RANGELAND AND PASTURE IMPROVEMENTS FOR SOUTHEASTERN NORTH DAKOTA

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

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ABSTRACT

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Degraded pasture and rangelands are becoming increasingly present in southeastern North Dakota and throughout the Northern Great Plains. Problems associated with degraded pasture and rangelands include loss of biodiversity, increased invasive species, reduced forage quality for cattle, loss of wildlife habitat, and reduced soil stability when compared to a healthy, functioning native prairie ecosystem. In an attempt to reverse this trend, three studies were conducted looking at a variety of different management techniques, all aimed to improve the overall health of degraded pasture and rangelands in southeastern North Dakota. The first study analyzed burn season and frequency, replicated in both grazed and ungrazed plots, to determine the most effective burning treatment for the control and reduction of Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*). At this point in the study there have only been two seasons of data collected, but initial results indicate that summer burning, regardless of frequency, is the most effective treatment at reducing Kentucky bluegrass cover. Smooth brome cover has not been reduced using any of the treatments except grazing, resulting in a reduction of its cover compared to ungrazed. The second study was an interseeding trial that analyzed a variety of different pre-seeding treatments including burning, herbicide, seeding only, and a burn herbicide combination. This was the initial year of the trial so results were limited to seedling establishment. Herbicide treatment, both in combination with burning and as a single treatment, resulted in the highest overall seedling establishment, but overall

treatment success cannot be determined without additional years of community level data. The third and final study analyzed the impact of a patch burn grazing system on disturbed northern tallgrass rangeland. At this point in the study, findings have not indicated a plant community level change under the patch burn grazing management system, but above average moisture may be contributing to the subdued results.

ACKNOWLEDGEMENTS

First and foremost I would like to thank my advisor, Dr. Edward Shawn DeKeyser. Over the past year his guidance and teachings have been the driving force behind everything I have accomplished and I deeply value all the opportunities he has provided me. Second I would like to thank my committee members, Drs. Jack Norland, Kevin Sedivec and Gary Clambey, for it has been their teachings and insights that have provided me with the foundation upon which this research was based. I would also like to thank Dennis Whitted for his countless hours of assistance in the field, as well as my fellow graduate students and technicians that assisted me in data collection and trial initiation.

Finally, I would like to thank my family and friends who have been there for me over the past two years and who have kept me motivated through this entire process. Specifically I would like to thank my mother and father who have always been a constant motivating force in my life, and Jena whose love and patience I could not be more grateful for.

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GENERAL INTRODUCTION

The focus of this study is on improving pasture and rangeland in southeastern North Dakota. The thesis comprises three papers, focusing on pasture and rangeland improvement through the use of several different management techniques. The first paper highlights the role of prescribed burns through an analysis of varying return frequencies and timing of burns. It also incorporates grazing as a factor by conducting the burns both in the presence and absence of grazing. The goal of this study was to identify the most effective burn treatment for reducing invasive cool season grass cover.

The second paper examines interseeding, analyzing year 1 of data to determine the most effective pre-seeding treatment for seedling establishment. The pre-seeding treatments consisted of burning and herbicide, either as separate treatments or in combination with one another. The overall goal of this study was to analyze the long-term plant community structural changes by treatment to determine most beneficial to rangeland health.

The third paper focused on analyzing a patch burn grazing management system and its effectiveness in the northern tallgrass prairies. The concept of a patch burn grazing system is that fire, applied in a rotational schedule throughout an open pasture, will influence the movement of large ungulate grazers. The primary benefit of this system is its ability to reintroduce patch dynamics into a landscape, which in turn provides greater biodiversity and improved wildlife habitat. Patch burn grazing has shown success in southern tallgrass and shortgrass prairies. The goal of this trial is to see if the same success can be achieved in a northern tallgrass prairie area.

LITERATURE REVIEW

Rangeland and pasture comprise approximately 35% of the total land area in the United States and account for more than $17 billion of revenue annually making them both environmentally and economically important (USDA-ERS, 2008). Many of these rangelands have been grazed for nearly 200 years and undergone changes in species composition and community structure (DiTomaso, 2000). A major threat facing today's rangelands are invasive species. An invasive plant in a rangeland setting is defined as a "plant spreading naturally (without direct human assistance) to significantly alter composition, structure, or ecosystem processes," and are commonly found colonizing disturbed or exposed areas such as poorly managed rangelands (Frost and Launchbaugh, 2003).

In the tallgrass prairies of the Northern Great Plains, two invasive plant species that are becoming increasingly problematic are Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*). These species are both perennial, cool season grasses that were introduced into the United States from Europe (Stubbendieck et al., 2003). In areas that have been historically dominated by native warm season grasses, Kentucky bluegrass and smooth brome have invaded and began replacing native plant species. To combat the encroachment of these two species a variety of different management and treatment options have been developed and researched with the goal of finding an economically viable means of reducing or minimizing their presence in rangelands.

One control measure that has been extensively researched is prescribed burning. Several studies have shown that the use of prescribed burns in rangelands has the ability to reduce the amount of invasive species cover and increase the total amount of native species found. In a 13 year study conducted by Svedarsky et al. (1986) in Minnesota along the eastern edge of the Red River Valley, both annual and biennial spring burning was found to result in Kentucky bluegrass cover decrease and big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*) cover increase. This study was aimed specifically at reducing Kentucky bluegrass cover so the exact date of the spring burns was not kept constant; rather the burns were conducted once the bluegrass was 10-15cm high. They believed that burning at this height would result in maximum suppression. This study was later replicated in southwestern Minnesota using the same height criteria yielding somewhat less impressive results (Becker, 1986).

In contrast to these findings, research has shown that the same burning regime implemented in the fall can have negative effects on the reestablishment of native warm season grasses (Volesky and Cannot, 2000). Volesky and Cannot (2000) showed the percent composition of little bluestem was reduced from 47% to 8% the year following a September burn in the Nebraska Sandhills, though it should be noted the percent composition did return to 46% three years post burn. These results indicate that season of burn likely plays an important role in the overall success of a fire management strategy.

Other factors that can impact the overall success of prescribed burns for Kentucky bluegrass control include soil moisture and soil fertility. Prescribed burns on dry sites with low soil moisture are more likely to result in Kentucky bluegrass reduction than burns on moist sites. Well-drained sandy soils are more favorably suited to the use of prescribed burning than are clay, less-well drained soils (Zedler and Loucks, 1969). Soil fertility can also play a role in post fire plant community composition (Knops, 2006). Over this 17 year study in south-central Minnesota it was determined that only on fertile soil does fire promote native plant species presence. Fire resulted in decreased Kentucky bluegrass cover regardless of soil fertility; however, only on fertile soils did vegetation rebound with an increased abundance of native warm season grasses.

Studies have shown that fire can have positive effects in controlling Kentucky bluegrass. However, its usefulness for controlling smooth brome is still debatable. In a three-year study (one year of burning, three years of monitoring) conducted at Pipestone National Monument, Minnesota, three treatment options (burning, mowing, and herbicide) were studied for their effectiveness in reducing smooth brome tiller densities. Herbicide was the only effective treatment, with burning and mowing having no tiller reduction (Wilson and Stubbendieck, 1996). Other studies have shown burning can be an effective management tool for controlling smooth brome, but timing and multiple successive burning years are required (DiTomaso et al., 2006). An experiment conducted in Nebraska studied the variation in smooth brome tiller reduction from burns conducted in early-May, mid-May, and late-May (Wilson, 1991). They found mid and late-May burning resulted in greater tiller reduction compared to early-May burns. They concluded the variation in success was a result of suppression occurring at various stages of tiller growth and elongation. These findings indicated that timing of prescribed burns is an important variable to a burn's overall impact, and frequency of burning could also be critical.

Livestock grazing is another management tool for the control of invasive species. Livestock grazing is commonly overlooked and a discarded form of control because overgrazing has led to many of today's rangeland problems (Coupland, 1961). While it is true that overgrazing can have negative effects such as loss of biodiversity and increased invasive species, a well regulated grazing schedule can result in a positive effect (Frost and

Launchbaugh, 2003). Historically, bison roamed the Great Plains acting as a keystone herbivore promoting increases in biodiversity, a role that is now filled by domestic livestock (Collins et al., 1998). A well regulated grazing schedule can favorably benefit the overall health of rangeland, and removing said grazers resulting in decreased biodiversity and increased invasive species presence (DeKeyser et al., 2009). Grazing, in combination with prescribed fire, is theorized to create greater benefits to rangeland than either treatment applied individually. However, it has not been demonstrated that this combination of management strategies is effective for combating Kentucky bluegrass or smooth brome.

Habitat loss and reduced forage production is a problem in southeastern North Dakota's pasturelands. Since European settlement to North America, more than 95% of its tallgrass prairie has been lost with the remaining remnants having undergone some degree of degradation (Knapp et al., 1999). It is the task of land managers to develop techniques that can be used for improving what remains and restoring what has been lost. One way to accomplish restoration is interseeding native range plants into disturbed or degraded pasturelands.

Interseeding is a process by which seeds are planted directly into existing vegetation without plowing (Bailey and Martin, 2007). One benefit of this seeding method is it allows the existing plant community to remain intact and provides and agricultural value to pastureland. This is an attractive quality to landowners due to less physical input and a reduced forage production loss compared to alternative seeding processes.

Interseeding has the potential to increase forage production. Studies have shown interseeded rangelands have as much as 143% greater above ground biomass compared to a control (Mortenson et al., 2005). A primary negative to interseeding is the requirement of a specialized drill for fluffy, native grass seeds (NRCS, 2006). Conventional drills can become clogged when used with native grass seed and seed at a greater than optimal depth (native grass seed should be seeded at a depth no greater than ½ inch).

Interseeding has had limited success in promoting the growth of native plant species (Rowe, 2010). Wilson and Gerry (1995) found that prairie plots untreated prior to seeding resulted in as many as 20 times fewer seedlings than those treated with herbicide. Subsequent studies have shown interseeding is most effective when used in combination with some form of cover reduction control (Bakker et al., 2003). Herbicide treatments temporarily suppress the majority of plants in the treated area, resulting in competition reduction for later seedling emergence. Timing of treatment application is important and should be based on the overall management goals. Studies have shown that spring herbicide treatments prior to the heading out of cool season grasses are effective in promoting increased cover composition by warm season grasses (DiTomaso, 2000). Studies have also shown that spring herbicide treatments can result in increased drought tolerance of perennial warm season grasses (Houston, 1977).

Two additional interseeding enhancement techniques are prescribed fire and grazing. Numerous studies have shown prescribed fire can be an effective tool for reducing growth of cool season grasses, thereby promoting greater cover composition of native warm season grasses (Hover and Bragg, 1981; DiTomaso, 2000; Engle and Bidwell, 2001). Reducing cool season grass competition results in increased light infiltration for seedling growth of warm season grasses. Grazing also has the ability to reduce standing cover and benefit biodiversity. Moderate levels of grazing tend to increase biodiversity when the grazers are generalists such as cattle or bison (Howe, 1999). Reducing the overall cover of dominant species provides openings for establishment of subdominant species, increasing biodiversity. When combining the use of grazing with interseeding it is recommended livestock be temporarily removed from newly seeded pastures (Schumacher, 1964).

