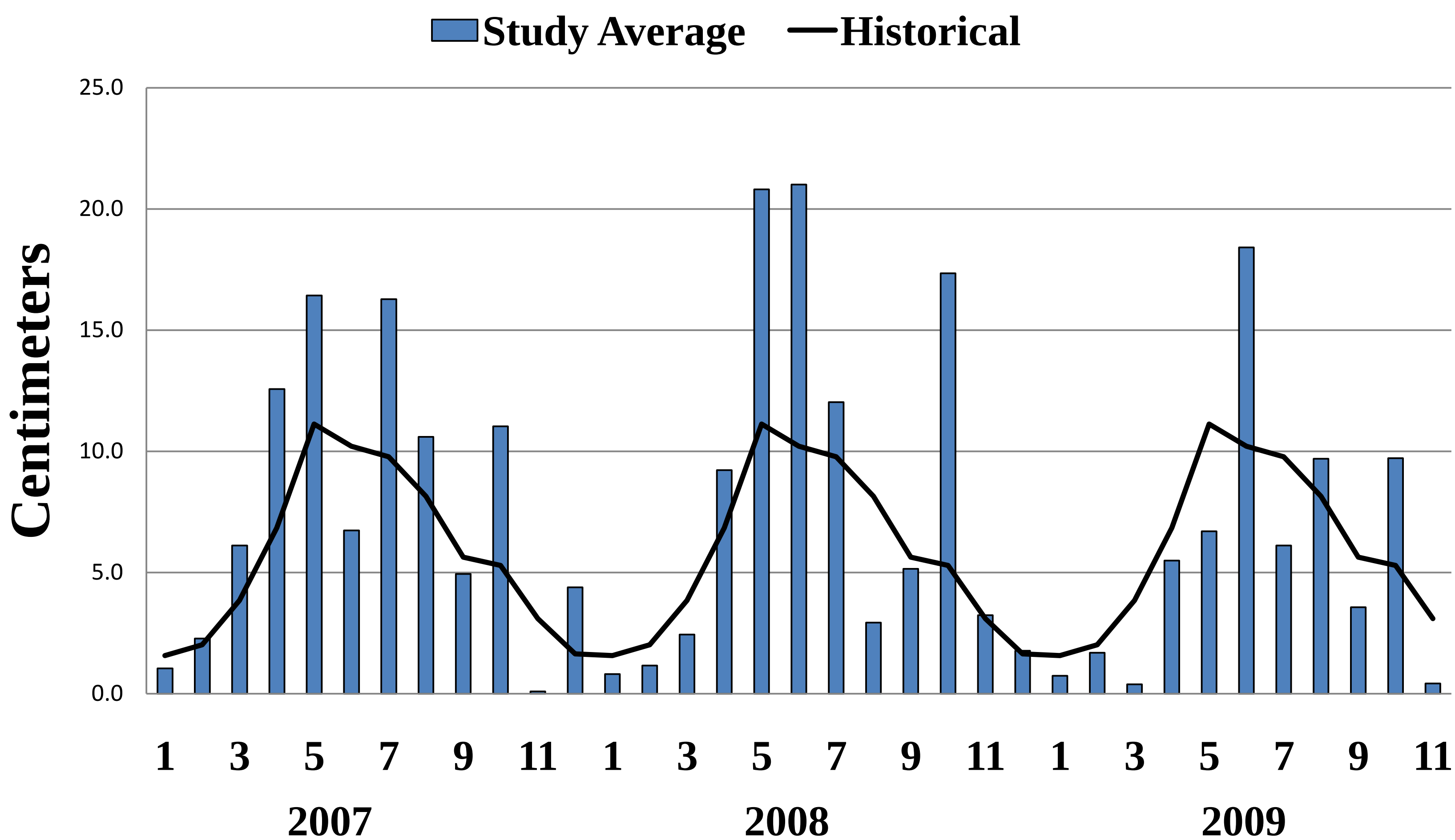

Fig. 10 Average monthly rainfall (line) on The Crane Trust and average rainfall (bars) during the study (2007-2009).

Application of diversity indices to characterize grassland vegetation structure as influenced by land management strategies.

INTRODUCTION

Many natural grassland processes such as fires, floods, and grazing have been modified or suppressed by humans. Altering disturbance patterns can cause severe habitat changes in species composition and vegetation structure and increase susceptibility to species invasion, including woody plant encroachment (Vickery et al. 2000, Askins et al. 2007). Traditional methods of grazing management and farming often simplify structural heterogeneity and plant species diversity and promote landscape fragmentation (Fuhlendorf and Engle 2001). The interaction of disturbances such as fire and grazing create a mosaic of habitat conditions influencing continuity of height, density, and aboveground biomass (Ryan 1986) creating heterogeneous landscapes. If historic levels of heterogeneity can be restored, rangelands have tremendous potential for maintaining or enhancing biodiversity (Christensen 1997, Wiens 1997). Plant diversity and vegetation structure on grassland habitats evolved with interaction between disturbance factors such as grazing and fire (Collins and Wallace 1990). Therefore, both sources of disturbance should be present at some level on grasslands to maintain ecological function.

The general pattern of vegetation of structural succession on grasslands starts with homogenization by fire, followed by grazing of dominant species and colonization by less palatable species. Low, sparse vegetation is maintained for certain amount of time before the vegetation recovers and litter accumulates (Collins and Glenn 1988, Collins and Wallace 1990). This successional process would create the habitat patchiness needed by diverse species of wildlife. If large scale grazing disturbance continues with high frequency and intensity, the resulting plant community composition will differ qualitatively from the original, creating a landscape mosaic not capable of sustaining local and migrant wildlife populations (Turner et al. 1998).

Wildlife in general are highly sensitive to spatial and temporal variation in vegetation structure (Rotenberry and Wiens 1980). Thus, creation of structural heterogeneity on grasslands can determine assemblages, composition, and diversity of wildlife and is recommended as management strategy to ensure habitat availability (Skinner et al. 1984, Herkert et al. 1993). In order to maintain and/or create these conditions, a good understanding of the structural variability of grasslands is needed.

The presence of highly diverse grasslands can improve wildlife species diversity. Grassland restoration strategies, where native flora diversity is promoted, have shown increased bird diversity (Warner 1992, Bryan and Best 1994, Burger 2000, McCoy et al. 2001). Although grassland birds are, at some level, not affected by botanical species composition, they are strongly impacted by vegetation architecture (Graber and Graber 1963). Vegetation structure can be affected by many factors including fire and grazing. Habitat conditions such as botanical composition, biomass cover, litter, structure, and vertical vegetation density can be altered by grazing and trampling (Knopf and Cannon 1982, Kauffman et al. 1983). Although fire can remove all ground cover, subsequent re-growth is closely related to grazing pressure, type of grazers, and their selectivity. Because of behavioral differences, depending on grazer type and grazing intensity, areas with similar plant diversity can differ in vegetation structure and patchiness (Bakker et al. 1983, Arnold 1987, Rosas et al. 2005). As a consequence, when grazing is present, plant diversity may have an impact on wildlife habitat structure.

Traditional grazing strategies in south central Nebraska, where high stocking rates are common during the whole season, change spatio-temporal patterns needed by wildlife. The use of these land management strategies, where vegetation structure variability is reduced, may be associated with a decline in wildlife species with habitat requirements in the other extreme of the vegetation structural spectrum (Saab et al. 1995). Fire and grazing to promote heterogeneity have been used to mimic historical disturbance regimes on grasslands (Fuhlendorf and Engle 2001) in order to create spatial and temporal heterogeneity. The use of fire on North American grasslands has been mainly directed to promote or maintain habitat for wildlife, favor native vegetation, and reduce woody species encroachment (Bragg 1995). Many variables influence the effect of prescribed burning on grasslands. Timing, frequency, and intensity of fire can radically change the plant community response to this type of stressor.

The use of grazing and fire to manage grasslands has been developed simultaneously with a better understanding of wildlife habitat requirements. A wide variety of techniques to measure habitat characteristics has provided important information to define wildlife habitat preference. Vegetation architecture, as defined by Sutherland and Green (2005), includes vegetation height, structure, and density; variables usually accepted as good descriptors of habitat characteristics for some species. Bibby et al. (1992) add to this list vegetation heterogeneity and composition, grazing density, and soil moisture. Species habitat selection and the idea of correlation between habitat conditions and use are the main two assumptions behind the need to measure vegetation conditions (Block et al. 1987).

Although structure survey techniques are widely accepted and used in grassland ecosystems, several problems have been identified. Given grassland natural variability, sample size and observer variability can produce significant differences in estimations (Block et al. 1987). James and Shugart (1970) suggested the use of standard sampling techniques to measure bird habitat but, because of the intrinsic variability among grasslands, this is extremely difficult to achieve. The use of obstruction profiles proved to be a good graphical representation of structural distribution of strata. Most research on vegetation structure has been done on tall plant communities such as forest and shrub lands, and techniques are well developed (Fliervoet and Werger 1984). During the last couple of decades, some authors have started to analyze structural differences on short and sparse vegetation assemblages (Diaz Barradas et al. 1992, Roxburgh et al. 1993). These measurements have been very successful in describing and helping to understand grassland bird ecology and habitat selection (Johnson 2007), but they are usually difficult to correlate to field conservation efforts. Visual obstruction at specific height and average height of the vegetation component can be easily related to bird selectivity, but it is difficult to translate into management strategies at site and landscape levels.

Diversity indices, although with some recognized deficiencies, are well understood and can be used to develop field conservation strategies more adequately and are relatively easy to apply under field conditions. For example, vegetation obstruction values reported from ornithology studies are difucult to translate into management and field conservation plans. Better understanding of vegetation structure transition, patchiness, and variability could complement our existing ecological knowledge which will help to close the gap between science and field conservation.

Objectives

The objective of this study was to adapt the use of diversity analysis, used in botany and plant ecology to describe vegetation structure, as a complementary tool to evaluate grassland vegetation structure. Four diversity analysis approaches were considered to describe grassland structural diversity:

1. Test the application of horizontal and vertical structural diversity developed by Blondel and Cuvillier (1977) to describe forest vegetation on grassland vegetation.
2. Determine how vegetation layers are distributed on grasslands under different land management strategies via structure profiles.
3. Use traditional biodiversity indices as Simpson and Shannon to evaluate presence-absence of vegetation layers on pastures with different combinations of fire and grazing pressure.
4. Use beta diversity indices to determine vegetation layer variation between sampling points at site level to better understand grassland habitat structural dynamics.

METHODS

Study Site

This study was conducted in the central Platte River valley area of Nebraska on The Crane Trust property during three years starting in summer 2007. Ten pastures from The Crane Trust and two from area producers were used as experimental units. The Crane Trust is comprised of about 4,000 ha of cropland, pastures, and hay meadows along the Platte River in Buffalo, Hall, and Phelps counties, Nebraska. All pastures included in this study are located in Hall County. Climate is continental, with 160 frost-free growing days. Mean average temperature is 10°C with January minimum average of 11.6°C and average August temperature of 29.3°C. Average precipitation is 630 mm, occurring mainly from May through September. Soils consist of loamy or sandy alluvial deposits (Henszey et al. 2004). In the area adjacent to the Platte River, ecosystems are characteristic of tallgrass prairie with woody encroachment of eastern cottonwood (*Populus deltoides*) forests interspersed with willows (*Salix* spp.) and eastern redcedar (*Juniperus virginiana*). Dominant vegetation includes sedges (*Carex* spp.), rushes (*Eleocharis palustris, Scirpus* spp.*, and Juncus* spp.), and prairie cordgrass (*Spartina pectinata*) in lowland meadows (Curier et al. 1985). Mesic grasslands are characterized by big bluestem (*Andropogan gerardii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutants*), Canada wildrye (*Elymus canadensis*), and switchgrass (*Panicum virgatum*). Common forbs include goldenrods (*Solidago* spp.) and prairie clovers (*Dalea* spp.). Many prairies contain non-native cool-season grasses including smooth bromegrass (*Bromus inermis*), Kentucky bluegrass (*Poa pratensis*), red top (*Agrostis stolonifera*), and tall fescue (*Lolium arundinaceum*).

Treatments

The first treatment, consisting of continuous season-long grazing, was considered as a control treatment and representative of the land management scheme most commonly used in this area. Under this system, pastures of variable sizes ranging from 20 to 100 ha were grazed with cow-calf pairs during summer and spring with medium to high stocking rates (>2.5 AUM/ha) without application of fire. The second treatment, patch-burn grazing, used large pastures (>80 ha) divided into four sections or burning units with no fences between them, with stocking rates ranging between 1.5 and 2 AUM/ha. In a 4-year rotation cycle, the whole pasture was burned after applying prescribed fire to each unit. The rationalization behind this system considers that newly burned areas would offer fresh forage regrowth which is preferred by cattle. As a consequence, a concentration of grazing pressure on burned areas and avoidance of previously burned sections create a condition where four different vegetation structure and litter accumulation levels should be present in each treatment pasture.

Finally, the third treatment consisted of a modified rest rotational grazing system, consisting of four pastures of 50 to 250 ha where one was burned each year. In this system only two pastures were grazed each year leaving two pastures without any type of disturbance. Considering a four-year rotation cycle, pasture 1 would be managed with an early spring prescribed burn and grazed during May and June with high stocking rates (>3.5 AUM/ha). After these two initial months, cattle would be moved to pasture 2, which was burned the year before, to be grazed during July and August. Finally, cattle were returned to pasture 1 on September 1st to finish the grazing season in mid-October.

Pastures 3 and 4 were not grazed. The following year pasture 4 (after been rested for 2 years) would be burned in the spring and paired with pasture 1 for grazing.

Experimental Design

The experimental design consisted of the three treatments described above with two replicates of each. All grasslands used in this research were historically used as pasture or hay meadows for the previous 5+ years and at least 1.6 km from the river bank. Former hay meadows used were conditioned as pastures at least 2 years before data collection. Rotational and patch-burning pastures were under a 3- to 4-year rotational prescribed burning for more than 10 years. Prescribed burning was conducted after snow melt in March or April.

Data Collection

Vertical cover was determined using a density board (Nudds 1977). This method is described as a board (10 cm wide x 150 cm tall) which is marked with colored stripes at alternating decimeters. Preliminary studies determined that the most accurate readings of visual obstruction were made at 1 m height and 4 m away from the pole (Sutherland 2005). The researcher recorded the amount of vegetation obstructing each 10 cm segment (layer) from the distance of 4 m. Vegetation obstruction of each layer was recorded as presence-absence and as percentage cover of each layer (Table 1). Sampling points were located every 33 m along five 100 m transects/site. A random distance (≤10 m) from the main transect was used to collect a sampling point for vertical cover records (4 sampling points/transect).

To determine structural diversity, I divided horizontal and vertical components. Following Blondel and Cuvillier (1977) modifications of the “stratoscope method”, I used the presence or absence of vegetation vertical cover within the board at all different height segments. In this way, up to 19 records (layers) were obtained per sampling point. The following variables were recorded and/or defined:

- HEIGHT: Average vegetation height observed on density board.
- TPLANT: Average height of tallest plant observed at each sampling point.
- COV01 to COV19: Percent vegetation cover for all vertical layers.
- NSTRAT: Number of layers in which vegetation was present.
- COVSUM: Total vegetation cover (all layers) per sampling point.
- NCOV: Maximum possible total percentage cover value per sampling point.
- FOL01 to FOL19: Presence-absence of vegetation cover per layer.
- DS: “Diversity of Stratification”

  DS = ld (n @ r)

with *n* = NCOV; *r* = actual percent cover value; *ld* = logarithmus dualis. This index measures the information content of the spatial vegetation distribution as suggested by Blondel and Cuvillier (1977)

- DH: “Horizontal diversity”

  DH = ∑ (i = 1) ^ k ld(p @ q)

with *p* = maximum possible numbers of positive recordings per layer; *q* = actual number; *k* = number of layers present (NSTRAT)

- DV: “Vertical diversity”

  DV = ∑ (t = 1) ^ l ld (u @ v)

with *u* = maximum possible number of positive recordings at one sampling point (NSTRAT); *v* = actual number; *l* = number of sampling points.

- DT: “Total diversity”

  DT = DH + DV

These structural diversity indices were used to build mixed models to describe plant architecture response to different grazing and fire disturbance patterns. The central idea behind these models is to simulate vegetation response to changes in disturbance, where structure changes were represented as sequential changes in architecture.

Structural beta diversity analysis was conducted to develop a better understanding of spatial patterns between sampling points within treatments. Following the definitions of Koleff et al. (2003), I evaluated beta diversity at four levels: 1) continuity and loss, as a way to evaluate the number of species shared between transects; 2) richness gradients, or change of species richness between transects; 3) continuity, to evaluate species similarity between transects; and 4) gain and loss, to measure species turnover or species shared between transects.

Finally, I tested the idea of analyzing structural data as species diversity. To conduct these analyses, I transformed vegetation cover to presence-absence data to construct data matrices. These structure matrices were constituted by rows representing sampling points and the columns indicate the different layers (up to 19) on each sampling point. Once these matrices were developed, BiodiversityR package (Kindt and Coe 2005) from R-software was used to conduct richness, abundances, and diversity analysis.

RESULTS

Vertical and horizontal structural diversity

Statistical analysis of structural components (Height, Nstrat, CovSum, and Ncov) and structural diversity (DS, DH, DV, and DT) showed significant difference between pasture ages after prescribed burning in 2007 (Table 2), 2008 (Table 3) and 2009 (Table 4). Vegetation height reached its higher level 3 years after prescribed burning. After 1 year under prescribed burning and grazing, all pastures showed higher structural values than those under continuous grazing.

Statistical mixed effect models showed an increase in structural variables on patch-burning and rotational treatments when compared to continuous grazing (Table 5). Fire-grazing interactions showed a positive effect on structural diversity values, although fire as a fixed effect had a negative effect on these same variables (Table 6). As expected, fire by itself negatively affected overall grassland structure decreasing structural and diversity values in the short term.

Vegetation structure profiles

Obstruction profiles showed how vegetation layers were distributed on pastures with different ages. Pastures burned and grazed showed a progressive change in distribution of cover during the fire cycle (Fig. 1). Fire and grazing limited vegetation growth during the first year; 51.3% of horizontal cover was attributed to the 0-10 cm layer and nearly 90% of observed vegetation structure was in the lower 30 cm. After this initial year, vegetation structure stabilized with > 90% of cover observed in the bottom 60 cm. Structure on pastures with continuous grazing was intermediate between the first and second year of those under fire and grazing treatments. Ninety percent of cover was distributed in the bottom 60 cm.

Vertical cover behaved differently under different treatments. Most vertical cover (≈ 59%) on rotational grazing pastures was observed in the bottom 10 cm during the first year when patch-burn grazing treatments started accumulating vegetation faster. By the middle of the grazing season, when structure data was collected, 90% of vertical cover was distributed on the bottom 40 and 30 cm on patch-burn and rotational grazing pastures, respectively (Fig. 2). Vertical structure of burned areas in patch-burn pastures stabilized after the first year. Rotational grazing pastures structure stabilized during year 1 and 2 but increased vertical cover in the lower 40 cm during the third year. During year 3 (last of the fire cycle), cover was more evenly distributed in the lower part of the structure on rotational but not patch-burning grazing; 40%, 25%, and 14% for patch-burning vs. 24%, 22%, and 17% for rotational in the lower10, 20, and 30 cm, respectively.

