EFFECTIVENESS OF MULTIPLE RESTORATION TECHNIQUES IN REDUCING THE ABUNDANCE OF KENTUCKY BLUEGRASS AND SMOOTH BROMEGRASS IN THE NORTHERN GREAT PLAINS

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ABSTRACT

Kentucky bluegrass (*Poa pratensis* L.) and smooth bromegrass (*Bromus inermus* L.) are cool-season, perennial, non-native grasses that are invading North Dakota grasslands. Two studies evaluated different restoration techniques aimed at reducing Kentucky bluegrass and smooth bromegrass abundance. The initial study, located on five different plant communities in a mixed grass prairie near Mandan, ND, noted some success at reducing Kentucky bluegrass through a combination of fire and chemicals. Therefore, a second study was initiated near Lisbon, ND to evaluate the effectiveness of fire and herbicides, alone or in combination, and the sequence for applying fire and herbicide. These treatments were applied to native tall grass with different initial invasion levels of Kentucky bluegrass. The results of the Mandan study indicated treatment responses differed depending on the community and invasive species while, the Lisbon study suggested that the level of initial invasion also determined treatment success.

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GENERAL INTRODUCTION

Kentucky bluegrass (*Poa pratensis* L.) and smooth bromegrass (*Bromus inermis* Leyss.) are cool-season perennial grasses introduced into the United States and often are found to invade rangeland. Kentucky bluegrass has been naturalized in all of the continental United States and Canada (Hitchcock 1950, Great Plains Flora Association 1986). Smooth bromegrass has been naturalized in the northern two thirds of the United States and Canada (Johnson and Larson 1999). Both species have adapted to a broad range of habitats and soil textures, most commonly on sites with abundant soil moisture (Stubbendieck et al. 1997, Sedivec and Barker 1998).

Kentucky bluegrass and smooth bromegrass initiate growth prior to many native species in the region (Stubbendieck et al. 1997, Vinton and Goergen 2006). Both species have strong rhizomatous growth forms allowing them to out-compete other grasses, thereby decreasing species diversity and altering species composition (Sather 1987, Sather 1996). After Kentucky bluegrass has invaded an area, it often becomes dormant during unfavorable conditions and then flourishes after conditions improve (Sprague 1933). Smooth bromegrass can respond immediately to elevated nitrogen levels in the soil and is able to recycle the nitrogen via litter breakdown, creating a positive reaction between growth and available nitrogen (Vinton and Goergen 2006).

Mid- to late-spring burning of tallgrass prairie can be effective in reducing non-native cool-season grasses, while also promoting native warm-season grasses (Rice 2005). The most favorable time of prescribed burning is when cool-season grass tillers are elongating and warm-season native grasses are still dormant (Anderson et al. 1970). Late spring burning can reduce Kentucky bluegrass biomass in areas where warm-season grasses are present, but effects will be short-lived where the warm-season component is missing (Schacht and Stubbendieck 1985). Late spring burns have been shown to be more effective in reducing smooth bromegrass if there are warm-season grasses and adequate soil moisture present (Blankespoor and Larson 1994, Willson and Stubbendieck 2000).

The most effective control method for smooth bromegrass is defoliation when the plant is in the boot stage (Sather 1987, Rice 2005). Kentucky bluegrass can withstand successive defoliations making it an excellent turf grass, however, limits effectiveness of mowing and grazing as control practices (Sprague 1933, Sather 1996). Still, intensive early grazing followed by a prescribed burn enhanced the growth of big bluestem and limited Kentucky bluegrass production (Smith and Owensby 1978).

Herbicides, such as glyphosate (N-(phosphonomethyl)) glycine and imazapic (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5oxo-1*H*-imadazol-2yl]-5-methyl-3-pyridinecarboxylic acid, have been used effectively for rangeland restoration even in native areas (Sather 1996). Applying herbicide treatments in the spring when warm-season grasses are dormant can control Kentucky bluegrass and smooth bromegrass without harming warm-season natives (Martin and Moomaw 1974, Willson and Stubbendieck 2000). The combination of herbicide treatments and spring burning has also been successful in reducing cool-season species (Washburn et al. 1999).

It is important to understand that Kentucky bluegrass and smooth bromegrass are continuing to increase on native rangeland throughout North Dakota. It is not yet determined what type of management is most effective in stopping or reversing this invasion. The primary objectives of this research were to: (1) compare five restoration techniques on a cool-season dominated mixed grass prairie, near Mandan, ND, and (2) to determine the impact of a fall or spring prescribed burn alone or in combination with herbicide treatments on non-native cool-season grasses and species composition of tall grass prairie on the Sheyenne National Grassland, near Lisbon, ND.

CHAPTER I: LITERATURE REVIEW

Kentucky Bluegrass

It is uncertain whether Kentucky bluegrass is a native to North America or introduced from Eurasia (Great Plains Flora Association 1986, Stubbendieck et al. 1997, Johnson and Larson 1999). It is speculated that it is a naturalized hybrid of the native and introduced species. Kentucky bluegrass is found in all of the continental United States and Canada, except in arid regions (Hitchcock 1950) and is said to have the widest distribution of any plant in the temperate portions of the northern hemisphere (Johnson and Larson 1999).

Kentucky bluegrass growth and expansion is favored by wet conditions and will go dormant if moisture is limiting during the summer (Sprague 1933, Stubbendieck et al. 1997). Kentucky bluegrass is adapted to a wide range of soil types (Stubbendieck et al. 1997), can withstand flooding with successive freezing, ice and snow (Beard 1964), and may germinate in water (Hoffman et al. 1980).

Kentucky bluegrass is unique in that its stem is located at the crown (Etter 1951). This solid material, which may only be a millimeter or two in length, is where the leaves, growing point, and roots attach. The leaves and buds arise from the nodes and for each of the two or three lower nodes a pair of adventitious roots occur, one on each side of the axillary bud. Young seedlings also have a short-lived primary root at the basal tip. In other plant species, this primary root develops into a tap root permanently fixing the plant to one spot; however, Kentucky bluegrass can develop roots wherever an axillary bud exists. This permits Kentucky bluegrass to gradually shift position while still maintaining its root system.

Each axillary bud can develop into either an early tiller or deferred rhizome (Etter 1951). Tillers are aerial shoots that develop their own root systems, yet, remain close to the parent plant and derive nutrients until maturity is attained (Etter 1951, Dahl and Hyder 1977). The number of aerial shoots per parent plant is usually no more than two (Etter 1951). Although tillers do produce a true rooting system, it is not extensive. Mature tillers do not translocate or receive carbohydrates to and from other tillers produced by the parent plant.

Tiller mortality is high during the growing season (Etter 1951). The main shoot typically dies after flowering and, of the two tillers, one is often dead before flowering is completed. By early winter nearly all original tillers will have died; therefore, the maintenance of the grass population from one year to the next is mainly dependant on the production of rhizomes.

Rhizomes are lateral shoots that develop underground (Etter 1951, Dahl and Hyder 1977). Rhizome production for Kentucky bluegrass is essential for plant survival due to the death of most tillers within a year (Etter 1951). Rhizomes that have been produced in the summer are primarily responsible for the inflorescences of the following year. Rhizomes are responsible for Kentucky bluegrass' sod-forming ability and can expand the horizontal growth of the plant as much as two square meters in two years (Kannenberg and Wrede 1934).

Kentucky bluegrass growth rate is the highest in early spring and early fall, and much slower in mid-summer, late fall, and winter (Etter 1951). Both temperature and photoperiod can influence the development of rhizomes (Brown 1939). As the days lengthen in the spring and temperatures increase, new rhizome production will diminish.

Lower temperatures favor growth of new leaves and increase leaf length (Darrow 1939). Optimum soil temperature for Kentucky bluegrass growth is approximately 15°C (Brown 1939, Darrow 1939). Higher soil temperatures around 35°C result in short, rigid plants (Darrow 1939). Under the higher temperature conditions, carbohydrates are consumed faster than what can be generated, resulting in fewer reserves for rhizome production. At 37°C or higher for a prolonged period of time, Kentucky bluegrass showed gradual evidence of injury, but recovered rapidly once temperatures decreased (Brown 1939).

Kentucky bluegrass root systems are also influenced by temperature (Darrow 1939). Like the above-ground biomass, the maximum growth rate for the root system was at a temperature of 15°C, although considerable growth also occurred at temperatures as low as 4°C (Brown 1939). Root growth rapidly declines as temperatures rise and cease at 26°C. At lower soil temperatures, roots are thick, succulent and white; whereas, roots produced in the summer months at higher soil temperatures are thin and brownish (Darrow 1939, Etter 1951). Half of the root system is newly produced each spring (Sprague 1933). Higher temperatures favored rapid maturation of the roots, while the lower soil temperatures promoted rapid elongation (Darrow 1939). Kentucky bluegrass root systems developed at lower soil temperatures were almost twice as deep as those produced at higher soil temperatures.

Early spring and early fall both have optimal temperatures with high growth rates in common; however, these two periods are very different (Etter 1951). In the spring, plant carbohydrate reserves are greater, day length progressively increasing, temperatures rising, and there is an accumulated nitrogen supply from the previous cooler months all of which favor an extended period of rapid growth. When day length become long and summer temperatures are high, the production of above-ground stems is delayed (Harrison 1934), but below-ground rhizome production is greater in late spring and early summer (Evans and Watkins 1939).

Rapid growth of rhizomes in the fall is limited to a few weeks, depending on fall precipitation (Etter 1951). Rhizomes that were produced in the summer months stay below the soil surface during long days and will emerge once light amount and intensity decrease (Harrison 1934). However, once fall begins, rhizome production for Kentucky bluegrass decreases with the shorter 8.5 hour days (Evans and Watkins 1939). Reserves are low after the mid-summer heat, and the shorter day lengths and cooler temperatures both favor carbohydrate accumulation which is associated with slower growth (Etter 1951). Nitrogen accumulation is also considerably less because of bacterial fixation in the summer months.

Smooth Bromegrass

Smooth bromegrass is native to Eurasia, Russia, central Europe, and China (Knobloch 1944, McKone 1985, Stubbendieck et al. 1997). The first recorded introduction of seed into the United States was in 1882 (Dibbern 1947). Smooth bromegrass is now established as far south as Tennessee, Kansas, and California and extends north into Canada and Alaska. In the northern two thirds of the United States, as well as Canada, smooth bromegrass is now naturalized (Johnson and Larson 1999).

