IMPACTS OF PRESCRIBED FIRE AND GRAZING ON NORTHERN GREAT PLAINS RANGELANDS

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Impacts of Prescribed Fire and Grazing on Northern Great Plains Rangelands

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MASTER OF SCIENCE

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ABSTRACT

Prescribed burning was utilized as a management tool on grasslands of the Northern Great Plains. We analyzed the use of fire to manipulate encroaching and unpalatable western snowberry (Symphoricarpos occidentalis), to promote browsing and improve nutritive quality. Fire was successful at altering the nutrient quality of western snowberry and selectivity of grazing livestock from plant specific to patch specific. Additionally, we evaluated the difference between burn season and frequency on plant community dynamics of an ungrazed tallgrass prairie invaded by Kentucky bluegrass (Poa pratensis). Fire promoted native forb and grass species, stressing that native species are well adapted to the historical disturbance. Our research emphasizes the need for restored fire regimes in the Northern Great Plains to benefit numerous aspects of prairie ecosystem function, stability, services, and productivity.

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DEDICATION

I dedicate this work to my Dad, Mom, and sister. Without their constant support and encouragement, I would not have excelled academically.

PREFACE

Chapter 1 and 2 are written as manuscripts to be submitted to a peer-reviewed journal. As of now, only Chapter 1, “Impacts of land management strategies on browse and nutritional quality of a resprouting shrub”, will be submitted to a journal. Both chapters are written following the style and formatting guidelines of *Rangeland Ecology and Management.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

GENERAL INTRODUCTION

Historically, fire was a natural occurrence in North America that influenced the development of rangeland systems. High frequency of fires in the Great Plains region lead to the formation of prairie systems as woody species were unable to reestablish at an efficient rate for high abundance and native herbaceous species that were able to flourish (Axelrod, 1985). Fires were predominantly started by lightning strikes or as a result of human activities and were important for maintaining the native plant community (Higgins, 1984; Axelrod, 1985). There was a rapid decline in frequency of widespread fires following European settlement due to suppression practices and loss of continuous landscape caused by fragmentation (Axelrod, 1985; Limb et al., 2016). Absence of fire allowed for woody vegetation encroachment and invasive plant species establishment in grasslands, which led to habitat and pasture degradation and the need for restoration of fire regimes. Prescribed burning is now used to promote heterogeneity of landscapes, control weed, invasive, and woody species (DiTomaso et al., 2006; Limb et al., 2010), reestablish wildlife habitats, and to improve forage quality in areas used for livestock production (Allred et al., 2011; Powell et al., 2018). The benefit and importance of fire in the Great Plains has been realized and prescribed burning is becoming an important management tool, despite social concern being a barrier to restoring historic fire regimes (Toledo et al., 2014; Limb et al., 2016).

In this study, we utilized prescribed burning as a management tool on grazed and ungrazed grasslands of the Northern Great Plains. First, we analyzed the use of fire to manipulate an encroaching and unpalatable western snowberry (*Symphoricarpos occidentalis*), to promote browsing and improve nutritive quality. Fire was successful at altering the nutrient quality of western snowberry and selectivity of grazing livestock from plant specific to patch specific.

Second, we evaluated the difference between burn season and frequency on plant community dynamics of an ungrazed tallgrass prairie invaded by Kentucky bluegrass (*Poa pratensis*). Fire promoted native forb and grass species, and a higher frequency of burns further reduces Kentucky bluegrass cover (Towne and Kemp, 2008), stressing that native species are well adapted to the historical disturbance. Our research emphasizes the need for restored fire regimes in the Northern Great Plains to benefit numerous aspects of prairie ecosystem function, stability, services, and productivity.

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CHAPTER 1: IMPACTS OF LAND MANAGEMENT STRATEGIES ON BROWSE AND NUTRITIONAL QUALITY OF A RESPROUTING SHRUB

Abstract

Woody encroachment alters plant community composition in rangelands worldwide. Encroachment of western snowberry (*Symphoricarpos occidentalis*) in the Northern Great Plains has decreased available and favorable forages for livestock consumption. Research on the effects of grazing western snowberry is limited, but show that grazing alone increases expansion because mature plants are not readily consumed. Manipulating forage quality characteristics by burning can be an effective mechanism to encourage large herbivores to consume undesirable plant species. Fire removes old plant material and promotes new growth of higher forage quality that cattle are more likely to consume, because of increased palatability and digestibility. Our study objectives were to 1) estimate the percent western snowberry browsed by cattle under different management types and 2) compare nutrient content of burned and unburned western snowberry with time since fire. We hypothesize that browse of western snowberry will be highest under patch-burn graze management, due to an initial increase in palatability and nutritive content following the prescribed burn. Percent western snowberry browsed was determined with stem and bite counts taken by placing a 1m^2 quadrat every five meters along four random 100 meter transects per replicate. Weekly samples of each western snowberry treatment were collected during the growing season to evaluate selected nutritional values. Browsing in patch-burn graze pastures was three and five times higher than in season-long and early-intensive grazed pastures. Prescribed burning initially lowered acid detergent lignin and increased crude protein and phosphorus content of western snowberry. All new growth had lower

fiber content and higher digestibility than old growth. Patch-burn grazing is a viable option for promoting cattle to graze unpalatable and undesirable plant species.

Introduction

Woody encroachment is a global phenomenon that threatens the structure, function, stability, and productivity of rangeland ecosystems (Archer, 1989; Van Auken, 2000, Cabral et al., 2003; Fensham et al., 2005). Changes in climate, increased atmospheric CO^2 (Archer 1995), altered fire regimes, and poor grazing management (Van Auken, 2009) have allowed further woody species establishment. Woody encroachment causes alterations in light quality (Peltzer and Konchy, 2001; Bartemucci et al., 2006), and available nutrients and water to other herbaceous plant species (Huxman et al., 2005). This leads to variations in rangeland vegetation composition, and decreased plant species diversity, richness and overall productivity (Briggs et al., 2005; Zarovalli et al., 2007; Van Auken 2009; Ratajczak et al., 2012; Limb et al., 2014). Within North America alone, it is estimated that 220 to 330 million hectares of grasslands are experiencing some degree of woody encroachment (Knapp et al., 2008; Van Auken 2009). Control and management strategies to restore rangeland structure, function, stability, and productivity are dependent upon the life history characteristics of the target woody species.

Management and control of woody species is important for maintaining herbaceous productivity, especially in regions used for livestock production (Peltzer and Kochy, 2001; Smart et al., 2007). Fire, grazing, mechanical (Clark and Wilson, 2001), and chemical (Ansley and Castellano, 2006) methods are commonly used to control woody encroachment. However, woody plant species respond differently to control methods based on whether the species has resprouting or non-resprouting characteristics (Bellingham et al., 2000). Mechanical and fire disturbances can reduce the cover of both types, but do not affect the underground portion of the plant, making individual use of these methods less suitable for resprouting species (Anderson and Bailey, 1979; Clark and Wilson, 2001; Davies et al., 2012). Chemical control, using herbicides, is effective as a management method for both types (Bowes and Spurr, 1995; Ansley and Castellano, 2006; Sbatella et al., 2011), but can be cost prohibitive and detrimental to other plant species (McCarty, 1967). Grazing can be effective for herbaceous plant management, but is often ineffective for woody plant control as low palatability reduces browsing (Fitzgerald and Bailey, 1984; Weber and Jeltsch, 2000; Briggs et al., 2002). Manipulating forage quality characteristics can be an effective mechanism to encourage large grazing animals to consume undesirable species (Cummings et al., 2007).

Forage quality is an evaluation of forage palatability, digestibility, nutrient content, and intake and can be influenced by climate, season, plant characteristics, structure, maturity, and disturbance (Renecker and Hudson, 1988). The structural and chemical make-up of a plant changes as it grows and matures; with lignin, cellulose, neutral detergent fiber (NDF), and acid detergent fiber (ADF) content increasing with advancing maturation, while crude protein (CP) content and palatability decreasing with maturation (Schindler et al., 2004). Low palatability of mature plants reduces grazing pressure, and this concept is evident in woody plant species (Plum and Dodd, 1993). Prescribed burning has been utilized to remove mature plant material and promote immature herbaceous plant growth (Plumb and Dodd, 1993; Seastedt and Knapp, 1993; Cook et al., 1994; Anderson et al., 2007; Raynor et al., 2015), which generally has high nutrient quality and lower lignin and cellulose content, making them more palatable and attractive for grazing (Mbatha and Ward, 2010). Further, patch burn systems allow for portions of a pasture to be burned, resulting in concentrated grazing in burned areas, changing the grazing selections from specific plant species to selection of the patch as a whole (Cummings et al., 2007). Limited evidence suggests that prescribed burning has shown potential to promote consumption of woody species regrowth by livestock (Debyle, 1989; Cook et al., 1994; Schindler et al., 2004). Within the Northern Great Plains, western snowberry expansions on rangelands is affecting the quality and quantity of forage available to grazing animals, making this a perfect model system for utilizing patch-burning to influence grazing of undesired woody species.

Western snowberry (*Symphoricarpos occidentalis*) is a native cool-season shrub with resprouting growth characteristics (Pelton, 1953). The deep and expansive root system of western snowberry allows for efficient nutrient and water uptake, and reduces the amount of resources for other herbaceous vegetation to access (Pelton, 1953). These inhibitive characteristics have led to alterations in plant community composition in regions of the Northern Great Plains (Pelton, 1953). The Northern Great Plains is predominately working landscapes some of which is utilized for grazing (Barker and Whitman, 1988), but woody encroachment by western snowberry, and other species, is reducing the availability of favorable forages for livestock and wildlife (McCarty, 1967; Grant et al., 2004; Van Auken, 2009). The historic fire return interval for the Northern Great Plains was three to ten years, but much of the region remains unburned since European settlement (Scholes and Archer, 1997; Allen and Palmer, 2011). This absence of fire causes woody species, such as western snowberry, to become abundant, undesirable forage and a barrier to grazing herbaceous forage (McCarthy, 1967; Raynor et al., 2015). Fire top-kills and reduces western snowberry cover; however, regrowth emerges rapidly and can temporarily increase stem density (Anderson and Bailey, 1979). Frequent burning could reduce western snowberry abundance and allow for regrowth with higher palatability and nutrition, increased the likelihood of browsing by livestock (Plumb and Dodd, 1993; Raynor et al., 2015).

Woody encroachment has a negative impact on the availability and accessibility of desirable forage for grazing animals. Shrubs are not a dominant component in livestock diets due to low palatability, but some browsing does occur (Fitzgerald and Bailey, 1984; Plumb and Dodd, 1994; Briggs et al., 2002). Patch-burn grazing management allows for removal of old plant material, promoting new vegetative growth with high palatability and nutrients (Wood, 1988; Debyle, 1989; McGranahan et al., 2014). This practice has shown effective to promote grazing of otherwise undesirable herbaceous species due to forage in the burned area being immature, selection will be for the burned area as a whole, rather than for specific desirable plants (Cummings et al., 2007; Raynor et al., 2015). Limited research is available on the effect patch burning and other grazing managements have on woody species consumption, including western snowberry, but what has been done indicates that herbivores may graze regrowth following fire more frequently than mature plants (Smart et al., 2007), potentially due to the palatability and nutritive content of mature plants being low (Gastler et al., 1951). Therefore, the objectives of this study were to 1) estimate the percent of western snowberry that was browsed by cattle under early intensive, season long, and patch burn graze management and 2) create a regression model of the nutritive quality of regrowth following a spring prescribed burn, mature shrubs one year post burn, and unburned mature shrubs. Based on cattle grazing preferences and the effect of burning on plant structure and nutrient content, we hypothesize that cattle will more readily graze western snowberry regrowth following prescribed fire when compared to mature unburned western snowberry, due to an initial increase in palatability and nutritive content following the prescribed burn.