Vegetation structural diversity

Structural diversity estimates, based on traditional diversity methods (i.e., Shannon, Simpson, etc.), showed a similar pattern on all sampled years. Pastures on continuous grazing treatment and no burning had the lowest Shannon, Simpson, and InvSimpson structural diversity values and the highest proportion of abundant layers determined by Berger-Parker index (Table 7). During these same years, a progressive increase in diversity values were observed as time since prescribed burning on pastures with fire and grazing.

Renyi's generalized diversity profiles (Fig. 3) revealed higher layer richness values for pastures between 1 and 3 years after prescribed burning on 2007, 2008, and 2009. During these same years, we can interpret from Renyi's profiles lower evenness of layer abundances on pastures without prescribed burning and those burned early that same year.

Beta diversity

Beta diversity indices can be interpreted as a similarity index, in this case between sampling points within pastures, where continuous grazing points had the highest number of shared layers or were more similar to each other. Although no significant differences were observed in terms of beta diversity of layers between sampling points within pastures (Table 8), some patterns were observed on all measurement. Pastures without prescribed burning and continuous grazing had the highest Ruggeiro's (βrlb) values showing higher levels of shared layers between sampling points. Lennon's (βgl) gradient index showed an increase of number of layers as pastures matured after prescribed burning. During the second year, the number of layers observed on burned pastures surpassed those without a burning treatment. Lennon's (βz) and Routledge (βI) diversity indices showed a reduction in the number of shared layers as pasture age post-fire increased. Magullan's index (βm) indicated lower average change in number of layers between sampling points within pastures with same age during 2007 and 2008. During 2009, pastures with no fire treatment showed average changes in layers observed closer to those observed in mature pastures under prescribed burning treatment (age class 3).

DISCUSSION

Variation in vegetation structure and structural diversity were observed within pastures, which is consistent with studies correlating grazing intensity with vegetation structure (Salo 2003, Townsend and Fuhlendorf 2010). The lowest diversity values on structural components (horizontal and vertical) and diversity were observed on those pastures recently burned and grazed and those under continuous grazing. Similar results were reported on grazed pastures by McCanny et al. (1996) at Grassland National Park in Canada. Davis and Duncan (1999) and Wilmshurst (1999) identified vegetation structural variation as a key factor to understand wildlife distribution. The interaction of both abiotic (fire) and biotic (grazing) factors directly influenced the structural characteristics of pastures (Sala 1988, Bertiller et al. 1995, Collantes et al. 1999). Higher diversity and structural values 1 and 2 years after prescribed burning observed in this study agree with intermediate disturbance hypothesis where areas tend to recover after disturbance reaching maximum diversity and later start to be dominated by late successional species creating more homogeneous areas (Connell 1978). This gradient of vegetation structure driven by rotational fire could be related to habitat structural heterogeneity at landscape level. Different areas would have different ages after disturbance creating a mosaic of structural complexities in the landscape promoting the habitat for a more diverse wildlife community.

The variation detected by this study supports Skinner's (1975) results, who suggests a positive relationship between grazing and an increase of heterogeneity and complexity of areas under grazing pressure. Although it is important to consider that the threshold between diverse vegetation structure and homogeneous areas are highly correlated to disturbance intensity and frequency, plant communities tend to decrease variability becoming structurally homogeneous after continuous stress (Sutter and Ritchison 2005).

Through the implementation of profiles, I was able to observe the progressive change in cover at layers close to the ground, results similar to those reported by Diaz Barradas et al. (1992, 2001). These studies explain this pattern in vegetation structure profiles as a result of the collective interaction of factors such as species composition change, autoecology response, and abiotic variables. Grazing and fire are known factors affecting grassland plant assemblages which are directly related to spatial and temporal variability of vegetation structure through changes on soil nutrient and microorganism cycles (Rossignol et al. 2006) and succession. As a common pattern, plant species assemblages on pastures under extensive grazing and/or fire pressure tend to switch into assemblages dominated by annual cool-season species (Rossignol et al. 2006). Even when the grasslands used on this study showed shifts in plant species composition (Ramirez et al. 2011 unpublished), diversity indices were able to detect differences in plant architecture between pastures. Grassland vegetation structure change over time can affect wildlife use. The use of profiles proved to be useful to detect this change. It may be a good technique to use in order to better understand grassland dynamics and its relationship to wildlife species.

I was able to observe larger diversity changes on pastures under rotational grazing by using traditional diversity indices to describe vegetation structure. This corresponds to systems where two pastures do not have grazing pressure each year allowing plant tissue accumulation and increase of structural complexity. Similar results were reported by Bowen and Kruse (1993) and Hagen et al. (2004). Pastures with low, sparse vegetation had the highest Ruggeiro's values indicating higher occurrence of the same layers among sampling points. In this case, layers closer to ground level, which can be interpreted as low-sparse vegetation with greater structural homogeneity. Lennon's, Routledge's, and Magullan's indices indicate a progressive change in number of layers as vegetation succession developed after initial disturbance. As vegetation and litter started to accumulate and more tall vegetation was observed, more layers created a more complex and diverse structure. Intermediate successional pastures showed higher variability of layers creating more vertical heterogeneous profiles and patchiness.

While the use of diversity values was able to distinguish between treatments and age classes, attention must be paid to natural gradients. For example, grazing preferences and habitat use of wildlife and livestock can create natural structural gradients following initial natural heterogeneity (Adler et al. 2001), i.e. natural land depression gradients can present plant communities varying from mesic-highly palatable species to wetland plant with lower palatability. Similarly, due to differences on forage species palatability, small scale variation on forage utilization may occur and affect vegetation structure (Fynn and O'Connor 2000).

The use of different diversity indices can detect structural variation on grasslands and describe how vegetation layers are distributed on sampled areas. A next step should include the correlation of wildlife data and these indices to identify their ability to estimate habitat use and the vegetation structural variability needed by different species. Being able to measure and detect habitat variability and its reaction to disturbance as fire and grazing could facilitate the understanding of how wildlife are distributed on grasslands (Picket and Cadenasso 1995, Turner et al. 1998). More detailed correlation between structural gradients and species presence/absence may help us better understand what structure variables some species may select for.

The use of pasture management tools, such as grazing and prescribed burning, have been recognized to improve overall habitat for wildlife, however, the effect of these tools on wildlife is not well understod for specific wildlife species (Derner et al. 2009). Structural diversity indices and vegetation profiles, added to the more traditional botanical composition and abiotic factors, could improve our understanding of grassland wildlife-habitat relationships. The use of diversity indices to describe grassland vertical structure can provide a better descriptor of the richness, relative abundance, and evenness of layers on sampled areas; information that can be used to describe areas according to spatial patterns. The use of these indices as vegetation structure indicators provide not only a value for wildlife habitat selection studies, but also a way to visualize the spatial arrangement of vegetation layers selected by wildlife.

A better understanding of the spatial characteristics of vegetation structure can lead to a better understanding of wildlife habitat use, especially grassland birds, helping to improve habitat conditions for nesting bird species (Vickery and Herkert 2001) before, during, and after breeding (Johnson and Temple 1990). The interaction between vegetation structure, topography, grazing, fire, and microclimate defines grassland habitats (Townsend and Fuhlendorf 2010), and more tools are needed to interpret and understand habitat variation and its relations to wildlife. The use of diversity analysis to describe vegetation structure can help close the gap between highly complex interactions and wildlife habitat selection. Better conservation and management strategies directed to create and/or enhance wildlife habitat can be developed and implemented with the use of better and more detailled descriptors of species habitat. The use of diversity analysis to describe structural characteristics and change on grassland ecosystems can be used as an extra tool to understand and stimulate ecosystem function and the habitat patterns needed by wildlife.

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Table1. Cover classes used to record visual obstruction on density board.

Record code	% Cover range
0	0
1	.1 - 5
2	6-15
3	16-25
4	26-50
5	50-75
6	76-95
7	96-100

Table 2. Analysis of variance of structural components and structural diversity on pastures with different ages after prescribed burning.

	2007											
	Age											
	0		1		2		3		4>		*F*	p
Structure												
Height	36.030	c	60.780	ab	48.380	bc	66.260	a	38.530	c	7.890	<0.001
Nstrat	5.585	b	9.550	a	7.100	b	9.000	a	6.067	b	6.160	<0.001
CovSum	11.569	d	22.313	b	17.950	bc	28.650	a	14.858	cd	12.450	<0.001
Ncov	40.950	b	66.850	a	49.700	b	63.000	a	42.470	b	6.160	<0.001
Diversity												
DS	54.700	d	86.740	ab	73.960	bc	97.600	a	66.340	cd	12.420	<0.001
DH	97.580	c	131.220	a	114.980	b	132.140	a	106.120	bc	8.230	<0.001
DV	18.860	b	32.030	a	23.980	b	32.000	a	19.770	b	7.470	<0.001
DT	116.440	c	163.250	a	138.960	b	164.150	a	125.880	bc	8.320	<0.001

Height: Average vegetation height observed on obstruction board (cm).
Nstrat: Number of layers in which vegetation was present.
CovSum: Total vegetation cover.
Ncov: Maximum possible total cover value per sampling point (%).
DS: Diversity of stratification.
DH: Horizontal diversity.
DV: Vertical diversity.
DT: Total diversity.

Table 3. Analysis of variance of structural components and structural diversity on pastures with different ages after prescribed burning.

	2008											
	Age											
	0		1		2		3		4>		*F*	p
Structure												
Height	39.570	b	66.710	a	68.710	a	73.070	a	46.430	b	11.590	<0.001
Nstrat	6.500	b	10.250	a	10.100	a	10.350	a	6.867	b	8.090	<0.001
CovSum	11.130	b	25.630	a	27.270	a	30.110	a	13.450	b	13.450	<0.001
Ncov	45.500	b	71.750	a	70.700	a	72.450	a	48.070	b	8.090	<0.001
Diversity												
DS	54.820	b	90.100	a	93.910	a	100.440	a	62.470	b	17.410	<0.001
DH	108.710	b	133.300	a	134.240	a	139.020	a	113.200	b	13.410	<0.001
DV	20.880	b	35.180	a	35.140	a	36.610	a	22.920	b	10.310	<0.001
DT	129.590	b	168.490	a	169.380	a	175.630	a	129.590	b	13.730	<0.001

Height: Average vegetation height observed on obstruction board (cm).
Nstrat: Number of layers in which vegetation was present.
CovSum: Total vegetation cover.
Ncov: Maximum possible total cover value per sampling point (%).
DS: Diversity of stratification.
DH: Horizontal diversity.
DV: Vertical diversity.
DT: Total diversity.

Table 4. Analysis of variance of structural components and structural diversity on pastures with different ages after prescribed burning.

	2009						
	Age						
	0	1	2	3	4>	*F*	p
Structure							
Height	22.090 [b]	38.210 [a]	46.640 [a]	38.230 [a]	37.630 [a]	5.720	<0.001
Nstrat	4.350 [b]	5.800 [ab]	7.200 [a]	6.700 [a]	6.133 [ab]	3.350	0.013
CovSum	7.063 [b]	14.488 [a]	16.688 [a]	13.288 [a]	13.000 [a]	4.540	0.002
Ncov	30.450 [b]	40.600 [ab]	50.400 [a]	46.900 [a]	42.930 [ab]	3.350	0.013
Diversity							
DS	39.370 [b]	64.600 [a]	71.590 [a]	59.860 [a]	56.200 [a]	5.500	0.001
DH	81.240 [c]	106.900 [ab]	119.220 [a]	105.180 [ab]	102.030 [b]	6.680	<0.001
DV	13.132 [b]	19.608 [a]	23.895 [a]	21.232 [a]	20.312 [a]	4.070	0.004
DT	94.370 [b]	126.510 [a]	143.120 [a]	126.410 [a]	122.340 [a]	6.080	<0.001

Height: Average vegetation height observed on obstruction board (cm).
Nstrat: Number of layers in which vegetation was present.
CovSum: Total vegetation cover.
Ncov: Maximum possible total cover value per sampling point (%).
DS: Diversity of stratification.
DH: Horizontal diversity.
DV: Vertical diversity.
DT: Total diversity.

Table 5. Results of testing continuous grazing vs. patch-burn and rotational treatments on structural diversity for fixed effects with random factors PASTURE and PASTURE*YEAR.from 2007 to 2009.

			Fixed Effects		
		Intercept	**Patch-burn**	**Rotational**	**Fire**
Height	Estimate	46.783	10.012	19.816	-20.588
	SE	5.96	7.146	7.146	-5.96
Nstrat	Estimate	6.356	1.529	2.655	-2.874
	SE	0.816	0.977	0.977	0.793
CovSum	Estimate	13.769	5.018	11.084	-11.899
	SE	2.591	3.106	3.106	2.591
Ncov	Estimate	44.489	10.708	18.583	-20.119
	SE	5.709	6.837	6.837	5.55

Height = Average vegetation height observed on obstruction board (cm).
Nstrat = Number of layers in which vegetation was present.
CovSum = Total vegetation cover.
Ncov = Maximum possible total cover value per sampling point (%).

Table 6. Results of testing continuous grazing vs. patch-burn and rotational treatments on structural diversity for fixed effects with random factors PASTURE and PASTURE*YEAR from 2007 to 2009.

			Fixed Effects		
		Intercept	**Patch-burn**	**Rotational**	**Fire**
DS	Estimate	39.075	11.311	20.538	-23.619
	SE	5.598	6.711	6.711	5.598
DV	Estimate	14.069	0.955	0.0177	-1.472
	SE	0.564	0.677	0.677	0.564
DH	Estimate	17.072	3.666	4.274	-4.881
	SE	2.667	3.172	3.172	2.115
DT	Estimate	31.141	4.629	4.3	-6.385
	SE	2.926	3.481	3.481	2.365

DS = Diversity of stratification.
DH = Horizontal diversity.
DV = Vertical diversity.
DT = Total diversity.

Table 7. Diversity values for 5 successional stages after prescribed burning and seasonal grazing pressure.

	Age				
	0	**1**	**2**	**3**	4>
2007					
Shannon	1.93	2.18	2.15	2.28	1.86
Simpson	0.83	0.866	0.869	0.883	0.816
InvSimpson	5.87	7.48	7.63	8.58	5.44
Berger-Parker	0.265	0.191	0.166	0.151	0.249
2008					
Shannon	2.03	2.37	2.25	2.38	1.96
Simpson	0.847	0.891	0.884	0.894	0.84
InvSimpson	6.52	9.18	8.59	9.42	6.26
Berger-Parker	0.213	0.146	0.147	0.138	0.218
2009					
Shannon	1.84	1.89	1.94	2.03	1.88
Simpson	0.812	0.82	0.836	0.842	0.803
InvSimpson	5.31	5.55	6.12	6.34	5.07
Berger-Parker	0.279	0.24	0.211	0.242	0.305

Table 8. Beta diversity values for pastures at 5 successional stages after prescribed burning and grazing pressure between 2007 and 2009.

	Age					
	0	**1**	**2**	**3**	***4 >***	***p***
Ruggeiro (βrlb)						
2007	0.569	0.537	0.558	0.513	0.579	*0.620*
2008	0.608	0.629	0.586	0.537	0.606	*0.068*
2009	0.591	0.519	0.628	0.519	0.615	*0.170*
Lennon (βgl)						
2007	0.405	0.390	0.250	0.276	0.299	*0.190*
2008	0.340	0.264	0.193	0.284	0.292	*0.420*
2009	0.340	0.322	0.208	0.433	0.374	*0.190*
Lennon (βz)						
2007	0.250	0.241	0.162	0.178	0.191	*0.200*
2008	0.210	0.171	0.129	0.182	0.185	*0.470*
2009	0.209	0.205	0.139	0.263	0.233	*0.190*
Routledge (βI)						
2007	0.101	0.097	0.073	0.078	0.083	*0.240*
2008	0.085	0.074	0.058	0.079	0.078	*0.550*
2009	0.083	0.087	0.063	0.102	0.096	*0.170*
Magullan (βm)						
2007	3.210	4.610	3.350	3.970	2.870	*0.230*
2008	3.400	4.310	3.090	4.650	2.970	*0.190*
2009	2.500	2.900	2.490	3.570	3.500	*0.570*