Smooth bromegrass is grown as forage in the United States and Canada and also found along roadsides, railroad right-of-ways, and slightly disturbed areas, often escaping into rangeland (Elliot 1949, Johnson and Larson 1999). It can be found on all soil types (Stubbendieck et al. 1997); however, mostly associated with wetter soils or low-lying areas, receiving greater than 330 to 355 mm of annual precipitation (Sedivec and Barker 1998).

The development of smooth bromegrass is in two phases (Knobloch 1944). The first phase is the process of the seedling developing into a vegetative plant. The leaves emerge and tillers and rhizomes arise from buds in the axils of the basal leaves. The adventitious root system is initiated and the plant is capable of storing food reserves. The second phase involves the reproduction of smooth bromegrass, where the internodes elongate, the inflorescence develops, pollination takes place, and the fruit matures.

Tillers and rhizomes develop from the buds in the axils of the lower leaves (Knobloch 1944). There are two periods of active tiller emergence for smooth bromegrass: the first beginning in March and extending to early May, and the second period in mid-June to mid-July (Lamp 1952). The early spring period of tiller development contributes considerably less than the summer period for the total number of tillers produced in a year. This decrease is due to the sequence of complex physiological changes involved in floral initiation, internodal elongation, anthesis, and fruit maturation.

Rhizomes aid in the lateral expansion of smooth bromegrass and its sod-forming capability (Knobloch 1944). Rhizome production in smooth bromegrass begins about three weeks after germination and increases as the plant ages (Wagner 1952). The total number of rhizomes produced in smooth bromegrass is strongly influenced by light intensity and temperature (Gall 1947). Once the rhizome tip reaches the soil surface, leaves will emerge (Knobloch 1944).

A photoperiod of 17 to 18 hours is favorable for normal development, elongation of the culms, panicle initials, and ripening of the fruit in smooth bromegrass (Gall 1947). For panicle production, a condition of short days and cool temperatures are required before exposure to a long photoperiod (Newell 1950). There is no apparent connection between rhizome production and photoperiod (Gall 1947).

Smooth bromegrass is a hermaphrodite, having both male and female reproductive organs; the flowers that do not set seed are still capable of acting as pollen donors (McKone 1985). It is also a self-incompatible species, meaning it rarely self-pollinates. Smooth bromegrass distributes nearly half of its reproduction efforts to pollen production (McKone 1987); however, only about a third of the florets will produce a fruit (McKone 1985).

Synchronous flowering is common (McKone 1985) and pollination can occur from plants up to 50 m away (Jones and Newell 1946). Anthesis occurs approximately 14 days after inflorescence (Gall 1947). Seed set of open pollinated plants is approximately 29%. The number of seeds produced is variable with 47 to 160 seed heads per plant and 156 to 10,080 viable seeds per plant (Lowe and Murphy 1955).

Smooth bromegrass roots can reach a depth of 1.4 m (Dibbern 1947), but 64% of the root weight is in the top 20 cm (Lamba et al. 1949). A “sod bound” condition can develop in old smooth bromegrass fields, in which shoot densities are decreased and nitrogen becomes deficient (Meyers and Anderson 1942). This condition could be due to a carbon/nitrogen imbalance (Benedict 1941, Meyers and Anderson 1942) or an allelopathic extract produced from decomposing smooth bromegrass roots that inhibit further root production (Grant and Sallans 1964).

Prescribed Burning

Mid-to-late spring burning of tall grass prairie is effective in reducing non-native cool-season grasses and promoting warm-season native grasses (Rice 2005). Species that are actively growing at the time of the burn are more susceptible to injury or death than dormant species (Anderson et al. 1970). In the northern mixed grass prairie, optimal timing of prescribed burning is when invasive cool-season grass tillers are elongating and the native grasses are dormant (Rice 2005). Delaying prescribed burning too long can damage the native cool-season grasses (Blankespoor and Larson 1994).

Burning is the most widely used control method for Kentucky bluegrass (Rice 2005). Burning in areas without a native warm-season grass component is not as effective in the long-term reduction of Kentucky bluegrass (Schacht and Stubbendieck 1985). Prescribed burning in areas with a sufficient amount of warm-season grasses can control Kentucky bluegrass longer due to the shift of the competitive advantage from Kentucky bluegrass to the native warm-season grasses. Single-year, late-spring prescribed burning is most effective in controlling Kentucky bluegrass only when moisture is low (Blankespoor and Bich 1991). Repeated annual or biannual prescribed burns have been shown to decrease Kentucky bluegrass cover from 70% to 35% in a 13 year period and increase big bluestem (*Andropogon gerardii* Vitman) threefold (Svedarsky et al. 1986). The benefits of consecutive spring annual or biannual burning of Kentucky bluegrass peaked 9 to 10 years after initiating a burn program.

Burning is not as effective in reducing smooth bromegrass as Kentucky bluegrass (Rice 2005). Prescribed burning did not result in any differences in tiller densities, standing crop, and leaf area index in smooth bromegrass in studies in Saskatchewan and

Minnesota (Grilz and Romo 1994, Willson and Stubbendieck 1996). However, other studies have shown that tiller density (Willson 1991), basal cover (Kirsch and Kruse 1972) and biomass (Old 1969) in smooth bromegrass can be reduced up to 50 % after a May burn during tiller elongation. Effectiveness of late spring burning of smooth bromegrass can be increased if there is a warm-season native grass component and adequate soil moisture is present (Blankespoor and Larson 1994, Willson and Stubbendieck 2000). A single burn allows partial to full recovery of smooth bromegrass by the following year (Willson and Stubbendieck 1997). Repeated burning at tiller elongation and later stages maintains low tiller densities and biomass in smooth bromegrass.

Defoliation

The most effective control method for smooth bromegrass is defoliation while it is in boot stage (Rice 2005). A single defoliation when smooth bromegrass is in the boot stage is effective (Sather 1987), but carbohydrate levels can be kept even lower throughout the summer by repeated defoliations (Paulsen and Smith 1968). Three to four defoliations a year can significantly reduce the persistence of smooth bromegrass (Paulsen and Smith 1968, Martin and Hovin 1980).

Mowing and grazing are not as effective in decreasing Kentucky bluegrass as prescribed fire (Sather 1996). Kentucky bluegrass is able to withstand frequent defoliations and is an increaser under grazing pressure. Kentucky bluegrass is not adversely affected in spring or summer defoliation treatments (Hover and Bragg 1981). Cattle grazing Kentucky bluegrass on native rangeland will shift from Kentucky bluegrass to the native species as soon as Kentucky bluegrass reaches the seed set stage, decreasing the native grasses (Weaver and Darland 1948). Kentucky bluegrass composition increases under season-long grazing followed by a prescribed burn, but can decrease on an intensive-early grazing system because of a more complete burn following the grazing treatment (Smith and Owensby 1978).

Herbicides

Herbicide treatments are an effective control measure in reducing Kentucky bluegrass and smooth bromegrass (Martin and Moomaw 1974, Willson and Stubbendieck 2000). Glyphosate applied in early spring at 2.24 kg/ha effectively reduced Kentucky bluegrass production without damaging the dormant native warm-season grasses (Martin and Moomaw 1974). Glyphosate applied at 1.12 kg/ha not only decreased Kentucky bluegrass production but increased the native warm-season grasses, especially big bluestem (Waller and Schmidt 1983). April and May applications of glyphosate at 2 kg/ha were effective in reducing smooth bromegrass in pure stands (Rayburn et al. 1981) and 1.12 kg/ha on rangeland (Waller and Schmidt 1983).

Combining prescribed burns with herbicide treatments have been shown to be an effective control measure in reducing invasive cool-season grasses (Rice 2005). Spring prescribed burning followed with an application of glyphosate (2.24 kg/ha) or imazapic (0.21 kg/ha) was effective in controlling tall fescue (*Festuca arundinacea* Schreb.) (Washburn et al. 1999). Imazapic application (0.18 kg/ha) one month after a spring burn was more effective in reducing tall fescue than the burn alone and herbicide alone treatments (Washburn et al. 2002). Warm-season grass response was also the greatest in the combined burn and herbicide treatments.

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CHAPTER II: A COMPARISON OF FIVE RESTORATION TECHNIQUES ON A COOL-SEASON INVADED GRASSLAND

Introduction

Kentucky bluegrass (*Poa pratensis* L.) and smooth bromegrass (*Bromus inermis* Leyss.) are cool-season perennial grasses introduced into the United States and often invade rangeland (Murphy and Grant 2005, Travnicek et al. 2005). Kentucky bluegrass is naturalized in all of the continental United States and Canada (Hitchcock 1950, Great Plains Flora Association 1986) and smooth bromegrass naturalized in the northern two thirds of the United States and Canada (Johnson and Larson 1999). Both species have adapted to a broad range of habitats and soil textures, most commonly on sites with abundant soil moisture (Stubbendieck et al. 1997, Sedivec and Barker 1998).

Kentucky bluegrass and smooth bromegrass initiate growth prior to most of the native species in the region (Stubbendieck et al. 1997, Vinton and Goergen 2006). Both species have strong rhizomatous growth forms allowing them to out-compete other grasses (Sather 1987, Sather 1996), thereby decreasing species diversity (Pritekel et al. 2006, Vaness and Wilson 2007) and altering species composition. Kentucky bluegrass and smooth bromegrass are able to disrupt ecosystem function by altering nitrogen cycling and carbon storage (Wedin and Tilman 1996).

Mid- to late-spring burning on tallgrass prairie has shown to be effective in reducing non-native cool-season grasses, while also promoting native warm-season grasses (Rice 2005). The most favorable time of prescribed burning is when cool-season grass tillers are elongating and warm-season native grasses are still dormant (Anderson et al. 1970). Late spring burning can reduce Kentucky bluegrass biomass in areas where warm-season grasses are present, but will be short-lived where the warm-season component is missing (Schacht and Stubbendieck 1985).

The most effective control method for smooth bromegrass is defoliation when the plant is in the boot stage (Sather 1987, Rice 2005). Kentucky bluegrass can withstand continuous defoliations making it an excellent turf grass that persists when using mowing and grazing as control practices (Sprague 1933, Sather 1996). However, these practices can be beneficial to other grass species in areas invaded by Kentucky bluegrass by removing the built-up litter that causes shading (Volland 1978).

In the Northern Great Plains, litter decomposition is relatively slow and mostly occurs during winter (Hendrickson et al. 2001). While smooth bromegrass may decompose faster than native grasses (Hendrickson et al. 2001), litter from ungrazed patches of Kentucky bluegrass often forms thick mats of dead leaves above the soil surface. The impact of these mats on persistence of Kentucky bluegrass or native grasses is unknown. However, litter and litter dynamics can impact vegetation structure (Facelli and Pickett 1991, Xiong and Nilsson 1999) by reducing productivity (Knapp and Seastedt 1986), species richness (Xiong and Nilsson 1999) and the strength of competitive interactions (Suding and Goldberg 1999).