A third issue that affects southeastern North Dakota's rangelands is a conversion to homogeneous landscapes and loss of biodiversity. Rangelands were historically heterogeneous landscapes composed of a patchwork of different mosaics and ecotypes (Fuhlendorf and Engle, 2001). This heterogeneity resulted from a variety of different disturbance regimes such as fire and grazing, which results in a patchier landscape. Traditional rangeland management promoted a uniform distribution of livestock resulting in more homogeneous landscapes and loss of biodiversity. Many subdominant or niche plant and animal species were negatively impacted by this landscape change, resulting in large decline in population (Coppedge et al., 2001; Fuhlendorf and Engle, 2001). Currently, many rangeland managers are attempting to reverse this trend and implement new management strategies aimed at restoring landscape heterogeneity while maintaining current levels of livestock production. One such strategy is patch burn grazing.

Patch burn grazing is a system which utilizes fire to dictate the location of livestock grazing rather than using fences. Burning of grasslands has resulted in an increased growth rate of prairie plants, greater quantity of plant production, and overall enhanced forage quality for large herbivores as compared to unburned areas (Engle and Bidwell, 2001). The combination of these factors results in grazers such as cattle and bison favoring these areas almost exclusively over unburned areas. Therefore, managers are capable of controlling livestock use every year by burning a different portion of a pasture rather than dividing the pasture into a series of smaller pastures and rotated periodically by the livestock manager (Fuhlendorf and Engle, 2004). Recently burned plots are favored by grazers with the grazing intensity decreasing each subsequent year that is unburned (Helzer and Steuter, 2005). This lack of grazing results in litter accumulation which provides fuel for future burns.

The primary benefit of patch burn grazing over traditional grazing methods is the reintroduction of patch dynamics into the landscape. Patch dynamics are seen as an essential element for maintaining species diversity in an ecological community (Pickett and White, 1985). In grassland ecosystems, numerous studies have shown how the loss of patch dynamics transforms from a heterogeneous to homogeneous landscape that result in a loss of biodiversity, highlighting the decline of many avian and plant species (Wiens, 1974; Taylor and Guthery, 1980; Knopf, 1994; Coppedge et al., 2001; Fuhlendorf and Engle, 2001). Patch burn grazing results in the majority of grazing taking place in recently burned areas (usually about 1/3 of the pasture depending upon burn schedule), allowing the remaining pasture to function with little to no disturbance. Vermeire et al. (2004) found that cattle grazing resulted in a 78% reduction in standing crop for burned sites compared to 19% reduction in areas outside the influence of burn area. Traditional grazing practices do not result in such variations, but rather result in a more evenly distributed moderate level of grazing throughout the pasture. It should also be noted that experimental findings have shown livestock and plant production in continuous grazing systems to be greater than or equal to rotational grazing systems (Briske et al., 2008).

An effective burn rotation schedule which has been identified for a patch burn grazing system for tallgrass prairie is three years (Fuhlendorf and Engle, 2004). Under this schedule 1/3 of the total pasture is burned yearly allowing the remaining 2/3 to be unburned. Recently burned areas provide higher forage quality for large herbivores, resulting in the majority of season long grazing occurring in these areas (Vinton et al., 1993). In the second year, a different 1/3 of the pasture is burned, and in the third year the remaining 1/3 is burned completing one full burn cycle. The process is then repeated. Under this system, vegetation response is characterized by a decrease in tallgrasses, resulting in greater sunlight infiltration and subsequent increase in forb cover. This increased forb composition will persist for roughly two years until litter begins to accumulate and tallgrasses regain dominance (Fuhlendorf and Engle, 2004). Forbs are important in tallgrass prairies because they contribute more to biodiversity than do grasses (Turner and Knapp, 1996). Some of the ecological benefits associated with forbs are improved habitat diversity, increased forage quality, soil stabilization, and important food sources for many upland birds and organisms (Shaw et al., 2005).

Patch dynamics have been shown to play a key role in a healthy, functioning ecosystem and critical to conservation and land management (Christensen, 1997). Currently, there are relatively few management strategies that have proven successful in restoring patch dynamics to degraded rangelands. Patch burn grazing is one system that has shown promise over the past two decades as studies indicate it is effective at both restoring patch dynamics and dictating the movement of livestock. Although additional supporting research is still needed, it appears that patch burn grazing may be a possible key to restoring the numerous degraded rangelands found throughout the Great Plains.

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PAPER 1. EFFECTS OF BURN SEASON AND FREQUENCY ON NORTHERN TALLGRASS PASTURE LAND

Introduction

Invasive perennial grasses are becoming increasingly problematic on rangelands in the Northern Great Plains. Two of the more common invasive grasses that managers are combating are Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*), unfortunately the management tools for combating these species are limited and lack refinement. One management tool that has shown promise is the use of prescribed burning; however, studies have been limited in scope in the Northern Plains. No clear indication as to the most effective season or return interval have been given, nor have studies looked at the impact of grazing in combination with various burn cycles. This study was intended to fill these gaps by analyzing how timing and frequency of burning with and without grazing impacted the overall structure of rangeland plant communities.

This study was conducted in the tall grass prairie region of southeast North Dakota. We looked at 14 different treatment combinations including burn season (spring, summer, fall), return interval (yearly, every 2 years), and grazing (grazing, non-grazed) to determine the most effective treatment for reducing Kentucky bluegrass and smooth brome cover and density. The hypothesis for this study were that spring burning with a return interval of two years in combination with grazing would be the most effective treatment for combating Kentucky bluegrass invasion. This hypothesis was based on previous studies that found multiple stressors to be more effective at combating Kentucky bluegrass than any one stressor alone (Collins et al., 1998). For smooth brome, a burn regime with a shorter return period will likely be most effective, as single or infrequent burns have shown little to no success in reducing its presence (Wilson and Stubbendieck, 1996; DiTomaso et al., 2006). In addition to reducing the presence of invasive cool season grasses, a greater fire frequency will result in reduced litter cover and increased bare ground.

Literature Review

Rangeland and pasture comprise approximately 35% of the total land area in the United States and account for more than $17 billion worth of revenue annually making them both environmentally and economically important (USDA-ERS, 2008). Many of these rangelands have been grazed for nearly 200 years and have undergone changes in species composition and community structure (DiTomaso, 2000). One of the major factors facing today's rangelands is invasive species. An invasive plant species in a rangeland setting is defined as "plant spreading naturally (without direct human assistance) to significantly alter composition, structure, or ecosystem processes" (Frost and Launchbaugh, 2003) and are commonly found colonizing disturbed or exposed areas such as poorly managed rangelands.

In the tall grass prairies of the Northern Great Plains, two invasive plant species that are becoming increasingly problematic are Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*). These species are both perennial, cool season grasses that were introduced into the United States from Europe (Stubbendieck et al., 2003). In areas that have been historically dominated by native warm season grasses, Kentucky bluegrass and smooth brome have invaded and began replacing native plant species. To combat the encroachment of these two species a variety of different management and treatment options have been developed and researched with the goal of finding an economically viable means of reducing or minimizing their presence in rangelands.

One control measure that has been extensively researched is prescribed burning. Several studies have shown that the use of prescribed burns in rangelands has the ability to reduce the amount of invasive species cover and increase the total amount of native species found. In a 13 year study conducted by Svedarsky et al. (1986) in Minnesota along the eastern edge of the Red River Valley, it was found that both annual and biennial spring burning resulted in a Kentucky bluegrass cover decrease and a big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*) cover increase. This study was aimed specifically at reducing Kentucky bluegrass cover so the exact date of the spring burns was not kept constant; rather the burns were conducted once the bluegrass was 10-15cm high. They believed that burning at this height would result in maximum suppression. This study was later replicated in southwestern Minnesota using the same height criteria yielding similar, albeit somewhat less impressive results (Becker, 1986).

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Other factors that can impact the overall success of prescribed burns for Kentucky bluegrass control include soil moisture and soil fertility. Prescribed burns on dry sites with low soil moisture are more likely to result in Kentucky bluegrass reduction than burns on moist sites. Well drained sandy soils are more favorably suited to the use of prescribed burning than are heavier, less well drained soils (Zedler and Loucks, 1969). Soil fertility has also been shown to play a role in post fire plant community composition (Knops, 2006). Over this 17 year study in south-central Minnesota it was determined that only on fertile soil does fire promote native plant species presence. Fire resulted in decreased Kentucky bluegrass cover regardless of soil fertility; however, only on fertile soils did vegetation rebound with an increased abundance of native warm season grasses.

Studies have shown that fire can have positive effects in regards to controlling Kentucky bluegrass. However, its usefulness for controlling smooth brome is still debatable. In a three year study (one year of burning, three years of monitoring) conducted at Pipestone National Monument, Minnesota, three treatment options (burning, mowing, and herbicide) were studied for their effectiveness in reducing smooth brome tiller densities. The results of this study showed that herbicide was the only effective treatment, with burning and mowing resulting in no significant tiller reduction (Wilson and Stubbendieck, 1996). Other studies have suggested that burning can prove to be an effective management tool for controlling smooth brome, but for it to be effective, timing and multiple successive burning years are required (DiTomaso et al., 2006). An experiment conducted in Nebraska studied the variation in smooth brome tiller reduction from burns conducted in early-May, mid-May, and late-May (Wilson, 1991). They found that mid and late-May burn plots resulted in greater tiller reduction compared to early-May burn plots. They suggested the reason for this variation was a result of suppression occurring at various stages of tiller growth and elongation. These findings indicated that timing of prescribed burns is an important variable to a burn's overall impact, and frequency of burning could also be critical.

Another management tool for the control of invasive species is the use of livestock grazing. Livestock grazing is a commonly overlooked and a discarded form of control because overgrazing has led to many of today's rangeland problems (Coupland, 1961). While it is true that overgrazing can have negative, effects such as loss of biodiversity and increased amounts of invasive species, a well regulated grazing schedule can result in just the opposite (Frost and Launchbaugh, 2003). Historically, bison roamed the Great Plains acting as a keystone herbivore promoting increases in biodiversity, a role that is now filled by domestic livestock (Collins et al., 1998). A well regulated grazing schedule can favorably benefit the overall health of a rangeland, and removing said grazers can result in decreased biodiversity and increased invasive species presence (DeKeyser et al., 2009). Grazing in combination with prescribed fire is theorized to result in greater positive benefits to rangeland than either treatment applied individually; however, it has not been demonstrated that this combination of management strategies is an effective tool for combating Kentucky bluegrass or smooth brome.

Determining the most effective season and frequency of prescribed burns can be of great benefit to rangeland managers attempting to control invasive species such as Kentucky bluegrass and smooth brome. Through analysis of various season and frequency combinations it can be determined when and how often an area should be burned in order to promote the establishment of native rangeland plants. The effects of grazing should also be analyzed in combination with burning to determine the best overall management strategy for the control of invasive species in rangelands.

Methods

This study was located on the Ekre Ranch in Richland County, North Dakota, 16 km west of Walcott, ND. The legal description of the site is T135N, R51W, ½ E Section 6. This area is found within the Sheyenne River Delta, an area formed by the prehistoric meanderings of the Sheyenne River into glacial Lake Agassiz (Bryce et al., 1998). The soil is classified as loamy fine sand and part of the Hamar series of the Serden-Maddock association (Thompson and Joos, 1975). The soil is poorly drained with slow runoff and a water table near the surface following periods of heavy rain and spring snow melt. The climate of the region is classified as continental with cold winters and hot summers (Manske and Barker, 1988). The average annual temperature of the region is 5.4°C with an average annual precipitation of 55.7 cm (NDAWN, 2011) over the past 5 years, with the majority occurring during the growing season of April through September. This region of the country is currently experiencing a wet cycle, receiving approximately 6.0 cm of additional precipitation yearly compared to long-term historical averages (NDAWN, 2011; Manske and Barker, 1988).