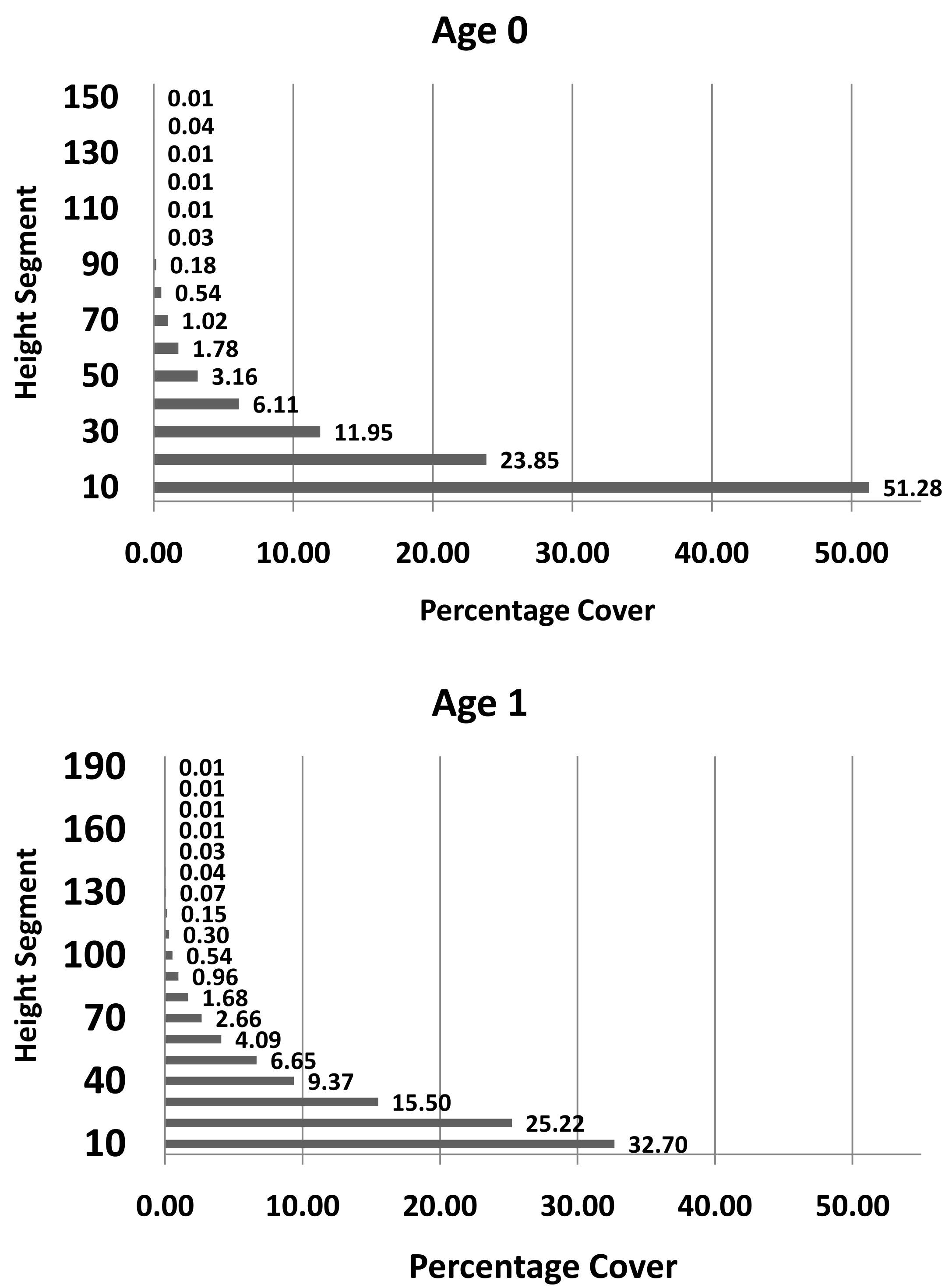
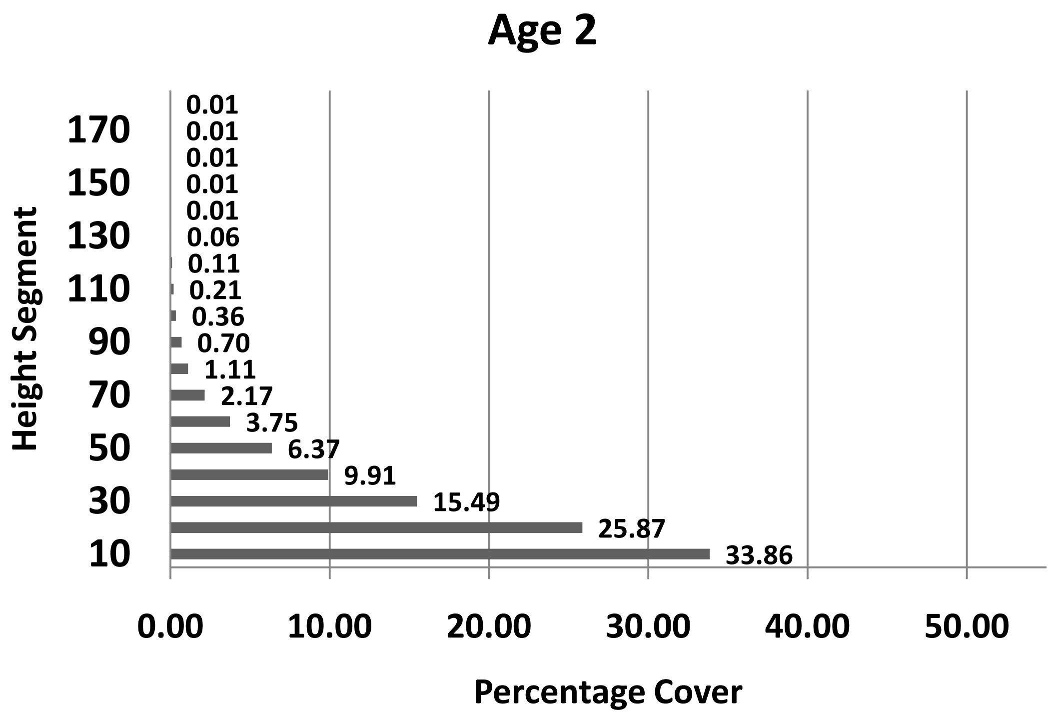


Figure 1. Structural profiles of vegetation on 5 succesional stages after prescribed burning and grazing pressure (0 to ≥ 4 years after fire) between 2007 and 2009.



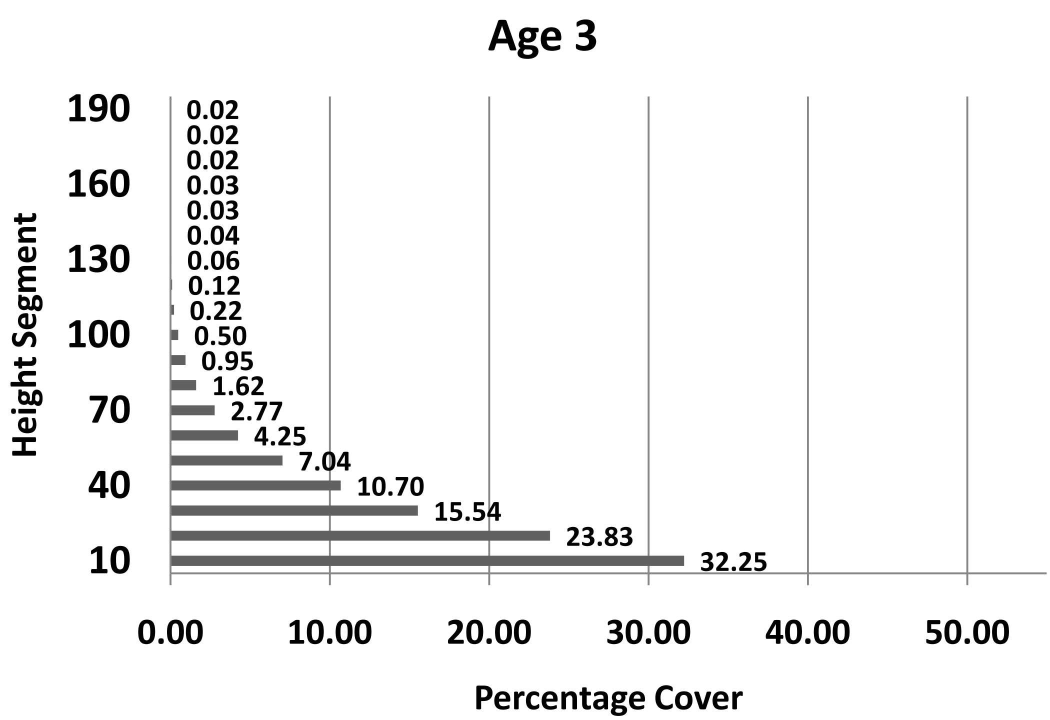


Figure 1 Cont.

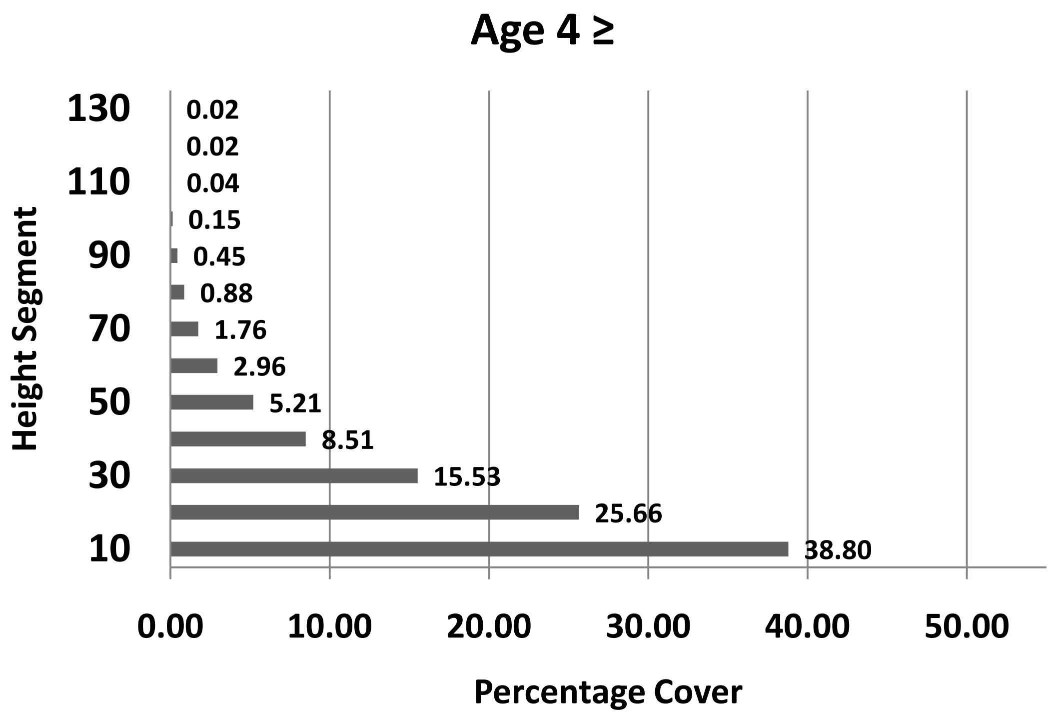
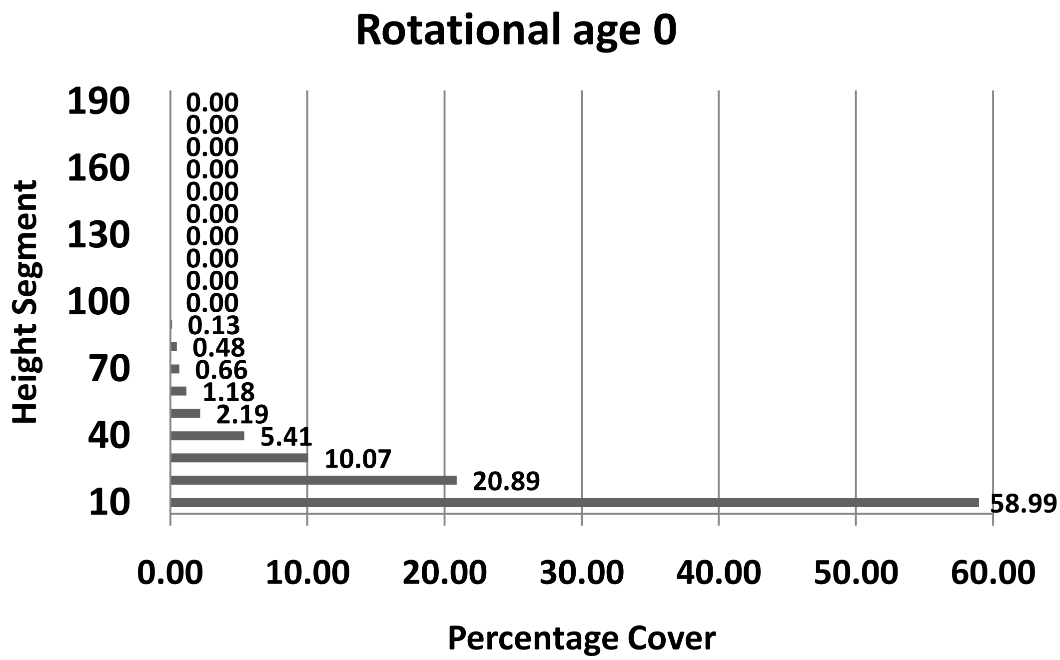


Figure 1 Cont.



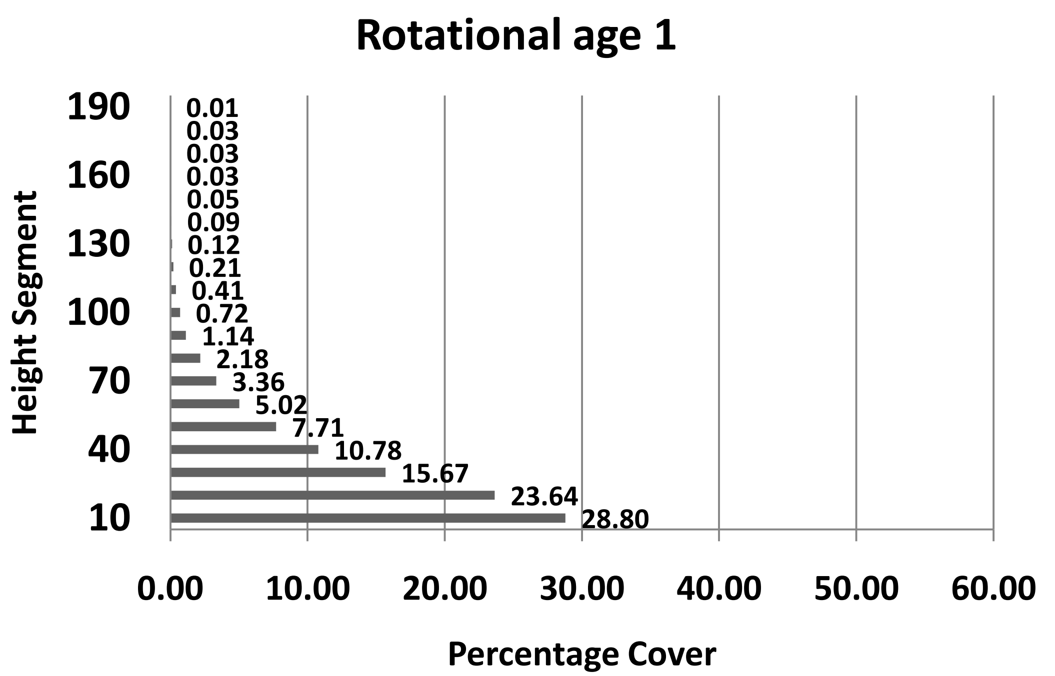
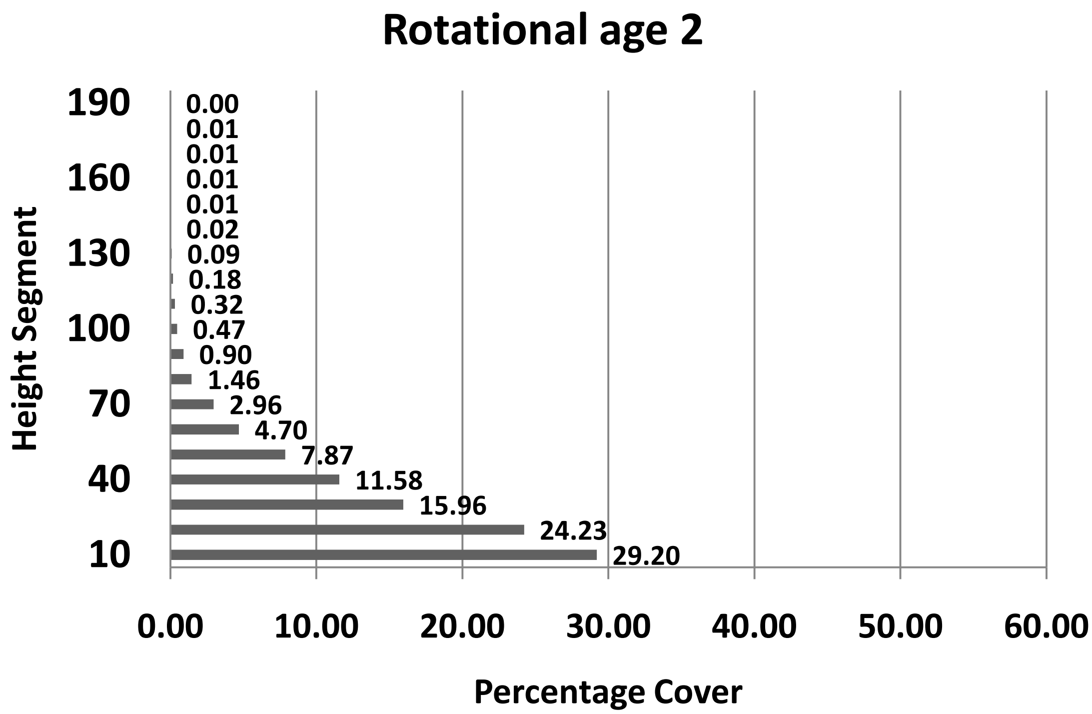


Figure 2. Structural profiles of vegetation on pastures under continuous, patch-burning and rotational grazing between 2007 and 2009. Rotational and patch-burning grazing systems include pastures with ages ranging from 0 to 3 years after fire. Continuous grazing pastures had more than 4 years after fire treatment.



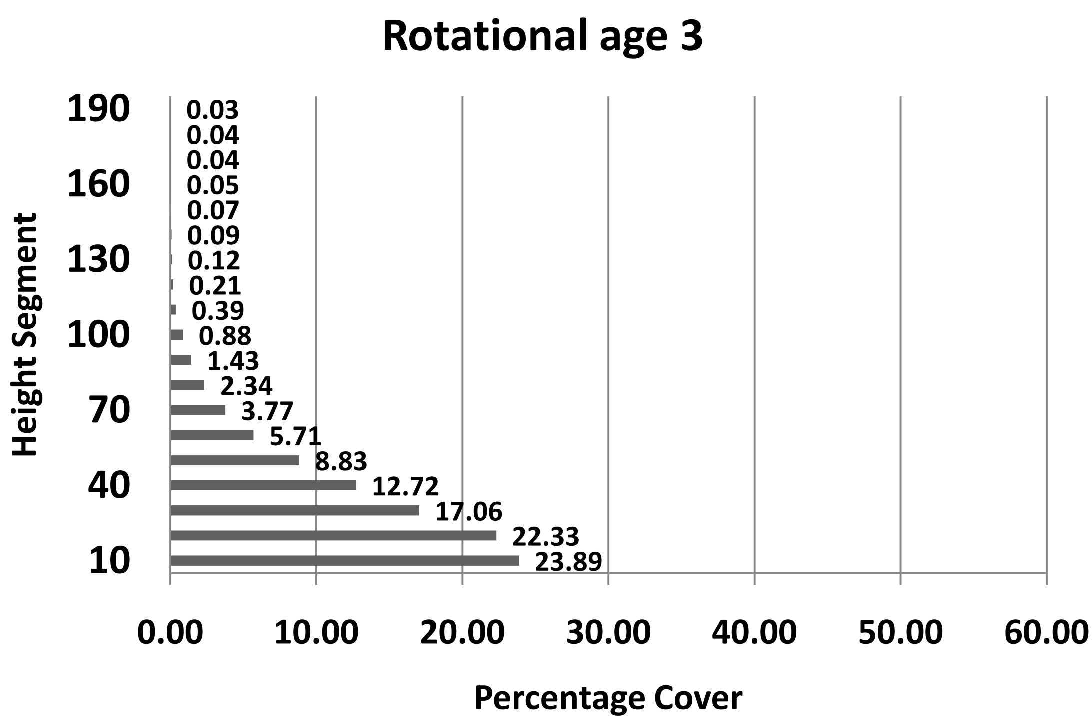
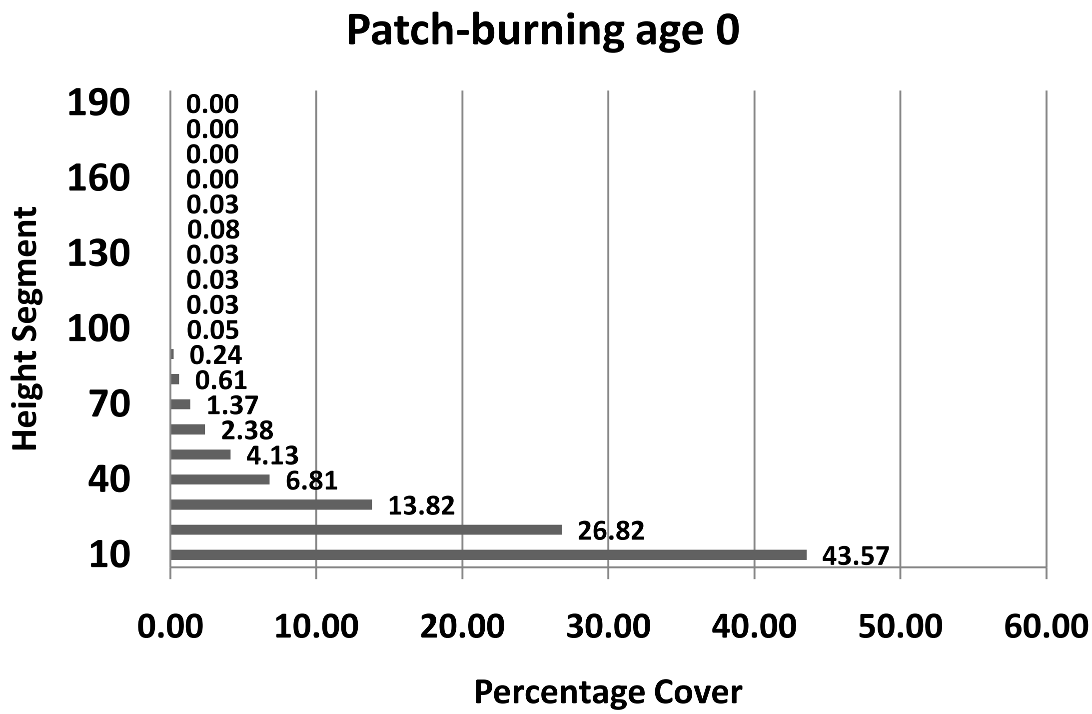


Figure 2 Cont.