Imazapic, (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5oxo-1*H*-imadazol-2yl]-5-methyl-3-pyridinecarboxylic acid, has been used effectively for rangeland restoration even in native areas (Sather 1996). Applying herbicide treatments in the spring when the warm-season grasses are dormant can control Kentucky bluegrass and smooth bromegrass without harming warm-season natives (Martin and Moomaw 1974, Willson and Stubbendieck 2000). The combination of imazapic and spring burning has also been successful in reducing cool-season invasive grasses (Washburn et al. 1999, Washburn et al. 2002).

The invasion of Kentucky bluegrass and smooth bromegrass in mixed grass rangelands has serious implications for the structure and function of these rangelands. In the Northern Great Plains, both native and invasive species have similar photosynthetic pathways, making it difficult to decrease introduced cool-season grasses without harming native species (Reed et al. 2005). In this study, we evaluated the effect of burning and herbicides alone and in combination along with mowing and litter removal on five different plant communities in the Northern Great Plains. We evaluated the effectiveness of different treatments to reduce the abundance of Kentucky bluegrass and smooth bromegrass in the species composition of different plant communities.

Methods

Study Area

The study was conducted at the Northern Great Plains Research Laboratory, in central North Dakota, approximately 9 km south of Mandan, ND (46°45´ N, 100°55´ W) (NE quarter Sec. 20, T138N, R81W). The specific project area was a 17 ha grassland that had never been cultivated and not hayed or grazed for more than 20 years prior to 2002.

Soils in the specific project area include the Belfield-Grail silty clay loam and the Temvic-Williams silt loam (Seiler and Aziz 2001). The Belfield-Grail soils occur on alluvial flats on uplands and Temvic-Williams soils occur on silty loess-mantled till plains. The study area had level to slightly sloping topography with a seasonal water table in some areas and moderately-well to well-drained.

The study area was historically wheatgrass-needlegrass prairie, consisting of moderately dense, short to medium tall grasses such as western wheatgrass (*Pascopyrum smithii* Rydb.), blue grama (*Bouteloua gracilis* (H.B.K) Lag. ex Steud.), needle-and-thread grass (*Hesperostipa comata* (Trin. & Rupr.) Barkworth ssp. *comata*), and green needlegrass (*Nasella viridula* (Trin.) Barkworth) (Kuchler 1964). The study area is currently dominated by Kentucky bluegrass and smooth bromegrass. Big bluestem (*Andropogon gerardii* Vitman) is present in lower-lying areas.

The climate of the area is semi-arid with cold winters and hot summers (Sieler and Aziz 2001). The average annual precipitation is 43.3 cm with most precipitation occurring in late spring and early summer (Figure 2.1).

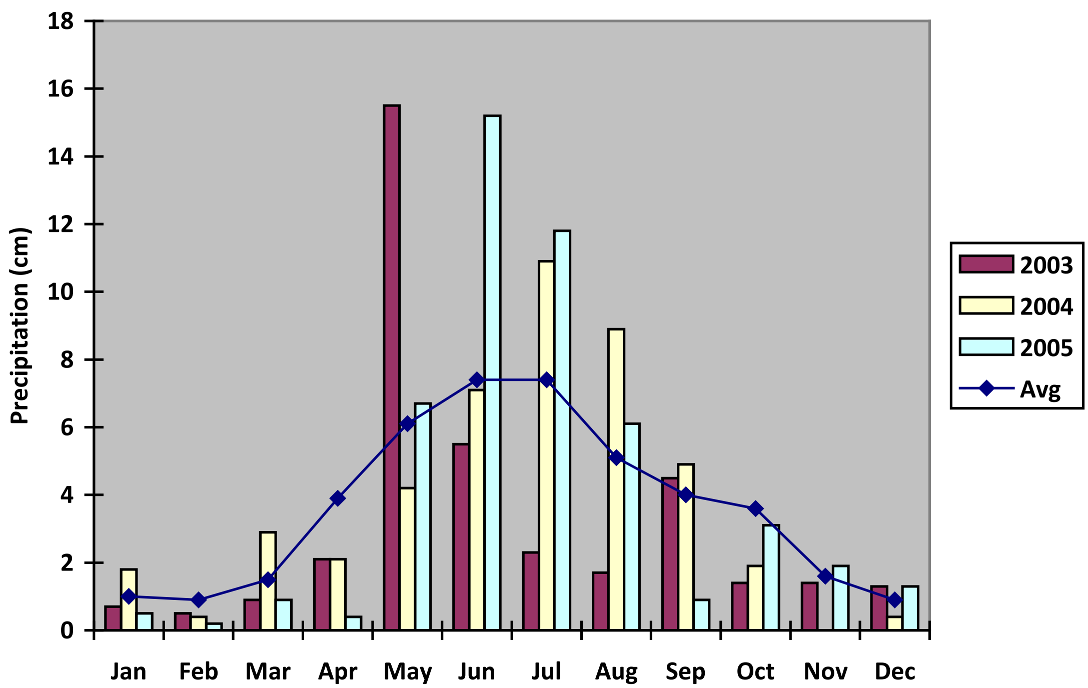

Figure 2.1. Precipitation data at Mandan Exp. Station, ND (NOAA 1971-2000).

Experimental Design

Ten sites were selected within five different plant communities, in the summer of 2002; each community was dominated by a different species or species group. Community categories were based on visual estimates of the dominant species and two sites for each community category included in the study. The visually selected communities were: 1) Kentucky bluegrass dominated, 2) smooth bromegrass dominated, 3) co-dominated by Kentucky bluegrass and smooth bromegrass, 4) native grass dominated, primarily big bluestem and 5) dominated by a mix of invasive species, including crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) and leafy spurge (*Euphorbia esula* L.) (Mix).

The experimental design was a nested design with the site nested within the community category and each of the restoration treatments occurring within each community category. Each community category included six 10x30 m plots randomly assigned to one of the following treatments: 1) control, 2) burn only (Burn), 3) burn combined with an imazapic application (Burn/Herbicide), 4) treated with imazapic only (Herbicide Only), 5) mowed but not raked (Mowed) and 6) mowed and then raked (Mow/Raked).

Prescribed burns were conducted in late April 2003 and 2004. Imazapic was applied at 0.50 kg/ha when smooth bromegrass was 10-15 cm tall in 2003. In 2004, burns were unable to be conducted on the Burn + imazapic plots due to an extreme decrease in biomass, except for the native community sites. Imazapic application was decreased to 0.28 kg/ha in 2004 and applied when smooth bromegrass reached 10-15 cm in height. Mowing and raking were conducted in mid-May 2003 and 2004. In the plots which were mowed, the vegetation was cut to a maximum estimated height of 15 cm. In the mowed/raked treatment, litter was removed by power raking down to the soil surface following mowing.

Sampling

Species composition was estimated by counting all live shoots, by species, in three permanently fixed, 0.05 m^2 quadrats in each plot late-September from 2002-2005. The permanent quadrats were randomly located along transects in each plot. All individual species counted were later divided into the following species groups for evaluation purposes: 1) Kentucky bluegrass, 2) smooth bromegrass, 3) other introduced grass and forbs (OTHER), 4) native grass and 5) native forb. The OTHER grouping consisted typically of leafy spurge, crested wheatgrass, and yellow sweetclover (*Melilotus officinalis* (L.) Lam.).

Each species group was evaluated as to whether it increased or decreased in abundance in response to the restoration treatments within each of the five community types. This was accomplished by subtracting the percentage in the relative species composition of each species group in October of 2003, 2004, and 2005, from the baseline of October 2002. Results were presented as the relative change in species composition over time. The use of relative change in species composition is limited in that it does not indicate whether Kentucky bluegrass or smooth bromegrass absolute tiller numbers are increasing or decreasing. However, the use of relative species composition does provide advantages that outweighed this disadvantage. Relative species composition is a concept that is familiar to both land managers and researchers, and provides a means to place changes in tiller numbers for both introduced and native species into a common parameter.

Therefore, use of relative species composition allows for the evaluation of treatments based on their impact on species composition rather than absolute numbers.

Biomass was evaluated by clipping four 0.05 m^2 quadrats in the middle of the plots in October of 2002 and August from 2003-2005. Biomass was separated into live grass, dead grass, live forb and dead forb components.

Statistical Analysis

Plant density and biomass from 2002-2005 were analyzed using the PROC MIXED in SAS (Littell et al. 1996) with year, community category, and treatment being fixed effects and sites (community category) treatment x sites (community category) and replicate being the random effects. Year was considered the repeated effect and compound symmetry was the co-variance structure. Where needed, data were transformed to ensure normal residual distribution. The transformations used are indicated in the respective tables and figures. If needed, outliers were removed by using the UNIVARIATE procedure in SAS (SAS Institute Inc. 2008) to identify extreme observations. Mean separation was conducted using Tukey's mean separation procedure. All means were considered significantly different at a P value ≤ 0.10 unless otherwise indicated.

Results

Annual precipitation was less than the average long-term annual precipitation, in 2003 and 2004; while precipitation was slightly greater than average in 2005 (Figure 2.1). Based on the long-term precipitation data, over 70% of total annual precipitation falls during the five month growing season from May through September. Precipitation during this period was 85, 95 and 118% of the long-term average for 2003, 2004 and 2005, respectively (Figure 2.1). Although monthly precipitation for May 2003 and August 2004 was over twice the long-term average, the increase in precipitation did not outweigh the lower precipitation during the remaining months (Figure 2.1).

Changes in Relative Species Composition

A year by community and treatment interaction occurred for each of the major species groups (smooth bromegrass, Kentucky bluegrass, OTHER, and native grass) except native forbs (Table 2.1). Because of these interactions, each of the species groups was evaluated by year.

Table 2.1. Probability values for changes in the relative species composition for Kentucky bluegrass (POPR), smooth bromegrass (BRIN), other introduced species (OTHER), native grasses (NG), and native forbs (NF) using PROC MIXRD in SAS.