The pasture associated with the test plots was considered degraded tallgrass prairie. This pasture has been cultivated in the past and was likely reseeded in the 1970's, with a minimal re-entry of tallgrass prairie species such as big bluestem (*Andropogon gerardii*), little bluestem (*Schizacyrium scoparium*), Indian grass (*Sorghastrum nutans*) and switch grass (*Panicum virgatum*). In addition to the warm season grasses there were a variety of cool season grasses within the study plots, most notably Kentucky bluegrass (*Poa pratensis*). Kentucky bluegrass is an introduced perennial grass that has been noted in the region as invading grasslands and replacing native forbs and grasses (Murphy and Grant, 2005; DeKeyser et al., 2009), and contributing heavily to overall pasture degradation. Cattle were rotationally grazed throughout the pasture with the exception of a 0.57 hectare enclosure that had been left un-grazed for seven years prior to study initiation. This un-grazed enclosure was dominated by Kentucky bluegrass.

The experimental design for this study consisted of two sites, with each site containing a randomized complete block design (RCBD) and three replications. The sites were both 0.57 hectares in size with one fenced off from cattle activity, while the other was open to grazing. Fire with varying return intervals and seasons was applied to each experimental site using a RCBD. There were three different burn seasons (spring, summer, and fall), two different return intervals (yearly, every two years), and an unburned control resulting in seven different treatment combinations for each block. Each treatment was replicated three times, resulting in 21 plots per site. The experimental layout is shown in Figures 1.1 and 1.2.

Fall Yearly	Spring Yearly	Spring 2 Years	Fall 2 Years	Summer Yearly	Summer 2 Years	Control
Summer Yearly	Summer 2 Years	Control	Fall 2 Years	Spring Yearly	Spring 2 Years	Fall Yearly
Spring 2 Years	Summer 2 Years	Summer Yearly	Spring Yearly	Fall Yearly	Control	Fall 2 Years

Figure 1.1. Experimental design for non-grazed block in burn season and frequency trial in southeastern North Dakota on the Ekre Grassland Preserve.

The initial burn cycle for the test plots began in November, 2008, when all fall plots were burned, followed by the spring plots burned in April, 2009. The summer plots were

Spring Yearly	Fall 2 Years	Spring 2 Years	Summer Yearly	Control	Summer 2 Years	Fall Yearly
Spring 2 Years	Fall Yearly	Summer 2 Years	Fall 2 Years	Control	Spring Yearly	Summer Yearly
Spring Yearly	Fall Yearly	Summer Yearly	Summer 2 Years	Control	Spring 2 Years	Fall 2 Years

Figure 1.2. Experimental design for grazed block in burn season and frequency trial in southeastern North Dakota on the Ekre Grassland Preserve.

burned in August, 2009; however, the burns were unsuccessful in the grazed block due to lack of fuel. This resulted in the grazed summer plots being excluded from the trial. The final burns occurred in the fall of 2009, and spring and summer of 2010. These burns were the yearly plots, allowing the 2 year plots a year of rest.

Data from each plot was collected on September 23, 2009 and August 16, 2010. Visual estimates were used to determine percent cover of vegetation (by species), litter, and bare ground using a $0.25m^2$ quadrat, with six quadrats collected per plot. Species recorded in this study are listed in Appendix A.

A two-way ANOVA was performed for both the grazed and ungrazed blocks using PROC MIXED SAS software procedure, Version 9.1.3 of the SAS System for Windows (Copyright © 2000-2004 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). The dependent variables were bare ground cover, litter cover, forb cover, sedge cover, fern cover, grass cover, smooth brome cover, and Kentucky bluegrass cover. The data was transformed prior to analysis using arcsine square root ($b=2/\pi*\arcsin((X_{i,j})^{1/2})$) and mean comparison of treatments used LSMEAN with Tukey adjustment.

Community composition was analyzed using perMANOVA (permutation MANOVA) (PC-ORD version 5.21 software). The grazed and ungrazed blocks were analyzed independently for fire treatments and year using a relative Sorensen distance measure with a two-way factorial design and 9,999 permutations. Within the ungrazed plot, a Non Multidimensional Scaling (NMS) analysis using Sorensen distance measure was conducted using PC-ORD version 5.21 software (McLane and Medford, 1999).

Results

Separate ANOVA analyses were computed for both grazed and ungrazed blocks to identify differences between treatments, and between years within treatments. We identified several differences ($p < 0.05$) between treatments; however, there were few differences between years. The results are shown below in Tables 1.1-1.4.

Table 1.1. Average percent cover and standard error of bare ground and litter on the burn treatments in the ungrazed block at the Ekre Grassland Preserve in southeastern North Dakota in 2010.

	Bare[7]	Litter
Control	2.5±1.2[a]	28.9±6.8 [acd]
Fall 2 Year[1]	1.7±1.1[ab]	24.1±12.1[abcd]
Fall Yearly[2]	10.6±12.7[bc]	13.7±11.8[bcd]
Summer 2 year[3]	15.3±8.5[c]	16.8±6.8[abcd]
Summer Yearly[4]	15.5±8.7[c]	27.8±24.4[abc]
Spring 2 Year[5]	9.8±4.5[bc]	22.8±8.1[abcd]
Spring Yearly[6]	9.1±10.3[bc]	12.5±7.9[bd]

[1]Fall 2 Year indicates a burn treatment applied in the fall every other year
[2]Fall Yearly indicates a burn treatment applied in the fall every year
[3]Summer 2 Year indicates a burn treatment applied in the summer every other year
[4]Summer Yearly indicates a burn treatment applied in the summer every year
[5]Spring 2 Year indicates a burn treatment applied in the spring every other year
[6]Spring Yearly indicates a burn treatment applied in the spring every year
[7]Different letters within a column indicate a significant difference ($p \leq 0.05$)

The ungrazed control plots had significantly less ($p < 0.05$) bare ground than all other ungrazed burn treatments except the fall 2 year treatment (Table 1.1). The fall 2 year treatment had less bare ground than both the summer 2 year and summer yearly treatments. The litter on the control plots were higher than both the fall yearly and spring yearly treatments, with the summer yearly also higher than spring yearly. The only year effects were found on the fall yearly for bare ground and summer yearly for litter. Fall yearly bare ground was greater ($p < 0.05$) in 2010 compared to 2009 and summer yearly litter was reduced ($p < 0.05$) in 2010 from 2009.

The fall yearly treatment had greater ($p < 0.05$) bare ground and lower ($p < 0.05$) litter than the control and fall 2 year for the grazed plots (Table 1.2). There were no differences between years for either bare ground or litter in the grazed treatments.

Table 1.2. Average percent cover and standard error of bare ground and litter for burn treatments in the grazed block at the Ekre Grassland Preserve in southeastern North Dakota in 2010.

	Bare[5]	Litter
Control	9.1 ± 3.9^{a}	16.5 ± 6.2^{a}
Fall 2 Year[1]	11.3 ± 6.8^{a}	16.7 ± 3.7^{a}
Fall Yearly[2]	26.6 ± 9.4^{b}	6.9 ± 3.4^{b}
Spring 2 Year[3]	18.3 ± 7.3^{ab}	13.8 ± 3.4^{ab}
Spring Yearly[4]	24.6 ± 9.2^{ab}	10.1 ± 6.7^{ab}

[1]Fall 2 Year indicates a burn treatment applied in the fall every other year
[2]Fall Yearly indicates a burn treatment applied in the fall every year
[3]Spring 2 Year indicates a burn treatment applied in the spring every other year
[4]Spring Yearly indicates a burn treatment applied in the spring every year
[5]Different letters within a column indicate a significant difference ($p \leq 0.05$)

The percent cover for carex species, forbs, and grasses was not different ($p > 0.05$) between treatments or between years for both grazed and ungrazed blocks (Table 1.3). Percent cover of Kentucky bluegrass and smooth brome between treatments was not different ($p > 0.05$) on the grazed block (Table 1.4); however, differences ($p < 0.05$) were found on the ungrazed block (Table 1.5).

Table 1.3. Average percent cover of Carex spp., forbs, and grasses for burn treatments in the ungrazed block at the Ekre Grassland Preserve in southeastern North Dakota in 2010.

	Carex	Forb	Grass
Control	2.67	2.89	20.63
Fall 2 Year[1]	2.22	1.13	17.63
Fall Yearly[2]	8.5	3.45	14.3
Summer 2 year[3]	4.83	3.56	13.54
Summer Yearly[4]	2.08	2.4	14.42
Spring 2 Year[5]	9.92	3.16	20.29
Spring Yearly[6]	8.17	3.27	11.42

[1]Fall 2 Year indicates a burn treatment applied in the fall every other year
[2]Fall Yearly indicates a burn treatment applied in the fall every year
[3]Summer 2 Year indicates a burn treatment applied in the summer every other year
[4]Summer Yearly indicates a burn treatment applied in the summer every year
[5]Spring 2 Year indicates a burn treatment applied in the spring every other year
[6]Spring Yearly indicates a burn treatment applied in the spring every year

Table 1.4. Average percent cover and standard error of Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) for burn treatments in the grazed block at the Ekre Grassland Preserve in southeastern North Dakota in 2010.

	Kentucky Bluegrass	Smooth Brome
Control	32.1±8.5	7.4±3.2
Fall 2 Year[1]	29.0±9.0	5.6±2.0
Fall Yearly[2]	32.4±5.9	10.2±4.0
Spring 2 Year[3]	27.5±5.8	5.6±1.5
Spring Yearly[4]	27.3±6.0	7.6±5.1

[1]Fall 2 Year indicates a burn treatment applied in the fall every other year
[2]Fall Yearly indicates a burn treatment applied in the fall every year
[3]Spring 2 Year indicates a burn treatment applied in the spring every other year
[4]Spring Yearly indicates a burn treatment applied in the spring every year

Table 1.5. Average percent cover and standard error of Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) for burn treatments in the ungrazed block at the Ekre Grassland Preserve in southeastern North Dakota in 2010.

	Kentucky[7] Bluegrass	Smooth Brome
Control	49.9±6.5[a]	10.1±2.2[ab]
Fall 2 Year[1]	46.8±10.9[ab]	8.0±3.5[a]
Fall Yearly[2]	38.5±5.4[abc]	10.5±3.6[ab]
Summer 2 Year[3]	30.5±9.9[bc]	15.4±3.8[b]
Summer Yearly[4]	27.8±15.6[c]	13.9±3.2[b]
Spring 2 Year[5]	39.4±4.9[abc]	9.4±3.8[ab]
Spring Yearly[6]	38.3±6.6[abc]	10.2±4.2[ab]

[1]Fall 2 Year indicates a burn treatment applied in the fall every other year
[2]Fall Yearly indicates a burn treatment applied in the fall every year
[3]Summer 2 Year indicates a burn treatment applied in the summer every other year
[4]Summer Yearly indicates a burn treatment applied in the summer every year
[5]Spring 2 Year indicates a burn treatment applied in the spring every other year
[6]Spring Yearly indicates a burn treatment applied in the spring every year
[7]Different letters within a column indicate a significant difference ($p \leq 0.05$)

The burn treatment fall 2 year had lower ($p < 0.05$) smooth brome cover than summer 2 year and summer yearly treatments on the ungrazed block. Kentucky bluegrass cover was greater ($p < 0.05$) in the control compared to summer 2 year and summer yearly, and fall 2 year was greater ($p < 0.05$) than summer yearly treatment. There were no differences ($p > 0.05$) between years for either Kentucky bluegrass or smooth brome.