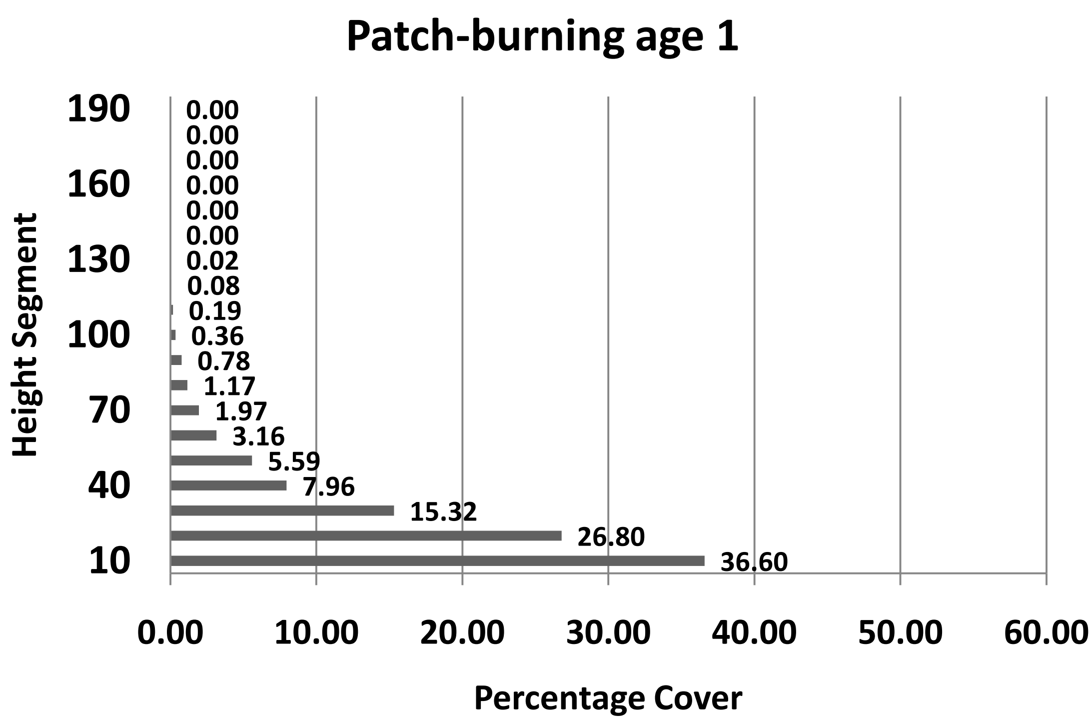
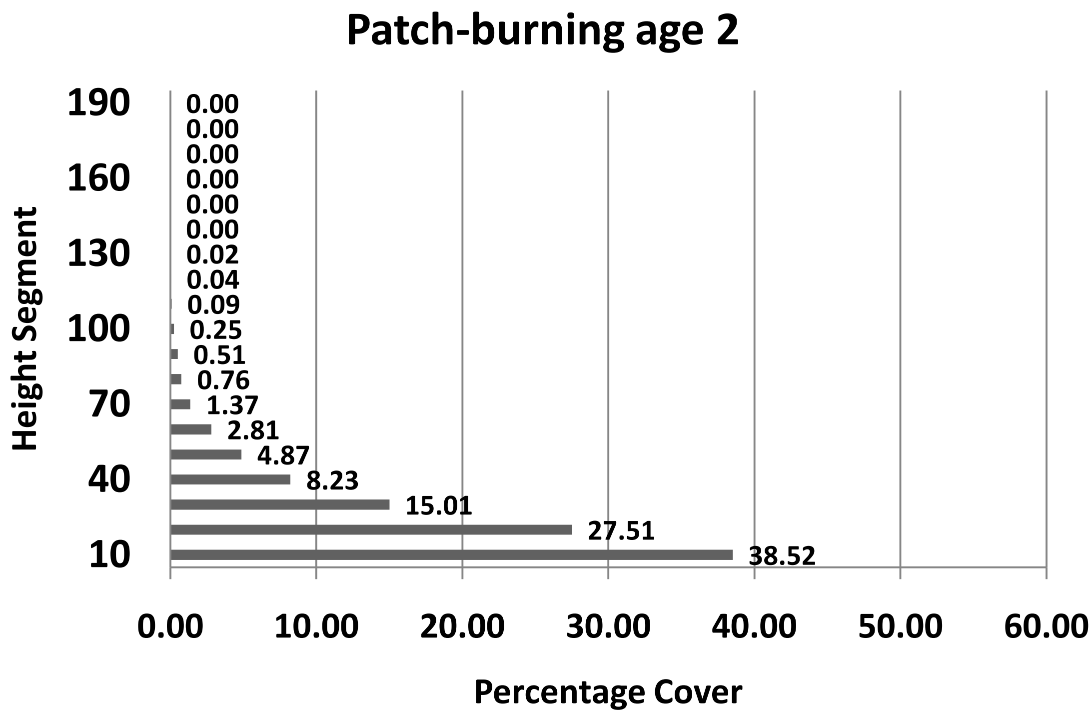


Figure 2 Cont.



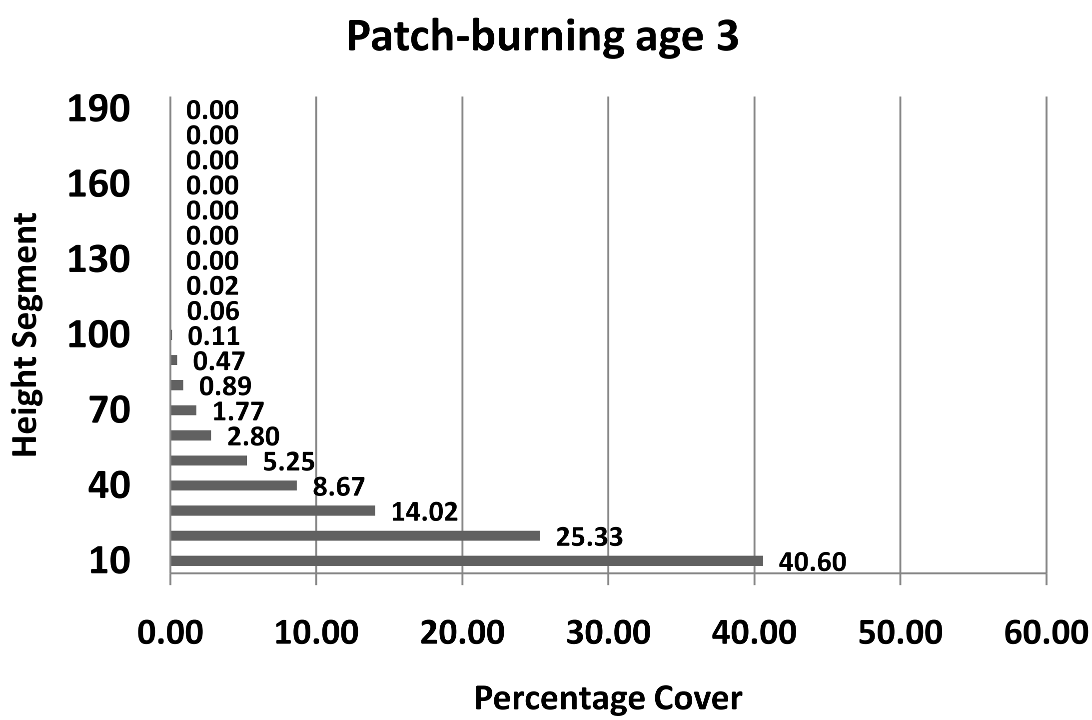


Figure 2 Cont.

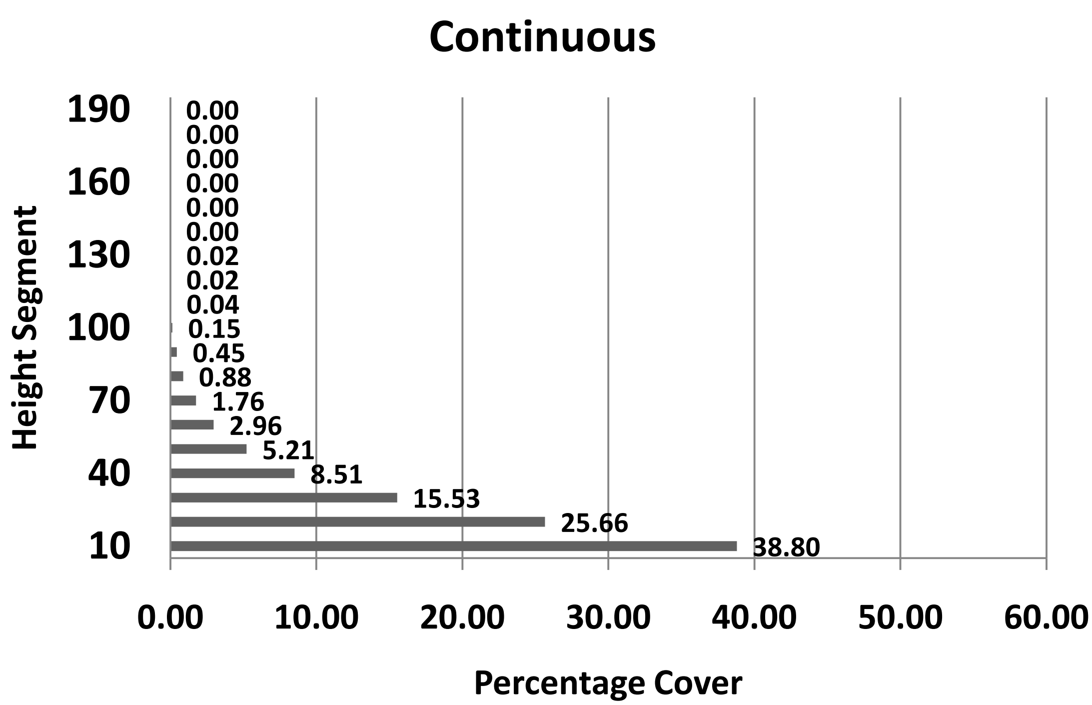


Figure 2 Cont.

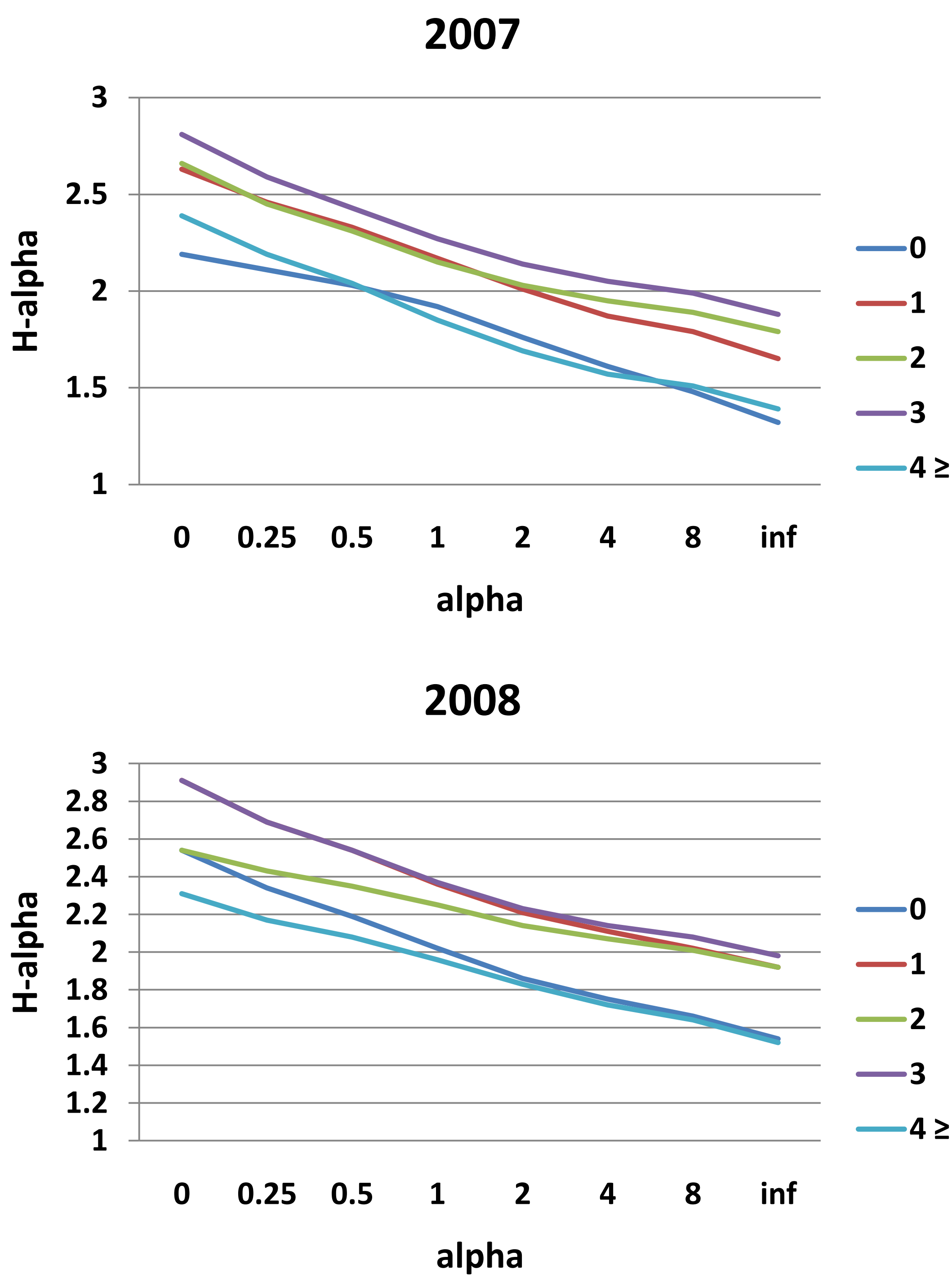


Figure 3. Renyi's generalized diversity profiles on pastures at 5 successional age classes after prescribed burning and grazing pressure between 2007 and 2009.

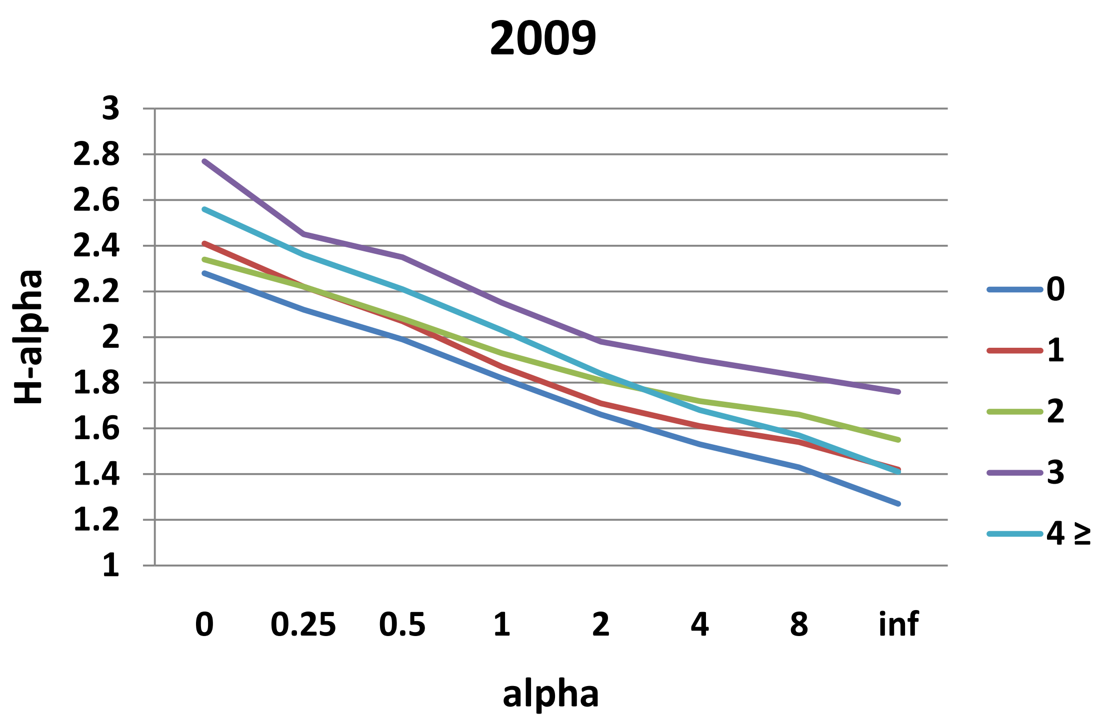


Figure 3 Cont

Effect of management strategies and time since prescribed burning on forage quality in pastures the central Platte River valley of Nebraska, USA.

INTRODUCTION

Grasslands are ecosystems that are maintained primarily by frequent disturbances. Some of the disturbances come from drought, but additional disturbances come from fire and grazing (Briggs et al. 2005) which are important for maintenance of natural grasslands. These disturbances create a complex spatio-temporal distribution of successional stages (Collins 1987) and, as a consequence, different plant communities with different forage qualities. The general pattern on natural grasslands is the presence of fire, natural or anthropogenic, followed by grazing animals, formerly bison, looking for fresh nutritious forage regrowth (Janis et al. 2002). These two processes drive grassland dynamics (Noy-Meir 1995, Johnson and Matchett 2001), as well as the plant communities linked to them. Severe ecosystem changes, such as shifts in species composition and susceptibility to exotic species invasion or woody plant encroachment, occur when fire and/or grazing patterns are altered (Vickery et al. 2000) reducing the forage quality.