	Relative Species Composition					Biomass		
Effect	POPR	BRIN	OTHER[1]	NG	NF[2]	Total	Live Grass	Live Forb
Year (YR)	0.2638	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.004
Community (COMM)	0.6835	0.1729	0.9780	0.1350	0.8901	0.1219	0.0424	0.2849
YR*COMM	0.0031	<0.0001	0.0131	0.0540	0.5374	0.0109	0.0412	0.9901
Treatment (TRT)	0.0262	0.0348	0.1940	0.0649	0.1428	<0.0001	<0.0001	0.1171
YR*TRT	0.0970	0.0288	0.0254	0.1967	0.7756	0.0125	<0.0001	0.4693
COMM*TRT	0.5254	0.0430	0.5241	0.1126	0.2555	0.9994	0.0144	0.1778
YR*COMM*TRT	0.2448	0.0787	0.5937	0.5238	0.2715	0.3494	0.3676	0.9993

[1] Log transformed
[2] Outliers removed

Kentucky Bluegrass

The response of Kentucky bluegrass to different treatments did not interact with community category in 2003 and 2004 however there was a treatment by community category interaction in 2005 ($F_{20,25}$ = 1.94, P = 0.0592, Table 2.2). In 2003 and 2004, the Burn/Herbicide treatment reduced Kentucky bluegrass more than the untreated controls (Table 2.3). The Burn/Herbicide treatment also reduced Kentucky bluegrass more than the Mowed or Mowed/Raked treatments in 2004. Kentucky bluegrass, in the smooth bromegrass dominated and Kentucky bluegrass dominated community categories in 2005, responded differently to treatments when compared to other community categories and the responses of these communities in 2003 and 2004 (Figure 2.2A), although none of the treatments were different from the controls.

Table 2.2. Probability values for community (Comm) and treatment (Trt) and the interactions for Kentucky bluegrass (POPR), smooth bromegrass (BRIN), other introduced species (OTHER), native grasses (NG) and native forb (NF) by year for 2003, 2004 and 2005.

	Year		
	2003	2004	2005
POPR			
Comm	0.4451	0.4118	0.9926
Trt	0.0775	0.0148	0.0065
Comm x Trt	0.3319	0.6535	0.0592
BRIN[1]			
Comm	0.0977	0.0707	0.3458
Trt	0.0527	0.0231	0.0248
Comm x Trt	0.0043	0.0326	0.3575
NG			
Comm	0.2904	0.0248	0.9240
Trt	0.1534	0.1597	0.0388
Comm x Trt	0.4563	0.5011	0.0242
OTHER			
Comm	0.8717	0.9352	0.4428
Trt	0.1634	0.0206	0.2252
Comm x Trt	0.8705	0.4445	0.0358

[1] BRIN was log-transformed for all years.

Table 2.3. Change in relative species composition (%) and standard error (SE) for fall 2003 and 2004 compared to the baseline of fall 2002 for Kentucky bluegrass (POPR) and other introduced grasses and forbs (OTHER). Different lower case letters within each column indicate significant differences at the P<0.10.

POPR	2003		Year	2004	
Treatment	%	(SE)		%	(SE)
Burn	-5.6	(3.3)ab		-13.9	(5.5)ab
Burn + Chemical	-10.4	(3.3)a		-16.8	(5.5)a
Control	-0.6	(3.3)b		-2.1	(5.5)bc
Chemical Only	-1.5	(3.4)ab		-3.8	(5.5)abc
Mowing	-2.6	(3.3)ab		-1.3	(5.5)bc
Raking	-3.7	(3.3)ab		0.8	(5.5)c
OTHER					
Treatment					
Burn	7.92	(2.1)		12.39	(2.9)a
Burn + Chemical	2.25	(2.1)		4.81	(2.9)ab
Control	3.26	(2.1)		4.04	(2.9)b
Chemical Only	4.80	(2.1)		4.57	(2.9)ab
Mowing	4.62	(2.1)		4.40	(2.9)ab
Raking	3.65	(2.1)		1.48	(2.9)b

Native Grasses and Forbs

Native grass increased (P<0.1) in the relative species composition in the Native Dominated community category compared to small increases or decreases in the other community categories in 2004 (10.68±4.4% vs. -3.68±4.4%, 0.21±4.4%, .73±4.4% and 1.68±4.4%; mean ± standard error for Smooth Bromegrass Dominated, Exotic Mix Dominated, Kentucky Bluegrass Dominated, Co-Dominated community categories; respectively). In 2005, there were differences between treatments in the Native Dominated and Kentucky Bluegrass Dominated community categories (Figure 2.2B). Native grasses in the Native Dominated community category increased (P<0.1) under the Burn/Herbicide treatment but decreased (P>0.1) in the Mowed, Mowed/Raked treatments and untreated control plots. However, in the Kentucky Bluegrass Dominated community category, the

Burn/Herbicide treatment decreased (P<0.1) native grasses compared to the Burn treatment (Figure 2.2B), but neither differed (P<0.1) from the control.

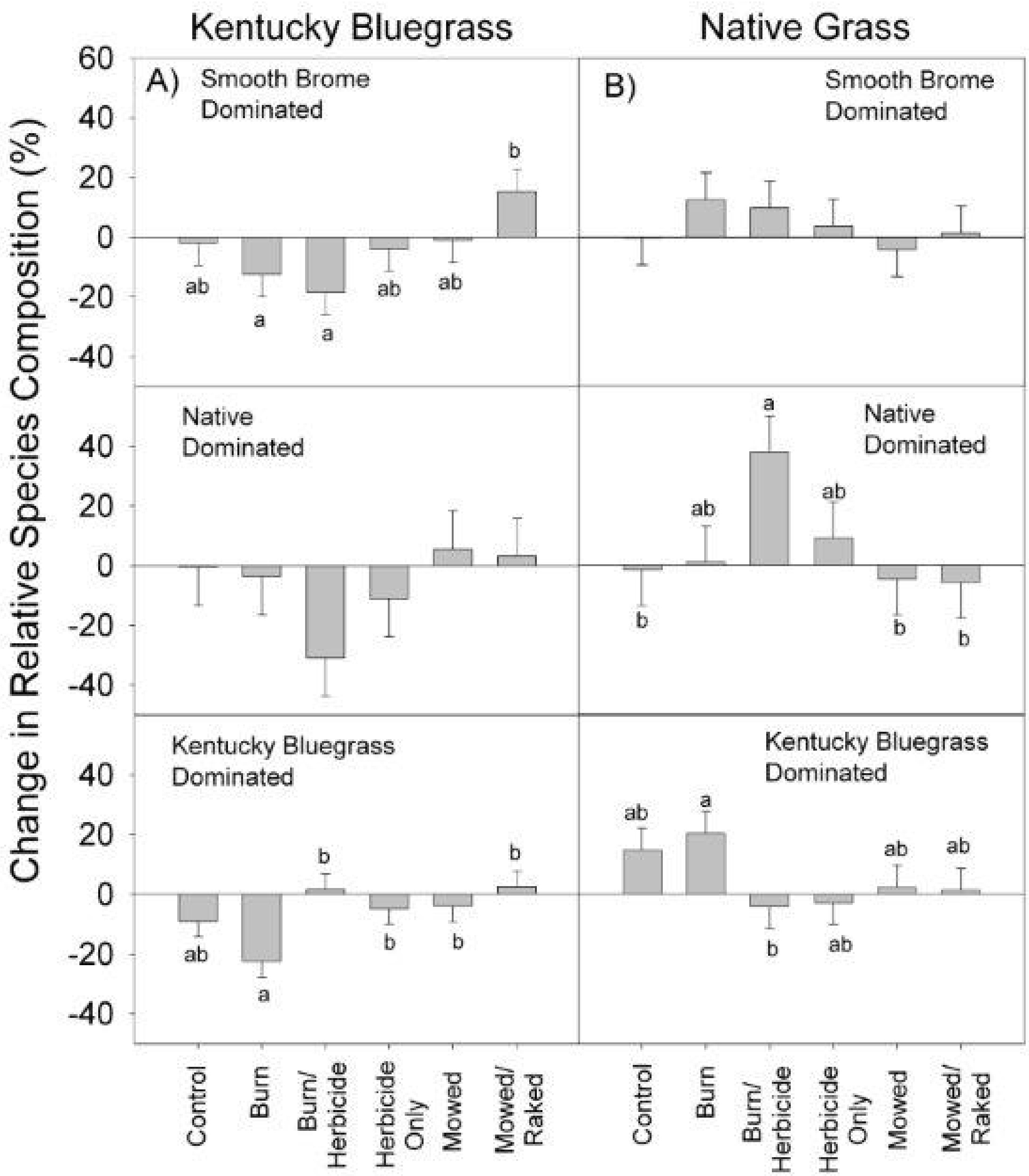

Figure 2.2. Percent change in relative species composition between 2002 baseline and fall 2005 for A) Kentucky bluegrass and B) native grass in response to different treatments for communities dominated by smooth bromegrass, native grass, and Kentucky bluegrass. Different lower case letters within each community indicate significant differences at the P<0.10.

Native forbs were only affected by year ($F_{2,60}$ =30.58, P<0.0001, Table 2.2). The change in the percent native forbs in relative species composition compared to 2002 baseline data, was greater for 2004 and 2005 than 2003 (1.0 and 0.9% increase in 2004 and 2005; respectively, compared to a 0.1% increase in 2003).

Smooth Bromegrass

The response of smooth bromegrass to different treatments was limited to the Smooth Bromegrass Dominated community category in 2003 and 2004. In 2003, smooth bromegrass increased (P<0.1) more in the Herbicide Only treatments than the untreated control or the Mowed treatments (Figure 2.3A). Treatment responses of smooth bromegrass did not differ (P<0.1) from the untreated controls in 2004 (Figure 2.3B). By 2005, the community category by treatment interaction had disappeared ($F_{20,25}$ = 1.12, Table 2.2) but smooth bromegrass was reduced (P<0.1) more for the Mowed/Raked treatment (-5.94±2.8%) than the Herbicide Only treatment (2.13±2.8%) or the untreated control (3.08±2.8%).

Other Invasive Species (OTHER)

The OTHER category was comprised of a mix of other introduced grasses and forbs. This category had treatment differences in 2004 ($F_{5,25}$ =3.28, P= 0.0206, Table 2.2) and a treatment by community interaction in 2005 ($F_{20,25}$ = 2.15, P=0.0358, Table 2.2). Between 2002 and 2004, species in the OTHER category increased (P<0.1) more in the Burn Only treatment (12.39±2.9%) than the Mowed/Raked treatment (1.48±2.9%) or untreated controls (4.04±2.9%). In 2005, OTHER invasive species increased (P<0.1) more in the Burn/Herbicide treatments (14.88± 3.0%) than the Burn Only (1.63± 3.0%), Herbicide Only (1.78± 3.0%) or Mowed/Raked (2.06 ± 3.0%) treatments in the Exotic Mix

Dominated community category. In the Kentucky Bluegrass Dominated community, OTHER invasive species increased (P<0.1) more in the Herbicide Only treatment (7.04±2.3%) than they were reduced (P<0.1) in the Mowed/Raked treatment (5.20±2.3%). In both the Co-Dominated and Kentucky Bluegrass Dominated community categories, treatments did not differ (P<0.1) from the controls and there were no differences (P<0.1) between treatments in the other community categories in 2005.