The plant community composition was different ($p <0 .002$, adjusted for multiple comparisons) between treatments within the ungrazed block, but not within the grazed plot. Ungrazed treatments with significantly varying plant communities are shown in Table 1.6.

The Nonmetric Multidimensional Scaling (NMS) for the ungrazed treatments were best described using three dimensions. Axis one accounted for 37% of the variation, Axis two 32% of the variation, and Axis three 13% of the variation. Axis 1 and Axis 2 were

Table 1.6. Plant community composition p-values for significantly varying ($p < 0.002$, adjusted for multiple comparisons) treatment interactions within ungrazed plot at Ekre Grassland Preserve in southeastern North Dakota.

Treatment vs. Treatment	p value
Fall 2 Year vs. Summer 2 Year	0.0018
Fall 2 Year vs. Summer Yearly	0.0001
Fall Yearly vs. Summer Yearly	0.0002
Spring Yearly vs. Summer Yearly	0.0003

graphed as they explained the greatest amount of variation at 69% (Figure 1.3). The emergent pattern from this graph was summer burns, both yearly and 2 year, were in the negative region of Axis 2, while the spring and fall burns were located primarily in the positive region for both the yearly and 2 year burns. Axis 1 showed a separation between spring and fall burns. Fall burns tended to fall in the negative region of Axis 1, while spring burns fell primarily in the positive region. Kentucky bluegrass had an r-value of 0.629 with axis 2 and so high cover values were correlated with positive values while smooth brome had an r-value of -0.656 and had high cover values correlated with negative values of axis 2.

Discussion

Initial results have indicated a noticeable difference between grazed and ungrazed plots, similar to other studies that documented plant community structure varies significantly in the presence of grazing, or lack of grazing (Murphy and Grant, 2005; DeKeyser et al., 2009). Our results to date have indicated very little variation among burn

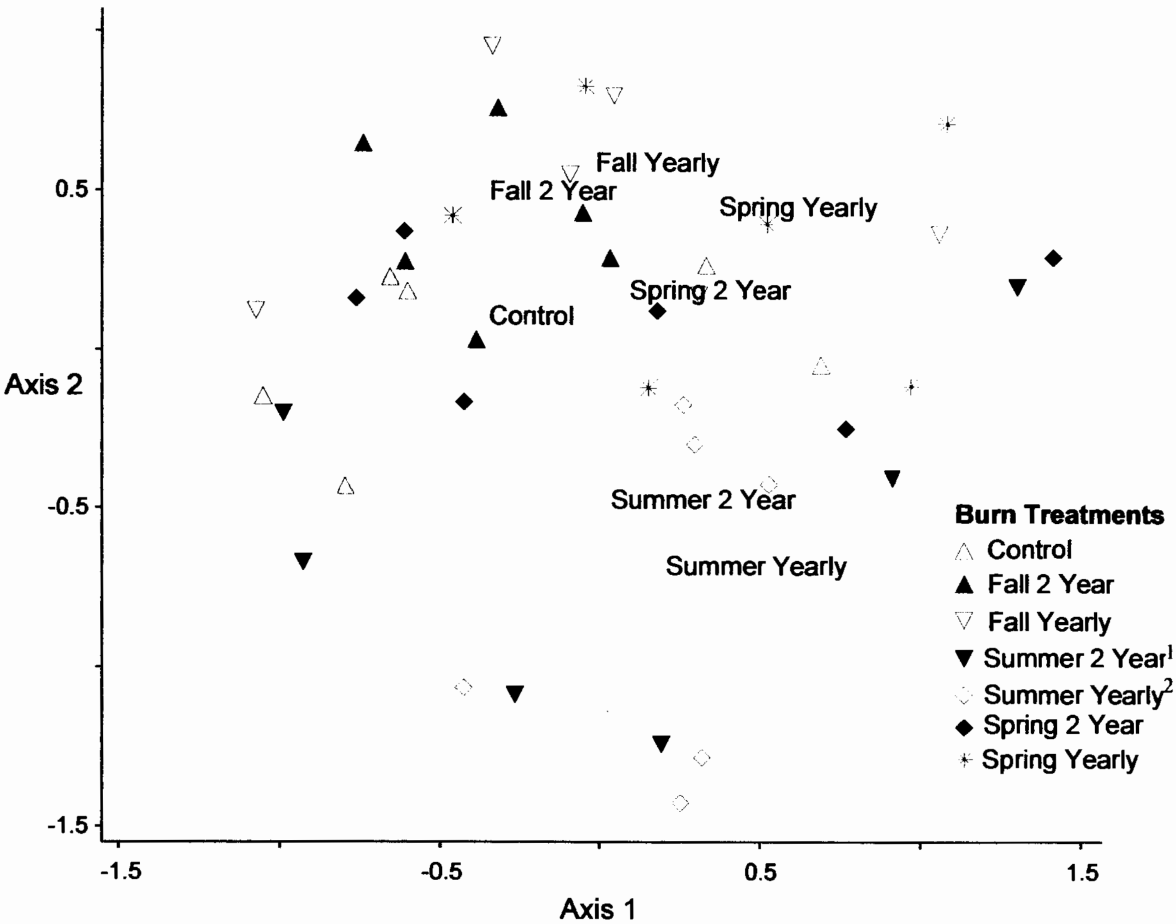

Figure 1.3. NMS ordination of ungrazed plot treatments for burn season and frequency in southeastern North Dakota showing Axes 1 and 2. Treatment titles on graph are located at their respective centroids.

[1]Summer 2 Year burn treatment varies significantly from Fall 2 Year burn treatment.

[2]Summer Yearly burn treatment varied significantly from Fall 2 Year, Fall Yearly, and Spring Yearly burn treatments.

treatments within the grazed plot. The only variation between treatments was a greater percent cover of bare ground and less percent cover of litter for fall yearly when compared to both the control and fall 2 year treatments. The unburned control would naturally have higher litter content and reduced bare ground cover than blocks which undergo yearly burning, and blocks which are burned yearly rather than every two years are more likely to have higher bare ground and reduced litter. Aside from this variation, the grazed plot has shown no differences among treatments or within treatments between years. This lack of treatment variation may be due to insufficient fuel loads at times of fire.

The ungrazed plot showed greater variation among treatments. Summer burns appear to be different than spring and fall burns. Summer burns have resulted in the highest percent of bare ground, highest percent of smooth brome cover, and the lowest percent of Kentucky bluegrass cover. A significant community level variation occurs between summer burns, both yearly and 2 year, and other spring and fall burn treatments. These findings are similar to other studies which have shown summer burning resulted in greater species diversity than spring burning (Towne and Kemp, 2008) and greater Kentucky bluegrass reducing capability than fall burning (Volesky and Cannot, 2000). The greatest contrast is shown between summer and fall burns with summer burns having less Kentucky bluegrass cover and greater smooth brome cover. Fall burns in our study did not reduce Kentucky bluegrass Cover. Volesky and Cannot (2000) showed fall burning resulted in warm season grass reduction and no difference in cool season grass cover.

Spring burns in past studies have shown success in reducing Kentucky bluegrass cover (Becker, 1986; Svedarsky et al., 1986; Engle and Bidwell, 2001); however, at this point in our study we are not seeing any changes. The springs of 2009 and 2010 have been abnormally wet, resulting in moderately successful burns. This may be one reason why spring burns have shown only limited success in reducing invasive species cover. As a side note, it should be mentioned that the control plots have thus far resulted in the highest average Kentucky bluegrass and litter cover, although not all differences have been significant.

While the season of burning has shown differences between treatments, frequency of fire return has not. Previous studies investigating fire as a control mechanism for Kentucky bluegrass have concluded that biennial and annual burnings have comparable results in regards to Kentucky bluegrass reduction (Knops, 2008). However, smooth brome has been found to be less susceptible to fire and for fire to be a successful control mechanism, multiple successive years of burning are required (Wilson and Stubbendieck, 1996; DiTomaso, 2006). At this point of our study, only one full burn cycle has been completed and only two years of data collected. Additional years of data will be required before any conclusions can be drawn in regards to the impact of frequency.

The contrast between grazed and ungrazed plots was distinct in this study. Studies have shown that a pasture with a well-managed grazing system compared to a dormant or ungrazed pasture contains greater species diversity, reduced invasive species, reduced litter, and increased patchiness (West, 1993; Collins et al., 1998; Frost and Launchbaugh, 2003). All of these trends can be seen in this study with the exception of patchiness (the area encompassed by this trial is too small to draw any conclusions regarding landscape patchiness). A comparison of the grazed and ungrazed treatments reveals that litter cover is less in the grazed block, Kentucky bluegrass and smooth brome cover is less in the grazed block, and total species present in the grazed block was 83 compared to 56 in the ungrazed. These variations could be why burning treatments have shown little variation within the grazed area while the ungrazed area is producing significant differences.

Conclusion

This study is still in an early stage with only one full burn cycle completed to date. It appears that summer burning, regardless of the frequency, is more effective than both spring and fall burning for reducing Kentucky bluegrass cover; however, it increases bare ground. From a livestock management perspective the loss in cover using a summer burn as a management tool could potentially result in a loss of forage. If these finding continue and summer burning is determined most effective in reducing Kentucky bluegrass cover, future studies would be required to determine the economic viability of such a management strategy. To date, none of the treatments have shown any impact when applied in combination with the grazing. If this trend continues, there will be no need to address the economic viability from a livestock production standpoint as there will be no benefit gained from its implementation. Additional years of data are required before any definitive conclusions can be drawn, and if significant treatment variations are observed, a larger scale trial would be in order.

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PAPER 2. INTERSEEDING OF NATIVE PLANTS INTO NORTHERN TALLGRASS PASTURELAND

Introduction

Interseeding of multiple native plant species is a relatively new concept and management strategy within the Northern Great Plains. Interseeding is a process by which native or introduced species are planted directly into existing vegetation without tillage, allowing the existing plant community to remain intact. This makes it an appealing option for restoring or increasing production of actively grazed pasture land. A common practice to help the emergence of new seedlings is the use of competition reduction prior to seeding (Wilson and Gerry, 1995; Bakker et al., 2003). If the existing cover is not temporarily suppressed, newly seeded plants do not compete well against existing vegetation. The goal of this trial was to analyze multiple pre-seeding treatments to determine impacts on seedling establishment and forage production. This study will also compare the impacts of grazing versus non-grazing on newly interseeded pastureland.

Two pre-seeding treatments were studied in this experiment, herbicide application and prescribed fire. These treatments were applied individually and in combination, and were done so in grazed and un-grazed test plots. As a reference or baseline for these treatments there were also control plots in which no interseeding or treatments were applied, as well as seed only plots in which interseeding was conducted but without any pre-seeding treatment application. Predictions for this study were that the combination treatment of herbicide with burning would yield the highest seedling counts as it was likely to result in the greatest amount of competition reduction. It was also predicted that the burn herbicide treatment, in combination with grazing, would result in the highest quality forage production. This prediction is based on previous studies that have shown interseeding to be more effective when used in combination with cover reduction and grazed rangelands have greater plant species diversity than un-grazed rangelands (Wilson and Gerry, 1995; Howe, 1999).

Literature Review

Tall grass prairies once covered over 160 million acres of North America, today, less than 5% still remain (Knapp et al., 1999). The advent of European settlement brought with it widespread land use changes in the form of agriculture. The majority of tall grass prairies were tilled under and converted into crop fields, effectively removing native plant species (Packard and Mutel, 1997). The few remnants that do remain do so primarily in the form of state or federally funded preserves, or as pasturelands used for livestock grazing, the majority of which have undergone some degree of degradation. To combat this loss of native habitat it is the task of land managers to develop techniques that can be used for both protecting what remains and restoring what has been lost. One way in which they may be able to accomplish this task is through interseeding native rangeland plants back into disturbed or degraded pasturelands.