In the past, the ultimate objective of livestock enterprises was to maximize profit and optimumize use of nutrients in the forage resource. To improve economic productivity, patchy-heterogeneous grazing was eliminated (Burboa-Cabrera 1997). However, the conservation of grasslands requires a mosaic approach where several patches of vegetation composition and structure are present (Skinner et al. 1984, Renken and Dinsmore 1987, Howe 1994). Some have proposed low stocking rates, rotational grazing (Kauffman and Kruger 1984), or periodic rest periods (Kauffman et al. 1983) as an approach to maintaining range health, but few studies have considered the interaction of these factors to achieve ecosystem health and forage quality (Hartnett et al. 1996, Coppedge et al. 2001, Fuhlendorf and Engle 2004, Fynn et al. 2004)

Grasslands are important from both agronomic and ecological perspectives (Briggs et al. 2005). The Great Plains have an important role in food production; these extensive landscapes are heavily used as pasture to raise livestock. However, the compatibility of production and conservation objectives can be achieved when management practices are focused on maintaining diverse grasslands (Hartnett et al. 1996, Collins et al. 1998, Coppedge et al. 2001, Fuhlendorf and Engle 2004).

Cattle grazing effects on grasslands are dependent on a number of factors including timing and grazing pressure. Too many animals on a pasture can result in decrease in forage yield and availability, but, if animals are moved after short intervals, grazing stress over forage plants can be reduced and sometimes beneficial plant responses can be achieved. Most grassland plant communities assemblages evolved under some type of grazing pressure, and these assemblages can be stabilized when grazing patterns are mantained. Frequency and intensity are fundamental factors to consider for grazing systems. Plant response to these two factors has been identified in relation to forage quality, quantity, palatability, plant survival, and establishment (Taylor et al. 1993). Under moderate grazing intensity and frequency, plant biodiversity, forage productivity, and quality tend to improve while the reverse occurs in highly stocked continuously grazed systems (Mitchley 2001, White et al. 2004). Low productivity from grazed pastures can be related to decreased vigor and growth rates. There is a close relationship between grazing and plant diversity, biomass production, and forage quality. Botanical composition can be altered by grazing at the time that both more palatable and nutritious species are affected and low quality forage can be promoted (Hart 1993), then plants avoided by grazers can compete successfully and non target species become predominant (Valentine 1990).

In general terms, prescribed burning can affect forage production in two main ways: increasing soil nitrogen availability and, as a consequence, increasing forage crude protein (Augustine et al. 2010), and removing old standing dead and litter and increasing young highly nutritious plants (Waterman and Vermeire 2011). As a consequence, forage plants on pastures under treatment with fire return to similar phenological stages balancing forage quality along the pasture for a short period of time (Hobbs et al. 1991). Quality is maintained as a consequence of intensive grazing pressure maintaining grass in the vegetative stage. According to Anderson et al. (2007), fire and grazing can affect the quality of forage directly or indirectly through plant species diversity. The presence of palatable nutritious species richness and/or abundance can greatly affect the quality of forage available to cattle.

My objective was to determine how the forage quality of grasslands along the Platte River in south central Nebraska would change in response to different land management strategies and time since prescribed burning on pastures influenced by long-term season-long continuous grazing or fire rotation. My two main hypothesis are that pastures with prescribed burning and lower grazing pressure can potentially produce higher quality forage then that produced on continuously grazed pastures; secondly, that pastures historically used under season-long continuous grazing would no longer have the capability to maintain high quality forage during the grazing season. I considered patch-burn, rotational grazing, and season-long continuous grazing as the three approaches to evaluate. Patch-burn and rotational grazing have been formerly used as alternative grazing systems in Nebraska, but no detailed scientific evaluation has been done in the Platte River valley. Season-long continuous grazing is the preferred method used by most cattle producers in these pastures and wet meadows.

METHODS

Study Site

This study was conducted in the central Platte River valley area of Nebraska on The Crane Trust property during three years starting in summer 2007. Ten pastures from The Crane Trust and two from area producers were used as experimental units. The Crane Trust is comprised of about 4,000 ha of cropland, pastures, and hay meadows along the Platte River in Buffalo, Hall, and Phelps counties, Nebraska. All pastures included in this study are located in Hall County. Climate is continental, with 160 frost-free growing days. Mean average temperature is 10°C with January minimum average of 11.6°C and average August temperature of 29.3°C. Average precipitation is 630 mm, occurring mainly from May through September. Soils consist of loamy or sandy alluvial deposits (Henszey et al. 2004). In the area adjacent to the Platte River, ecosystems are characteristic of tallgrass prairie with woody encroachment of eastern cottonwood (*Populus deltoides*) forests interspersed with willows (*Salix* spp.) and eastern redcedar (*Juniperus virginiana*). Dominant vegetation includes sedges (*Carex* spp.), rushes (*Eleocharis palustris, Scirpus* spp.*, and Juncus* spp.), and prairie cordgrass (*Spartina pectinata*) in lowland meadows (Curier et al. 1985). Mesic grasslands are characterized by big bluestem (*Andropogan gerardii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutants*), Canada wildrye (*Elymus canadensis*), and switchgrass (*Panicum virgatum*). Common forbs include goldenrods (*Solidago* spp.) and prairie clovers (*Dalea* spp.). Many prairies contain non-native cool-season grasses including smooth bromegrass (*Bromus inermis*), Kentucky bluegrass (*Poa pratensis*), red top (*Agrostis stolonifera*), and tall fescue (*Lolium arundinaceum*).

Treatments

The first treatment consisting of continuous season-long grazing was considered as a control treatment and representative of the land management scheme most commonly used in this area. Under this system, pastures of variable sizes ranging from 20 to 100 ha were grazed with cow-calf pairs during summer and spring with medium to high stocking rates (>2.5 AUM/ha) without application of fire. The second treatment, patch-burn grazing, used large pastures (>80 ha) divided into four sections or burning units with no fences between them. The stocking rated ranged between 1.5 and 2 AUM/ha. In a 4-year rotation cycle, the whole pasture was burned after applying prescribed fire to each unit. The rationalization behind this system considers that newly burned areas would offer fresh forage regrowth which is preferred by cattle. As a consequence, a concentration of grazing pressure on burned areas and avoidance of previously burned sections would create a condition where four different vegetation structure and litter accumulation levels should be present in each treatment pasture.

Finally, the third treatment consisted of a modified rest rotational grazing system, consisting of four pastures of 50 to 250 ha where one was burned each year. In this system only two pastures were grazed each year leaving two pastures without any type of disturbance. Considering a four-year rotation cycle, pasture 1 would be managed with an early spring prescribed burn and grazed during May and June with high stocking rates (>3.5 AUM/ha). After these two initial months, cattle would be moved to pasture 2, which was burned the year before, to be grazed during July and August. Finally, cattle were returned to pasture 1 on September to finish the grazing season in mid-October. Pastures 3 and 4 were not grazed. The following year pasture 4 (after been rested for 2 years) would be burned in the spring and paired with pasture 1 for grazing.

Experimental design

The experimental design consisted of the three treatments described above with two replicates for rotational and patch-burn treatments and three for continuously grazed pastures. All grasslands used in this research were at least 1.6 km from the river bank historically and used as pasture or hay meadows for the previous 5+ years. All selected areas were under continuous grazing or fire rotation management for at least 10 year prior this research. Former hay meadows were conditioned as pastures at least 2 years before data collection. Rotational and patch-burning pastures were managed with fire every 3- to 4-years for more than 10 years. Prescribed burning was conducted after snow melt in March or April.

Data collection

Forage sampling was conducted during the last week of May, June, July, and August from each pasture from 2007 through 2009. During 2009, samples from the July collection were lost due to problems with the drying room and contamination by fungus.

The sampling protocol consisted of collecting a composite sample of forage from each pasture. To achieve this, 50 random forage clippings at ground level from 20 x 50 cm quadrants were collected and placed in paper bags. Four samples were collected from pastures under patch-burning grazing to correspond to the four areas burned in different years. Pastures on rotational and continuous grazing treatments were individually sampled. The criteria used to take forage samples was to collect a mixture all grasses, grass-like plants, legumes, and forbs excluding those plant species known to be avoided by cattle such as smooth sumac (*Rhus glabra*) or mature prairie cordgrass (*Spartina pectinata*).

Sample analysis

Following collection, paper bags containing the samples were placed in a forced air oven set at 60°C for 72 hours. Dried samples were ground using a Willey mill to pass a 1 mm screen in preparation for analyses. The Ward Laboratories Inc. in Kearney, NE analyzed the samples for dry matter (DM), crude protein (CP), acid detergent fiber (ADF), total digestible nutrient (TDN), net energy-maintenance (NEM), net energy-gain (NEG), and net energy-lactation (NEL) following standard National Forage Testing Association procedures (Undersander et al. 1993)

Data were analyzed using analysis of variance (ANOVA) and mixed-models. ANOVA calculations were performed using the Minitab® statistical software program (Minitab Inc. 2009). Mixed model analyzes were performed using R-Software (R Team 2011).

RESULTS

Forage analyses showed significant differences among all variables between years (Table 1). As expected, because of higher ADF values (41%), 2007 had lower nutritional values than in 2008 and 2009. Although no significant differences between treatments were observed in all years (Table 2), 2008 showed highly significant differences for all forage quality values (Table 3). This pattern change on forage quality for pastures under different treatments could be related to a change on average rainfall during 2008 when rainfall was abnormally high in May and June (Fig. 1).

When divided by time since prescribed burning, no significantly different forage quality values were detected (Table 4). Crude protein decreased on all treatments as the year progressed (Fig. 2), acid detergent fiber increased (Fig. 3) and as direct relationship TDN (Fig. 4), NEM (Fig. 5), NEG (Fig. 6), and NEL (Fig. 7) decreased. Continuously grazed pastures showed a decrease in ADF and an increase on digestibility and net energy values later during the season.

When analyzed with mixed models, forage quality on continuously grazed pastures showed higher CP, TDN, NEM, NEG, and NEL and lower ADF values when compared to patch-burn and rotational grazing treatments (Table 5). When I consider the fixed effect of prescribed burning I observed an increase in CP, TDN, NEM, NEG, and NEL and a decrease in ADF.

DISCUSSION

Similar forage quality values across treatments could be influenced by plant species composition and maturity. This study area received unusual amounts of rainfall from 2007 to 2009. This phenomenon could be linked to a change in plant diversity as reported by Currier (1989) and Ramirez (unpublished), where higher water tables produced plant assemblages with higher abundance of species adapted to wet conditions as swales sedge (*Carex aqutillis*), spikerush (*Eleocharis obtusa*), or even warm-season grasses as switchgrass (*Panicum virgantum*) which is palatable for cattle during vegetative stage but is avoided later during the season once it becomes coarse (Mitchell et al. 1994). Pastures under rotational and patch-burn grazing were dominated by native warm-season species, and pastures under continuous grazing showed plant assemblages highly dominated by introduced cool-season grasses as Kentucky bluegrass (*Poa pratensis*) and smooth bromegrass (*Bromus inermis*). Akin and Burdick (1975) found higher values of digestibility for cool-season grasses due to a reduced amount of digestible vascular and structural tissues. In general, cool-season forage has higher quality than warm-season grasses (Barnes et al. 2003). Reid et al. (1988) found lower CP values for warm-season grasses when compared to cool-season grasses.

When water availability is not limited, intensive grazing can keep plants in a prolonged vegetative stage. Plant growth stage greatly affects nutrient concentration and availability. During plant growth and development, cell cytoplasm is high due to a lower proportion of fiber in the form of cellulose, hemicelluloses, and lignin (Salisbury and Ross 1992). As forage plants mature, cellular changes take place altering cell wall thickness and reducing nutritive value. Twidwell et al. (1987) found that ADF of switchgrass increased as plants matured and resulted in a drop in *in vitro* digestibility. Under favorable environmental conditions, as those observed between 2007 and 2009, cool-season grasses can start a second vegetative stage of short duration resulting in increased forage quality even when quantity remains low (Huston and Pinchak 1991). TDN of forage in August increased in pastures under continuous grazing, which could be linked to regrowth of cool-season grasses. The observed decrease on ADF and increased digestibility on continuously grazed pastures could be linked to a higher proportion of cool-season grasses (Ramirez, unpublished data). Given weather patterns during this study where water availability was not limited later during the season, most cool-season grasses resumed growth late in the season which improved forage quality.

The above average rainfall pattern observed between 2007 and 2009 probably stimulated cool-season grasses by increasing available nitrogen as a response of mineralization and deposition of ash and atmospheric nitrogen, which increase forage quality (USGS 1999). Sandras and Baldock (2003) reported that frequent rainfall events could mineralize more than 70 kg N/ha when seasonal precipitation exceeded 300 mm.

Even when forage quality values behaved similarly across all treatments and time since prescribed burning, it is important to consider quantity as a limited factor. Pastures under continuous grazing maintained high quality forage but in low quantities. One year after prescribed burning, all pastures under rotational and patch-burn grazing had higher biomass production then those continuously grazed as inferred from higher average vegetation height and litter accumulation (Ramirez unpublished, see chapter 2).

CONCLUSION

In general, most improvements in forage quality observed in this study can be attributed to earlier growth and delayed senescence. Young tissues were of higher quality because of an increase of digestible cell solubles relative to cell wall constituents. Furthermore, low quality forage later in the season was related to highly lignified old plants (Bidwell 1974). Overall, since animals have the ability to graze selectively, it is often unreliable to relate improvements in forage quality directly to improvements in animal diets (Valentine 1990). Grazing selectivity may dramatically improve the nutritional makeup of cattle diets which otherwise would be severely underestimated by observing improvements in the forage alone.

Unfortunately, forage quality during this study was likely masked by unusual environmental conditions where water availability stimulates plant growth on cool-season species dominated pastures. No specific advantages on pastures historically used fire rotation was observed when compared with continuously grazed areas. Further interpretations should consider the fact that the occurrence of these weather conditions is low and most likely forage quality will behave differently on average and dry years.

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Table 1. Mean forage quality values for all pastures under continuous, rotational, and patch-burn grazing treatments.

	Year							
	2007		**2008**		**2009**		**F**	***P***
CP	9.118b	b	10.772	a	10.04	ab	8.11	0.001
ADF	40.988	a	37.783	b	38.818	b	14.66	0.001
TDN	57.105	b	60.682	a	59.53	a	14.65	0.001
NEM	1.210	b	1.329	a	1.291	a	14.69	0.001
NEG	0.645	b	0.753	a	0.719	a	14.43	0.001
NEL	1.281	b	1.368	a	1.341	a	14.75	0.001

CP: Crude Protein, %.
ADF: Acid Detergent Fiber, %.
TDN: Total Digestible Nutrients, %.
NEM: Net Energy-Maintenance, Mcal/Kg.
NEG: Net Energy-Gain, Mcal/Kg.
NEL: Net Energy-Lactation, Mcal/Kg.

Table 2. Mean forage quality values for pastures under continuous, rotationa,l and patch-burn grazing treatments between 2007 to 2009.

	Treatment							
	Continuous		**Patch-Burn**		**Rotational**		**F**	***p***
CP	10.820	a	9.760	a	9.860	a	2.130	0.121
ADF	38.620	a	40.010	a	38.680	a	2.960	0.054
TDN	59.750	a	58.190	a	59.680	a	3.040	0.051
NEM	1.299	a	1.247	a	1.296	a	2.960	0.054
NEG	0.726	a	0.680	a	0.723	a	2.840	0.061
NEL	1.346	a	1.308	a	1.344	a	3.020	0.051

CP: Crude Protein, %.
ADF: Acid Detergent Fiber, %.
TDN: Total Digestible Nutrients, %.
NEM: Net Energy-Maintenance, Mcal/Kg.
NEG: Net Energy-Gain, Mcal/Kg.
NEL: Net Energy-Lactation, Mcal/Kg.

Table 3. Mean forage quality values for pastures under continuous, rotational, and patch-burn grazing treatments for 2007, 2008 and 2009.

	2007							
	Treatment							
	Continuous		**Patch-Burn**		**Rotational**		**F**	***p***
CP	9.467	a	8.737	a	9.525	a	1.110	0.337
ADF	41.417	a	41.091	a	40.450	a	0.220	0.806
TDN	56.658	a	56.978	a	57.725	a	0.210	0.808
NEM	1.195	a	1.205	a	1.230	a	0.200	0.821
NEG	0.632	a	0.643	a	0.663	a	0.190	0.828
NEL	1.270	a	1.277	a	1.295	a	0.210	0.812
	2008							
CP	12.250	a	10.394	a	11.625	a	2.710	0.076
ADF	36.583	ab	39.450	a	35.788	b	4.650	0.014
TDN	62.000	ab	58.813	b	62.925	a	4.680	0.014
NEM	1.374	a	1.268	b	1.402	a	4.640	0.014
NEG	0.794	a	0.697	b	0.903	a	4.630	0.014
NEL	1.401	a	1.323	b	1.423	a	4.650	0.014
	2009							
CP	10.733	a	10.283	a	9.440	a	0.540	0.585
ADF	37.611	a	39.611	a	39.520	a	0.860	0.432
TDN	60.900	a	58.992	a	58.760	a	0.890	0.421
NEM	1.336	a	1.274	a	1.265	a	0.850	0.435
NEG	0.761	a	0.703	a	0.695	a	0.840	0.440
NEL	1.373	a	1.327	a	1.321	a	0.870	4.270

CP: Crude Protein, %.
ADF: Acid Detergent Fiber, %.
TDN: Total Digestible Nutrients, %.
NEM: Net Energy-Maintenance, Mcal/Kg.
NEG: Net Energy-Gain, Mcal/Kg.
NEL: Net Energy-Lactation, Mcal/Kg.

Table 4. Mean forage quality values for pastures at different ages after prescribed burning for patch-burn, rotational, and continuous grazing treatments between 2007 and 2009.