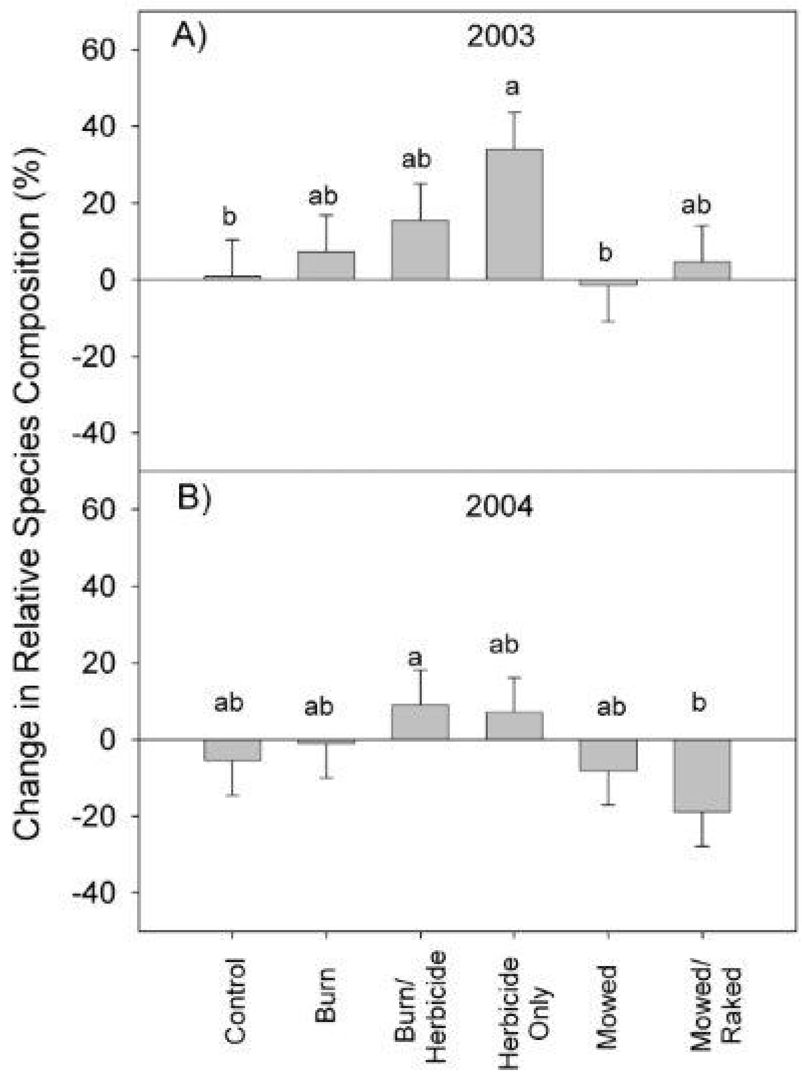

Figure 2.3. Percent change in relative species composition by treatment for smooth bromegrass between Fall 2002 and A) 2003 and B) 2004. Different lower case letters within each year indicate significant differences at the P<0.10.

Live Biomass

Live grass biomass had an interaction between year and treatment ($F_{10,60}$ = 7.34, P<0.0001) and between year and community category ($F_{8,60}$ = 2.19, P=0.0412, Table 2.1). Therefore, live grass biomass was analyzed by year. In 2003, there was a treatment by community category interaction for live grass biomass ($F_{20,25}$ = 2.45, P=0.0178). In 2004, there were differences between treatments ($F_{5,25}$= 8.52, P <0.0001) and community categories ($F_{4,5}$ = 10.62, P=0.0116) for live grass biomass. In 2005, live grass biomass had no differences (P<0.1) for either treatment or community category.

2003 Live Grass biomass

The Burn/Herbicide treatment produced less (P<0.1) live grass biomass than any of the other treatments in the Co-Dominated community category and produced less (P<0.1) live grass biomass than the Burn Only, Herbicide Only, and control treatments in the Smooth Bromegrass Dominated community category (Figure 2.4). The Burn/Herbicide treatment also reduced (P<0.1) biomass production compared to Burn Only treatment in the Kentucky Bluegrass Dominated community, but was not different (P<0.1) from the control (Figure 2.4).

2004 Live Grass Biomass

The Burn/Herbicide (1470.1±212.9 kg ha^{-1}) and Herbicide Only treatments (1385.2±212.9 kg ha-1) produced less (P<0.1) live grass biomass than Burn Only (1734.4±212.9 kg ha^{-1}), Mowed (1827.1±212.9 kg ha^{-1}) or Mowed/Raked (1829.6 ±212.9 kg ha^{-1}) treatments or the untreated control (2207.8 ±212.9 kg ha^{-1}) in 2004. The Native Dominated community category produced more (P<0.1) live grass biomass (3241.1±493.9

Kg ha^{-1}) than did any other community (1431.4±493.9, 1339.6±493.9, 1176.4±493.9 and 1523.3±493.9 kg ha^{-1} for Smooth Bromegrass Dominated, Exotic Mix Dominated, Kentucky Bluegrass Dominated and Co-Dominated community categories; respectively).

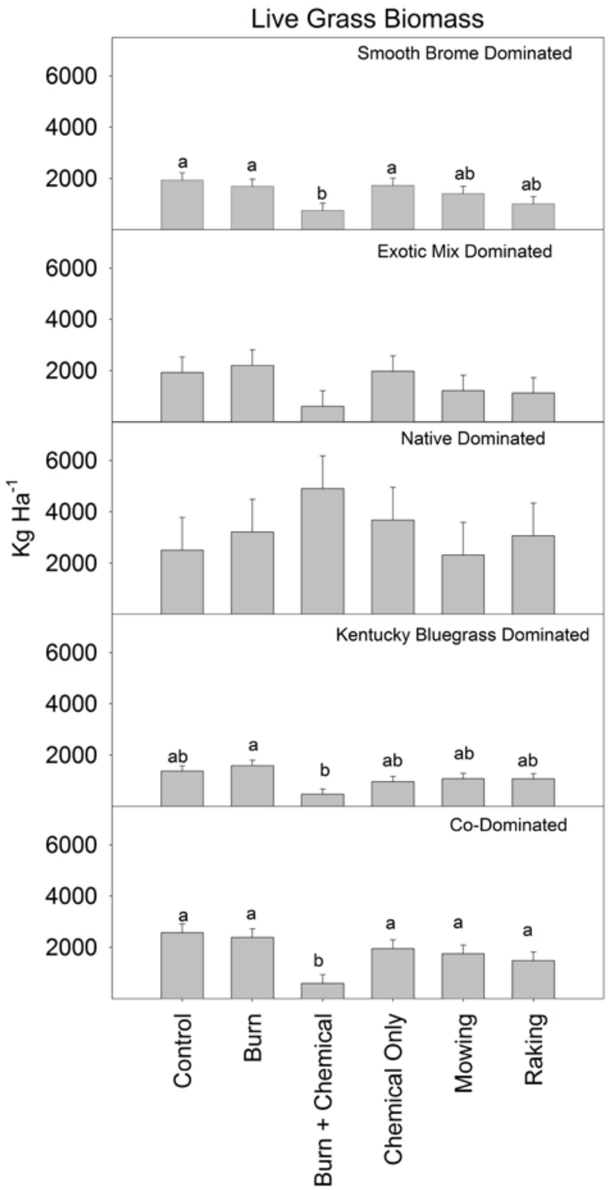

Figure 2.4. Treatment response of live grass biomass in communities dominated by smooth bromegrass, a mixture of exotic species, native grass, Kentucky bluegrass and Kentucky bluegrass and smooth bromegrass (Co-Dominated) for 2003. Different lower case letters within each community indicate significant differences at the P<0.10.

Live Forb Biomass

There were differences between years in live forb biomass ($F_{2,60}$= 9.03, P=0.0004). There was less (P<0.1) live forb biomass in 2004 than in 2003 or 2005 (136.5 ± 62.2 kg ha^{-1} vs. 266.5 ± 62.2 and 365.8 ± 62.2 kg ha^{-1} for 2003 and 2005; respectively).

Discussion

Rangeland managers have a variety of management tools for restoring rangelands. However, the effectiveness of a technique is often evaluated by considering the impact on the population of a target species without considering the effects at the community level (DiTomaso et al. 2006). By evaluating the effectiveness of different restoration treatments and treatment combinations on two different invasive perennial grass species, the most effective treatment for an invasive grass species will vary depending on the community it is found in and other factors such as yearly rainfall. Treatment responses changed over time which suggests that incorporating active adaptive management strategies (Shea et al. 2002, McCarthy and Possingham, 2007) may be an appropriate basis for developing strategies for management of invasive species.

Kentucky bluegrass and smooth bromegrass are often found on the same rangelands (Murphy and Grant 2005) and both grasses may visibly dominate a community as demonstrated by the Co-Dominated community category. Although both species are perennial C_3 grasses (Waller and Lewis 1979), they had different responses to treatments. Kentucky bluegrass became less dominant within the relative species composition with the Burn Only or the Burn/Herbicide treatments across all communities in the first two years following treatment initiation. However, reduced dominance of smooth bromegrass occurred on plots that were mowed and plant material was removed by raking (Mowed/Raked treatment). Over time, Kentucky bluegrass responses to treatment tended to differ between community categories while the impact of community categories on smooth bromegrass responses to treatment was reduced over time, and by 2005, the response of smooth bromegrass to treatments was similar for all five communities.

Differences in the responses of the two species may have occurred for several reasons. First, smooth bromegrass may have been burned too early for maximum impact. Fire has the biggest impact on smooth bromegrass tiller density when burning is conducted at tiller elongation or later (Mitchell et al. 1996, Willson and Stubbendieck 1997). Information on the relationship between morphological development and growing degree days (Frank 1996; Frank et al. 1997) indicates that smooth bromegrass would have still been in the vegetative stage when burning occurred. However, Kentucky bluegrass may have also benefited from a later burn date. In the northern Great Plains, there is some evidence that burning later such as mid-May can also reduce Kentucky bluegrass at least during dry years (Engle and Bultsma 1984). Fire was applied to the Burn Only plots for two consecutive years and repeated burns have been shown to reduce both Kentucky bluegrass (Knops 2006) and smooth bromegrass (Stacy et al. 2005).