Methods

Site Description

The study was conducted at the North Dakota State University Central Grasslands Research Extension Center in Stutsman and Kidder Counties northwest of Streeter, ND USA (46°45’N, 99°28’W). The station lies within the Missouri Coteau ecoregion (USDA-NRCS, 2006), dominated by fine-loamy mollisols and characterized by irregular rolling plains resulting from the collapse of superglacial sediment (Bluemle, 1991). The climate is characterized as continental with majority (73%) of precipitation occurring between May and September, with a 68 mm monthly average during the growing season. August (20°C) is the warmest month and January (-12°C) the coldest month, based on the 30 year average (North Dakota Agriculture Weather Network, NDAWN, 2017). The vegetation is classified as a mixed-grass prairie (Whitman and Wali, 1975), dominated by Kentucky bluegrass (*Poa pratensis*), western wheatgrass (*Pascopyrum smithii*), green needlegrass (*Nassella viridula)* and blue grama (*Bouteloua gracilis*), with other important species including sedges *(Carex spp.*), sages (*Artemisia spp.*), goldenrods (*Solidago spp.*) and western snowberry *(Symphoricarpos occidentalis*). Plant nomenclature and descriptions follow the national plants data base (USDA, 2017).

Data Collection

Grazing treatments to determine percent browsed included season-long grazing, patch-burn grazing, early-intensive grazing, and idle management (i.e. no grazing or burning), each replicated three times within twelve 16 ha pastures. Season-long and patch-burn pastures were stocked at 3.04 AUMs/hectare and grazed 1 May to 5 September. Patch-burning began in 2014 on a four year burn rotation where one fourth of each pasture was burned annually during the dormant season. Early-intensive pastures were grazed at the same stocking rate, but double the stocking density starting 1 May, and removing cattle after 2 months, or approximately 30 June. This grazing management achieves similar grazing pressure as season-long and patch burn graze pastures by grazing more cattle for a shorter period of time.

To estimate western snowberry browse per grazing treatment, we established four 100 m transects in each treatment pasture and recorded the number of individual stems within a 1m x 1m quadrat at 5 m intervals. We then estimated western snowberry browsed (Interagency Technical Reference, 1996). Percent browsed data was collected in August. Grazing treatments were compared using ANOVA procedures and Tukey's b mean separation in IBM® SPSS Statistics 24. Results were considered significant at $p \leq 0.05$.

Western snowberry samples collected for nutritional and digestibility analysis were clipped from idle pastures to represent unburned western snowberry, from patch-burn pastures the first growing season following burns and one year post burn at weekly intervals from mid-May to mid-September. All samples were clipped to ground level, separated into old growth and new growth and weighed. New growth samples were labeled as 2017 post-burn regrowth, 1-year post-burn new growth, and non-burn new growth. Old growth samples were labeled as 1-year post-burn old growth and non-burn old growth. Samples were then placed in a Grieve oven at 65° C for 72 hours to achieve 100 percent dry matter.

The forage quality categories determined by wet chemistry and presented on a dry matter basis were acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent lignin (ADL), in-vitro organic matter digestibility (IVOMD), in-vitro dry matter digestibility (IVDMD), crude protein (CP), ash, calcium (Ca), and phosphorus (P). CP content represents the total nitrogen (N) in a forage as %CP and equal to %N times 6.25. Forage nutritive content of all samples was analyzed by North Dakota State University Animal Science Nutrition Lab. For laboratory procedures see Appendix A. Individual forage quality categories were analyzed using ANOVA, regression, and Tukey's b mean separation in IBM® SPSS Statistics 24. We used a combination of Akaike information criterion and biological appropriateness to fit the regression relationship between time in weeks and forage quality category (AIC; Burnham and Anderson, 1998). Specific model parameters are reported in Appendix B to improve graph readability. Results were considered significant at $p \leq 0.05$.

Results

The percent of western snowberry browsed (Figure 1.1) increased following spring prescribed fire. Percent browsed was higher ($p \leq 0.05$) within the patch-burn grazed treatment (25.70 ± 6.71%) than season-long grazed (5.59 ± 1.54%), early-intensive grazed (8.32± 1.60%), and idle (0%) treatments. There was no difference ($p \geq 0.05$) between percent browsed within the season-long and early-intensive grazed treatments; however, both had a higher ($p \leq 0.05$) percent browse than the idle treatment.

The dietary fiber and lignin content, ADF (Figure 1.2A), NDF (Figure 1.2B) and, ADL (Figure 1.2C), and IVOMD (Figure 1.3A) and IVDMD (Figure 1.3B) of western snowberry was different between old growth and new growth the duration of the sampling period. There was a treatment effect within new growth ADF content, with the 2017 post-burn regrowth (12.58± 1.86%) and 1-year post-burn new growth (15.24 ± 0.27%) lower than non-burn new growth (18.22 ± 0.32%) at three weeks after burning. The ADF content of 2017 post-burn regrowth was higher than 1-year post-burn and non-burn new growth at 11 through 14 weeks post burn. The ADF content of 1-year post-burn old growth was lower than non-burn old growth from four through seven weeks post-burn. The NDF content of 2017 post-burn regrowth was higher than 1-

year post-burn and non-burn new growth at 11 through 14 weeks post burn. The ADL content of western snowberry in the 2017 post-burn regrowth (3.44± 0.44%) was lower than 1-year post-burn regrowth (6.32 ± 0.28%) and non-burn new growth (10.56 ± 0.24%) at three weeks post-burn. The ADL content of 1-year post-burn old growth (18.02± 0.33%) was lower than non-burn old growth (19.44 ± 0.19%) at three weeks post-burn. IVOMD of 2017 post-burn regrowth (74.89 ± 1.55%), 1-year post-burn new growth (71.50 ± 0.10%), and non-burn new growth (66.84 ± 0.22%) were each different from each other at three week post-burn.

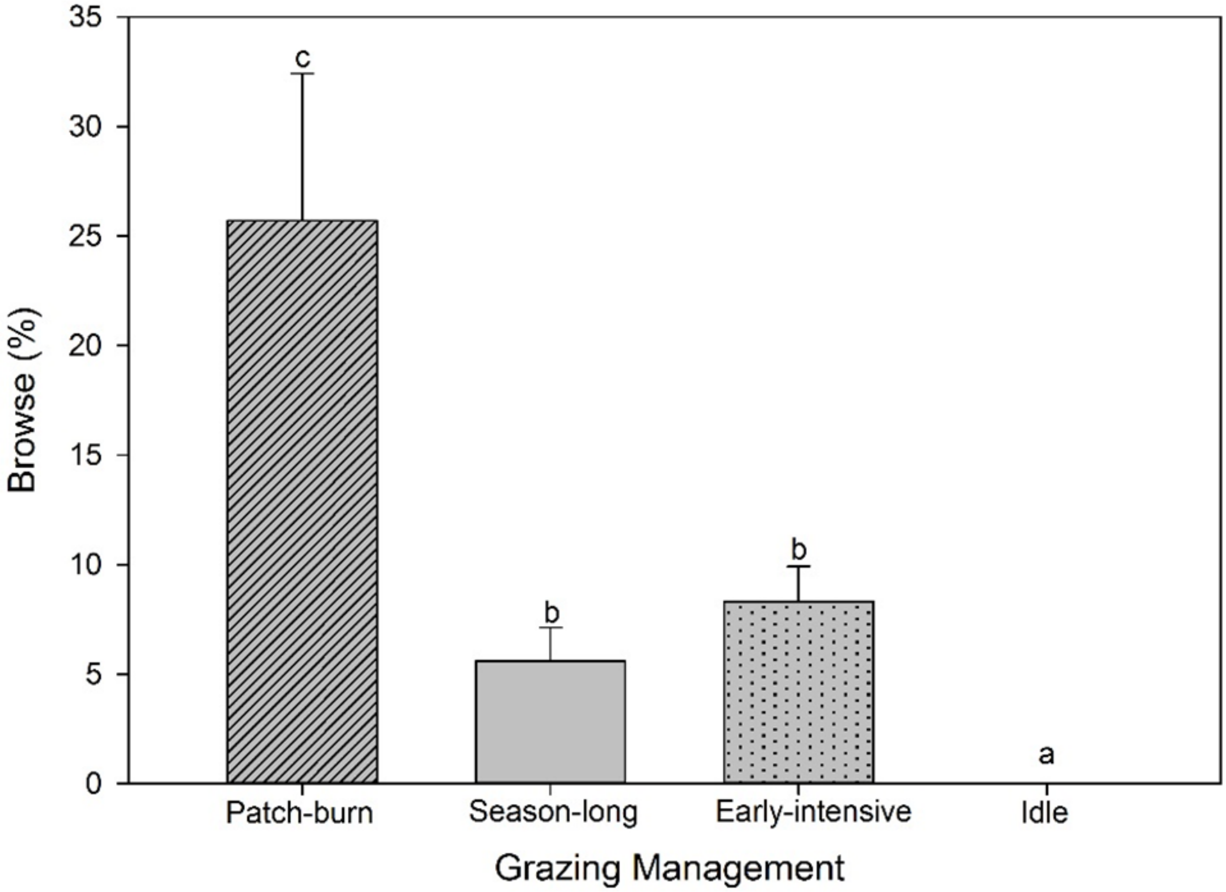

Figure 1.1. Percent western snowberry browsed by cattle in the patch-burn grazed, season-long grazed early-intensive grazed and idle pastures at the Central Grasslands Research and Extension Center near Streeter, ND, USA. Patch-burn graze management showed the highest percentage of western snowberry browsed. Standard error bars are included and treatments with similar letters are not different.

Crude protein (Figure 1.4) and ash (Figure 1.5A) content of western snowberry old growth was lower than new growth during the duration of the sampling period. The CP content of the 2017 post-burn regrowth was higher than 1-year post-burn and non-burn new growth from three through seven weeks post-burn. The ash content of 2017 post-burn regrowth (6.99 ± 0.23%) and 1-year post-burn new growth (6.44 ± 0.02%) were higher than non-burn new growth (5.74 ± 0.004%). Ca (Figure 1.5B) and P (Figure 1.5C) changed inversely of each other over time. The Ca content of western snowberry increased within all growth types and treatments. There was no consistent treatment differences, indicating a seasonal influence. The P content of western snowberry was different between old and new growth until 14 weeks post burn. The P content of the 2017 post-burn regrowth (0.6885 ± 0.0017%), 1-year post-burn new growth (0.2843 ± 0.0053%) and non-burn new growth (0.2489 ± 0.0020%) were different at three weeks post burn. The 2017 post-burn regrowth was higher in P content than 1-year post-burn regrowth and non-burn growth through six weeks post burn.

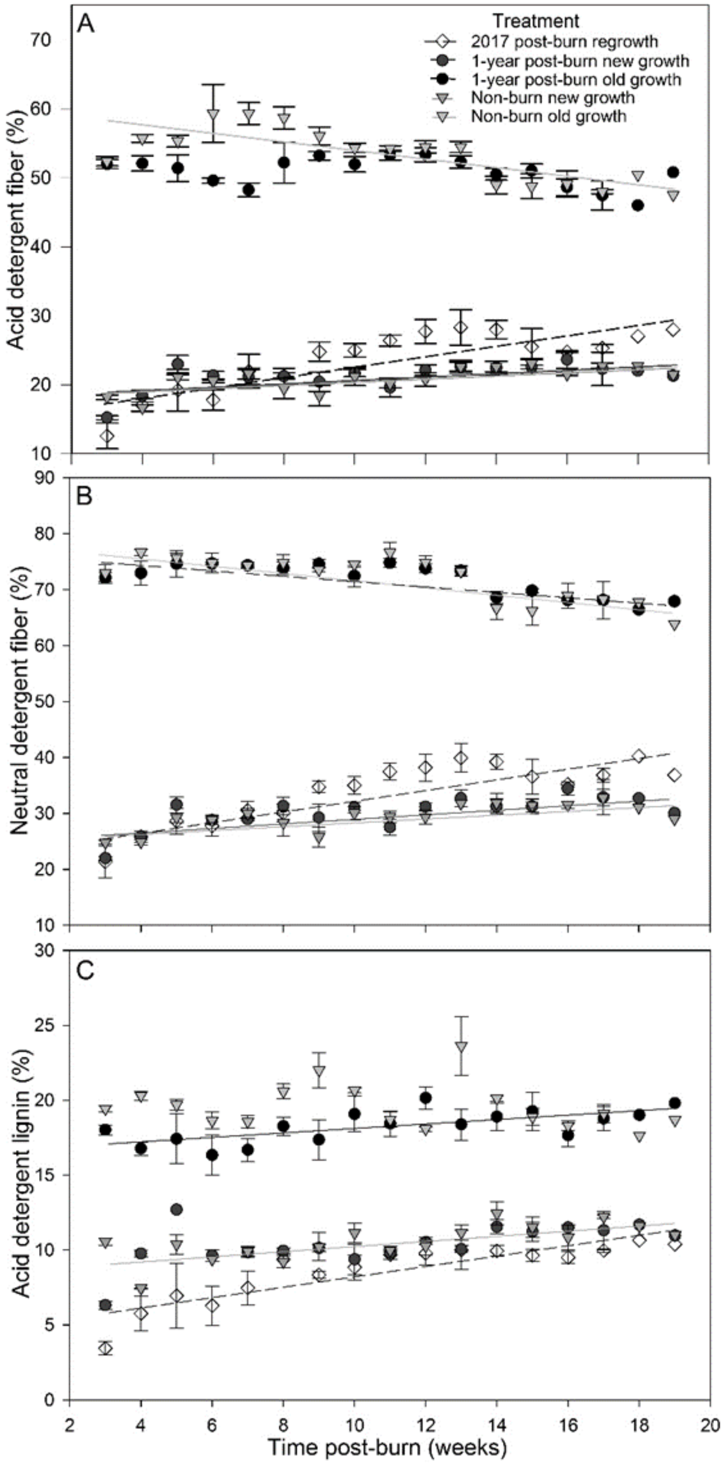

Figure 1.2. A) Acid detergent fiber, B) neutral detergent fiber, and C) acid detergent lignin content of western snowberry 2017 post-burn regrowth, 1-year post burn old and new growth, and non-burn old and new growth at the Central Grasslands Research and Extension Center near Streeter, ND, USA. All new growth samples were significantly lower in fiber and lignin content than old growth samples. Lines indicate a significant regression model. All graphs follow the legend presented on the ADF graph.