Sample 1

	Patch-Burn				**Rotational**				**Continuous**		
Age	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**4**	**F**	***p***
CP	11.5[a]	10.73[a]	9.8[a]	11.36[a]	13.91[a]	11.98[a]	11.06[a]	10.11[a]	12.51[a]	1.94	0.075
ADF	36.91[a]	36.46[a]	38.8[a]	36.4[a]	34.01[a]	34.83[a]	36.83[a]	39.55[a]	37.04[a]	1.53	0.172
TDN	61.68[a]	62.13[a]	59.58[a]	62.21[a]	64.9[a]	63.96[a]	61.76[a]	58.73[a]	61.52[a]	1.52	0.175
NEM	1.359[a]	1.376[a]	1.291[a]	1.378[a]	1.464[a]	1.433[a]	1.361[a]	1.263[a]	1.355[a]	1.53	0.173
NEG	0.782[a]	0.797[a]	0.721[a]	0.800[a]	0.877[a]	0.849[a]	0.784[a]	0.695[a]	0.778[a]	1.53	0.173
NEL	1.389[a]	1.401[a]	1.339[a]	1.403[a]	1.469[a]	1.446[a]	1.391[a]	1.318[a]	1.386[a]	1.52	0.175

Sample 2

	Patch-Burn				**Rotational**				**Continuous**		
Age	**0**	**1**	**2**	**3**	**0**	**1**	**2**	**3**	**4**	**F**	***p***
CP	10.35[ab]	10.11[b]	10.55[ab]	10.86[ab]	13.73[a]	10.45[ab]	10.2[ab]	10.42[ab]	10.32[b]	2.12	0.052
ADF	38.41[ab]	39.067[ab]	40.6[a]	38.88[ab]	35.18[b]	37.06[ab]	37.75[ab]	38.43[ab]	38.2[ab]	1.68	0.129
TDN	59.95[ab]	59.26[ab]	57.51[b]	59.43[ab]	63.56[a]	61.51[ab]	60.71[ab]	59.95[ab]	60.24[ab]	1.68	0.128
NEM	1.304[ab]	1.281[ab]	1.223[b]	1.287[ab]	1.422[a]	1.354[ab]	1.329[ab]	1.304[ab]	1.313[ab]	1.65	0.136
NEG	0.740[ab]	0.732[ab]	0.658[b]	0.717[ab]	0.838[a]	0.778[ab]	0.754[ab]	0.732[ab]	0.740[ab]	1.64	0.139
NEL	1.348[ab]	1.331[ab]	1.289[b]	1.335[ab]	1.437[a]	1.385[ab]	1.367[ab]	1.348	1.355[ab]	1.67	0.13

Table 4. Continuation

Sample 3

Age	Patch-Burn 0	Patch-Burn 1	Patch-Burn 2	Patch-Burn 3	Rotational 0	Rotational 1	Rotational 2	Rotational 3	Continuous 4	F	*p*
CP	9.37 ^{ab}	8.02 ^{ab}	9.35 ^{ab}	8.87 ^{ab}	11 ^{a}	8.17 ^{ab}	8.65 ^{ab}	6.75 ^{b}	10.25 ^{ab}	2.26	0.051
ADF	39.67 ^{a}	41.77 ^{a}	42.02 ^{a}	40.35 ^{a}	36.92 ^{a}	41.92 ^{a}	39.12 ^{a}	39.8 ^{a}	40.11 ^{a}	0.82	0.591
TDN	58.55 ^{a}	56.18 ^{a}	55.92 ^{a}	57.82 ^{a}	61.65 ^{a}	56.07 ^{a}	59.2 ^{a}	58.45 ^{a}	58.16 ^{a}	0.84	0.58
NEM	1.258 ^{a}	1.179 ^{a}	1.168 ^{a}	1.232 ^{a}	1.359 ^{a}	1.172 ^{a}	1.277 ^{a}	1.252 ^{a}	1.240 ^{a}	0.82	0.593
NEG	0.690 ^{a}	0.618 ^{a}	0.608 ^{a}	0.667 ^{a}	0.782 ^{a}	0.611 ^{a}	0.707 ^{a}	0.684 ^{a}	0.673 ^{a}	0.82	0.595
NEL	1.314 ^{a}	1.257 ^{a}	1.249 ^{a}	1.296 ^{a}	1.389 ^{a}	1.253 ^{a}	1.329 ^{a}	1.311 ^{a}	1.302 ^{a}	0.82	0.588

Sample 4

Age	Patch-Burn 0	Patch-Burn 1	Patch-Burn 2	Patch-Burn 3	Rotational 0	Rotational 1	Rotational 2	Rotational 3	Continuous 4	F	*p*
CP	9.26 ^{a}	8.48 ^{a}	7.43 ^{a}	8.95 ^{a}	8.28 ^{a}	6.91 ^{a}	6.86 ^{a}	7.63 ^{a}	10.02 ^{a}	1.32	0.258
ADF	41.65 ^{a}	43.26 ^{a}	44.2 ^{a}	42.81 ^{a}	41.23 ^{a}	44.43 ^{a}	42.15 ^{a}	40.75 ^{a}	39.62 ^{a}	1.55	0.164
TDN	56.21 ^{a}	54.56 ^{a}	53.56 ^{a}	55.06 ^{a}	56.83 ^{a}	53.25 ^{a}	55.81 ^{a}	57.38 ^{a}	58.63 ^{a}	1.55	0.167
NEM	1.178 ^{a}	1.123 ^{a}	1.087 ^{a}	1.138 ^{a}	1.198 ^{a}	1.077 ^{a}	1.165 ^{a}	1.217 ^{a}	1.259 ^{a}	1.55	0.165
NEG	0.628 ^{a}	0.566 ^{a}	0.533 ^{a}	0.579 ^{a}	0.635 ^{a}	0.523 ^{a}	0.605 ^{a}	0.653 ^{a}	0.690 ^{a}	1.58	0.157
NEL	1.257 ^{a}	1.216 ^{a}	1.191 ^{a}	1.229 ^{a}	1.271 ^{a}	1.184 ^{a}	1.247 ^{a}	1.285 ^{a}	1.316 ^{a}	1.54	0.167

Age: Time after prescribed burning.
CP: Crude Protein, %.
ADF: Acid Detergent Fiber, %.
TDN: Total Digestible Nutrients, %.
NEM: Net Energy-Maintenance, Mcal/Kg.
NEG: Net Energy-Gain, Mcal/Kg.
NEL: Net Energy-Lactation, Mcal/Kg.

Table 5. Results of testing continuous grazing vs. patch-burn and rotational treatments on forage quality values for fixed effects with random factors PASTURE and PASTURE*YEAR from 2007 to 2009.

			Fixed Effects		
		Intercept	**Patch-burn**	**Rotational**	**Fire**
CP	Estimate	10.82	-1.238	-1.009	0.765
	SE	0.638	0.762	0.934	0.555
ADF	Estimate	38.591	1.554	0.381	-0.658
	SE	1.124	1.337	1.592	0.895
TDN	Estimate	59.789	-1.751	-0.407	0.709
	SE	1.258	1.496	1.778	0.992
NEM	Estimate	59.025	-2.638	-0.665	1.0612
	SE	1.908	2.269	2.698	1.505
NEG	Estimate	33.017	-2.395	-0.678	1.053
	SE	1.737	2.066	2.459	1.378
NEL	Estimate	61.145	-1.938	-0.456	0.782
	SE	1.398	1.663	1.979	1.107

CP = Crude Protein, %.
ADF = Acid Detergent Fiber, %.
TDN = Total Digestible Nutrients, %.
NEM = Net Energy-Maintenance, Mcal/Kg.
NEG = Net Energy-Gain, Mcal/Kg.
NEL = Net Energy-Lactation, Mcal/Kg.

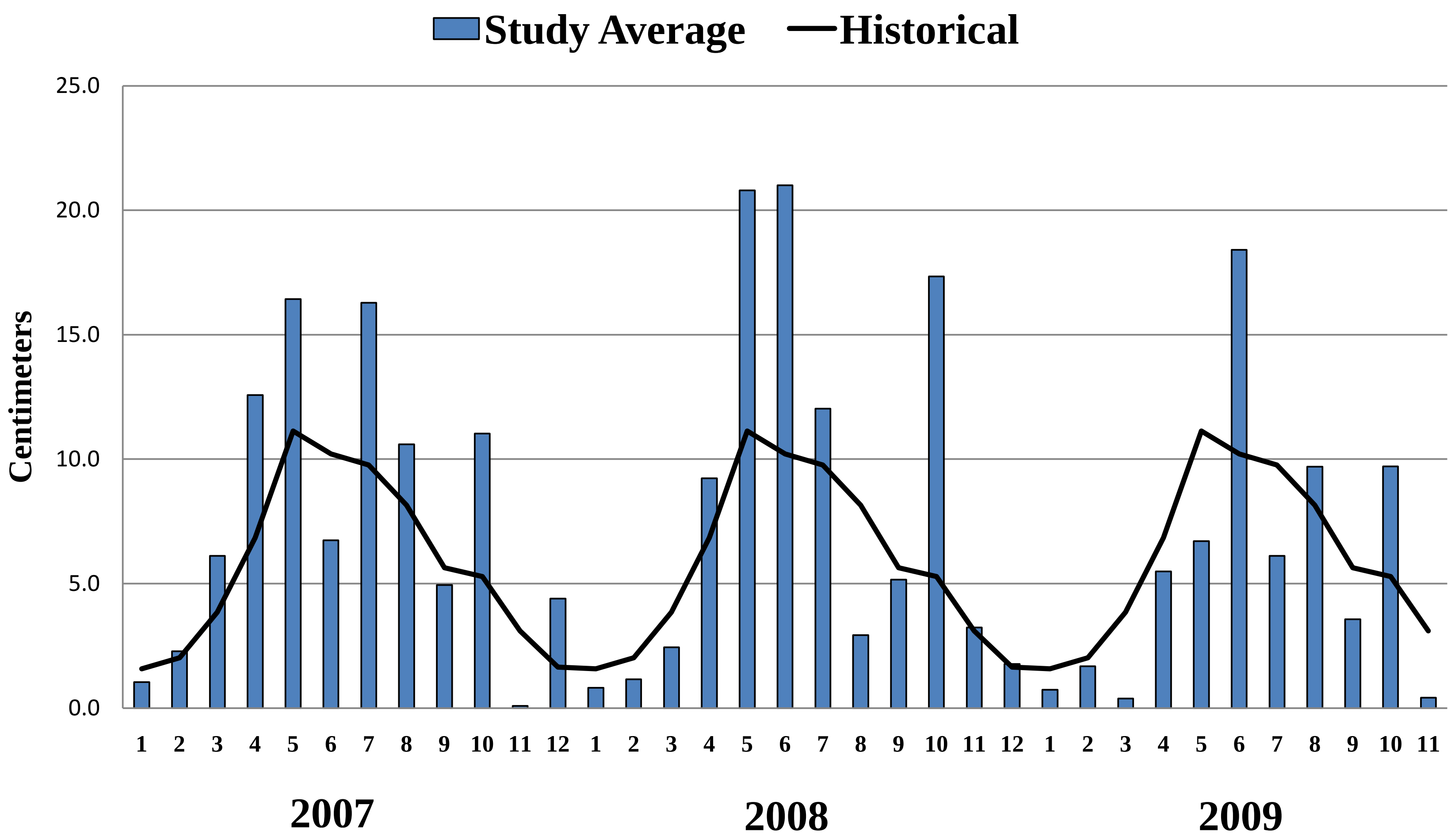

Figure 1. Average monthly rainfall (line) on The Crane Trust and average rainfall (bars) during the study (2007-2009)

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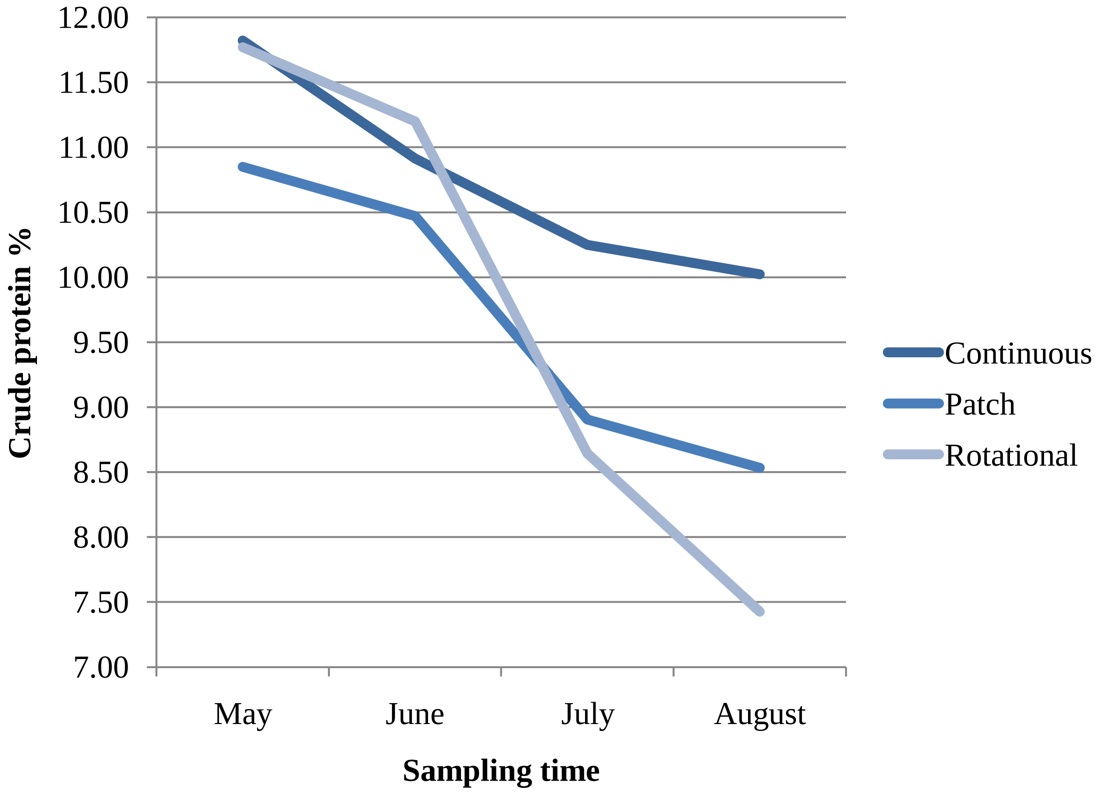

Figure 2. Crude protein (CP) values on pastures under continuous, patch-burn, and rotational grazing treatments between 2007 and 2009. Sampling time 1, 2, 3, and 4 correspond to late May, June, July, and Augus, respectively.

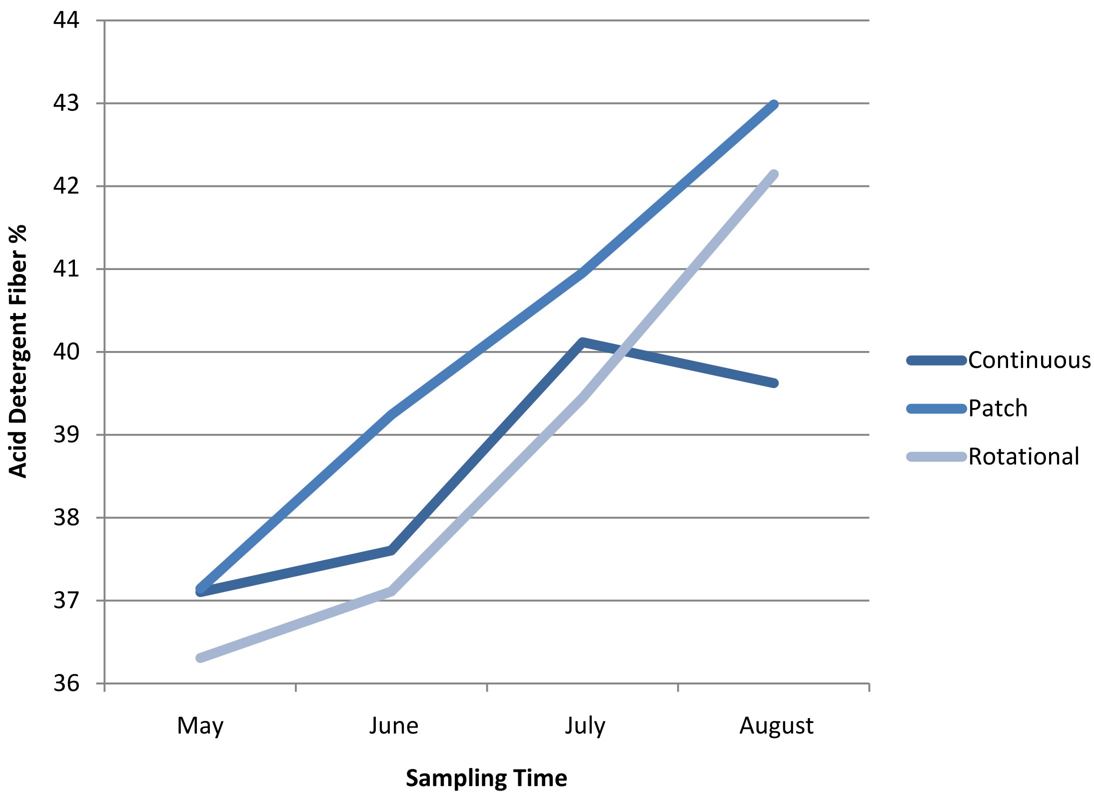

Figure 3. Acid Detergent Fiber (ADF) values on pastures under continuous, patch-burn, and rotational grazing treatments between 2007 and 2009. Sampling time 1, 2, 3, and 4 correspond to late May, June, July, and August, respectively.

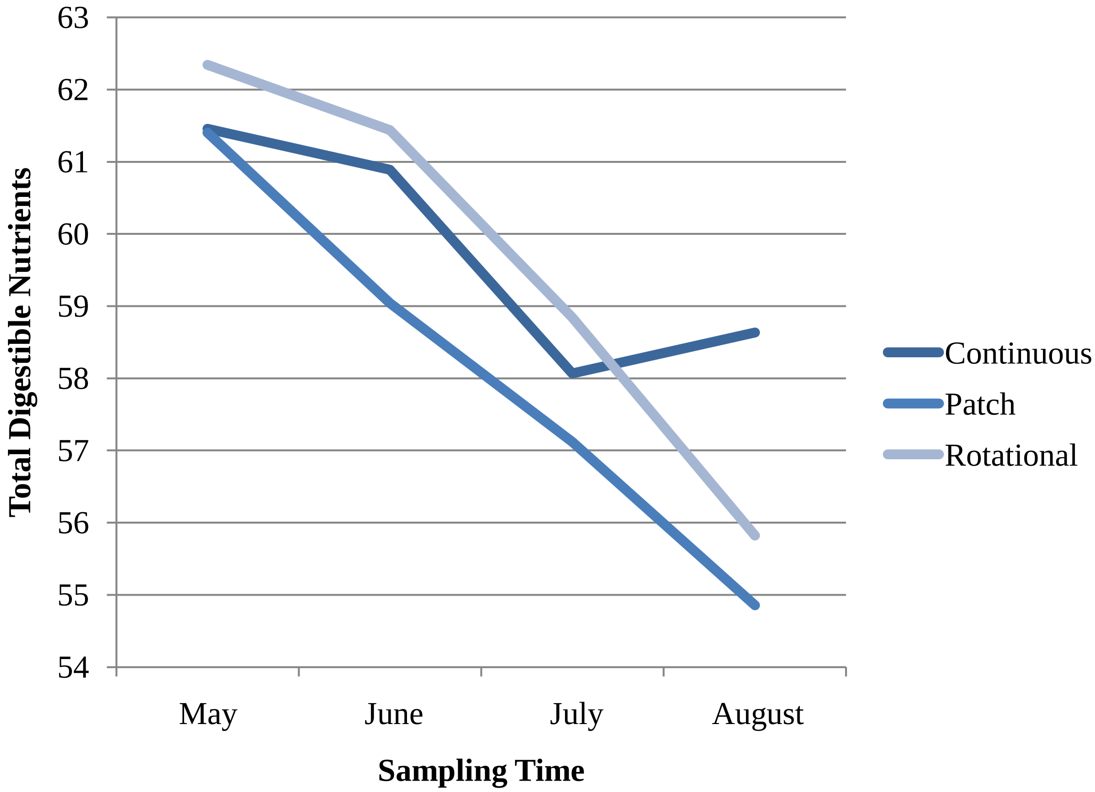

Figure 4. Total Digestible Nutrients (TDN) values on pastures under continuous, patch-burn, and rotational grazing treatments between 2007 and 2009. Sampling time 1, 2, 3, and 4 correspond to late May, June, July, and August, respectively.