Second, the two invasive species responded differently to burning followed by herbicide application. For example, the Burn/Herbicide treatment generally decreased Kentucky bluegrass especially in 2003 and 2004, but had no significant impact on the abundance of smooth bromegrass. Kentucky bluegrass has been shown to be more susceptible to herbicides, such as atrazine, than smooth bromegrass (Masters et al. 1992). Also, burning removed the heavy thatch layer characteristic of a Kentucky bluegrass dominated site which may have improved herbicide effectiveness (DiTomaso et al. 2006). Burning followed by imazapic (Burn/Herbicide) restricted live grass biomass in most community categories in 2003, reducing thatch for the second application of imazapic in 2004. Imazapic has been successfully used to enhance the seedling establishment of warm-season grasses (Masters et al. 1996), so the success of a burning and herbicide application in enhancing the native grass abundance on the primarily big bluestem dominated native communities was not surprising. However, in the cool-season dominated communities, burning followed by imazapic (Burn/Herbicide) often decreased live grass biomass although the negative impact on live grass had disappeared by the end of the study.

The third potential reason for the different species responses to treatment is differences in responses to defoliation. The Mowed/Raked treatment, which was mowing followed by raking, resulted in the greatest reduction in smooth bromegrass abundance but either increased or had limited impact on Kentucky bluegrass responses. The different responses may be linked to differences in plant morphology. The short stature of Kentucky bluegrass limits tissue accessibility and keeps apical meristems near the soil surface limiting exposure to defoliation (Briske 1991). Smooth bromegrass, which has more exposed meristems, tends to decrease under grazing (Murphy and Grant 2005, Stacy et al. 2005).

Although only two sites per community category were studied, the data suggest that treatment responses can be impacted by community type. This was especially evident in 2005 when Kentucky bluegrass, native grasses, and OTHER species responded differently to restoration treatments in different community categories. Some restoration treatments by community category interactions were easy to interpret. Imazapic targets cool-season (C_3) grasses, such as those that dominated the Kentucky Bluegrass Dominated and Co-Dominated community categories, but does not impact big bluestem, a C_4 species that dominated the Native Dominated community (Masters et al. 1996). Therefore, the native grass component would be expected to increase in the Native Dominated community category. June, July, and August had greater precipitation than average in 2005 which would also benefit the warm-season native species in the native community.

Other interactions are more difficult to explain. In 2005, the Burn/Herbicide treatment reduced Kentucky bluegrass by nearly 20% in the relative species composition in the Smooth Bromegrass Dominated community categories but had limited impact in the Kentucky Bluegrass Dominated community category. Among the possible explanations are treatment- induced changes in interspecies composition and below-ground processes. Competition has major impacts on plant responses (Mueggler 1972) and both smooth bromegrass (Nermberg and Dale 1997) and Kentucky bluegrass (Tilman and Wedin 1991) are highly competitive, especially in fertile environments. In general, the Burn/Herbicide treatment increased the amount of smooth bromegrass in the species composition while decreasing Kentucky bluegrass. Disturbances have been reported to favor one species over another (Buckley et al. 2007, Firn et al. 2008) as well as the subsequent colonization. This may have shifted the competitive interactions to favor smooth bromegrass in the Smooth Brome Dominated community. Alternatively, restoration treatments may have impacted below-ground processes. Smooth bromegrass has been reported to exhibit self-facilitation through soil modification (Jordan et al. 2007) and soil microorganisms can impact community structure and diversity (Hartnett and Wilson 1999). The direct mechanism is unknown because neither direct competition nor below-ground processes were directly measured in our study. The different responses between community categories emphasize the need to plan for responses at the community as well as at the population level (DiTomaso et al. 2006).

Treatment responses were also affected by year. The year effect is illustrated by smooth bromegrass treatment responses becoming more similar between communities, but Kentucky bluegrass and the OTHER species treatment responses became less similar between communities. The year effect was also evidenced with the native forb and live grass biomass responses. The impact of year may have been driven by differences in precipitation, such as the effect of increased precipitation on native forbs in 2004 and 2005. Increased precipitation during June, July, and August may have also increased responses of the primarily C_4 grasses in the Native Dominated community category. Other factors driving the year effect may have been the cumulative impact of treatments when applied more than once. Most treatments were applied for two consecutive years when possible and this frequency may have impacted outcomes. Fire frequency can impact Kentucky bluegrass (Knops 2006) and repeated fire or grazing reduces smooth bromegrass (Stacy et al. 2005). Time can also affect the response of invasive species to herbicides. For example, herbicide control of Canada thistle [*Cirsium arvense* (L.) Scop.] has been shown to change over time (Travnicek et al. 2005).   The changes in treatment responses over time highlight the importance of long term planning and monitoring in an invasive plant control strategy.

Management Implications

Control of invasive perennial grasses is a difficult and complex task. This study pointed out the importance of considering which invasive species is targeted, the community the invasive species is in, and the importance of monitoring invasive species responses to treatment. The different responses of these two perennial invasive grasses indicated that the same treatment would produce different responses. Kentucky bluegrass was reduced most consistently by Burn/Herbicide treatment, but this same treatment increased smooth bromegrass. Similar effects were observed with the Mowed/Raked treatment. This treatment, which mimicked a grazing situation most closely, reduced the abundance of smooth bromegrass but increased Kentucky bluegrass.

The data also showed the influence of community category on treatment responses. Treatments to control the same invasive species had different effectiveness depending on the dominant species in the community category. Also, the use of the Burn/Herbicide treatment in all of the community categories, except the warm-season native, severely limited live grass productivity which would be a concern for land managers. The land manager would need to determine if potential enhancements in species composition are worth the initial decline in productivity. Finally, the changes in treatment responses over time showed the importance of incorporating active adaptive management (McCarthy and Possingham 2007, Shea et al. 2002) techniques into invasive species control strategies. As an example, if this study was concluded after year two, the results would have been limited, and management recommendations would have been different. Effective management strategies for controlling Kentucky bluegrass and smooth brome need to consider species, community composition, and length of time since the treatments were applied.

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CHAPTER III: COMBINING PRESCRIBED BURNS AND HERBICIDE TREATMENTS FOR THE CONTROL OF KENTUCKY BLUEGRASS

Introduction

Kentucky bluegrass (*Poa pratensis* L.) is introduced from Eurasia (Great Plains Flora Association 1986, Stubbendieck et al. 1997, Johnson and Larson 1999), naturalized in all of the continental United States and Canada, except in arid regions (Hitchcock 1950), and is said to have the widest distribution of any plant in the temperate portions of the northern hemisphere (Johnson and Larson 1999). Kentucky bluegrass spreads in wet conditions and will go into dormancy if moisture is limiting during the summer (Sprague 1933, Stubbendieck et al. 1997). Kentucky bluegrass is adapted to a wide range of soil types (Stubbendieck et al. 1997) and can withstand flooding with successive freezing, ice, and snow (Beard 1964).

Burning is the most widely used control method for Kentucky bluegrass (Rice 2005). Burning in areas without a native warm-season grass component is not as effective in long-term reduction of Kentucky bluegrass (Schacht and Stubbendieck 1985). Prescribed burning in areas with a sufficient amount of warm-season grasses can control Kentucky bluegrass longer due to the shift of the competitive advantage from Kentucky bluegrass to the native warm-season grasses.

Combining prescribed burns with herbicide treatments are also effective in reducing invasive cool-season grasses (Rice 2005). Spring prescribed burning followed by an application of glyphosate (2.24 kg/ha) or imazapic (0.21 kg/ha) was effective in controlling tall fescue (*Festuca arundinacea* Schreb.) in a Kentucky grassland (Washburn et al. 1999). A positive warm-season grass response also was shown in the combined burn and herbicide treatments.

The objective of this study was to determine the impacts of prescribed burning alone or in combination with herbicide treatments as well as the timing of prescribed burning on non-native cool-season grasses and species composition of tall grass prairie on the Sheyenne National Grassland near Lisbon, ND.

Methods

Study Area

The study was conducted on the Sheyenne National Grassland in southeastern North Dakota, approximately 16 km east of Lisbon, ND. The specific project area included the Biesterfeld (46º39´ N, 97º47´ W) (NW quarter Sec. 27, T134N, R54W) and Froemke (46º47´ N, 97º44´ W) (NW quarter Sec. 35, T135N, R54W) allotments. Both allotments were grazed by cow/calf units; therefore, two exclosures were placed on the Biesterfeld allotment in October 2004 and one enclosure placed on the Froemke allotment in June 2005.

The Sheyenne National Grassland is administered by the U.S. Forest Service and managed by the Sheyenne Valley Grazing Association (Edland 2002). The Sheyenne National Grassland is also known as the Sandhills, which is part of the Lake Agassiz Plain, sand-delta and beach ridges eco-region. The primary commercial use of the Sheyenne National Grassland is beef production.

The area has a sub-humid continental climate characterized by cold winters and warm summers (Edland 2002). The average annual precipitation is 52.2 cm, with 78% of the total occurring in April through September (Figure 3.1). The long-term average temperatures for the 125 day growing season ranges from 5.9° C to 21.6° C (Figure 3.2).

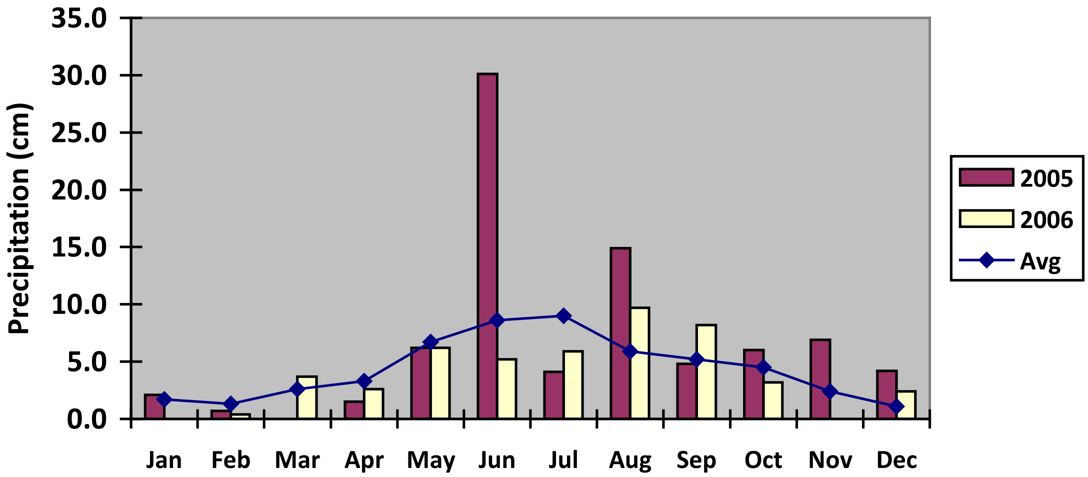

Figure 3.1. Monthly precipitation (cm) at McLeod, ND for 2005 and 2006 with the long-term average from 1971-2000 (NOAA).