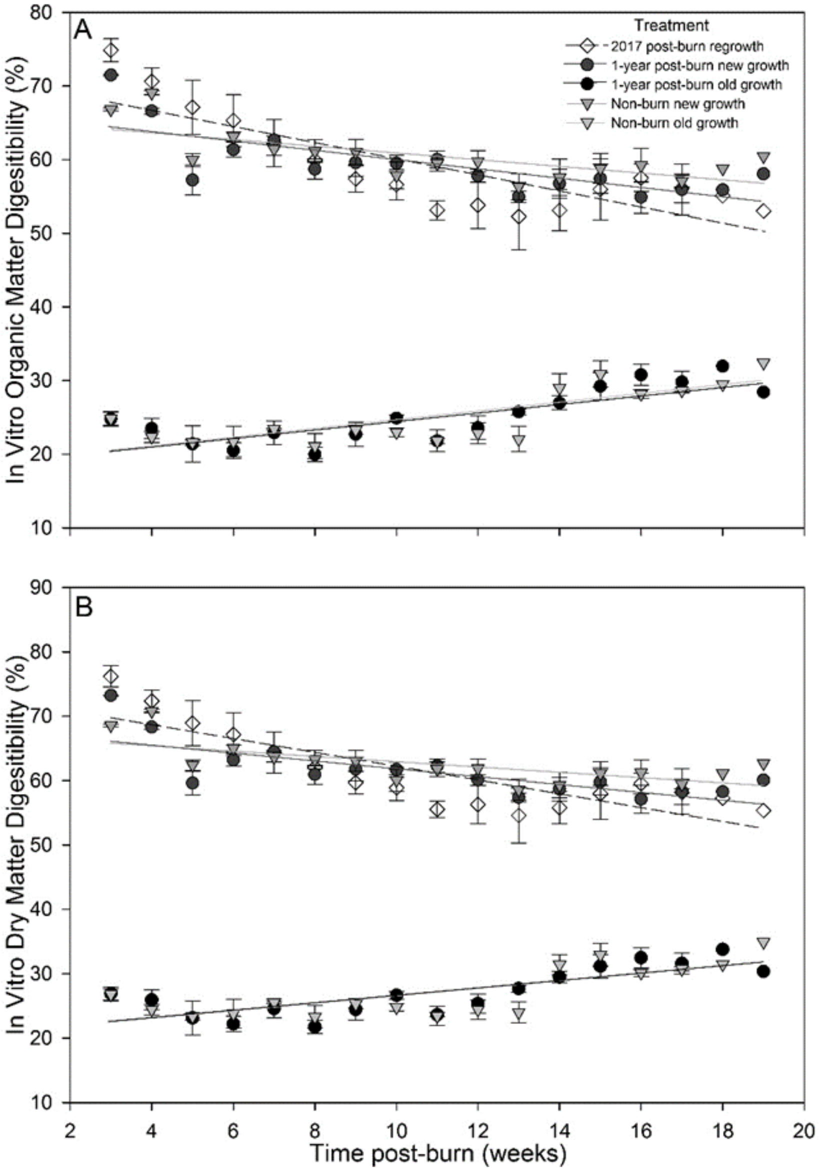

Figure 1.3. A) In vitro organic digestibility and B) in vitro dry matter digestibility of western snowberry 2017 post-burn regrowth, 1-year post burn old and new growth, and non-burn old and new growth at the Central Grasslands Research and Extension Center near Streeter, ND, USA. All new growth samples were higher in digestibility than old growth samples. Lines indicate a significant regression. All graphs follow the legend presented on the IVOMD graph.

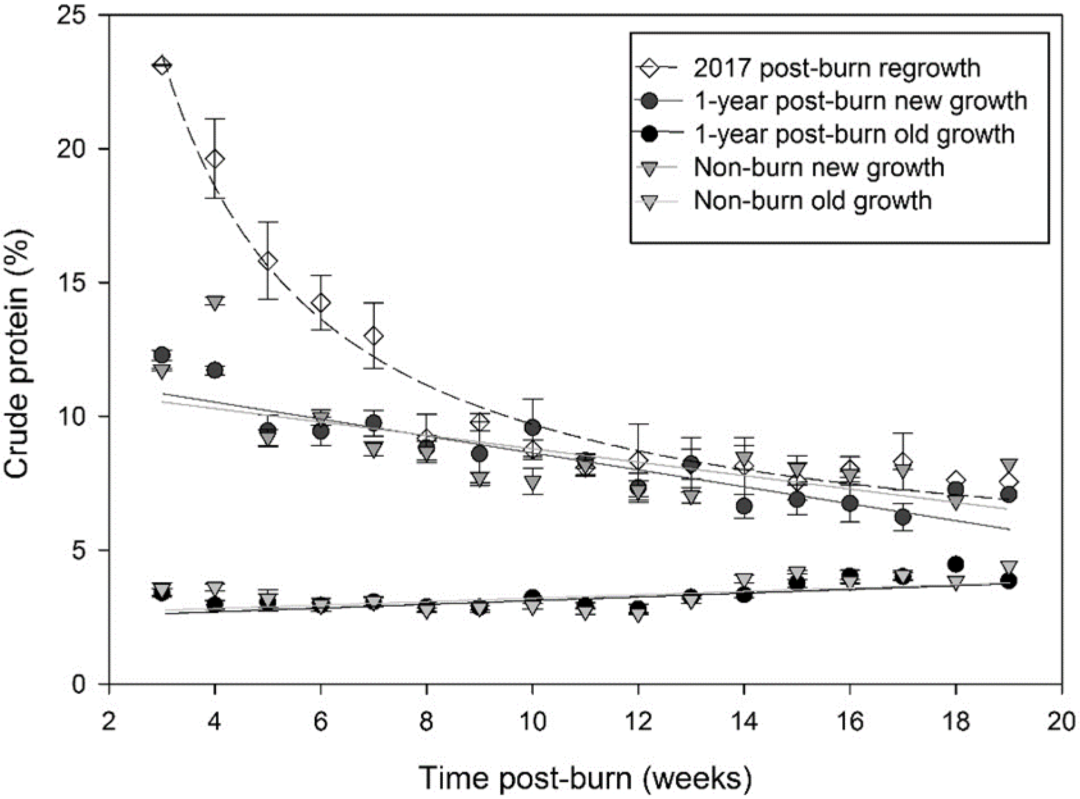

Figure 1.4. Crude protein (CP) of content of western snowberry 2017 post-burn regrowth, 1-year post burn old and new growth, and non-burn old and new growth at the Central Grasslands Research and Extension Center near Streeter, ND, USA. The 2017 post-burn regrowth CP content was higher than all other treatments through seven weeks post-burn. Lines indicate a significant regression.

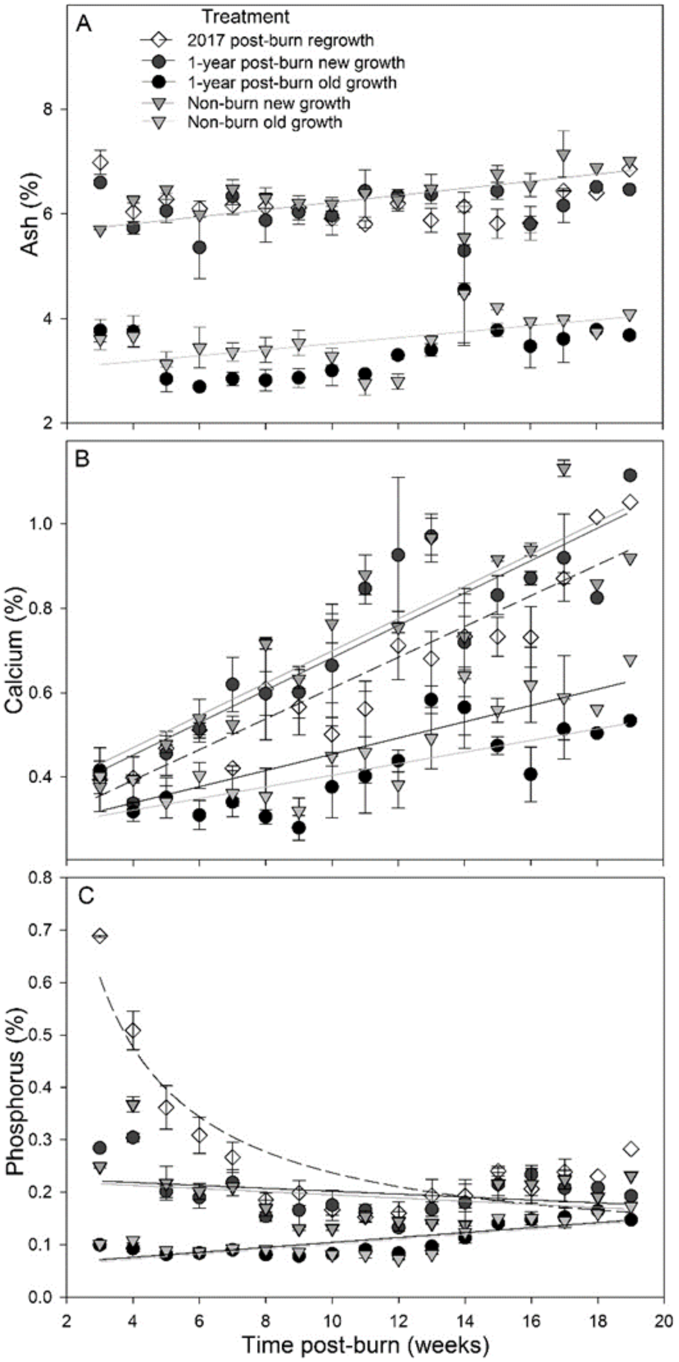

Figure 1.5. A) Ash, B) Ca, and C) P content of western snowberry 2017 post-burn regrowth, 1-year post burn old and new growth, and non-burn old and new growth at the Central Grasslands Research and Extension Center near Streeter, ND, USA. A) All new growth samples were significantly higher in ash content than old growth samples. B) Ca content increased with time for all samples and there was no consistent differences between treatments and growth types. C) P content of all new growth types were different at three weeks post burn, and 2017 post-burn regrowth remained higher until seven weeks post burn. New growth and old growth were different until 14 weeks post burn. Lines indicate a significant regression. All graphs follow the legend presented on the Ash graph.