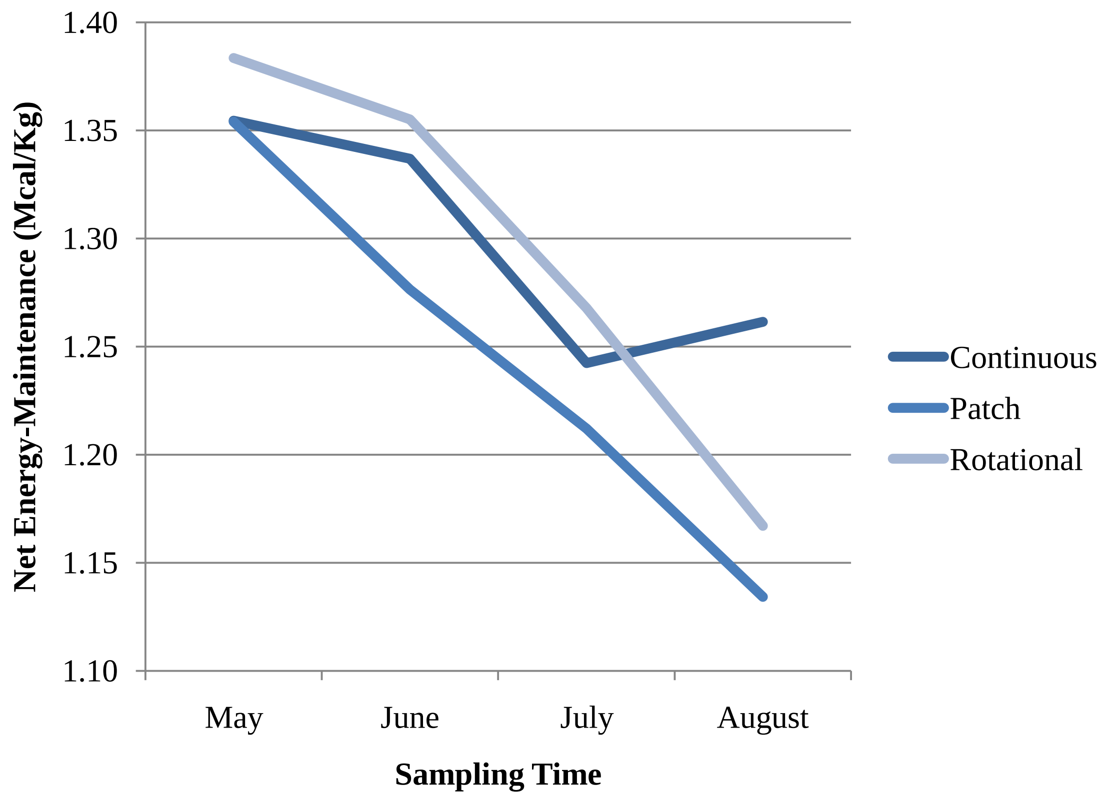

Figure 5. Net Energy-Maintenance (NEM) values on pastures under continuous, patch-burn, and rotational grazing treatments between 2007 and 2009. Sampling time 1, 2, 3, and 4 correspond to late May, June, July, and August, respectively.

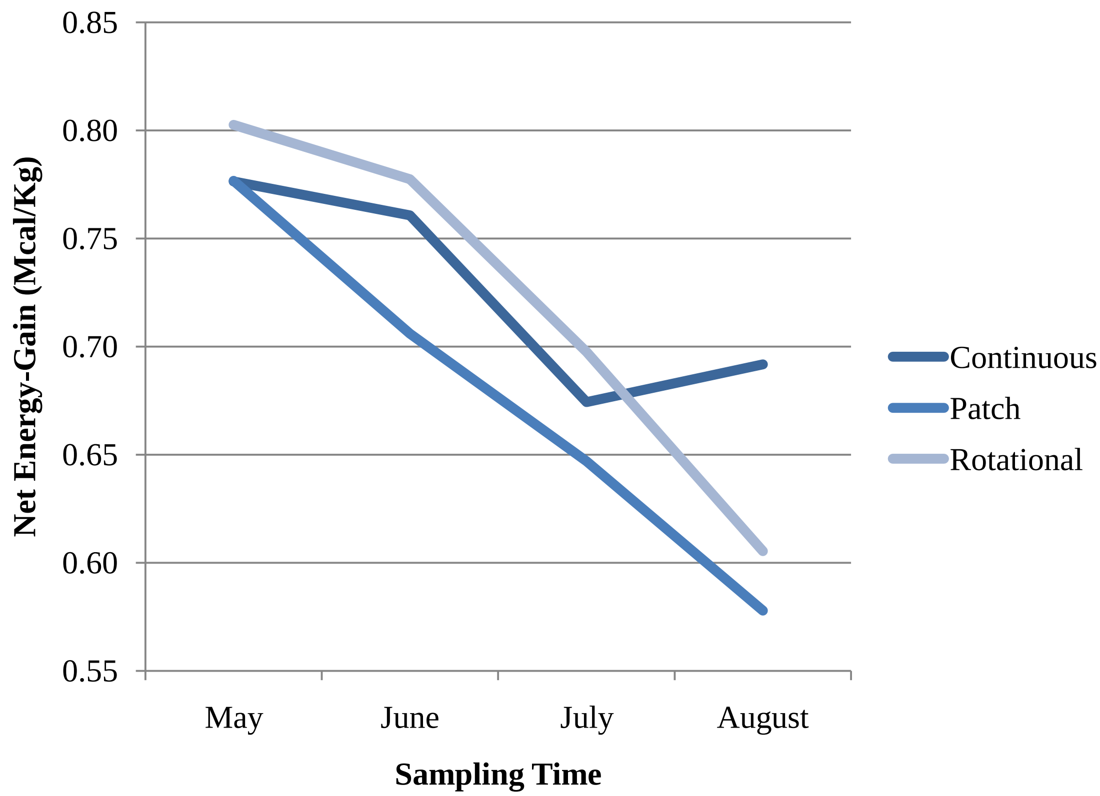

Figure 6. Net Energy-Gain (NEG) values on pastures under continuous, patch-burn, and rotational grazing treatments between 2007 and 2009. Sampling time 1, 2, 3, and 4 correspond to late May, June, July, and August, respectively.

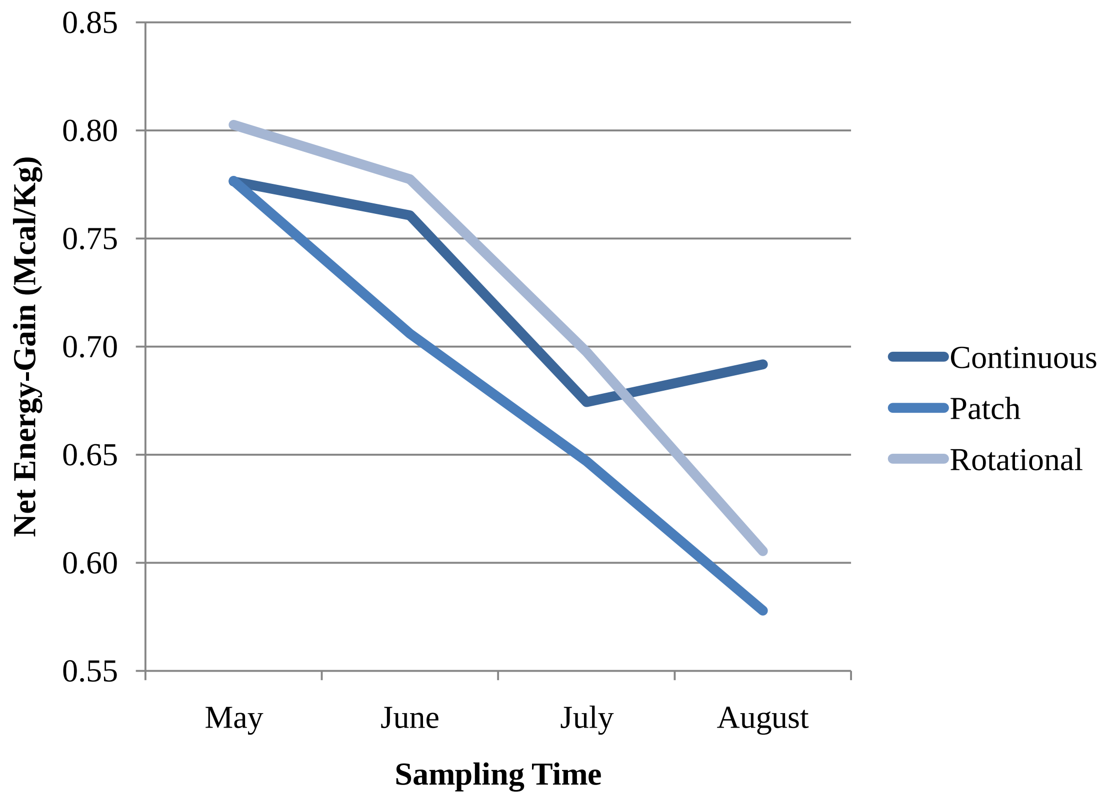

Figure 7. Net Energy-Lactation (NEL) values on pastures under continuous, patch-burn, and rotational grazing treatments between 2007 and 2009. Sampling time 1, 2, 3, and 4 correspond to late May, June, July, and August, respectively.

Weight gains and management costs of cow-calf pairs on pastures under three different management strategies in South Central Nebraska, USA.

INTRODUCTION

Grasslands are important from both agronomic and ecological perspectives (Briggs et al. 2005). The Great Plains region has an important role in food production. These extensive landscapes are heavily used as pastureland and/or hayland for beef cattle production or for cereal grain production. Production and conservation goals are not always fully compatible and, in some instances, they are opposite. However, the compatibility of those two goals can be achieved when management practices are focused to maintain diverse prairie plant communities (Hartnett et al. 1996, Collins et al. 1998, Coppedge et al. 2001, Fuhlendorf and Engle 2004). Beef cattle producers not only face challenges with forage production and grassland health, but also many decisions related to profitability. When trying to express ecological and conservation points of view, managers should be able to support management recommendations with economical data. Success of ranching and cattle production is linked to economic factors, and conservation activity should be supported by potential profit or reduction of long-term inputs. Low profitability in the beef industry has increased awareness of multiple use possibilities of ranches and the use of other rangeland resources linked to biodiversity (Hanselka 1998).

Grazing systems have been identified as beneficial in both ecological and economical terms. Heitschmidt and Walker (1996) identified moderate continuous grazing as a management approach with good economical advantages. Although rotational and patch-burn grazing systems have been used for several years at different scales in the central Platte River Valley in Nebraska, research has not quantified the possible economical outcomes of these management strategies. Many tools are now available to achieve economical success with grazing operations. Fuhlendorf and Engle (2001) proposed a model where fire and grazing interactions could be used to promote range productivity and animal performance. Continuous season-long grazing where rangeland is highly stocked has been identified as potentially detrimental for cattle performance (Redfearn and Bidwell 2000). Overstocking of grasslands can produce negative long-term effects on plant communities reducing the amount of desirable grasses and increasing the abundance of undesirable forages (Ramirez unpublished)

Many factors are involved in the economical sustainability of grazing operations. Decreases in grazing profitability can come directly from reduction of animal performance related to factors such as lower forage quality and/or quantity and a reduction of product for marketing or indirectly from an increase in production costs (Heitshmidt et al. 2004). For these reasons, it is important to be able to evaluate the potential effect of alternative management strategies, such as those using prescribed burning, to define the best ranching practices under given specific conditions.

My objective was to compare the effect of alternative grazing systems involving prescribed burning to season-long continuous grazing on cattle performance and their related costs. To achieve this objective, I compared different grazing strategies on three levels: 1) cow and calf seasonal weight gains, 2) operating costs, and 3) labor needed to run each management system.

METHODS

Study Site

This study was conducted in the central Platte River valley area of Nebraska on The Crane Trust property during three years starting in summer 2007. Ten pastures from The Crane Trust and two from area producers were used as experimental units. The Crane Trust is comprised of about 4,000 ha of cropland, pastures, and hay meadows along the Platte River in Buffalo, Hall, and Phelps counties, Nebraska. All pastures included in this study are located in Hall County. Climate is continental, with 160 frost-free growing days. Mean average temperature is 10°C with January minimum average of 11.6°C and average August temperature of 29.3°C. Average precipitation is 630 mm, occurring mainly from May through September. Soils consist of loamy or sandy alluvial deposits (Henszey et al. 2004). In the area adjacent to the Platte River, ecosystems are characteristic of tallgrass prairie with woody encroachment of eastern cottonwood (*Populus deltoides*) forests interspersed with willows (*Salix* spp.) and eastern redcedar (*Juniperus virginiana*). Dominant vegetation includes sedges (*Carex* spp.), rushes (*Eleocharis palustris, Scirpus* spp.*, and Juncus* spp.), and prairie cordgrass (*Spartina pectinata*) in lowland meadows (Curier et al. 1985). Mesic grasslands are characterized by big bluestem (*Andropogan gerardii*), little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutants*), Canada wildrye (*Elymus canadensis*), and switchgrass (*Panicum virgatum*). Common forbs include goldenrods (*Solidago* spp.) and prairie clovers (*Dalea* spp.). Many prairies contain non-native cool-season grasses including smooth bromegrass (*Bromus inermis*), Kentucky bluegrass (*Poa pratensis*), red top (*Agrostis stolonifera*), and tall fescue (*Lolium arundinaceum*).

Treatments

The first treatment consisting of continuous season-long grazing was considered as a control treatment and representative of the land management scheme most commonly used in this area. Under this system, pastures of variable sizes ranging from 20 to 100 ha were grazed with cow-calf pairs during summer and spring with medium to high stocking rates (>2.5 AUM/ha) without application of fire. The second treatment, patch-burn grazing, used large pastures (>80 ha) divided into four sections or burning units with no fences between them. The stocking rated ranged between 1.5 and 2 AUM/ha. In a 4-year rotation cycle, the whole pasture was burned after applying prescribed fire to each unit. The rationalization behind this system considers that newly burned areas would offer fresh forage regrowth which is preferred by cattle. As a consequence, a concentration of grazing pressure on burned areas and avoidance of previously burned sections would create a condition where four different vegetation structure and litter accumulation levels should be present in each treatment pasture.

Finally, the third treatment consisted of a modified rest rotational grazing system, consisting of four pastures of 50 to 250 ha where one was burned each year. In this system only two pastures were grazed each year leaving two pastures without any type of disturbance. Considering a 4-year rotation cycle, pasture 1 would be managed with an early spring prescribed burn and grazed during May and June with high stocking rates

(>3.5 AUM/ha). After these two initial months, cattle would be moved to pasture 2, which was burned the year before, to be grazed during July and August. Finally, cattle were returned to pasture 1 on September 1st. to finish the grazing season in mid-October. Pastures 3 and 4 were not grazed. The following year pasture 4 (after been rested for 2 years) would be burned in the spring and paired with pasture 1 for grazing.

Experimental Design

The experimental design consisted of the three treatments described above with two replicates for rotational and patch-burn treatments and three for continuously grazed pastures. All grasslands used in this research were at least 1.6 km from the river bank historically and used as pasture or hay meadows for the previous 5+ years. All selected areas were under continuous grazing or fire rotation management for at least 10 years prior this research. Former hay meadows were conditioned as pastures at least 2 years before data collection. Rotational and patch-burning pastures were managed with fire every 3- to 4-years for more than 10 years. Prescribed burning was conducted after snow melt in March or April.

Data Collection and Analysis

Expense records were gathered from producers from 2007 through 2009. At the beginning of the field season, a set of record sheets was delivered to each producer to keep track of expenses by month. The information to be collected included number of cow-calf pairs per herd, average body weights for cows and calves at the beginning and end of the season, mineral and salt costs, vaccination costs, operating costs, and number of hours invested on a monthly basis per herd. Although mineral supplementation plans varied between ranchers, I kept track of these expenses in order to detect possible extreme changes in expenses. The cattle used in this study were supervised by two local veterinarians with similar management plans, so vaccination records were used to identify increases in vaccination needs between treatments. To compare all grazing systems, I considered the assumption of equal expenses related to fixed costs. Some variables such as breeding charges, insurance, fence and water supply repairs, and utilities are not affected by specific grazing systems and were not considered for comparisons. Operating costs included general expenses incurred to manage each herd, such as vehicle mileage and extemporary veterinary expenses. All cattle used for this study, although from different ranchers, spent the winter grazing on corn stalks and calved between March and April.

One-way ANOVA was used to identify differences between treatments. Analysis of variance calculations were performed using the Minitab® statistical software program (Minitab Inc. 2009).

RESULTS

Weight gains were significantly different between treatments for cows and calves (Fig. 1). Cows in the continuous grazing treatment had the highest weight gains (96.5 ± 8 kg) compared to patch-burn (36 ± 2.7 kg) and rotational (21 ± 7 kg) treatments. Calves grazing on pastures under continuous grazing had average weight gains 25 and 12% higher than rotational and patch-burn grazing systems, respectively (Fig. 1).

Mineral and salt costs on pastures under continuous grazing was significantly higher ($11.58 ± .15) per cow-calf pair per season than those observed on patch-burn ($5.27 ± 0.08) and rotational grazing ($6.11 ± 0.53) treatments (Fig. 2). Following an opposite pattern, the cost for vaccination per cow-calf pair on continuously grazed pastures was more than 50% lower ($2.64 ± 0.03) than the one observed on patch-burn ($6.36 ± 0.49) and rotational ($6.59 ± 0.55) systems. General operating costs were similar for continuous and patch-burn treatments but higher on rotational grazing.

The man hours per month needed to run grazing systems was higher on herds grazing rotational systems (48.75 ± 5.4 hours) but was not significantly different from the 30 ± 2 or 24.5 ± 1.5 hours needed to manage continuous or patch-burning grazing systems (Fig 3).