Interseeding is a process by which seeds are planted directly into existing vegetation without plowing (Bailey and Martin, 2007). One benefit of this seeding process is that it allows the existing plant community to remain intact and potentially usable (from an agricultural standpoint) so that when performed on active pastureland there is no production loss. This is an attractive quality to landowners as it requires less physical input and potentially reduced production loss as compared to alternative seeding processes. Interseeding also has the potential to increase forage production. Studies have shown interseeded rangelands to have as much 143% greater above ground live biomass when compared to a control (Mortenson et al., 2005). The primary drawback to interseeding is that it requires a specialized drill built specifically for the fluffy seeds of native grasses (NRCS, 2006). Conventional drills often become clogged when used with native grass seeds and place seeds at a greater than optimal depth (native grass seed should be seeded at a depth no greater than ½ inch).

Interseeding by itself has had limited success in promoting the growth of native plant species (Rowe, 2010). Wilson and Gerry (1995) found that untreated plots resulted in as many as 20 times fewer seedlings than those that were treated prior to seeding. In support of these findings, subsequent studies have shown that interseeding is most effective when used in combination with some form of cover reduction control (Bakker et al., 2003). One control measure that has been proven effective is the use of herbicide prior to seeding (Wilson and Gerry, 1995). Herbicide treatments temporarily suppress the majority of plants in the treated area, resulting in competition reduction for later seedling emergence. Timing of treatment application is important and should be based on the overall management goals. Studies have shown that spring herbicide treatments, prior to the heading out of cool season grasses, are effective in promoting increased cover composition by warm season grasses (DiTomaso, 2000). Studies have also shown that spring herbicide treatments can result in increased drought tolerance of perennial warm season grasses (Houston, 1977).

Another control measure that has been widely used for prairie restoration, but only on a limited basis in combination with interseeding, is the use of prescribed fire. Numerous studies have shown that prescribed fires can be a useful tool for reducing growth of cool season grasses, thereby promoting greater cover composition of native warm season grasses (Hover and Bragg, 1981; DiTomaso, 2000; Engle and Bidwell, 2001). Reducing cool season grasses results in greater light infiltrating, promoting seedling growth of warm season grasses. The majority of literature on prescribed fire for prairie restoration cites the spring as the best season for burning if the overall management goal is to reduce the presence of invasive cool season grasses and increase native warm season grasses (Hover and Bragg, 1981). Kentucky bluegrass (*Poa pratensis*) and smooth brome (*Bromus inermis*) are two problematic invasive cool season grasses currently threatening eastern North Dakota's prairies (Murphy and Grant, 2005; Grant et al., 2009). Studies have shown that fire is an effective management tool for reducing the overall cover of both species, with Kentucky bluegrass being more heavily impacted by a single burn than smooth brome (Svedarsky et al., 1986; DiTomaso et al., 2006).

A final management tool and common practice throughout the tallgrass prairie region is livestock grazing. Grazing by large herbivores is an activity that has taken place throughout the Great Plains for thousands of years, long before European arrival (Collins et al., 1998). Following European settlement and the introduction of domesticated livestock, overgrazing became increasingly problematic, resulting in many of the rangeland problems that exist today. While it has been shown that grazing in excess can result in negative consequences such as loss of species diversity and increases in invasive species, studies have also shown that more moderate levels of grazing can actually be beneficial to overall rangeland health (Frost and Launchbaugh, 2003). In most cases, moderate levels of grazing tend to increase biodiversity so long as the grazers are generalists such as cattle or bison that graze on dominant species in an area rather than keying in on a select few

(Howe, 1999). Reducing the overall cover of dominant species provides openings for establishment by subdominant species leading to increases in biodiversity. When combining the use of grazing with interseeding it is recommended that livestock be temporarily cut off from newly seeded pastures as they tend to target seedlings (Schumacher, 1964).

Studies have shown that interseeding can be an effective tool for restoring degraded rangelands, but its impact is much more pronounced when combined with one or more forms of cover reduction prior to seeding. Cover reduction such as herbicide, controlled burns, and grazing have all proven to provide positive benefits to rangelands when applied independently, but there has been limited research looking at applying these treatments in combination with one another, or in combination with interseeding. Determining how these treatments impact rangeland quality when combined with interseeding can be of great benefit to rangeland managers and may be a critical link to restoring lost and degraded prairies throughout the Great Plains.

Methods

The study site for this project was 12.1 hectares (30 acres) of pastureland located on the Ekre Grassland Preserve in Richland County, North Dakota. The legal description of the site is T135N, R51W, NE¼ Section 6. The entire study area had been rotationally grazed with cattle for several years prior to study commencement; however, in order to study the impacts of grazing, half (6.1 hectares) of the study area was fenced off to livestock use, while the other half remained actively grazed. The study area is part of the prehistoric meanderings of the Sheyenne River, an area known as the Sheyenne River Delta (Bryce et al., 1998). The soil of the study site is composed primarily of loamy fine sand from the Hecla and Hamar series of the Serden-Maddock association (Thompson and Joos, 1975). The soil is moderately well drained with rapid permeability. The water table of the area is very near the surface both in the spring and following periods of heavy rain. Blowing soil can be a hazard in this area when soil is left exposed or un-vegetated.

The climate of this region is classified as continental, with cold winters and hot summers. It has an annual mean temperature of 5.4 °C and an average rainfall of 55.7cm, 79% of which falls during the growing months of April through September (NDAWN, 2011; Manske and Barker, 1988). The pasture in which the test plots were located is considered degraded tall grass prairie. This pasture was once cultivated and probably reseeded in the 1970's, with a minimal re-entry of tallgrass prairie species such as big bluestem (*Andropogon gerardii*), little bluestem (*Schizacyrium scoparium*), Indian grass (*Sorghastrum nutans*) and switch grass (*Panicum virgatum*). There are also a variety of cool season grasses found within the pasture and test plots, most notably Kentucky bluegrass (*Poa pratensis*). Kentucky bluegrass is an introduced perennial grass that has been noted in the region as invading grasslands and replacing native forbs and grasses (Murphy and Grant, 2005; DeKeyser et al., 2009), and was contributing heavily to overall pasture production. Prior to study initiation, a forage production analysis was conducted for every pasture on the Ekre Grassland Preserve. The pasture on which this study was located was found to be under producing by nearly 500 lbs/acre compared to the historic climax plant community, and was the lowest scoring pasture on the preserve (Edward DeKeyser, personal contact).

The layout for this trial was a split plot, complete block experimental design. The split plot variable for this trial was grazing, with one plot being fenced off from grazing while the other remained actively grazed by cattle in a rotational grazing system. The between plot variables for this trial were seeding, fire, and herbicide treatment, each applied both individually and in combination. The herbicide used for this study was RoundUp® Concentrate Plus (The Scotts Company LLC, Worldwide Rights Reserved) which was mixed with water at a 60/1 ratio. This mixture was then applied to the appropriate plots using a boom sprayer at approximately 23 liters/hectare.

Each plot was divided into three replications of five blocks, resulting in 15 blocks per plot and 30 total blocks. The blocks were 40X100 meters in size or approximately .41 hectares. Each replication consisted of a control, a seed only, a burn seed combination, a herbicide seed combination, and a burn herbicide seed combination. The experimental layout of the trial area is shown below in Figures 2.1 and 2.2.

Control	Burn Seed Herbicide	Control
Burn, Herbicide, Seed	Seed Only	Burn, Herbicide, Seed
Seed Only	Burn, Seed	Burn, Seed
Burn, Seed	Control	Herbicide, Seed
Herbicide, Seed	Herbicide, Seed	Seed Only

Figure 2.1. Design for interseeding treatments on grazed plots located in southeastern North Dakota on the Ekre Grassland Preserve.

Seed Herbicide	Burn Seed	Burn Seed
Control	Herbicide, Seed	Herbicide, Seed
Burn, Herbicide, Seed	Seed Only	Control
Seed Only	Control	Seed Only
Burn, Seed	Burn, Herbicide, Seed	Burn, Herbicide, Seed

Figure 2.2. Design for interseeding treatments on ungrazed plots located in southeastern North Dakota on the Ekre Grassland Preserve.

The burning and herbicide treatments were applied 3 weeks prior to interseeding of the range plants to avoid negatively impacting the planted seeds. Interseeding was completed using a Truax FLEX II drill, model FLXII-818, designed specifically for seeding prairie plants. The drill seeded with 8 inch spacing and had a seeding depth ranging from 1/8 to 1/2 inch deep (Carl Piper, personal contact). The seed used was all clean and de-bearded. All blocks, with the exception of the six controls, were seeded on July 16th and 17th, 2010. The soil conditions at the time of seeding were moist to wet with some standing water in low lying areas. The seed mixture selected for this project consisted of 13 different native prairie grasses along with two native clovers. The ratios and seeding density for each species was intended to reflect that of native tall grass prairie communities historically located in the pasture (Table 2.1).

Table 2.1. Plant species and associated seeding density for interseeding trial located in southeastern North Dakota on the Ekre Grassland Preserve.

Species	**Kg/hectare**	**Species**	**KG/hectare**
Prairie Sandreed *Calamovilfa longifolia*	1.12	Sandbluestem *Andropogon hallii*	0.34
Big Bluestem *Andropogon gerardii*	2.69	Prairie Junegrass *Koeleria macrantha*	0.01
Switchgrass *Panicum virgatum*	0.56	Porcupinegrass *Hesperostipa spartea*	0.11
Blue Grama *Bouteloua gracilis*	0.17	Little Bluestem *Schizachyrium scoparium*	0.56
Canada Wildrye *Elymus canadensis*	0.56	Western Wheatgrass *Pascopyrum smithii*	0.56
Indiangrass *Sorghastrum nutans*	0.28	Purple Prairieclover *Dalea purpurea*	0.28
Green Needlegrass *Nassella viridula*	0.28	White Prairieclover *Dalea candida*	0.28
Prairie Cordgrass *Spartina pectinata*	0.17		

Seedling data collection was conducted in mid-August, 2010. Data were collected using a $0.25m^2$ quadrat recording presence and absence of plant species as well as the number of seedlings present by species for the 15 interseeded species. Species recorded in this study are listed in Appendix B. Twelve quadrats were recorded per block, the distribution of which was a grid pattern of 3x4, making sure to remain a minimum of two meters away from any neighboring block so as to avoid any edge effect.

For the initial round of data collection there was no between plot treatment due to the fact that cattle were absent from both plots between the time period of seeding and data collection. Therefore, the data were analyzed as though there were six replications per treatment. These data were run through a 1-way ANOVA table using the PROC MIXED SAS software procedure, Version 9.1.3 of the SAS System for Windows (Copyright © 2000-2004 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA). The percentage data were transformed prior to analysis using arcsine square root: $b=2/\pi*\arcsin((x_{i,j})^{1/2})$, and LSMEAN was used for mean comparison using the Tukey adjustment.

Results

Results were limited to seedling establishment as only one year of data was available. Seedling establishment was different ($p < 0.05$) between plots treated with herbicide and those not 12 months after treatment (MAFT) (Tables 2.2 and 2.3). The average number of seedlings per quadrat for both grasses and forbs (*Dalea species*) was greatest in the two treatments that included herbicide.