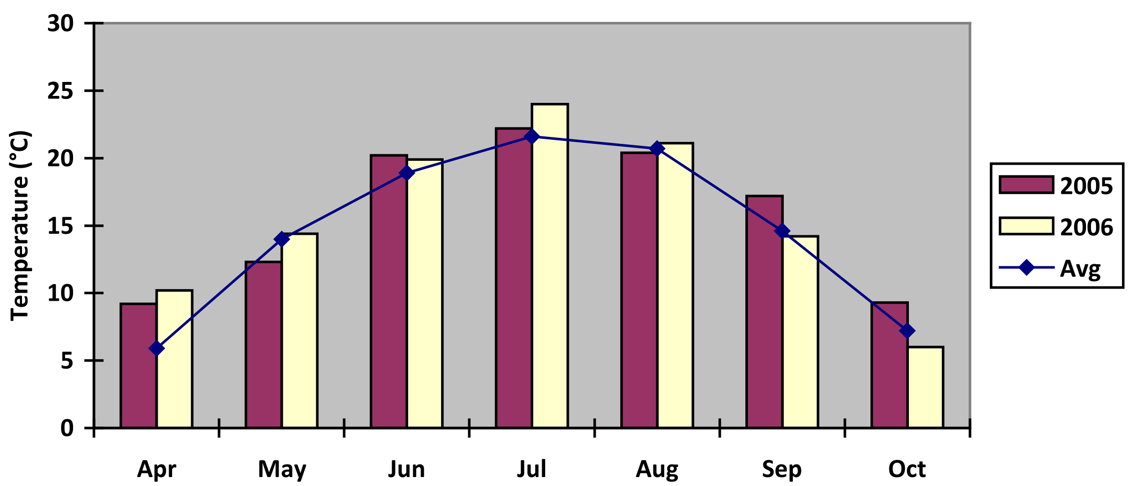

Figure 3.2. Mean growing season temperatures (°C) by month at McLeod, ND for 2005 and 2006 with the long-term average from 1971-2000 (NOAA).

Predominant soils at the research site were Hecla-Garborg loamy fine sands (USDA: Sandy, mixed frigid Typic Endoaquolls and Sandy, mixed, frigid Oxyaquic Hapludolls) (Soil Survey Staff 2011). The study area consisted of level to slightly sloping topography with a high water table and few poorly drained depressions. The loamy fine sand textured soils were deposited as alluvium and resorted by wind (Edlund 2002). Wind erosion is a concern for these soil types.

The Sheyenne National Grassland is known for a diversity of plant species (Seiler and Barker 1985). A variety of cool- and warm-season grasses, grass-like plants, forbs, shrubs, and trees are present. Originally the Sheyenne National Grassland was dominated by a dense vegetation of tall grasses; such as, big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), switchgrass (*Panicum virgatum* L.) and indian grass (*Sorghastrum nutans* (L.) Nash), as well as several forb species (Kuchler 1964). However, Kentucky bluegrass has invaded and is now the dominant species.

Experimental Design

Three sites were selected, each having a different percentage of Kentucky bluegrass (KBG) infestation: low (38%), moderate (69%) and high (91%). Within these sites seven treatments were applied: 1) fall burn with no herbicide treatment, 2) fall burn with spring applied imazapic, 3) fall burn with spring applied glyphosate, 4) spring burn with no herbicide treatment, 5) spring burn with fall applied imazapic, 6) spring burn with fall applied glyphosate, and 7) control.

The experimental design was a randomized complete block design in a split-plot arrangement with the prescribed burns as the whole plot and chemical treatments as subplots. Strips (10x60 m) were randomly selected in 4 replicates per site; half to be burned in late October 2005 and half in early May 2006. The herbicide treatments were randomly assigned to subplots within the burn on 10x20 m plots. The fall herbicide treatments were applied in late October 2005 within the area to be burned in the spring of 2006. The spring herbicide treatments were applied in May 2006 within the burn plots conducted in the fall of 2005. Glyphosate was applied at 2.24 kg/ha and imazapic applied at 0.43 kg/ha.

Sampling

Species composition was estimated using the 10-point pin frames (Cook and Stubbendieck 1986) with 50 frames recorded in each plot in July 2005 before treatments were applied and July 2006 after treatments were applied. Biomass was evaluated by clipping three 31.5x15.5 cm quadrats per subplot and sorted by species. Biomass was estimated at peak the historic production period in the first week of August in 2005 and 2006.

Statistical Analysis

Species composition in 2005 and 2006 were analyzed utilizing the mixed procedure of SAS 9.1. Species were grouped into native grass, introduced grass, native forb, introduced forb, and native shrub. Percentage of species by a group was analyzed after litter and bare ground were removed from the data set. A Tukey's HSD test was used to separate means between sites and treatments. Differences were tested using a P-level of 0.1. Contrast statements were used to separate different treatments. Replications within the sites were considered random effects, and sites and treatments fixed effects. Prior to statistical analysis the 2005 native grass species composition data were log transformed and the (introduced grass data were arcsine transformed. The 2006 native and introduced grass species composition data had a site by treatment interaction and were separated by site. Native forb and native shrub data were log transformed prior to statistical analysis.

Biomass from 2005 and 2006 were analyzed by using the mixed procedure of SAS 9.1. Species were grouped as native grass, introduced grass, native forb, introduced forb, and native shrub. A Tukey's HSD test was used for mean separation and significant differences between sites and treatments were tested using a P-level of 0.1. Contrast statements were used to separate different treatments. Replications were considered random effects, and sites and treatments were fixed. Prior to analysis, 2005 and 2006 native grass and 2006 native forb biomass were log transformed. Introduced grass biomass in 2006 was separated by site due to a site by treatment interaction. Introduced forb had a non-normal residual distribution despite numerous attempts of transformation and was not analyzed.

Results

Species Composition

The 2005 species composition provided baseline data for each treatment. Sites were selected on the amount of native and introduced grass present; therefore, results will be focused only on native and introduced grass. Both native and introduced grass species composition showed differences ($P<0.1$) between all three sites (Fig. 3.3). There were no differences ($P<0.1$) in the species composition baseline data between replicates within each site in either the native or introduced grass in 2005.

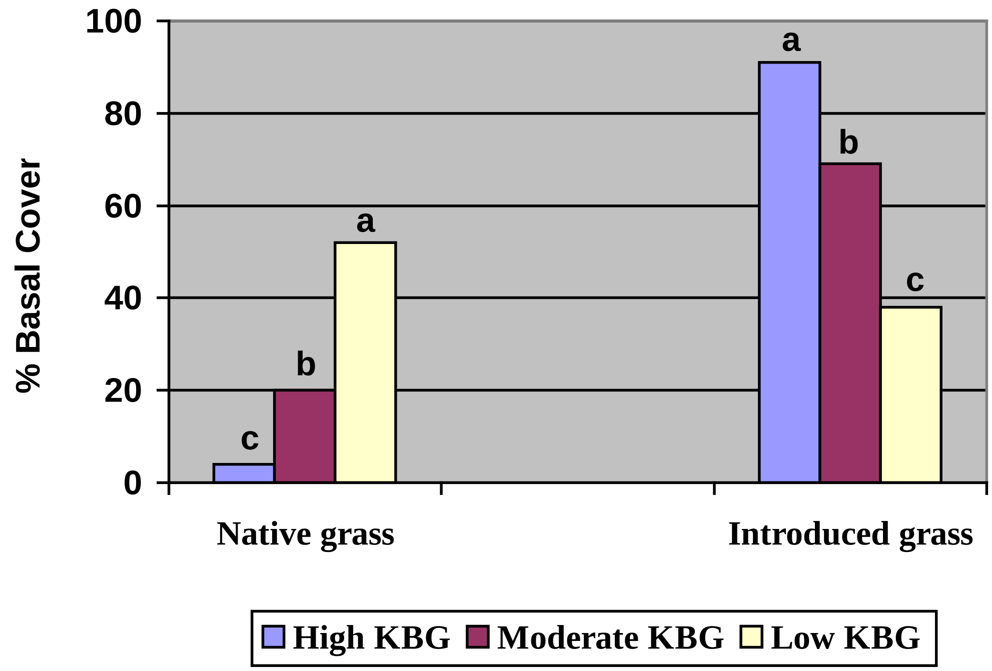

Figure 3.3. Native and introduced grass basal cover (%) for high, moderate, and low Kentucky bluegrass (KBG) invaded sites in 2005. Different lower case letters within native or introduced grass indicate significant differences at the $P<0.10$.

High Kentucky Bluegrass

The fall burn combined with a spring application of glyphosate was the only treatment to increase ($P<0.1$) native grass basal cover (%) compared to the control and the fall and spring burns alone 12 months after treatment (Table 3.1). Introduced grass basal cover response to treatments by site showed that in the high Kentucky bluegrass site. A fall burn combined with a spring application of glyphosate was the only treatment to decrease ($P<0.1$) introduced grass basal cover compared to the control and the fall and spring prescribed burns alone 12 months after treatment (Table 3.1).

Table 3.1. Native and introduced grass basal cover (%) by treatments in the high, moderate, and low Kentucky bluegrass (KBG) sites in 2006.

Treatment	High KBG		Moderate KBG		Low KBG	
	Native	Intro.	Native	Intro.	Native	Intro.
Fall burn with no herbicide	8b*	86a	19bc	62ab	41b	45a
Fall burn with spring imazapic	18ab	77a	37ab	46b	80a	9c
Fall burn with spring glyphosate	27a	26b	57a	6d	81a	6c
Spring burn with no herbicide	6b	88a	18bc	62ab	77a	14bc
Spring burn with fall imazapic	6b	85a	17bc	69a	58ab	27ab
Spring burn with fall glyphosate	10b	72a	46a	30c	78a	3c
Control	8b	84a	12c	61ab	50b	35ab

*Within columns, means followed by the same letter are not significantly different according to Tukey's (0.10).

<u>Moderate Kentucky Bluegrass</u>

Glyphosate, combined with either the fall or spring prescribed burns, increased ($P<0.1$) native grass basal cover (%) compared to fall and spring burns alone and the control. A fall burn with spring applied imazapic increased ($P<0.1$) native grass basal cover compared to the control in the moderate Kentucky bluegrass site 12 months after treatment (Table 3.1).