DISCUSSION

The effect of grazing system on cattle performance has varied widely. Some studies have shown no difference in cattle performance comparing continuous and rotational grazing (Bertelsen et al. 1993, Banta et al. 2002); whereas, others have reported lower animal performance on rotational grazing systems (Whittier and Schmitz 1990). In our case, continuous grazing showed higher cattle weight gains for both cows and calves. Cattle on patch-burning and rotational grazing spent all winter on corn stalks and were supplemented with hay. Cattle in the continuous grazing treatment were not supplemented during the winter. They started the grazing season in lower body condition and possibly gained more weight due to compensatory weight gains (Ramirez, personal observation). At the same time, crude protein values of forage from continuously grazed pastures were higher later in the season (Ramirez unpublished, see chapter 4) most likely improving cattle performance.

Forage quality and quantity is affected by environmental conditions such as rainfall (Valentine 1990). From 2007 through 2009, above average precipitation (Fig. 4) likely affected forage quality in continuous grazing treatments. Given the right environmental conditions, such as proper rainfall and natural nitrogen mineralization, pastures under stress can potentially maintain forage production and support cattle needs. Continuous grazing can maintain a limited standing forage crop, but beneficial environmental conditions can maintain forage availability (Barnes et al. 2003) and, as a consequence, cattle weight gains are maintained.

Pastures under rotational grazing management require more labor at the time that two out of four pastures were grazed each year, reducing the efficiency of beef production per hectare. Patch-burning and continuous grazing required a single larger pasture and no cattle movement decreasing management requirements. Higher cattle performance on rotational grazing are required to offset the cost of management and maintenance demanded by extra labor, fence, and water.

Due to the nature of the grazing strategies used where different stocking rates were used on different pastures in this study, the ability to determine the main cause of improved animal performance is difficult to determine. Heistchmidt et al. (1982)

estimated that stocking rates could have a greater effect than the type of grazing system on average daily gains and total gain per unit of land.

Mineral and salt use was higher on continuously grazed pastures, and the use of different mixtures by each cattle owner complicated my ability to discriminate specific reasons for this phenomenon. Factors such as the use of mineral feeders, supplement form, season, soil conditions, or taste preferred by cows can potentially affect mineral intake (Stewart 2010). Forage analyses, as part of this same study (Ramirez unpublished), did not detect differences on forage quality between treatments further complicating the possibility to isolate possible factors affecting mineral consumption.

Rotational grazing systems require extra labor and operating costs, due to the necessity to move cattle between pastures when compared with continuous and patch-burning grazing. It is also important to consider the fact that 4-pasture rotational grazing systems require no less than 50% extra fence. Although labor needed to manage continuous and patch-burning grazing systems was similar, the time and resources needed to perform prescribed burning would give the economic advantage to continuous grazing as the least labor demanding system.

Continuous grazing appears to be the best option to graze pastures from a purely economic standpoint, but several other factors should be considered. Weather patterns observed between 2007 and 2009 produced favorable environmental conditions masking some possible deleterious effects of continuous grazing, such as low forage production on average or dry years. Long-term research under drought or average conditions could help to better establish the potential profit of patch-burn and rotational grazing. Discussions related to plant diversity and structure (See chapters 2 and 3) and their implications for wildlife should be considered before further conclusions are made related to the advantage of continuous grazing as land management approach. Long term grassland health and performance are closely related to plant diversity and resilience, and conclusions on the economical advantages of grazing systems must consider the overall range health.

Although only 3 years of data were included in this study, these results showed factors to be considered for future research. Cattle on continuously grazed areas did not have supplemental feeding during the winter and still performed better than cattle in other treatments. Therefore, how important or at what level is winter supplemental feeding needed? Patch-burning and rotational grazing systems most likely require several years to stabilize in terms of stocking rate adaptations, management, and forage production, and long-term evaluation are needed.

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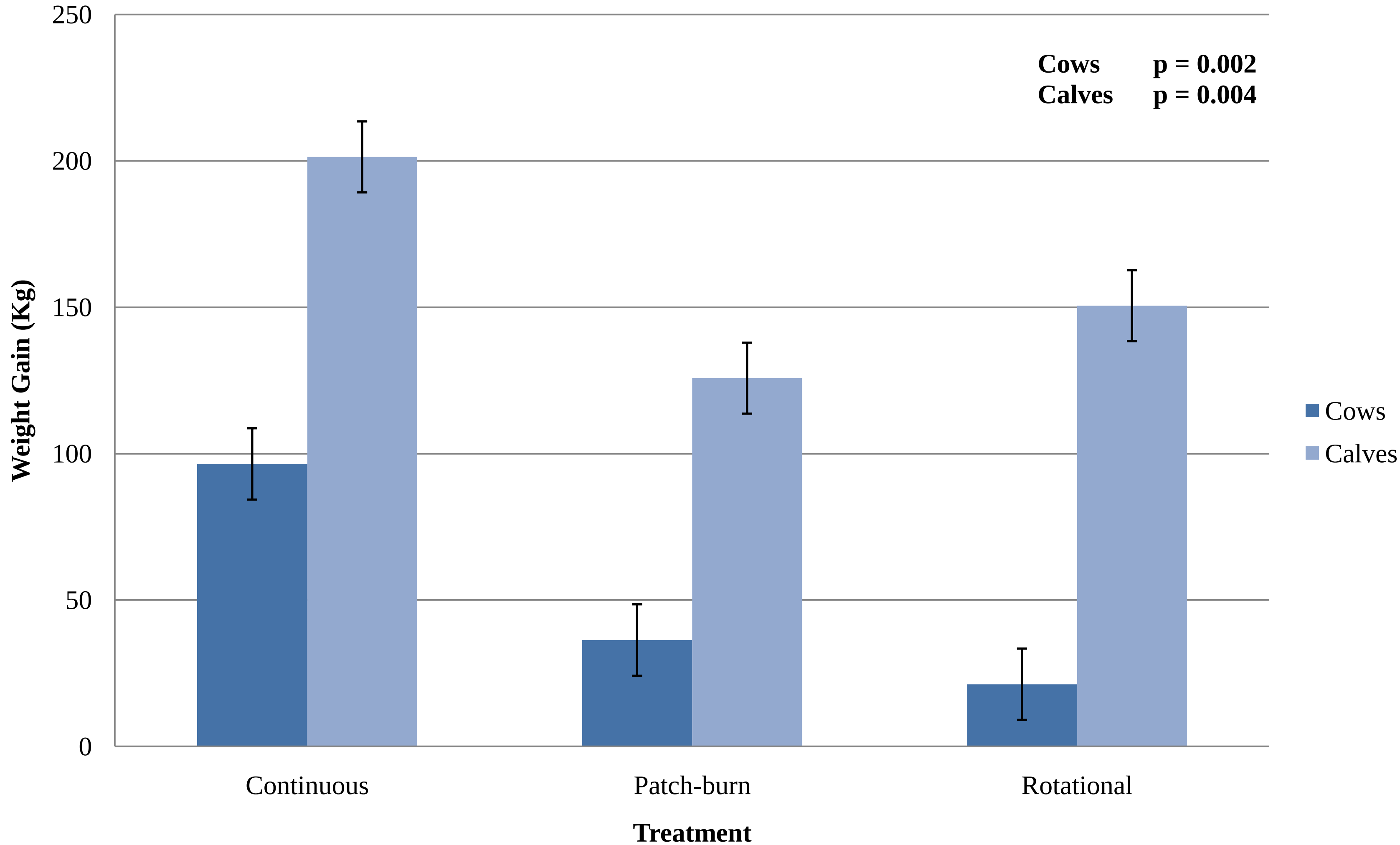

Figure 1. Average weight gain per animal type on continuous, patch-burn, and rotational grazing systems (2007-2009).

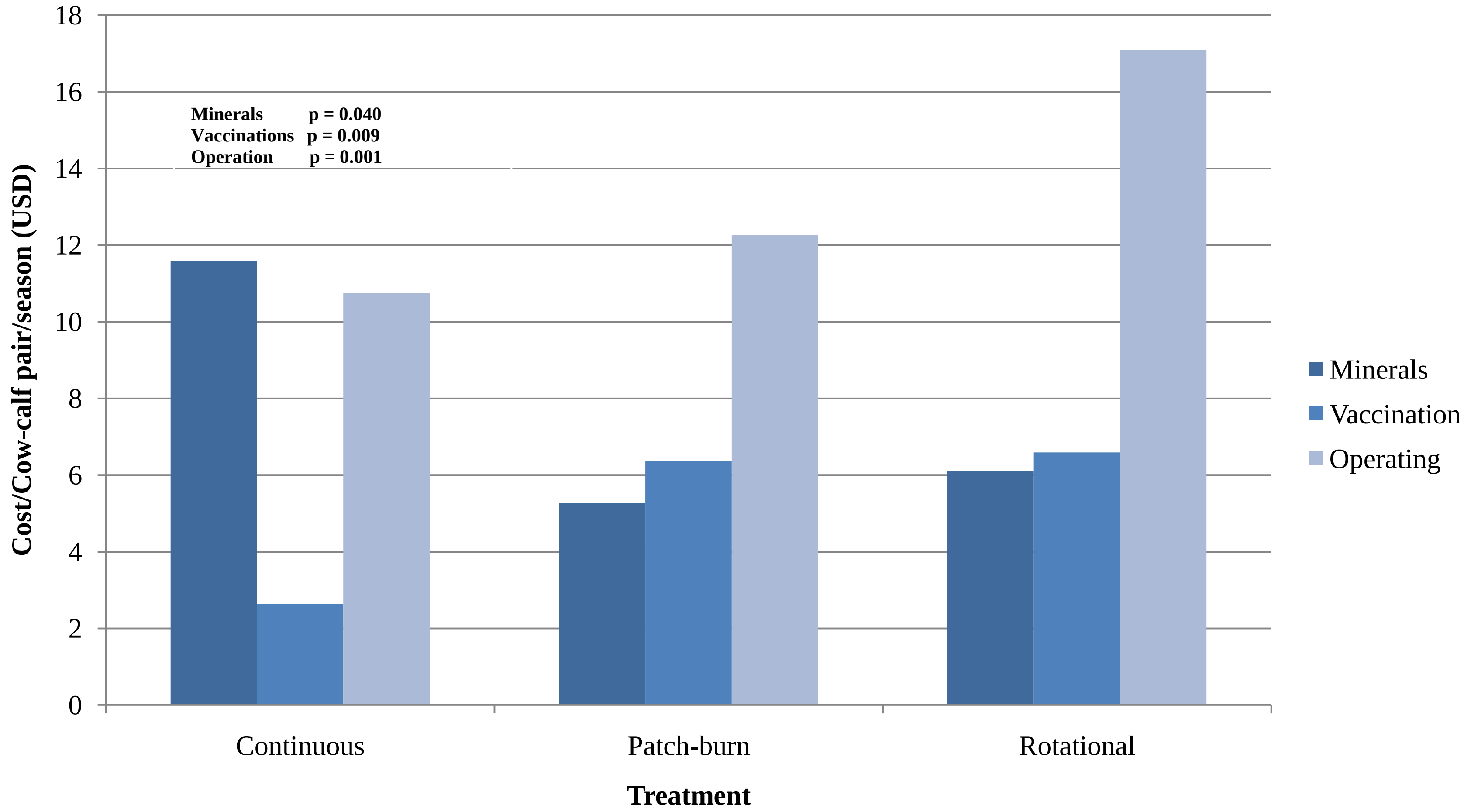

Figure 2. Average cost per cow-calf pair per season for continuous, patch-burn, and rotational grazing systems (2007-2009).

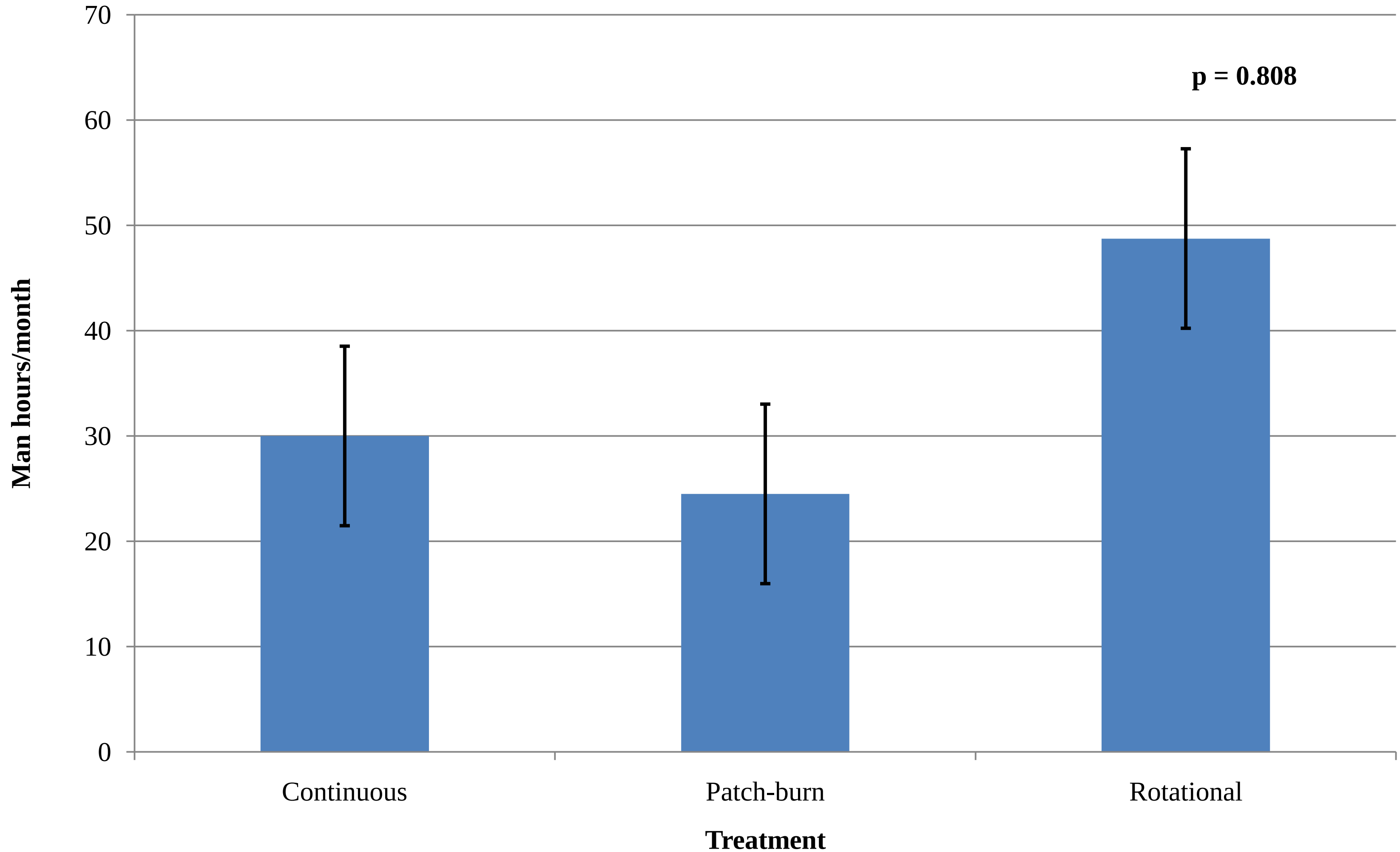

Figure 3. Average man hours invested per month for continuous, patch-burn, and rotational grazing systems (2007-2009).

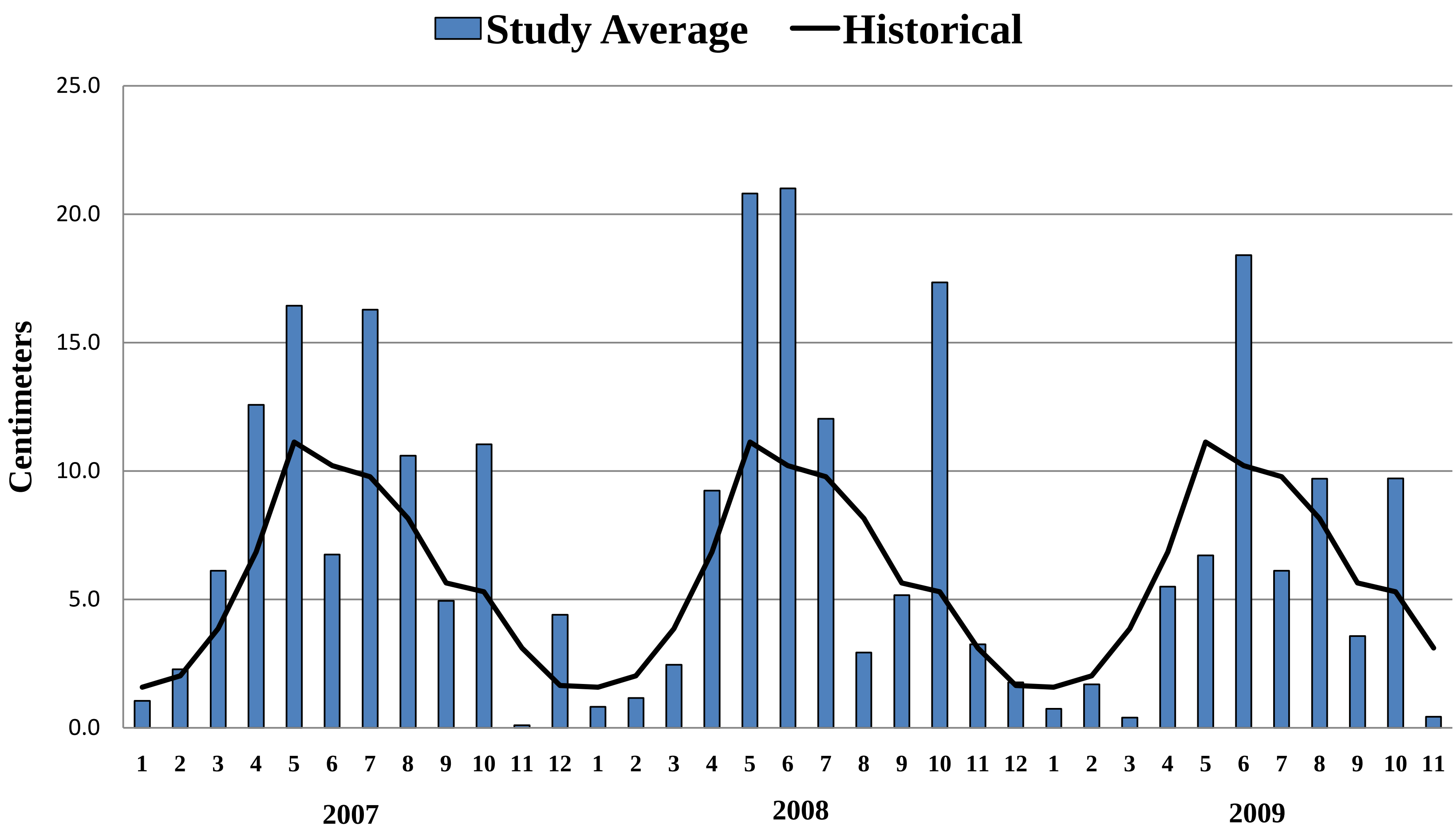

Figure 4. Average monthly rainfall (line) on The Crane Trust and average rainfall (bars) during the study (2007-2009).

APPENDIX I

Density board used to estimate vegetation vertical cover