Table 2.2. Average number of grass seedlings/m^2 by treatment 12 MAFT in southeastern North Dakota on the Ekre Grassland Preserve.

Treatment	Average # of Seedlings/(m^2)[1]
Burn, Herbicide, Seed	34.3a
Herbicide, Seed	25.7a
Burn, Seed	5.2b
Seed Only	3.0b
Control	0.0b

[1]Different letters within column indicate a significant difference ($p \leq 0.05$).

Table 2.3. Average number of forb seedlings/m^2 by treatment 12 MAFT in southeastern North Dakota on the Ekre Grassland Preserve.

Treatment	Average # of Seedlings/(m^2)[1]
Burn, Herbicide, Seed	7.6a
Herbicide, Seed	10.8a
Burn, Seed	4.0ab
Seed Only	4.0ab
Control	0.0b

[1]Different letters within column indicate a significant difference ($p \leq 0.05$).

Grass seedlings/$m^2$for both herbicide treatments were different ($p \leq 0.05$) between all other treatments; however, forb seedlings/m^2 was only different ($p \leq 0.05$) from the control.

Among the grasses, the three most common species identified in the seedling counts were big bluestem, little bluestem, and switchgrass. These three grasses were run individually using ANOVA (Tables 2.4, 2.5, and 2.6).

Herbicide treatments had greater ($p \leq 0.05$) seedlings/m^2 for both big bluestem and switch grass compared to all other treatments; however, little bluestem was only different ($p \leq 0.05$) between burn, seed, herbicide and control.

Table 2.4. Average number of big bluestem seedlings/m^2 by treatment 12 MAFT in southeastern North Dakota on the Ekre Grassland Preserve.

Treatment	**Average # of Seedlings/(m^2)[1]**
Burn, Herbicide, Seed	21.2a
Herbicide, Seed	19.4a
Burn, Seed	9.2b
Seed Only	11.5b
Control	0.0b

[1]Different letters within column indicate a significant difference ($p \leq 0.05$).

Table 2.5. Average number of little bluestem seedlings/m^2 by treatment 12 MAFT in southeastern North Dakota on the Ekre Grassland Preserve.

Treatment	**Average # of Seedlings/(m^2)[1]**
Burn, Herbicide, Seed	8.6a
Herbicide, Seed	7.1ab
Burn, Seed	6.6ab
Seed Only	8.0ab
Control	0.0b

[1]Different letters within column indicate a significant difference ($p \leq 0.05$).

Table 2.6. Average number of switchgrass seedlings/m^2 by treatment 12 MAFT in southeastern North Dakota on the Ekre Grassland Preserve.

Treatment	**Average # of Seedlings/(m^2)[1]**
Burn Seed Herbicide	12.6a
Seed Herbicide	14.5a
Burn Seed	6.0b
Seed Only	0.0b
Control	0.0b

[1]Different letters within column indicate a significant difference ($p \leq 0.05$).

Discussion

This is the initial year of the study so results were limited to seedling establishment. Our findings indicate that the use of a herbicide treatment prior to seeding resulted in greater seedling establishment than treatments without herbicide. In addition, herbicide treatment in combination with burning was the most effective pre-seeding treatment for seedling establishment, indicating a direct correlation between amount of pre-seeding cover reduction and likelihood of seedling establishment. These results were not surprising as it was predicted upon trial initiation that overall cover reduction would have a large impact on seedling germination and establishment. These findings support Bakker et al. (2003) who concluded that interseeding is most effective when used in combination with some form of cover reduction. In contrast to the plots treated with herbicide, plots which underwent no pre-seeding treatment resulted in little to no seedling found. This lack of establishment is an indication that interseeding by itself is an ineffective restoration practice and must be used in combination with some form of cover reduction.

Although the use of herbicide was the most effective pre-treatment in this trial, it should be noted that burning also had positive impacts in regards to seedling establishment. The ANOVA results did not indicate that there was a significant difference ($p > 0.05$) between burn only and no treatment plots, but that may have been due in part to a wetter than average spring. The controlled burns conducted for this experiment were done so with a less than adequate fuel load and high soil moisture content. The combination of these factors may have resulted in a reduced overall impact, allowing existing vegetation to rebound at a more rapid rate. Studies have shown that above average spring moisture can result in poor burns and increased mid-season biomass (Gibson and Hulbert, 1987), both of which result in reduced opportunities for seedling germination. In the case of forb and little bluestem seedling counts, the use of herbicide was not shown to be different ($p > 0.05$) from burning alone, indicating burning may have potential under more favorable conditions. Bailey and Martin (2007) reported that interseeding is a slow developing process that may take 4-5 years before full effects can be seen. It is possible that additional seedling germination may take place in subsequent years. Previous studies have shown burning to be an effective treatment for promoting the growth of native warm season grasses (DiTomaso, 2000; Engle and Bidwell, 2001). Spring burning promotes the growth of warm season grasses by suppressing cool season grasses and warming the soil which stimulates nutrient release (Bailey and Martin, 2007). Future studies are needed to analyze the potential benefits of burning as a pre-seeding treatment for interseeding restoration projects. If positive results can be shown, burning has the potential to be an economically viable alternative to herbicide.

Conclusion

While seedling establishment is an important aspect to interseeding success, it is not the only factor that will dictate the overall impact of this study. The long-term goal of this study was to determine how the plant community's structure and dynamics change over time, and what portion of this change can be attributed to interseeding. Thus far we have shown the use of herbicide pre-seeding treatment is effective at promoting first year seedling growth, but subsequent year community level dynamics is necessary to conclude the overall effectiveness at promoting native plant communities and improving rangeland production. In addition, the introduction of grazing as a variable will add another dynamic to this study's scope.

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PAPER 3. PATCH BURN GRAZING ON NORTHERN TALLGRASS PRAIRIE

Introduction

Since the advent of European settlement, rangelands throughout the Great Plains have been experiencing losses in biodiversity (Coppedge et al., 2001; Fuhlendorf and Engle, 2001). Increased abundance of invasive species and the conversion to homogeneous landscapes have all contributed to the decline of many plant and animal species. It has been suggested that many of these changes were spurred on by rangeland management practices such as heavy season long grazing and rotational grazing. Under these systems, grazing is evenly distributed throughout available pasture land resulting in all areas being impacted evenly. Patch burn grazing is a relatively new management practice aimed at reversing this trend and restoring patchwork back into disturbed landscapes. Initial studies have shown promise, resulting in greater forb species diversity and cover, as well as greater landscape heterogeneity (Fuhlendorf and Engle, 2004). The goal of this study is to add additional support to the overall impacts of patch burn grazing and to evaluate its effectiveness in the Northern Great Plains.

The logic behind patch burn grazing is based on the tendency of large grazers to favor recently burned areas over those burned less recently. This preference allows managers to use fire as a means of dictating where grazing will take place, rather than relying fences. For this study, a patch burn grazing system with a fire return interval of three years was established in southeastern North Dakota. The pasture was stocked with cattle that were free to graze the entire pasture season long. Bordering this trial was a control pasture that was also stocked with cattle and grazed season long, but which was absent of fire. Vegetation and ground cover was recorded from representative ecological sites to determine any variation in plant communities and overall biodiversity between the sites and over time. It was predicted that the initial response would be characterized by a reduction in tall grass cover and increased forb abundance. This increased abundance of forbs was predicted to persist for roughly two years, at which time litter accumulation would again favor a tallgrass dominated landscape. These predictions were based on a similar study conducted by Fuhlendorf and Engle (2004) in the Southern Great Plains.

Literature Review

Rangelands were historically heterogeneous landscapes composed of a patchwork of different mosaics and ecotypes (Fuhlendorf and Engle, 2001). This heterogeneity resulted from a variety of different disturbance regimes such as fire and grazing, which resulted in a patchier landscape than that of today. Traditional rangeland management promoted a uniform distribution of livestock throughout the available grazing area resulting in more homogeneous landscapes and a loss of biodiversity. Many subdominant or niche plant and animal species were negatively impacted by this landscape change and saw large declines in population (Coppedge et al., 2001; Fuhlendorf and Engle, 2001). Currently, many rangeland managers are attempting to reverse this trend and implement new management strategies aimed at restoring landscape heterogeneity while maintaining current levels of livestock production. One such strategy is the use of patch burn grazing.

Patch burn grazing is a management system which utilizes fire to dictate the location of livestock rather than fences. Burning of grasslands has been shown to result in an increased growth rate of prairie plants, greater quantity of plant production, and overall enhanced forage quality for large herbivores as compared to unburned areas (Engle and Bidwell, 2001). The combination of these factors results in grazers such as cattle and bison favoring burned areas over unburned areas. This allows managers to dictate where livestock graze via burning, rather than dividing a large pasture into a series of smaller pastures through which livestock are rotationally grazed (Fuhlendorf and Engle, 2004). Recently burned plots are favored most heavily by grazers with the grazing intensity decreasing with each subsequent year that passes without fire (Helzer and Steuter, 2005). This lack of grazing results in litter accumulation which provides fuel for future burns.

The primary benefit of a patch burn grazing system over traditional grazing systems is the reintroduction of patch dynamics into the landscape. Patch dynamics are seen as an essential element for maintaining species diversity in an ecological community (Pickett and White, 1985). In grassland ecosystems, numerous studies have shown how the loss of patch dynamics and the transformation from heterogeneous to homogeneous landscapes have resulted in a loss of biodiversity, highlighting the decline of many avian and plant species (Wiens, 1974; Taylor and Guthery, 1980; Knopf, 1994; Coppedge et al., 2001; Fuhlendorf and Engle, 2001). Patch burn grazing results in the majority of grazing taking place in recently burned areas (usually about 1/3 of the pasture depending upon burn schedule), allowing the remaining pasture to function with little to no disturbance. Vermeire et al. (2004) found that cattle grazing resulted in a 78% reduction in standing crop for burned sites compared to just a 19% reduction in areas outside the influence of burning. Traditional grazing practices do not result in such variations, but rather result in a more evenly distributed moderate level of grazing throughout the pasture, leaving little in the way of un-impacted areas. It should also be noted that experimental findings have shown livestock and plant production in continuous grazing systems (such as a patch burn grazing system) to be greater than or equal to rotational grazing systems (Briske et al., 2008).

An effective burn rotation schedule which has been identified for patch burn grazing systems in tallgrass prairie is three years (Fuhlendorf and Engle, 2004). Under this schedule, 1/3 of the total pasture is burned yearly allowing the remaining 2/3 to rest. Recently burned areas provide higher forage quality for large herbivores relatively speaking, resulting in the majority of season long grazing occurring in these areas (Vinton et al., 1993). In the second year, a different 1/3 of the pasture is burned and in the third year the remaining 1/3 is burned completing one full burn cycle. The process is then repeated. Under this system, vegetation response is characterized by a decrease in tallgrasses, resulting in greater sunlight infiltration and subsequently an increase in forb cover. This increased forb composition will persist for roughly two years until litter begins to accumulate and tallgrasses again regain dominance (Fuhlendorf and Engle, 2004). Forbs are important in tallgrass prairies because they contribute more to biodiversity than do grasses (Turner and Knapp, 1996). Some of the ecological benefits associated with forbs are improved habitat diversity, increased forage quality, soil stabilization, and important food sources for many upland birds and organisms (Shaw et al., 2005).