A fall burn combined with spring application of imazapic decreased ($P<0.1$) introduced grass basal cover compared to a spring burn combined with the fall application of imazapic (Table 3.1). Glyphosate combined with either a fall or spring prescribed burn decreased ($P<0.1$) introduced grass basal cover (%) compared to the control, and fall and spring burns alone 12 months after treatment.

Low Kentucky Bluegrass

Native grass basal area increased ($P<0.1$) when plots were burned in the spring, were sprayed with imazapic in the fall followed by a spring burn, or burned in the fall followed by an application of glyphosate or imazapic compared to fall burn only or the controls 12 months after treatment (Table 3.1). The spring burn alone decreased ($P<0.1$) introduced grass compared to the fall burn alone 12 months after treatment (Table 3.1). The fall burn combined with a spring application of imazapic and both fall and spring prescribed burns combined with glyphosate decreased ($P<0.1$) introduced grass basal cover compared to the control, the fall burn alone, or the spring burn combined with fall applied imazapic 12 months after treatment.

Forbs and Shrubs

The moderately infested Kentucky bluegrass site had significantly more native forbs than the high or low Kentucky bluegrass infested sites in 2006. Both fall and spring burn treatments combined with glyphosate had more ($P<0.1$) native forbs than the spring burn with a fall application of imazapic or both fall and spring prescribed burns alone. The fall burn combined with a spring application of glyphosate resulted in more ($P<0.1$) native shrubs than the fall burn combined with the spring applied imazapic or the fall burn alone 12 months after treatment.

Biomass

The native and introduced grass biomass was different ($P<0.1$) between all three sites (Fig. 3.4). There were no differences ($P<0.1$) between treatments in either the native or introduced grass biomass.

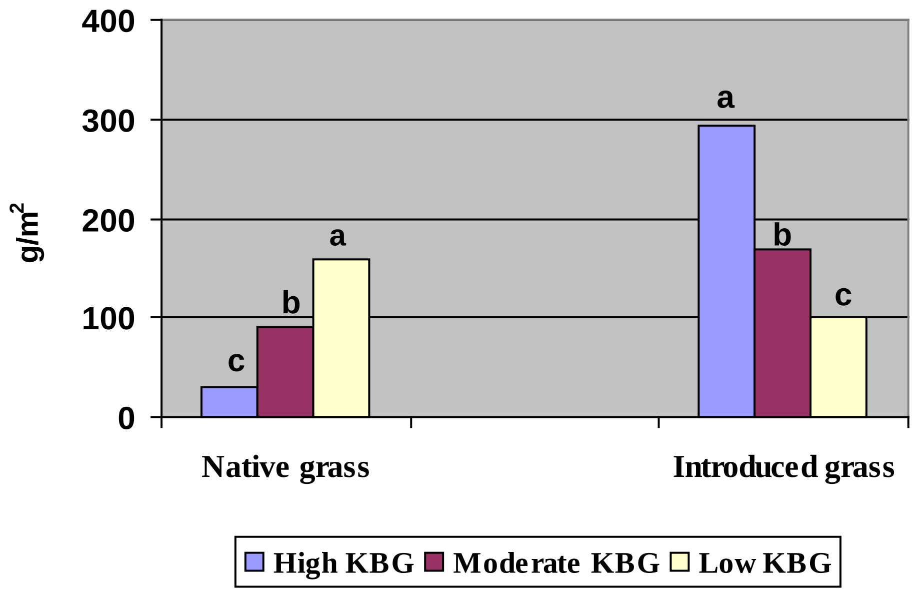

Figure 3.4. Native and introduced grass biomass from in the High, Moderate, and Low Kentucky bluegrass (KBG) sites in 2005. Different lower case letters within native or introduced grass indicate significant differences at the P<0.10.

There was not a treatment by site interaction for native grass, native forb, native shrub and introduced forbs. Native grass biomass response was higher (P<0.1) when fall glyphosate application was followed by spring burning compared to the control, the spring burn with the fall applied imazapic, or the fall burn alone across all three sites (Table 3.2). Native forb biomass response to herbicide application following burning showed that the spring burn combined with a fall application of imazapic increased (P<0.1) native forbs compared to the control across all sites (Table 3.2).

Native shrub biomass response to herbicide application following burning showed a fall burn with a spring application of imazapic decreased (P<0.1) native shrub biomass compared to the fall burn alone and the fall burn combined with the spring applied glyphosate (Table 3.2). The moderate Kentucky bluegrass site had more (P<0.1) shrubs compared to the high Kentucky bluegrass site.

Table 3.2. Biomass (g/m^2) response to herbicide after burning in the High, Moderate, and Low Kentucky bluegrass infested sites in 2006.

Treatment	Native grass	Native forb	Intro. forb	Native shrub
Fall burn with no herbicide	78.7b*	70.2ab	22.5**	33.1a
Fall burn with spring imazapic	155.8ab	79.1ab	0.0	0.4b
Fall burn with spring glyphosate	146.5ab	60.5ab	31.6	19.3a
Spring burn with no herbicide	77.4ab	72.9ab	15.3	13.9ab
Spring burn with fall imazapic	73.9b	133.7a	10.9	10.9ab
Spring burn with fall glyphosate	221.9a	61.4ab	4.3	16.0ab
Control	67.3b	51.8b	30.4	9.0ab

*Within columns, means followed by the same letter are not significantly different according to Tukey's (0.10).
**Within column, introduced forb values are shown, but significance is not shown due to a non-normal residual distribution despite numerous attempts of transformation.

Introduced grass biomass responses indicated the fall burn with spring applied imazapic or the spring burn with fall imazapic or glyphosate application decreased ($P<0.1$) introduced grass biomass compared to all other treatments in the high and moderate Kentucky bluegrass sites. The spring burns decreased ($P<0.1$) introduced grass biomass compared to the control in both the high and moderate Kentucky bluegrass sites. The low Kentucky bluegrass site had a similar pattern; however, the fall burn alone had a greater increase ($P<0.1$) in introduced grass biomass compared to a fall burn with either herbicide application or glyphosate application followed by a spring burn (Table 3.3).

Table 3.3. Introduced grass biomass (g/m^2) response to herbicide after burning in the High, Moderate, and Low Kentucky bluegrass infested sites in 2006.

Treatment	High KBG	Moderate KBG	Low KBG
Fall burn with no herbicide	193.2ab*	147.4a	101.4a
Fall burn with spring imazapic	21.6c	8.0c	4.7b
Fall burn with spring glyphosate	1.3c	1.1c	1.9b
Spring burn with no herbicide	140.9b	78.4b	58.9ab
Spring burn with fall imazapic	159.4ab	94.1b	48.3ab
Spring burn with fall glyphosate	49.5c	23.8c	1.0b
Control	208.6a	107.2ab	56.4ab

*Within columns, means followed by the same letter are not significantly different according to Tukey's (0.10).

Discussion

Combining prescribed burning and herbicide treatments was more effective in reducing Kentucky bluegrass compared to burning alone. Glyphosate combined with a prescribed burn was more effective in reducing Kentucky bluegrass than the combination of imazapic with a prescribed burn. The fall prescribed burn combined with a spring application of glyphosate decreased introduced grass basal cover and increased native grass percent basal cover on all three sites. This treatment also decreased introduced grass biomass in the high and moderate Kentucky bluegrass sites.

Three effective treatments were shown to reduce Kentucky bluegrass and increase native warm-season grasses. Glyphosate combined with either the fall or spring prescribed burns appeared to be the most promising treatments. The fall prescribed burn with the spring application of glyphosate was effective in decreasing introduced grass and increasing native grass percent basal cover, regardless of the amount of Kentucky bluegrass present. This treatment also decreased introduced grass biomass in the high and moderate Kentucky bluegrass sites.

The spring prescribed burn combined with a fall application of glyphosate decreased introduced grass and increased native grass basal cover in the moderate and low Kentucky bluegrass sites. This treatment was the only treatment to increase native grass biomass on all three sites while also decreasing introduced grass biomass on the high and moderate Kentucky bluegrass sites.

The fall burn with a spring application of imazapic decreased introduced grass basal cover on the low Kentucky bluegrass site and increased native grass basal cover on the moderate and low Kentucky bluegrass sites. Washburn et al. (2002) stated that using imazapic at a high rate of 0.71 kg/ha was more effective in controlling heavy stands of tall fescue, whereas, using a low rate of 0.28 kg/ha was effective only in areas with less tall fescue and more native grasses. It is possible that imazapic used at a higher rate combined with a prescribed burn could have been more effective in controlling Kentucky bluegrass on the high and moderate Kentucky bluegrass sites.

The results of this study agree with Schacht and Stubbendieck (1985), in that only the low Kentucky bluegrass site showed an increase in native warm-season grass basal cover with a spring prescribed burn. Introduced grass was significantly decreased in the low Kentucky bluegrass site compared to the fall prescribed burn.

Management Implications

Results of this study characterize only one growing season and are therefore preliminary. Further investigation will be required to determine the long-term effects of the treatments. However, this study did result in some important findings, such as species composition shifts depending on the site and treatment.

Though preliminary, the results indicated that glyphosate combined with either a fall or spring prescribed burn was the most effective in controlling introduced grass in the high and moderate Kentucky bluegrass infested sites. A spring prescribed burn alone would be the most economical treatment for the low Kentucky bluegrass site due to the already low amount of Kentucky bluegrass.

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GENERAL CONCLUSION

The results from the Mandan study showed that smooth bromegrass and Kentucky bluegrass responded quite differently to the five management tools applied. The Mow/Rake treatment was the most effective tool in reducing smooth bromegrass but increased Kentucky bluegrass. The Burn/Chemical treatment had the greatest effect on reducing Kentucky bluegrass but too much on sites without a native grass component. To a land manager, Kentucky bluegrass is better than no grass.

The results from the Burn/Chemical treatment on the native grass community at the Mandan study looked like the most promising tool for reducing Kentucky bluegrass as long as there was a warm-season native grass component present. This is why we chose the Sheyenne National Grassland as our second study site. It was heavily infested with Kentucky bluegrass, however still had a fair amount of native warm-season grasses present. The fall burn with glyphosate applied in the spring increased native grass basil cover the most while decreasing Kentucky bluegrass in all three sites. The remaining treatments changed in effectiveness depending on the percentage of Kentucky bluegrass infestation. In regards to native grass biomass, the only treatment that was significantly higher from the control was the fall applied glyphosate followed by a spring burn.

The results from both the Mandan study and the Sheyenne National Grassland study show the importance of fully understanding what species you are trying to control and the amount of that species present before deciding which management tool to use.