Discussion

Woody encroachment in grassland ecosystems results in alterations of rangeland plant community composition and productivity (Pelton, 1953; Archer, 1989). In a Northern Great Plains ecosystem invaded by western snowberry, we compared percent shrub browsed by livestock under patch-burn grazed, season-long grazed, early-intensive grazed, and idle management. Our study revealed that browse of western snowberry in patch-burn grazed pastures was three and five times greater than in season-long and early-intensive grazed pastures, respectively. Fire removes mature plant material and debris, effectively resetting the growth cycle of vegetation, allowing new growth which is higher in palatability, digestibility, and nutrients (Plumb and Dodd, 1993; Seastedt and Knapp, 1993; Cooks et al., 1994; Anderson et al., 2007; Mbatha and Ward, 2010; Raynor et al., 2015). Our results and other research suggest that livestock prefer grazing in disturbed areas where vegetation is in early growth stages due to overall higher forage quality (Schindler et al., 2004; Cummings et al., 2007; Limb et al., 2010; Allred et al., 2011; Clark et al., 2016). Similar to other burning treated woody plant studies, we conclude that a combination of changes in nutrient composition and concentrated grazing in burned areas contributed to the higher percentage of western snowberry browsed in pastures under patch-burn graze management.

We found as western snowberry new growth matured, fiber and lignin content increased and digestibility decreased, regardless of treatment. Western snowberry new growth, including 2017 post-burn regrowth, averaged 30 and 40 percent lower ADF and NDF content than old growth. This is consistent with traditional herbaceous forages that when ADF and NDF concentrations rise, the proportion of digestible plant tissue is reduced (Buxton and Redfearn, 1997; Dufek et al., 2014). Additionally, our results followed similar trends to other shrub species in which ADF and NDF content was similar in leaves or new growth of burned and unburned shrubs (Schindler et al., 2004). ADL content of 2017 post-burn regrowth at three weeks post burn was 3.0% lower than 1-year post-burn and non-burn new growth, comparable to what has been seen for burned honey mesquite regrowth (Schindler et al., 2004). The lower ADL content of 2017 post-burn regrowth at three weeks post burn corresponds with 2017 post-burn regrowth IVOMD being higher than 1-year post-burn and non-burn new growth. Digestibility decreased for all new growth over the course of the sampling period, a consequence of increasing ADF, NDF, and ADL as the shrub matured and required more structural components. The difference in fiber content and digestibility between new growth and old growth gives reason to infer that new growth is more likely to be consumed than old growth. Patch-burning increased the chance of western snowberry growth being consumed because old growth, which is low in palatability and digestibility, had been removed from the plant structure, and the likelihood of livestock consuming any old growth was significantly reduced.

In a Northern Great Plains patch-burn system, western snowberry responded similar to common livestock forage species with increased crude protein content in regrowth after burning. 2017 post-burn regrowth crude protein was 23% at three weeks post-burn, declining to 9% by eight weeks post-burn, at which point it was not different than 1-year post-burn and non-burn new growth, and the rate of decrease slowed. This same pattern of high crude protein, rapid decline and leveling out approximately mid-way through the growing season has been seen for herbaceous vegetation as whole samples and other individual desirable and undesirable species following prescribed burning (Cook et al., 1994; Dufek et al., 2014; McGranahan et al., 2014; Powell et al., 2018). Young plants have a higher amount of crude protein available to grazing animals that decreases with maturity due to increasing fiber and lignin content (Hoffman et al., 1993; Buxton and Redfearn, 1997). Patch burning removed the grazing inhibition of western snowberry. Livestock returning to graze a disturbed area frequently following a burn can be contributed to the crude protein and mineral content of vegetation meeting the dietary needs for a longer period of time during the grazing season.

The average ash and total mineral content of western snowberry new growth was 6.2% for the duration of the sampling period. This is comparable to average ash content of legume and grass forages at 7.0%, but can vary greatly by species and location (Mayland and Sneva, 1983; Platače and Adamovičs, 2014; Hejcman et al., 2016). Calcium and phosphorus, endogenous macro minerals, content in western snowberry changed inversely as time progressed, a common trend in most plant species (Sinclair et al., 2006). Calcium content of all growth increased with maturity, following the same pattern as highly utilized herbaceous vegetation (Sinclair et al., 2006). During the 2017 post-burn regrowth phosphorus levels followed a similar pattern as crude protein, in which there was initially a drastic increase, followed by a rapid decline until eight weeks post-burn, at which point the rate of decline slowed and not different between new growth treatments. Forage mineral content is important to understand to determine if additional supplementation is need to meet minimal animal dietary requirements.

Management Implications

Fire presence in a woody encroached ecosystem is necessary to preserve native species, stability, function and productivity of rangelands (Van Auken, 2009). Woody species are generally not a large proportion of cattle diets and can disrupt grazing distribution and forage accessibility. Prescribed burning temporarily eliminates the canopy of woody species colonies and removes debris, allowing for regrowth vegetation that is higher in palatability, digestibility, and nutrient quality. Furthermore, patch-burning can increase the consumption of less palatable species by changing herbivore selection from plant specific to area specific, promoting grazing of all immature vegetation (Cummings et al., 2007; Allred et al., 2011; Dufeck et al., 2014; Powell et al., 2018). Forage quality is dependent upon phenological stage; therefore, disrupting the growth cycle of western snowberry, allowing it to become a species of nutritional importance to the herbivore if consumed. The results of our study and others (Cummings et al., 2007; Dufek et al., 2014) indicate that consumption of undesirable and nuisance species by livestock can be promoted by implementing prescribed burning into pasture management practices and potentially serves as a control method. This study can provide preliminary information for additional research on the long term effects of fire-grazing interactions on western snowberry persistence and its dietary importance when consumed.

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CHAPTER 2: IMPACTS OF PRESCRIBED FIRE ON INVADED NORTHERN TALLGRASS PRAIRIE PLANT COMMUNITIES

Abstract

Non-native invasive plant species have led to changes in plant community composition by displacing native species, ultimately decreasing species richness and diversity. Kentucky bluegrass (*Poa pratensis*), a non-native grass, has invaded a majority of rangelands within the Northern Great Plains. Prescribed fire can potentially reduce Kentucky bluegrass and increase native grass and forb richness and diversity in the tallgrass prairie. Our objectives were to investigate the effects of burn season and frequency on Kentucky bluegrass and native plant community dynamics. We conducted this study in a non-grazed pasture within the tallgrass prairie of the Sheyenne National Grassland in southeastern North Dakota, USA. To assess effects of burn season on plant community composition and Kentucky bluegrass suppression, we burned 3 ha plots at mid-growing season and dormant season, and compared to a non-burned control, each replicated six times. To assess the effect of burning frequency on plant community composition and Kentucky bluegrass suppression, three mid-growing season plots were burned a second time the following year. Prior to the initial burn, species composition, abundance, litter and bare ground were recorded within 30 random 1-m^2 frames within each replicate using a modified Daubenmire cover-class method. Post-fire composition and abundance were recorded at mid-summer for three growing seasons. Standing biomass was collected within each replicate using 12 randomly distributed 0.25-m^2 frames clipped to ground level and oven dried at 105°C until constant weight was achieved. We used nonmetric multidimensional scaling to compare plant community composition of treatments. Kentucky bluegrass was affected by yearly precipitation and burning, with relative cover decreasing two years after summer fire. Native

grasses and forbs had a positive response to prescribe burning. Restoring fire to native prairie appears to be a viable option to reduce exotic species while promoting natives, but the need for follow up management is evident.

Introduction

Biological invasions occur when non-native species are introduced to a new ecosystem where they establish and spread (Mack et al., 2000; Andersen et al., 2004). Some non-native species such as cattle, cereal grains, and soybeans are considered non-threatening because of the economic benefit they bring (Westbrook 1998), but many have aided in the arrival of parasites, pests, and other diseases once unknown to the new region of colonization (Nunn & Qian 2010). (Nunn and Qian, 2010). Exotic species that result in major economic damage and ecosystem degradation, such as losses in biodiversity and function are invasive (Mack et al., 2000; Anderson et al., 2004). Anthropogenic disturbance, such as land fragmentation due to urbanization and cultivation, and improper rangeland management, disrupts natural ecosystem function and aids in the establishment of invasive plant species (Cully et al., 2003; Sinkins and Otfinowski, 2012). Non-native plant species have resulted in the most economic and ecological damage in terms of land quality degradation. Establishment of invasive plant species consequently leads to lower crop production, increased herbicide use, decreased forage quantity and quality, lower diversity and richness, and degraded wildlife habitats (Grant et al., 2009).

The North American Great Plains, predominately a grassland region used for grazing (Barker and Whiteman, 1988), is considered one of the most endangered ecosystems, as many native plant and animal species populations continue to decline due to rising invasive species populations (Samson and Knopf, 1994; DeKeyser et al., 2015). In this region, invasive plant species establish, reproduce, and spread easily due to the lack of natural competitors and disturbance, such as fire (Westbrook 1998). The historic fire return interval for the Northern Great Plains was three to ten years, but much of the region remains unburned since European settlement (Scholes and Archer, 1997; Allen and Palmer, 2011). Exotic species are generally not adapted to the effects of fire, and have been shown to decrease in abundance following fire; whereas native species readily recover after the disturbance (Zedler and Loucks, 1969; Smith and Knapp, 1999). The North American Great Plains is infested with a range of invasive plants including; leafy spurge (*Euphorbia esula),* smooth brome grass (*Bromus inermis),* and Kentucky bluegrass (*Poa pratensis)* (DeKeyser et al., 2013; Toledo et al., 2014).

Kentucky bluegrass is a perennial cool-season grass that has altered many native plant communities due to inhibitive and competitive characteristics (Miles and Knops, 2009; Toledo et al., 2014). Low photosynthetic needs and the ability to have a high rate of tillering gives Kentucky bluegrass an early growth and reproductive advantage over native species. A dense thatch or litter layer forms as Kentucky bluegrass spreads, which consequently alters sunlight and water infiltration to the soil surface (Murray and Juska, 1977; Taylor et al., 1982; Bosy and Reader, 1995; Toledo et al., 2014). This accumulated thatch can also eliminate light and reduce air temperature cues, creating an unsuitable environment for seed germination and act as a barrier to seedling emergence (Bosy and Reader, 1995). Kentucky bluegrass forage nutritional quality is high early in the growing season, but nutritive value decreases greatly by early summer season due to rapid maturation (Hockensmith et al., 1997). Therefore, Kentucky bluegrass within pastures many be beneficial for early grazing, but if left unmanaged, native species will be lost and herbaceous productivity and quality on rangelands will be greatly reduced.

Reducing Kentucky bluegrass dominance in the Northern Great Plains is important for ecological and economic services. This invasive grass affects livestock production, wildlife habitat, soil nitrogen cycling, and plant community composition of rangelands (Printz and Hendrickson, 2015). Common methods of control include herbicide, grazing, mechanical, and fire. Grazing and mechanical methods used solely have had poor results as a reduction method because of the promotion of tillering. Grazing has been shown to be an effective tool at reducing the thatch layer and standing dead material due to trampling (Murray and Juska, 1977; Lacey and Sheley, 1996; Sinkins and Otfinowski, 2012). The use of herbicide alone and herbicide combined with fire has been shown successful at reducing Kentucky bluegrass cover. Herbicides are often cost prohibitive and can potential harm and reduce native plant species unintentionally (Bahm et al., 2011; Adkins and Barnes, 2013). Fire has been utilized as a natural control method for suppressing Kentucky bluegrass. Fire removes the thatch layer created by Kentucky bluegrass and lowers its competitive advantage by allowing sunlight and water to reach the soil surface, triggering germination of native species seeds from the seedbank. Dead plant material ties up nutrients, so burning allows for a fast rate of decomposition and quicker release of nutrient that can be utilized by immature emerging shoots (Curtis and Partch, 1948). The season and frequency at which a fire occurs may affect native species abundance and composition, as well as Kentucky bluegrass cover (Towne and Kemp, 2008).

Season of fire, thus timing of prescribed burn, impacts cool-season (C3) and warm-season (C4) plants differently because of growth physiology and season of growth (Towne and Owensby, 1984; Towne and Kemp, 2008). Spring fires interrupts the early growing season of C3 plants and can stimulate earlier growth of C4 species, due to exposed soil warming sooner. Summer fires allow for ample C4 plant regrowth and limited C3 plant regrowth because of depleted nutrient and energy stores. By mid to late summer, most C3 plants have reached maturity and will not have substantial regrowth following a burn. This decreases species competition which allows for more nutrient uptake and space occupation by C4 plants before the dormant season. Spring and summer fires have been shown effective at reducing Kentucky bluegrass (C3) and increasing native C4 species (Towne and Owensby, 1984; Towne and Kemp, 2008). Summer fires have greatest benefit to forbs and increase species richness and diversity (Towne and Kemp, 2008). Fall or dormant season fire affects vegetation composition and has resulted in decreased Kentucky bluegrass cover. The spring following a dormant season burn, soil temperatures increase more rapidly, allowing for early warming of the soil and stimulating C4 species growth. Increasing fire frequency by reducing the fire return interval has shown to inhibit Kentucky bluegrass expansion at a greater rate than a single burn (Li et al., 2013; Printz and Hendrickson 2015). Bringing fire back into the Northern Great Plains ecosystem has the potential to reduce invasive Kentucky bluegrass and positively influence native grass and forb composition in the tallgrass prairie.