When conducting controlled burns, season is often an important variable that must be taken into consideration. Studies have shown that the overall impact of prescribed fire in rangeland ecosystems is dependent upon the time of year in which the fire is conducted (Becker, 1986; Volesky and Cannot, 2000). For patch burn grazing systems, the majority of literature cites the spring as the most common time of year to burn (Engle and Bidwell, 2001; Helzer and Steuter, 2005). A few studies, however, have looked at alternate burning seasons. Fuhlendorf and Engle (2004) looked at the overall impacts of spring versus summer burning in the southern tallgrass prairies of Oklahoma and concluded that season had very little ecological impact in regards to patch burn grazing systems. In support of these findings, Vermeire et al. (2004) also evaluated fall burning in the northern mixed grass prairies of Montana. They too concluded that there is little variation between burn seasons and that cattle showed no preference for one season over another.

Patch dynamics have been shown to play a key role in a healthy functioning ecosystem and are seen as critical to conservation and land management (Christensen, 1997). Currently, there are relatively few management strategies that have proven successful in restoring patch dynamics to degraded rangelands. Patch burn grazing is one system that has shown promise over the past two decades as studies indicate it is effective at both restoring patch dynamics and dictating the movement of livestock. Although additional supporting research is still needed, it appears that patch burn grazing may be a key to restoring the numerous degraded rangelands found throughout the Great Plains.

Methods

This study site was located on the Sheyenne National Grasslands in Richland County, North Dakota, T134N, R52W, Section 17, south ½. The Sheyenne National Grasslands is located on the Glacial Sheyenne Delta which was formed as melt water dumped into Glacial Lake Agassiz near the end of the Wisconsin Glaciation (Bryce et al., 1998). The deposits consist of sand, clay, and gravel and are underlain by a nearly impervious layer of lake sediment resulting in a relatively high water table throughout the area (Manske and Barker, 1988). The region has an average annual temperature of 5.4 °C and has a continental type climate with hot summers and cold winters. Average rainfall for the area is 55.7 cm, the majority of which falls during the growing season of April through September (NDAWN, 2011; Manske and Barker, 1988).

Within this study there were two distinct ecological sites for which data were collected, sub-irrigated (mid) and wet meadow (low). Sub-irrigated sites were found on the higher elevation portions of the pasture and had soils composed of fine sandy loams as part of the Embden series of the Embden-Glyndon-Tiffany association. These soils are moderately well drained with slow runoff and moderately rapid permeability (Thompson and Joos, 1975). The wet meadow ecological sites were found in the areas of lower elevation and were composed of loamy soils. These soils are part of the Arveson series of the Embden-Glyndon-Tiffany association and are characterized by slow runoff and a water table that is at or near the surface following periods of heavy rain or spring snow melt (Thompson and Joos, 1975). The pasture itself is classified as tall grass prairie with big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), and switch grass (*Panicum virgatum*) being the dominant vegetation in the higher elevation ecological sites while the lower elevation ecological sites were composed primarily of sedges and rushes.

This experiment consisted of a randomized design with two treatments, patch burn grazing and no burn grazing. The trial area was divided into two similar sized blocks. The west block was grazed season long with yearling cattle serving as the control. The east block underwent a patch burn treatment in which 1/3 of the pasture was burned each spring with a fire return interval of three years. This pasture was also grazed season long with yearling cattle. The east and west pastures were 62.7 and 64.7 hectares in size, respectively. The east pasture was stocked with 46 head of cattle for 6 months resulting in

0.32 hectares/AUM, while the west pasture was stocked with 52 head of cattle for 5.5 months at 0.32 hectares/AUM (calculations were adjusted to account for yearling cattle). The original study design contained two additional pastures with similar layouts; however, these pastures were excluded from the trial in the spring of 2009 as the result of excess moisture and an inability to burn.

Within each block there were three wet meadow ecological sites and three sub-irrigated ecological sites sampled, resulting in 12 ecological sites sampled. At each site, sampling was conducted along a 25 meter transect using both a $0.25m^2$ quadrat and 10 pin-point frame. Quadrat sampling was conducted every meter on alternating sides of the transect. Data recorded from quadrat sampling included forb counts by species and presence/absence of graminoids by species. These data were then used to determine density and relative frequency. The 10 pin-point frame were collected every meter on both sides of the transect as a means of determining basal cover. The 10 pin-point frame were used to determine bare ground, litter, forb, sedge, or grass by species. Species recorded in this study are listed in Appendix C.

Statistical analysis for this trial was conducted using the perMANOVA (permutation MANOVA) program in PC-ORD (version 5.21 software). This program analyzed the community composition of the pastures using the Sorensen distance measure with 9,999 permutations.

Results

There were no significant differences ($p > 0.05$) found between the control and experimental pastures. Community level plant structure was not altered under the patch burn grazing treatment and no differences ($p < 0.008$, adjusted for multiple comparisons) were found between the patch burn and traditional grazing treatments (Table 3.1).

Table 3.1. p-values for treatment vs. treatment interactions for the patch burn grazing trial on the Sheyenne National Grasslands in southeastern North Dakota. Significance is given at $p < 0.008$ (adjusted for multiple comparisons).

Treatment vs. Treatment	**p-value**
PBG* Low vs. PBG* Mid	0.01
PBG* Low vs. Control Low	0.50
PBG* Low vs. Control Mid	0.21
PBG* Mid vs. Control Low	0.10
PBG* Mid vs. Control Mid	0.09
Control Low vs. Control Mid	0.20

*Patch Burn Graze

Conclusion

At this point in the study there has been no evidence of plant community alteration under patch burn grazing in tallgrass prairie. Two thirds of the initial burn cycle has been completed to date, leaving one spring burn left to be completed. Wet springs have resulted in the exclusion of two of the three original trial pastures and only limited burning success has been achieved in the remaining pasture. The combination of these factors has resulted in poor and limited data that is not likely representative of a well-managed patch burn grazing system. Additional years of data may reveal differences between the two plots, but more than likely additional studies will be required.

One possible factor that may be contributing to the continuing homogeneity of the landscape is the use of yearling cattle. The majority of previous patch burn grazing studies have used cow/calf pairs as the dominant grazers rather than yearling cattle (Vermeire et al., 2004; Helzer and Steuter, 2005). It has been documented that yearling cattle when compared to cow/calf pairs behave differently both in their daily movement patterns and in their forage selection (Rittenhouse, 1999). Yearling cattle tend to travel greater distances and utilize available pasture more evenly than cow/calf pairs, and when a calf is nursing, the movement of cow/calf pairs is even further reduced (Bailey, 1999). This factor was not included in the original scope of this study, but is a topic that warrants further investigation. In order to accurately depict the role of patch burn grazing in a tallgrass prairie setting future studies will need to be conducted on a larger scale with multiple replications.

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GENERAL CONCLUSIONS

The general conclusions from these three studies include:

1. Prescribed burning in the summer resulted in reduced Kentucky bluegrass cover and increased smooth brome cover compared to spring and fall prescribed burns within the ungrazed block. The grazed block showed no variations between treatments, but did have a plant community structure different from the ungrazed block. Future years of data collection are recommended.

2. Treatments involving the use of herbicide resulted in higher seedling counts than treatments absent of herbicide in an interseeding management system. The emerging trend from this study was that greater cover reduction resulted in greater seedling establishment. This was the initial year of the study limiting results to seedling establishment. Future years of data collection and the introduction of grazing will determine the effectiveness of interseeding as a pasture improvement management tool in the Northern Great Plains.

3. Patch burn grazing in the Northern Tallgrass Prairie has not resulted in any treatment variations. Excess moisture and reduced study size have hindered this study. It is not recommended that this trial be continued past this point.

4. The three trials at this point have shown varying levels of success. It is our hope that results from one trial will have implications in others. Determining an effective burn season and frequency could be used in combination with either interseeding or a patch burn grazing system.

APPENDIX A. SPECIES LIST FOR BURN FREQUENCY AND SEASON PAPER

Species*	Origin	Life	Physiognomy
Acer negundo	Native	P	TREE
Achillea millefolium	Native	P	FORB
Ambrosia psilostachya	Native	P	FORB
Ambrosia artemisiifolia	Native	A	FORB
Andropogon gerardii	Native	P	GRASS
Anemone canadensis	Native	P	FORB
Antennaria neglecta	Native	P	FORB
Apocynum cannabinum	Native	P	FORB
Artemisia ludoviciana	Native	P	FORB
Asclepias syriaca	Native	P	FORB
Asclepias verticillata	Native	P	FORB
Bouteloua curtipendula	Native	P	GRASS
Bromus inermis	Introduced	P	GRASS
Calamagrostis stricta	Native	P	GRASS
Calamovilfa longifolia	Native	P	GRASS
Carex species	Native		SEDGE
Chamaesyce glyptosperma	Native	A	FORB
Chenopodium glaucum	Introduced	A	FORB
Cirsium flodmanii	Native	P	FORB
Cirsium undulatum	Native	P	FORB
Cirsium vulgare	Introduced	B	FORB
Conyza canadensis	Native	A	FORB
Cornus sericea	Native	P	SHRUB
Dichanthelium leibergii	Native	P	GRASS
Dichanthelium wilcoxianum	Native	P	GRASS
Elymus canadensis	Native	P	GRASS
Equisetum arvense	Native	P	FORB
Equisetum laevigatum	Native	P	FORB
Eragrostis spectabilis	Native	P	GRASS
Erigeron philadelphicus	Native	B	FORB
Erigeron strigosus	Native	A	FORB
Erysimum asperum	Native	B	FORB
Euthamia graminifolia	Native	P	FORB
Glycyrrhiza lepidota	Native	P	FORB
Hesperostipa comata	Native	P	GRASS
Hesperostipa spartea	Native	P	GRASS
Heterotheca camporum	Native	P	FORB
Juncus species	Native		RUSH

Species*	Origin	Life	Physiognomy
Koeleria macrantha	Native	P	GRASS
Lactuca serriola	Introduced	A	FORB
Lithospermum incisum	Native	P	FORB
Lobelia spicata	Native	P	FORB
Lycopus americanus	Native	P	FORB
Lycopus asper	Native	P	FORB
Medicago lupulina	Introduced	P	FORB
Medicago sativa	Introduced	P	FORB
Melilotus species	Introduced		FORB
Mirabilis hirsuta	Native	P	FORB
Oenothera biennis	Native	B	FORB
Oligoneuron rigidum	Native	P	FORB
Oryzopsis asperifolia	Native	P	GRASS
Oxalis stricta	Native	P	FORB
Panicum capillare	Native	A	GRASS
Paspalum distichum	Native	P	GRASS
Pediomelum argophyllum	Native	P	FORB
Phalaris arundinacea	Native	P	GRASS
Physalis virginiana	Native	P	FORB
Poa pratensis	Introduced	P	GRASS
Polygala verticillata	Native	A	FORB
Portulaca oleracea	Introduced	A	FORB
Potentilla norvegica	Native	P	FORB
Rosa arkansana	Native	P	SHRUB
Rosa woodsii	Native	P	SHRUB
Salix species	Native		SHRUB
Salsola tragus	Introduced	A	FORB
Schizachyrium scoparium	Native	P	GRASS
Setaria pumila	Introduced	A	GRASS
Sisyrinchium campestre	Native	P	FORB
Solidago canadensis	Native	P	FORB
Solidago missouriensis	Native	P	FORB
Sonchus arvensis	Introduced	P	FORB
Sorghastrum nutans	Native	P	GRASS
Sporobolus compositus	Native	P	GRASS
Sporobolus cryptandrus	Native	P	GRASS
Sporobolus airoides	Native	P	GRASS
Symphoricarpos occidentalis	Native	P	SHRUB
Symphyotrichum depauperatum	Native	P	FORB
Symphyotrichum lanceolatum	Native	P	FORB
Taraxacum officinale	Introduced	P	FORB
Toxicodendron rydbergii	Native	P	SHRUB

Species*	Origin	Life	Physiognomy
Tragopogon dubius	Introduced	B	FORB
Trifolium pratense	Introduced	P	FORB
Trifolium repens	Introduced	P	FORB
Verbena stricta	Native	P	FORB
Viola pedatifida	Native	P	FORB

*Species names are from The PLANTS Database: USDA, NRCS. 2010. The PLANTS Database (http://plants.usda.gov, 25 March 2011). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

APPENDIX B. SPECIES LIST FOR INTERSEEDING PAPER

Species*	Origin	Life	Physiognomy
Acer negundo	Native	P	TREE
Agalinis tenuifolia	Native	A	FORB
Agrostis hyemalis	Native	P	GRASS
Agrostis stolonifera	Introduced	P	GRASS
Amaranthus retroflexus	Native	A	FORB
Ambrosia psilostachya	Native	P	FORB
Andropogon gerardii	Native	P	GRASS
Anemone canadensis	Native	P	FORB
Antennaria neglecta	Native	P	FORB
Apocynum cannabinum	Native	P	FORB
Artemisia frigid	Native	P	FORB
Artemisia ludoviciana	Native	P	FORB
Asclepias syriaca	Native	P	FORB
Asclepias verticillata	Native	P	FORB
Bouteloua curtipendula	Native	P	GRASS
Bouteloua gracilis	Native	P	GRASS
Bromus inermis	Introduced	P	GRASS
Calamagrostis stricta	Native	P	GRASS
Calamovilfa longifolia	Native	P	GRASS
Carex species	Native		SEDGE
Chamaesyce glyptosperma	Native	A	FORB
Chenopodium album	Native	A	FORB
Cirsium flodmanii	Native	P	FORB
Conyza canadensis	Native	A	FORB
Cyperus schweinitzii	Native	P	SEDGE
Dalea purpurea	Native	P	FORB
Dichanthelium leibergii	Native	P	GRASS
Dichanthelium oligosanthes	Native	P	GRASS
Dichanthelium wilcoxianum	Native	P	GRASS
Echinochloa crus-galli	Introduced	A	GRASS
Epilobium ciliatum	Native	P	FORB
Equisetum arvense	Native	P	FORB
Equisetum laevigatum	Native	P	FORB
Eragrostis spectabilis	Native	P	GRASS
Erigeron philadelphicus	Native	B	FORB
Erysimum asperum	Native	B	FORB
Euphorbia esula	Introduced	P	FORB
Euthamia graminifolia	Native	P	FORB
Galium boreale	Native	P	FORB

Species*	Origin	Life	Physiognomy
Glycyrrhiza lepidota	Native	P	FORB
Hesperostipa comata	Native	P	GRASS
Heterotheca camporum	Native	P	FORB
Juncus species	Native		FORB
Koeleria macrantha	Native	P	GRASS
Linum lewisii	Native	P	FORB
Linum sulcatum	Native	A	FORB
Lithospermum incisum	Native	P	FORB
Lobelia spicata	Native	P	FORB
Lycopus americanus	Native	P	FORB
Medicago lupulina	Introduced	P	FORB
Medicago sativa	Introduced	P	FORB
Melilotus species	Introduced		FORB
Monarda fistulosa	Native	P	FORB
Nassella viridula	Native	P	GRASS
Oenothera biennis	Native	B	FORB
Oxalis stricta	Native	P	FORB
Panicum capillare	Native	A	GRASS
Panicum virgatum	Native	P	GRASS
Paspalum distichum	Native	P	GRASS
Physalis virginiana	Native	P	FORB
Plantago major	Introduced	P	FORB
Poa pratensis	Introduced	P	GRASS
Polygonum convolvulus	Introduced	A	FORB
Populus deltoides	Native	P	TREE
Portulaca oleracea	Introduced	A	FORB
Ratibida columnifera	Native	P	FORB
Rosa arkansana	Native	P	SHRUB
Salix species	Native		SHRUB
Schizachyrium scoparium	Native	P	GRASS
Setaria pumila	Introduced	A	GRASS
Sisyrinchium campestre	Native	P	FORB
Sisyrinchium montanum	Native	P	FORB
Solidago canadensis	Native	P	FORB
Solidago missouriensis	Native	P	FORB
Solidago nemoralis	Native	P	FORB
Sorghastrum nutans	Native	P	GRASS
Sporobolus airoides	Native	P	GRASS
Sporobolus compositus	Native	P	GRASS
Sporobolus cryptandrus	Native	P	GRASS
Sporobolus heterolepis	Native	P	GRASS
Symphoricarpos occidentalis	Native	P	SHRUB

Species*	Origin	Life	Physiognomy
Symphyotrichum depauperatum	Native	P	FORB
Symphyotrichum lanceolatum	Native	P	FORB
Taraxacum officinale	Introduced	P	FORB
Toxicodendron rydbergii	Native	P	SHRUB
Tragopogon dubius	Introduced	B	FORB
Trifolium repens	Introduced	P	FORB
Ulmus pumila	Introduced	P	TREE
Verbena hastata	Native	P	FORB
Verbena stricta	Native	P	FORB
Viola pedatifida	Native	P	FORB

*Species names are from The PLANTS Database: USDA, NRCS. 2010. The PLANTS Database (http://plants.usda.gov, 25 March 2011). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

APPENDIX C. SPECIES LIST FOR PATCH BURN GRAZING PAPER

Species*	Origin	Life	Physiognomy
Agrostis gigantea	Introduced	P	GRASS
Agalinis tenuifolia	Native	A	FORB
Agrostis gigantea	Introduced	P	GRASS
Alopecurus aequalis	Native	P	GRASS
Ambrosia psilostachya	Native	P	FORB
Andropogon gerardii	Native	P	GRASS
Anemone cylindrica	Native	P	FORB
Antennaria neglecta	Native	P	FORB
Apocynum cannabinum	Native	P	FORB
Argentina anserine	Native	P	FORB
Artemisia ludoviciana	Native	P	FORB
Asclepias incarnata	Native	P	FORB
Asclepias ovalifolia	Native	P	FORB
Asclepias syriaca	Native	P	FORB
Asclepias verticillata	Native	P	FORB
Bassia scoparia	Introduced	A	FORB
Bromus inermis	Introduced	P	GRASS
Calamagrostis canadensis	Native	P	GRASS
Calamagrostis stricta	Native	P	GRASS
Calamovilfa longifolia	Native	P	GRASS
Campanula rotundifolia	Native	P	FORB
Carex atherodes	Native	P	SEDGE
Carex aurea	Native	P	SEDGE
Carex brevior	Native	P	SEDGE
Carex pellita	Native	P	SEDGE
Carex praegracilis	Native	P	SEDGE
Carex sartwellii	Native	P	SEDGE
Carex vulpinoidea	Native	P	SEDGE
Chamaesyce glyptosperma	Native	A	FORB
Cirsium arvense	Introduced	P	FORB
Cirsium flodmanii	Native	P	FORB
Cirsium undulatum	Native	P	FORB
Convolvulus arvensis	Introduced	P	FORB
Conyza canadensis	Native	A	FORB
Dalea candida	Native	P	FORB
Dalea purpurea	Native	P	FORB
Dichanthelium leibergii	Native	P	GRASS
Dichanthelium oligosanthes	Native	P	GRASS
Dichanthelium wilcoxianum	Native	P	GRASS

Species*	Origin	Life	Physiognomy
Eleocharis macrostachya	Native	P	SEDGE
Eleocharis palustris	Native	P	SEDGE
Elymus canadensis	Native	P	GRASS
Elymus repens	Introduced	P	GRASS
Elymus trachycaulus	Native	P	GRASS
Equisetum arvense	Native	P	FORB
Equisetum laevigatum	Native	P	FORB
Erigeron philadelphicus	Native	P	FORB
Erigeron strigosus	Native	A	FORB
Euphorbia esula	Introduced	P	FORB
Euthamia graminifolia	Native	P	FORB
Fragaria virginiana	Native	P	FORB
Galium boreale	Native	P	FORB
Geum triflorum	Native	P	FORB
Glycyrrhiza lepidota	Native	P	FORB
Helianthus pauciflorus	Native	P	FORB
Hesperostipa comata	Native	P	GRASS
Hesperostipa spartea	Native	P	GRASS
Hordeum jubatum	Native	P	GRASS
Hypoxis hirsuta	Native	P	FORB
Juncus arcticus	Native	P	RUSH
Juncus interior	Native	P	RUSH
Juncus torreyi	Native	P	RUSH
Koeleria macrantha	Native	P	GRASS
Liatris ligulistylis	Native	P	FORB
Linum rigidum	Native	P	FORB
Lithospermum canescens	Native	P	FORB
Lithospermum incisum	Native	P	FORB
Lobelia spicata	Native	P	FORB
Lycopus americanus	Native	P	FORB
Lycopus asper	Native	P	FORB
Medicago lupulina	Introduced	P	FORB
Melilotus officinalis	Introduced	A	FORB
Mentha arvensis	Native	P	FORB
Muhlenbergia richardsonis	Native	P	GRASS
Oligoneuron rigidum	Native	P	FORB
Onosmodium bejariense	Native	P	FORB
Oxalis stricta	Native	P	FORB
Packera plattensis	Native	P	FORB
Panicum virgatum	Native	P	GRASS
Pascopyrum smithii	Native	P	GRASS
Pediomelum argophyllum	Native	P	FORB

Species*	Origin	Life	Physiognomy
Plantago major	Introduced	P	FORB
Plantago patagonica	Native	A	FORB
Poa palustris	Native	P	GRASS
Poa pratensis	Introduced	P	GRASS
Polygala alba	Native	P	FORB
Polygonum amphibium	Native	P	FORB
Polygonum convolvulus	Introduced	A	FORB
Potentilla norvegica	Native	P	FORB
Prunus virginiana	Native	P	SHRUB
Ranunculus cymbalaria	Native	P	FORB
Ranunculus macounii	Native	A	FORB
Ranunculus sceleratus	Native	P	FORB
Ratibida columnifera	Native	P	FORB
Rosa arkansana	Native	P	SHRUB
Rosa woodsii	Native	P	SHRUB
Rudbeckia hirta	Native	B	FORB
Rumex salicifolius	Native	P	FORB
Salix exigua	Native	P	SHRUB
Schizachyrium scoparium	Native	P	GRASS
Schoenoplectus pungens	Native	P	SEDGE
Sisyrinchium campestre	Native	P	FORB
Sium suave	Native	P	FORB
Solidago missouriensis	Native	P	FORB
Solidago mollis	Native	P	FORB
Sorghastrum nutans	Native	P	GRASS
Spartina pectinata	Native	P	GRASS
Spiraea alba	Native	P	SHRUB
Sporobolus cryptandrus	Native	P	GRASS
Stachys pilosa	Native	P	FORB
Symphoricarpos occidentalis	Native	P	SHRUB
Symphyotrichum depauperatum	Native	P	FORB
Symphyotrichum lanceolatum	Native	P	FORB
Teucrium canadense	Native	P	FORB
Trifolium repens	Introduced	P	FORB
Verbena stricta	Native	P	FORB
Viola nephrophylla	Native	P	FORB
Viola pedatifida	Native	P	FORB
Zizia aptera	Native	P	FORB
Zizia aurea	Native	P	FORB

*Species names are from The PLANTS Database: USDA, NRCS. 2010. The PLANTS Database (.usda.gov, 25 March 2011). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.