Research has been conducted analyzing the effects of fire on plant community composition in ungrazed tallgrass prairie regions (Seastedt et al., 1991; Towne and Kemp, 2008), but the number of available studies is limited. We propose to reevaluate the effects of season of burn on vegetation composition and Kentucky bluegrass in tallgrass prairie by implementing a growing and dormant season burn. Fire frequency will be assessed to determine if burning multiple years at a given season has a greater effect on plant community and Kentucky bluegrass cover. Conducting similar research in a tallgrass prairie will aid in confirming results of other studies and define any variation in our study from previous studies. Therefore, our objectives are to 1) investigate season of fire on northern tallgrass prairie plant community dynamics and 2) determine if season of fire and fire frequency influences Kentucky bluegrass cover. Based on the life cycles of C4 and C3 functional groups, and previous research (Li et al., 2013), we hypothesize that both seasons of burning will reduce Kentucky bluegrass cover and summer fires will favor native plant species and increased fire frequency will further reduce Kentucky bluegrass cover.

Methods

Site Description

This study was conducted on the USDA, Forest Service Sheyenne National Grassland, located in southeastern North Dakota, about 24 kilometers southwest of Kindred, in Richland County (97°7’ W, 46°31’ N). The Sheyenne National Grassland encompasses 28,400 ha of land comprised primarily of rangelands and pasture land. The study location was on the Viking Prairie unit, a 65 ha partial of native tallgrass prairie that is ungrazed and composed of sandy soils. The dominant native prairie grasses were little bluestem (*Schizachyrium scoparium*), big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), and Indiangrass (*Sorghastrum nutans*). The dominant native forbs included goldenrods (*Solidago spp.*), western snowberry (*Symphoricarpos occidentalis Hook.*), and sages (*Artemisia spp.*),. Wetland vegetation included sedges (*Cyperaceae spp.*), northern reedgrass (*Calamogrostis stricta*), and asters (*Symphyotrichum spp.*). Kentucky bluegrass (*Poa pratensis*) and sweet clover (*Melilotus officinalis*), both abundant exotic species. Plant nomenclature and descriptions follow the national plants data base (USDA, 2017).

Climate in the area is continental with the winter months of December, January, and February have an average temperature of -10^{o} C and 16mm of average precipitation per month. The 30 year average temperatures during the growing season are 14^{o} C in May, 19^{o} C in June, 22^{o} C in July and 21^{o} C in August. Average precipitation during the growing season is 71 mm in May, 98 mm in June, 89 mm in July, and 54 mm in August. Weather data is based on the monthly normal from North Dakota Agricultural Weather Network (NDAWN, 2018).

Experimental Design

To assess the effect season and frequency of fire has on tallgrass prairie plant community dynamics, prescribed burns were conducted in 2014 and 2016 at mid-growing season (August) and in 2014 at dormant season (October). Three hectare plots were designated for each burn treatment and a non-burn control. Treatments are referred to as summer once (burned in 2014), summer twice (burned in 2014 and 2017), fall (burned in 2014), and control (non-burn). Treatments were replicated three times, with replicates of each burn treatment being by each other, allowing for one continuous burn for each treatment.

Data Collection

Species composition and abundance, and litter and bare ground were determined by collection data within 30 randomly distributed 1 x 1-m frames using a modified Daubenmire cover-class method, prior to the burn treatments in 2014 and 2016 (Daubenmire, 1959). Cover classes were 0-1, 1-2, 2-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, 90-95, 95-98, 98-99, and 99-100%. Productivity was evaluated by collecting standing biomass within each replicate using 12 randomly distributed 0.5 X 0.5-m frames clipped to ground level and oven dried at 105°C to constant weight. Post-fire data was recorded in the same manner at mid-summer for three growing seasons within the different burn season replicates, and for one growing season following each burn within the fire frequency replicates.

Statistical Analysis

Plant community species richness, evenness, Shannon’s diversity, and Simpson’s diversity were analyzed with ANOVA procedures using IBM® SPSS Statistics 24 to determine differences between treatments within each year. Plant community dissimilarity was determined using the Sorenson dissimilarity index and summer once, summer twice, and fall treatment dissimilarity with control was compared using previous ANOVA procedures. Average canopy cover of each plant species was calculated to the mid-point within each treatment replicate. We used PC-ORD^{TM} 6 software for Nonmetric Multidimensional Scaling (NMS) and PerMANOVA using Sorensen Distance to compare plant community composition for year, treatment, and year X treatment interaction. Kentucky bluegrass absolute and relative cover, standing dead canopy, basal litter and bare ground cover of each treatment with in year was compared using the previously stated ANOVA procedures. Results were considered significant at $p \leq 0.05$.

Results

We recorded a total of 139 plant species throughout the study across summer once, summer twice, fall, and control treatments. Richness (Figure 2.1A) was different between fall (35 ± 3.46) and summer once (43 ± 2.65) treatment areas in 2014, and the summer once (57.33 ± 5.51) and twice (62 ± 3.61) treatment replicates were different than the control (37.67 ± 5.86) in 2017. There was no difference in species evenness (Figure 2.1B) across treatments within each year of study. Shannon's diversity index (Figure 2.1C) of summer once was higher than all other treatments in 2014, and there was no difference between summer treatments and fall treatment was different than summer twice in 2017. Simpson's diversity index (Figure 2.1D) of summer once and fall treatment areas was different in 2014, and there were no difference across treatments post burning. There was no difference between dissimilarity (Figure 2.2) of each treatment with control compared within each year.

NMS analysis showed a two-dimensional solution with a final stress of 10.137. Axis one accounted for 62.2% and axis two for 30.2% of the cumulative variability of 92.4%. Plant species with strong positive or negative correlation to axis 1 (Table 2.1) were influenced by year effects like biological lifecycle, time since fire, and precipitation. Plant species with a negative correlation to axis 2 (Table 2.2) indicated a resilient and positive response to burning. NMS ordination for year (Figure 2.3) shows that plant community composition varied yearly as plots do not overlap. NMS ordination of year by treatment (Figure 2.4) revealed fall and control treatments had a more positive correlation with axis 2, meaning that plant community was not shifted as greatly due to fire. PerMANOVA results indicated a year x treatment interaction ($p= 0.0196$) and treatment effect following the 2014 prescribed burns, plus a year ($p= 0.0002$) effect over the four years of study. Following the 2014 prescribed fire, summer and fall burn treatments were not different and fall was not different than control areas. Increasing fire frequency made no difference between summer burn once and summer burn twice treatment areas following the 2016 prescribed fire. Plant community composition of summer once, summer twice, fall, and control treatment areas were different from each other each year.

Kentucky bluegrass was present in all treatment areas, but had strong positive correlation with axis 2 (0.756), meaning that its response following burn treatments was poor. Kentucky bluegrass had a negative correlation (-0.538) with axis 1, potentially due to low early season precipitation (Figure 2.5) in 2015 and 2016. Kentucky bluegrass absolute (Figure 2.6A) canopy cover was not different between treatments within each year. Absolute canopy cover across all treatments within each year indicated no difference in Kentucky bluegrass. Relative cover (Figure 2.6B) of Kentucky bluegrass was different between summer once (9.38% ± 0.098) and control (18.11% ± 2.42) treatment areas in 2014. In 2016 there was a difference in relative cover between summer once (2.48% ± 0.37) and summer twice (2.88% ± 0.26) treatments. There was a reduction in both absolute and relative cover of Kentucky bluegrass in all treatments from 2015 to 2017. White sweet clover had a strong positive correlation with axis 1 (0.458) and was present in all treatment areas in 2015, 2016, and 2017. There was absolute cover (Figure 2.6C) within summer twice treatment was higher than all other treatments and relative cover (Figure 2.6D) of summer twice was different than the control in 2017.

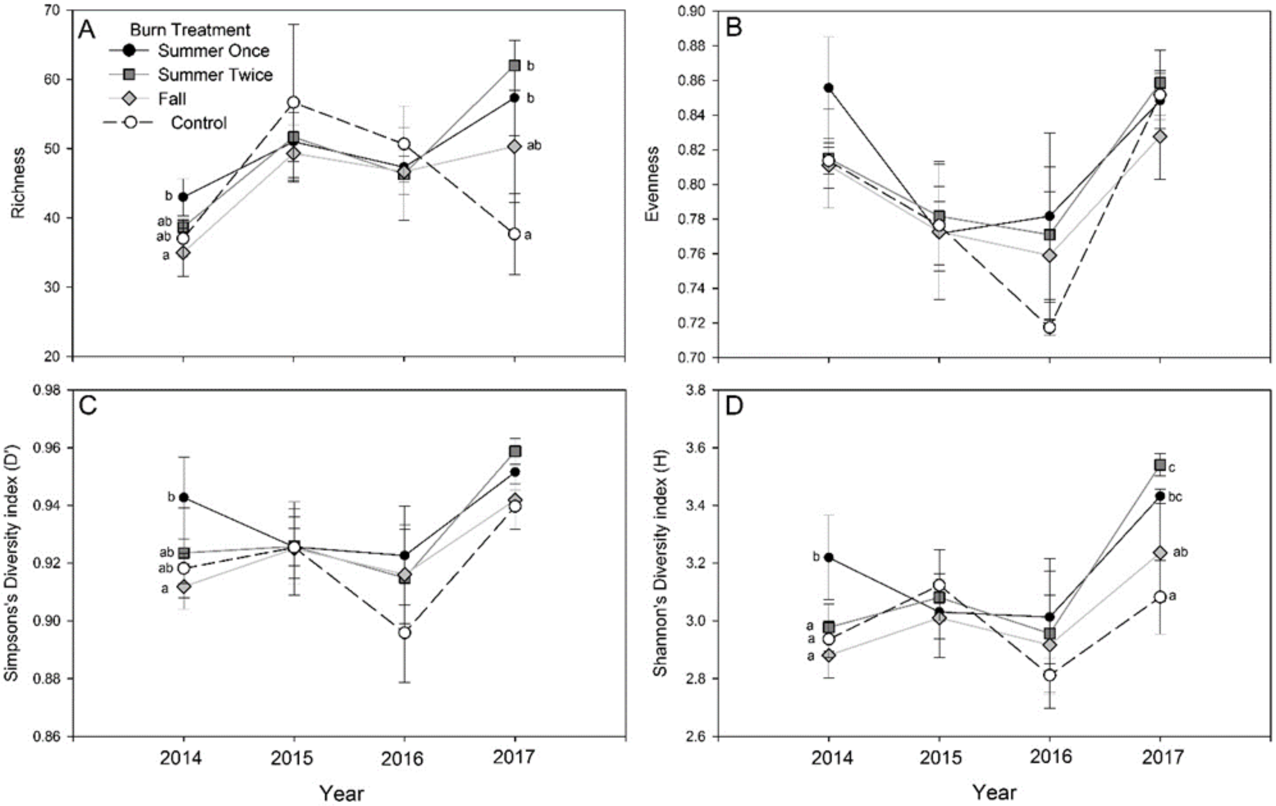

Figure 2.1. Plant community *A)* richness, *B)* evenness, *C)* Shannon’s Diversity index, *D)* Simpson’s Diversity index. All 2014 data was taken pre-burn and prescribed burns were conducted in 2014 for all treatments. The second mid-growing season burn for summer twice treatment occurred in 2016. Like or no letters indicate no significant difference between treatments within year. Data collected at the Viking Prairie unit of the Sheyenne National Grassland in ND, USA.

2014 pre-burn data indicated basal litter (Figure 2.7A) ground cover of summer once (75.70 ± 1.13%) was lower than fall (79.0 ± 0.38%) treatment areas. Burning reduced basal litter ground cover of all burn treatments compared to the control in 2015 and fall (6.3 ± 2.81%) was lower than summer once (18.68 ± 0.94%). Basal litter ground cover of all burn treatments remained lower than the control in 2016. 2017 basal litter ground cover of summer twice was lower than all other treatments following the second prescribed burn. Bare ground cover (Figure 2.7B) responded to burning inversely of basal litter ground cover. There was no difference between treatment areas in 2014 and all burn treatments had higher bare ground cover than the control in 2015. There was no difference between treatments in 2016 and bare ground cover of summer twice was greater than all other treatments in 2017 following the second prescribed burn. Standing dead (Figure 2.7C) canopy cover of summer once was higher than all other treatment areas in 2014. Burning reduced standing dead cover in all burn treatments compared to the control. Standing dead was not different between treatments in 2016 or in 2017 following the second prescribed burn. Productivity, measured by standing biomass (Figure 2.7D) was not different between treatments in 2014, 2015, or 2016. Standing biomass in 2017 of summer twice treatment was higher than all other treatments. Overall, prescribed burning did not influence productivity.

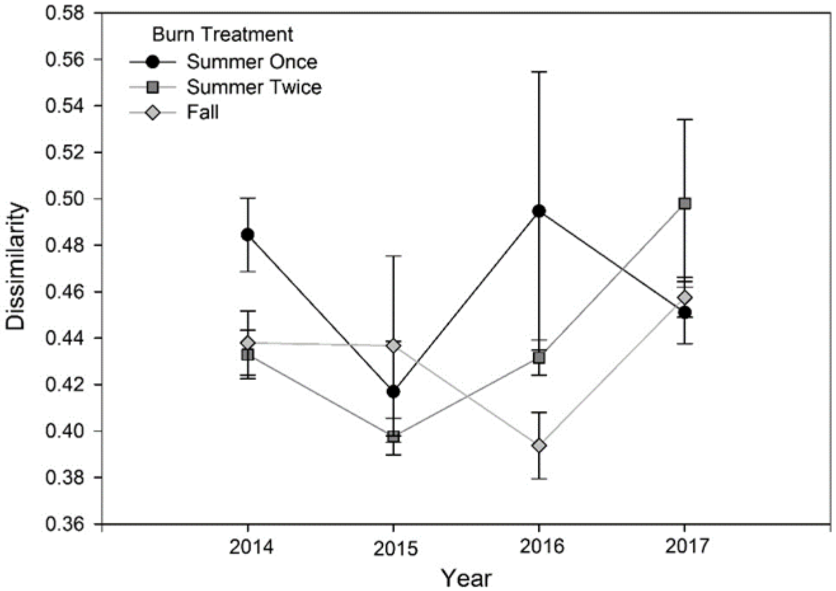

Figure 2.2. Dissimilarity of each treatment with the control. There was no difference between treatment dissimilarity with the control within each year. All 2014 data was taken pre-burn and prescribed burns were conducted in 2014 for all treatments. The second mid-growing season burn for summer twice treatment occurred in 2016. There was no significant difference between treatments within year. Data collected at the Viking Prairie unit of the Sheyenne National Grassland in ND, USA.

Table 2.1. Plant species with the greatest positive and negative correlations to axis 1. These species were influenced by on a year basis due to climate variation, like precipitation, life-cycle, and time since fire. Species identified at Viking Prairie unit of the Sheyenne National Grasslands, ND, USA.

Abbreviation	*Scientific name*	*Common name*	*Life-form**	*Life-cycle***	*Native/ Invasive*	*Indicator †*	*r*
MelAlb	*Melilotus alba*	White sweet clover	F	B	Invasive	UPL	0.458
AgrRep	*Agropyron repens*	Quack grass	G	P	Invasive	UPL	0.365
StaPal	*Stachys palustris*	Marsh hedge nettle	F	P	Native	UPL	0.357
PycTen	*Pycnanthemum tenuifolium*	Slender mountain mint	F	P	Native	FAC	0.306
VioNep	*Viola nephrophylla*	Northern bog violet	F	P	Native	FACW	0.306
CalPal	*Caltha palustris*	Marsh marigold	F	P	Native	OBL	0.290
GenAnd	*Gentiana andrewsii*	Bottle Gentian	F	P	Native	FAC	0.252
OenBie	*Oenothera biennis*	Common evening primrose	F	B	Native	FACU	0.250
AliTri	*Alisma triviale*	Northern water plantain	F	P	Native	OBL	0.247
SymEri	*Symphyotrichum ericoides*	Heath aster	F	P	Native	FACU	-0.513
VioPed	*Viola pedatifida*	Crow-foot violet	F	P	Native	FACU	-0.528
BroIne	*Bromus inermis*	Smooth brome	G	P	Invasive	UPL	-0.530
PoaPra	*Poa pratensis*	Kentucky bluegrass	G	P	Invasive	FACU	-0.538
SchSco	*Schizachyrium scoparium*	Little bluestem	G	P	Native	FACU	-0.548
FraVir	*Fragaria virginiana*	Wild strawberry	F	P	Native	FACU	-0.568
EriStr	*Erigeron strigosus*	Daisy fleabane	F	P	Native	FACU	-0.588
AmoCan	*Amorpha canescens*	Lead plant	S	P	Native	UPL	-0.599
DicWil	*Dichanthelium wilcoxianum*	Wilcox's Panic Grass	G	P	Native	UPL	-0.602
ZizApt	*Zizia aptera*	Heart-leaved Alexanders	F	P	Native	FAC	-0.609
SymOcc	*Symphoricarpos occidentalis*	Western snowberry	S	P	Native	UPL	-0.611
AmbArt	*Ambrosia artemisiifolia*	Annual ragweed	F	A	Native	FACU	-0.630
DalCan	*Dalea candida*	White prairie clover	F	P	Native	UPL	-0.677
AndGer	*Andropogon gerardii*	Big bluestem	G	P	Native	FACU	-0.716
RosArk	*Rosa arkansana*	Prairie rose	S	P	Native	FACU	-0.733

*Life-form: F=Forb, G=Graminoid, S=Shrub, T=Tree

**Life-cycle: A=Annual, B=Biennial, P=Perennial

†Great Plains Wetland Plant Indicator: UPL=Upland, FAC=Facultative, FACU=Facultative upland, OBL=Obligate, FACW=Facultative wetland (Lichvar et al., 2016)

Table 2.2. Plant species with the greatest positive and negative correlations to axis 2. These species were influenced by burn treatment. The more negative a correlation, the more cover response following burning. Species identified at Viking Prairie unit of the Sheyenne National Grasslands, ND, USA.

Abbreviation	*Scientific name*	*Common name*	*Life-form**	*Life-cycle***	*Native/ Invasive*	*Indicator †*	*r*
PoaPra	*Poa pratensis*	Kentucky bluegrass	G	P	Invasive	FACU	0.756
HesCom	*Hesperostipa comata*	Needle-and-thread	G	P	Native	UPL	0.711
SorNut	*Sorghastrum nutans*	Indiangrass	G	P	Native	FACU	0.662
PanVir	*Panicum virgatum*	Switchgrass	G	P	Native	FAC	0.659
PoaSec	*Poa secunda*	Sandberg bluegrass	G	P	Native	FACU	0.636
VioPed	*Viola nephrophylla*	Northern bog violet	F	P	Native	FACW	0.564
LotPur	*Lotus purshianus*	Prairie Bird's-foot Trefoil	F	A	Native	UPL	0.527
PasSmi	*Pascopyrum smithii*	Western wheatgrass	G	P	Native	FACU	0.516
Salix spp.	*Salix spp.*	Willow	S/T		Both		0.506
SpaPec	*Spartina pectinata*	Prairie cordgrass	G	P	Native	FACW	0.489
SymEri	*Symphyotrichum ericoides*	Heath aster	F	P	Native	FACU	-0.500
LiaPyc	*Liatris pycnostachya*	Prairie blazingstar	F	P	Native	FAC	-0.502
KoeMac	*Koeleria macrantha*	Prairie Junegrass	G	P	Native	UPL	-0.550
PhyVir	*Physalis virginiana*	Lance-leaved ground cherry	F	P	Native	UPL	-0.551
ApoCan	*Apocynum cannabinum*	Prairie dogbane	F	P	Native	FAC	-0.567
ZizApt	*Zizia aptera*	Heart-leaved Alexanders	F	P	Native	FAC	-0.571
AneCyl	*Anemone cylindrica*	Thimbleweed	F	P	Native	UPL	-0.578
SolMis	*Solidago missouriensis*	Missouri goldenrod	F	P	Native	UPL	-0.586
GalBor	*Galium boreale*	Northern bedstraw	F	P	Native	FACU	-0.611
LitCan	*Lithospermum canescens*	Hoary puccoon	F	P	Native	UPL	-0.632
SymLan	*Symphyotrichum lanceolatum*	White panicle aster	F	P	Native	FACW	-0.664
SolRig	*Solidago rigida*	Stiff goldenrod	F	P	Native	UPL	-0.678
PedCan	*Pedicularis canadensis*	Woody betony	F	P	Native	FACU	-0.712
EupEsu	*Euphorbia esula*	Leafy spruge	F	P	Invasive	UPL	-0.734

*Life-form: F=Forb, G=Graminoid, S=Shrub, T=Tree
**Life-cycle: A=Annual, B=Biennial, P=Perennial
†Great Plains Wetland Plant Indicator: UPL=Upland, FAC=Facultative, FACU=Facultative upland, OBL=Obligate, FACW=Facultative wetland (Lichvar et al., 2016)

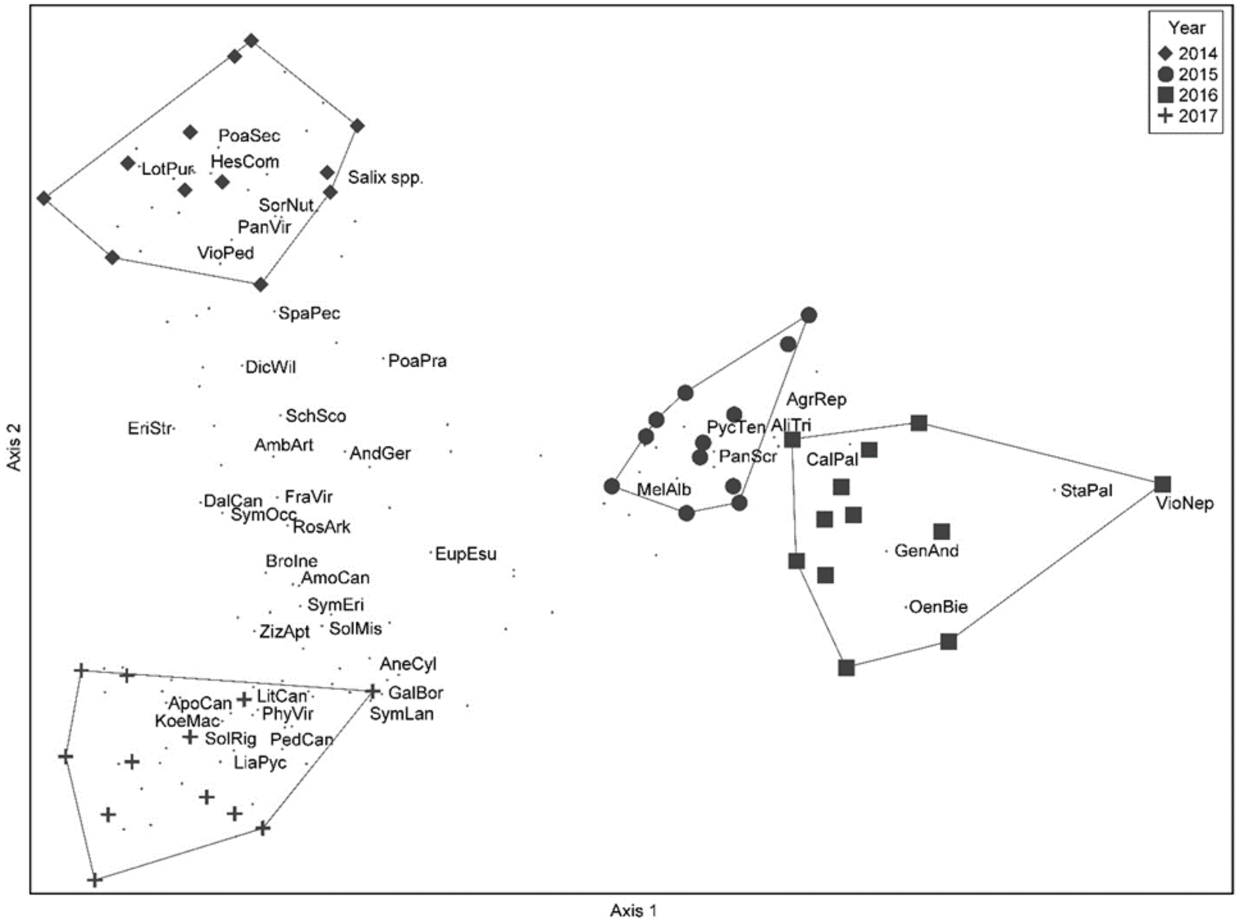

Figure 2.3. Non-metric multidimensional scaling (MMS) ordination of axis 1 and 2 with regards to year and vegetation composition. Year is indicated by marker shape, and individual treatment replications are labeled on the graphic. Individual plant species are specified by a point. All 2014 data was taken pre-burn and prescribed burns were conducted in 2014 for all treatments. The second mid-growing season burn for summer twice treatment occurred in 2016. Data collected at the Viking Prairie unit of the Sheyenne National Grasslands in ND, USA.

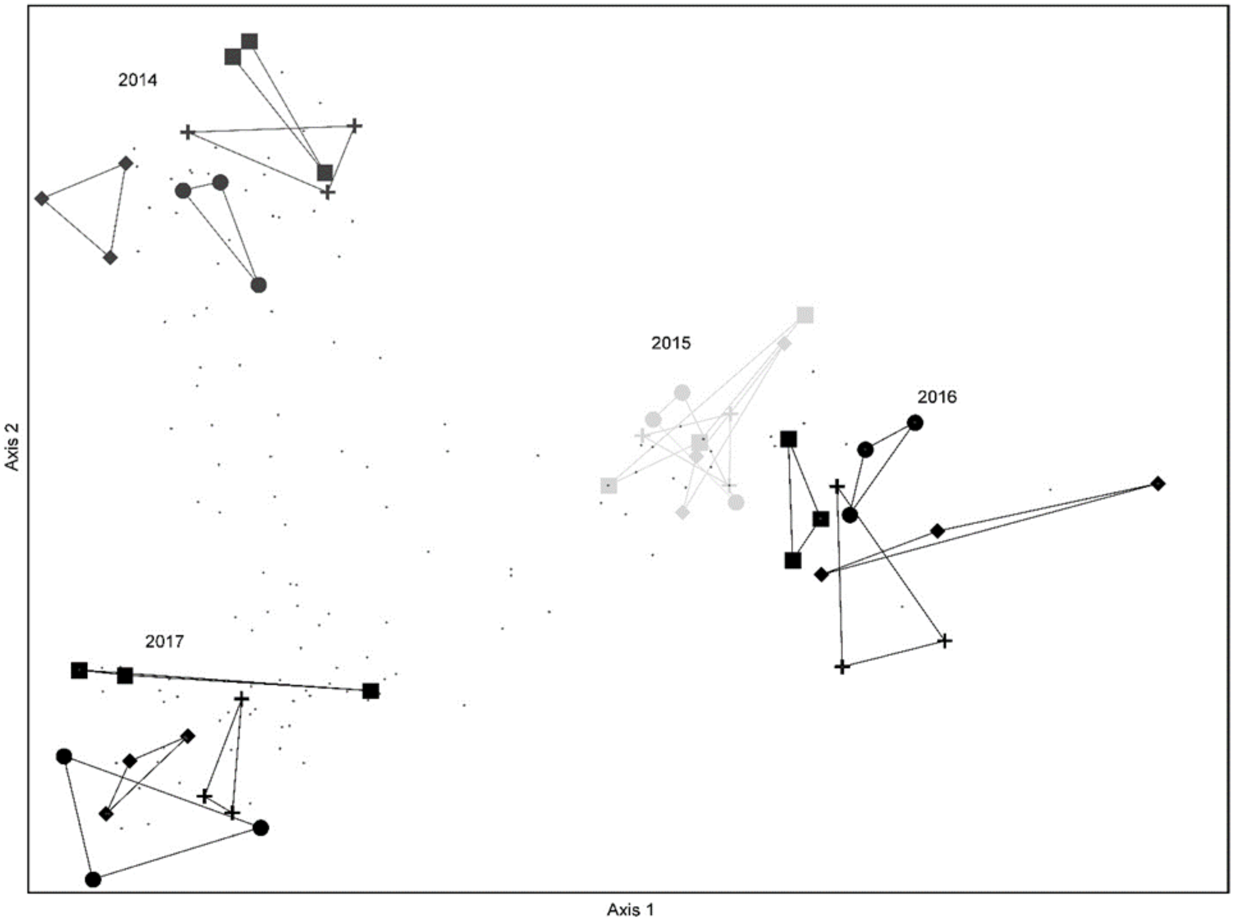

Figure 2.4. Non-metric multidimensional scaling (MMS) ordination of axis 1 and 2 with regards to year, treatment and vegetation composition. Treatments are indicated by shape and year is labeled on the graphic. Individual plant species are specified by a point and correspond to Figure 2.3. All 2014 data was taken pre-burn and prescribed burns were conducted in 2014 for all treatments. The second mid-growing season burn for summer twice treatment occurred in 2016. Data collected at the Viking Prairie unit of the Sheyenne National Grasslands in ND, USA.

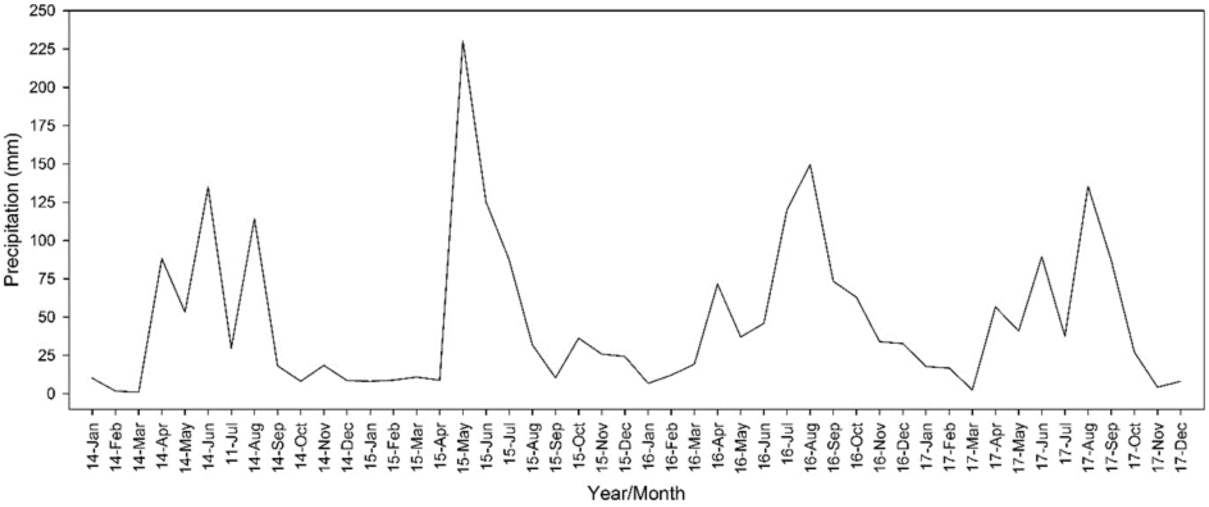

Figure 2.5. Total monthly precipitation in McLeod, ND, USA, 20 miles southwest of the Viking Prairie unit of the Sheyenne National Grasslands. Weather data acquired at the ND MC LEOD 3, ND US USC00325754 station and received from the National Environmental Satellite, Data, and Information Service of the National Oceanic and Atmospheric Administration (NOAA).

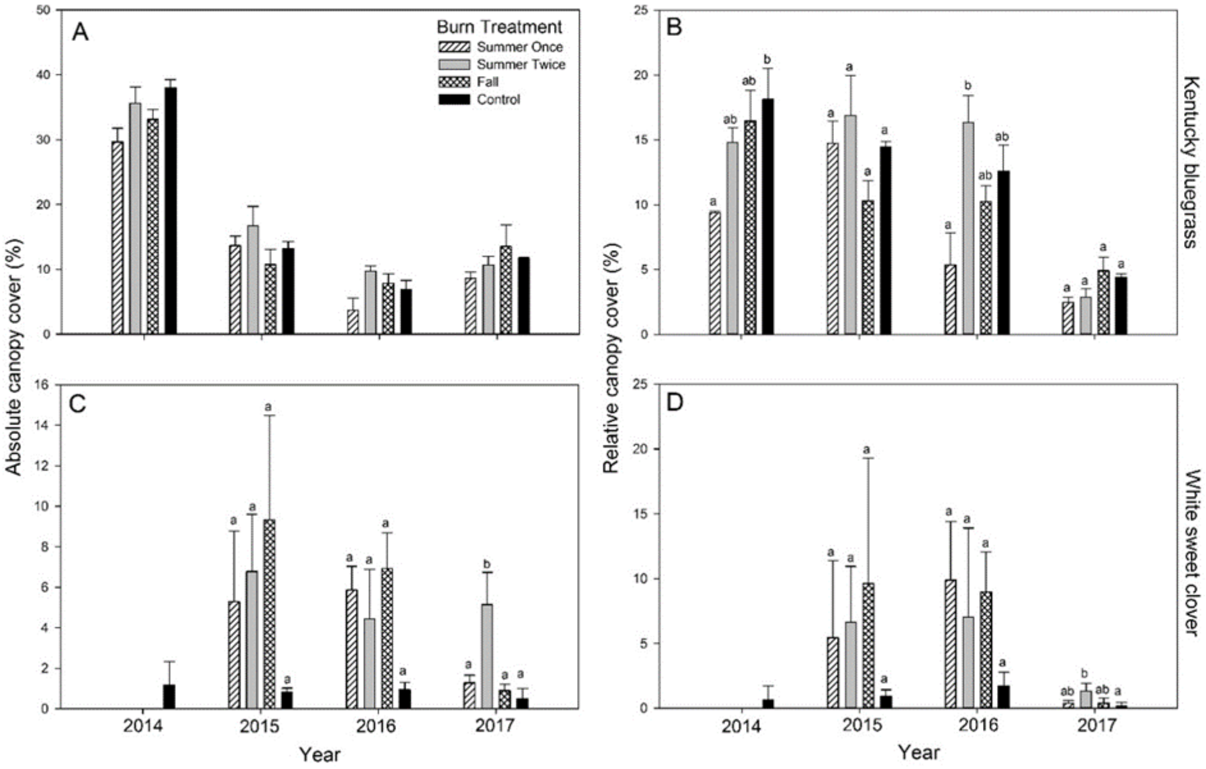

Figure 2.6. Absolute and relative canopy cover of Kentucky bluegrass and white sweet clover. A) There was an overall reduction of absolute cover of Kentucky bluegrass across all treatments from 2014 to 2017 potentially due to low early growing season precipitation. There was no difference across treatments within each year. B) Relative cover of Kentucky bluegrass reduced in the summer once treatment two-years post-burn and in the fall treatment one-year post-burn. C) Absolute canopy cover of white sweet clover changed yearly due to its biennial life cycle. D) Relative canopy cover of white sweet clover also changed due to its biennial life cycle. Data collected at the Viking Prairie unit of the Sheyenne National Grasslands in ND, USA

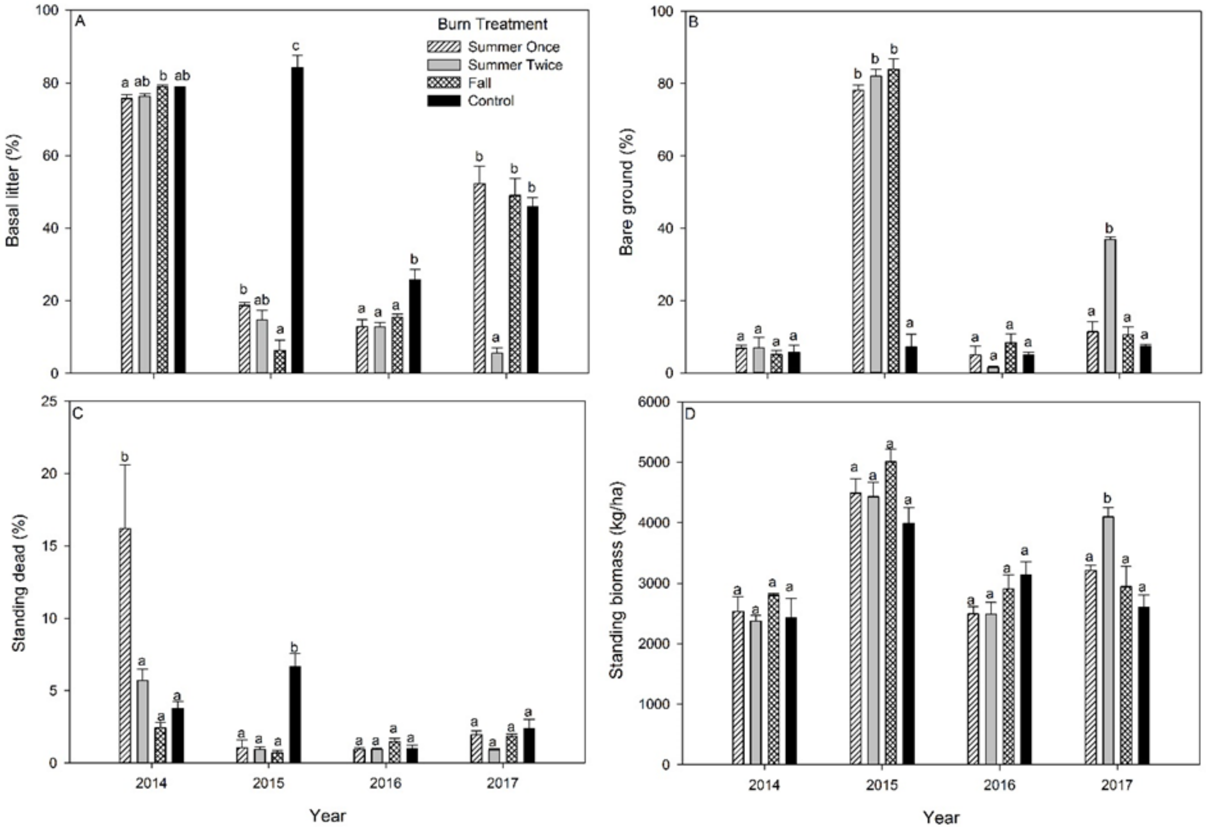

Figure 2.7. *A)* Basal litter ground cover of each treatment separated by year. There was a significant decrease in basal litter ground cover within burned areas in 2015, following the 2014 burns and again within the summer twice treatment in 2017, following the 2016 burn. *B)* Bare ground cover of each treatment separated by year There was a significant increase in bare ground cover within burned areas in 2015, following the 2014 burns and again within the summer twice treatment in 2017, following the 2016 burn. *C)* Standing dead canopy cover of each treatment separated by year. There was a significant decrease in standing dead canopy cover within burned areas in 2015, following the 2014 burns. *D)* Standing biomass in kilograms per hectare (kg/ha) of each treatment separated by year. Biomass of the summer twice treatment was higher than all other treatments in 2017. Data collected at the Viking Prairie unit of the Sheyenne National Grasslands in ND, USA.

Discussion

Exotic invasive plant species threaten rangeland plant community composition and productivity by outcompeting and displacing native species (Cully et al., 2003; Grant et al., 2009). In a Northern Great Plains tallgrass prairie ecosystem invaded by Kentucky bluegrass, we compared the effects of summer and fall burning on native plant community dynamics and Kentucky bluegrass abundance. Our study showed that, overall, the native plant community was unaltered by season of fire but summer fire reduced Kentucky bluegrass relative cover two years post summer burning. Summer prescribed fires can interrupt the growth cycle of warm-season species (Howe, 1994), but occur when Kentucky bluegrass has reached maturity, therefore limiting its regrowth within the current growing season. Flammability of plant material is highest during summer and fall seasons because mature plants and litter accumulation have lower moisture content than immature plant material in the spring (Bragg et al., 1982). Removal of the thatch layer produced by Kentucky bluegrass limits its inhibitive characteristics and allows for native seedling emergence (Bosy and Reader, 1995; Toledo, 2014; Limb et al., 2018). Furthermore, thatch moisture content can be assumed lowest during the summer season, based on studies of other seasonal plant litter and fine fuel moisture (Viegas et al., 2014; Kauf et al., 2015). Summer fire allows for a near complete depletion of the of the thatch layer, exposing the soil and allowing warm-season native species to be expressed (Towne and Kemp, 2008). Season of burn is important for fire behavior, and summer or fall fires may favor native perennials, but may not have as large of an impact on the target exotic species that spring fires harbor (DiTomaso et al., 2006).

We found a strong plant community response to yearly conditions driven by precipitation, plant life cycle, and time since fire. The results of our study coincide with others that growing-season precipitation influences the structure and function of grasslands and has potential to make environments more or less suitable for invasive species (Deguines et al., 2017). Kentucky bluegrass has a shallow root system, making it sensitive to precipitation events, which are becoming infrequent with greater rainfall at one time resulting in longer dry periods (McCann and Haung, 2008; Dong et al., 2014; Toledo, 2014; Jones et al., 2016; Bohrer et al., 2017). Hence, Kentucky bluegrass's negative correlation with axis one can be explained by low early growing season rainfall and inconsistent patterns of precipitation after 2014, which negatively affected canopy cover. The drastic reduction in relative cover of Kentucky bluegrass across all treatments in 2017 can be partly credited to less precipitation the duration of the growing season. Native forbs in our study showed a positive correlation with axis one, indicating resilience to variations in precipitation. This is similar to other research where abundance of forbs increased due to changing precipitation regimes (Engle et al., 1998; Towne and Kemp, 2008; Jones et al., 2016). Overall, global climate change is resulting in altered precipitation cycles and affecting rangeland plant community dynamics (Jones et al., 2016; Deguines et al., 2017).

White sweet clover (*Melilotus alba*) was highly abundant in 2015 and 2016 across all treatments. It can be three to eight feet high with a bush like stature that limits light availability to plant species beneath its canopy (Cole, 1991; Spellman and Wurtz, 2011). This is comparable to the effect shading caused by woody encroachment has on reducing native grass and forb cover, and increasing cover of shade tolerant Kentucky bluegrass (Gehring and Bragg, 1992; Briggs et al., 2002; Limb et al., 2010). Prescribed burning can be used for sweet clover control if conducted annually during the growth cycle and before maturity, as germination can be triggered by burning (DiTomaso et al., 2006). This concept was seen following the 2016 burn as the summer twice treatment had higher sweet clover cover than the control. Kentucky bluegrass's low photosynthetic need (Tegg and Lane, 2004) could have been an attribute to its perseverance following burning, due to an interaction with white sweet clover. Kentucky bluegrass's relative cover decline in 2017 coincides with the reduction in white sweet clover relative cover, likely due to the completion of its life cycle. Managing for Kentucky bluegrass and sweet clover simultaneously may be necessary for further reduction of Kentucky bluegrass cover and promotion of native plant species.

A single prescribed burn in either season, summer or fall, was not effective for substantial reduction of Kentucky bluegrass cover, indicating the need for more frequent burning or a combination of control methods. Burning annually in the spring has had great success at maintaining low to non-existent cover of Kentucky bluegrass in the Konza Prairie of Kansas (Towne and Kemp, 2008), but in the Northern Great Plains high moisture content of plant and litter material following snowmelt in the spring causes fires to not carry as effectively. Comparable to our summer twice treatment, biennial summer burning in the Konza Prairie resulted in an increase in warm season native grasses, like big bluestem and Indiangrass. Furthermore, biennial summer burns over 13 years decreased Kentucky bluegrass cover from 26.1% to 0.8% in the Konza Prairie (Towne and Kemp, 2008). Similarly, frequent burning every one to four years over the course of 27 years at the Cedar Creek Ecosystem reserve in Minnesota has resulted in minimal Kentucky bluegrass cover (Li et al., 2013). A combination of burning with herbicide also promotes native grasses and reduces Kentucky bluegrass cover, but can be detrimental to forb species, which will have negative consequences on pollinators (Masters et al., 1992; Hendrickson and Lund, 2010; Bahm et al., 2011). Prescribed burning followed by grazing has also been utilized to manage nuisance and invasive plant species, while supporting the persistence of native grasses and forbs (Cummings et al., 2007; Dufek et al., 2014). To control the rate of expansion and abundance of invasive Kentucky bluegrass and promote native species in a northern tallgrass prairie, prescribed burning with follow up management will be necessary.

Management Implications

Restoring fire in native tallgrass prairies is a viable option to preserve native species, and ecosystem stability, function, and productivity. Fire occurrence in any season with a frequency of less than four years has shown to be effective at limiting Kentucky bluegrass abundance (Towne and Kemp, 2008) with summer burns being the best suited for northern prairies (Li et al., 2013). Invasive species can be resilient to control methods, but a combination of managements may have added negative impacts (Hendrickson and Lund, 2010; Bahm et al., 2011). Specifically, addition of herbivores could have a lasting impact on resilient invasive species and promote heterogeneity and biodiversity of rangelands (Cummings et al., 2008; Dufek et al., 2014). Further, changing weather patterns will have a continuous influence on plant community composition and productivity on a yearly basis and harbor potential to make environments more or less suitable for invasive species. This study demonstrates the need for disturbance to maintain native tallgrass prairies and minimize the influence of exotic plant species on system dynamics (Jones et al., 2016; Deguines et al., 2017).

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APPENDIX A

Table A1. Association of Analytical Communities (AOAC) methods indicated in Official Methods of Analysis, 18th Edition, Revision 3, 2010, used to determine nutritional content by the North Dakota State University Animal Science Nutrition Laboratory.

Procedure	**Nutrient**	**AOAC Official Method #**	**AOAC Location**
Dry Matter, 95-100 C for Feeds	DM, 8 hr-overnight	934.01	4.1.03
Ash of Animal Feeds	Ash	942.05	4.1.10
Minerals in Animal Feed and Pet Food	Ca	968.08	4.8.14
Fiber (acid detergent) and Lignin (H2SO4) in Animal Feed	ADL	973.18	4.6.03

Table A2. ANKOM Technology, and In Vitro procedures used to determine nutritional content and digestibility by the North Dakota State University Animal Science Nutrition Laboratory.

Procedure	**Nutrient**	**Resources**
ANKOM method for Determining Neutral detergent Fiber and Acid Detergent Fiber	NDF and ADF	ANKOM Technology, 9/98. Based on procedures by H.K. Goering and P.J. Van Soest
In Vito Digestibility	IVOMD and IVDMD	Johnson, R.R. 1969. The development and application of in vitro rumen fermentation methods for forage evaluation. Proc. Natl. Conf. on Forage Qual. Eval. M-1. Nebraska Center for Continuing Education, Lincoln, Nebraska Oh, H.K., B.R. Baumgardt and J.M. Scholl. 1966. Evaluation of forages in the laboratory. Comparison of chemical analyses, solubility tests and in vitro fermentation. J. Dairy Sci. 19:850 Tilley, J.M.A. and R.A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Brit. Grassland Soc. 18:104 McDougall, E.I. 1948. Studies on rumen saliva. 1. The comparison and output of sheep's saliva. Biochem. J. 43: 99-109

APPENDIX B

Table B1. Regression models of all nutritive components and digestibility over time of western snowberry for 2017 post-burn regrowth, 1-year post-burn new growth, 1-year post burn old growth, non-burn new growth, and non-burn old growth. Linear regression models were the best fit for all samples, except for 2017 post-burn.

	2017 post-burn regrowth	**1-year post-burn new growth**	**1-year post-burn old growth**	**Non-burn new growth**	**Non-burn old growth**
ADF	p = .001 r^2 = .54 y = .82x + 14.99	p = .001 r^2 = .26 y = .28x + 18.29	p = .15	p = .001 r^2 = .37 y = .29 + 17.78	p = .00 r^2 = .38 y = -.58x + 59.85
NDF	p = .00 r^2 = .60 y = 1.01x + 23.17	p = .00 r^2 = .36 y = .46x + 25.27	p = .00 r^2 = .33 y = -.40x + 76.38	p = .00 r^2 = .39 y = .41x + 25.15	p = .00 r^2 = .44 y = -.60x + 78.78
ADL	p = .000 r^2 = .487 y = .36x + 4.85	p = .00 r^2 = .19 y = .16x + 8.62	p = .01 r^2 = .16 y = .16x + 16.58	p = .00 r^2 = .35 y = .18x + 8.58	p = .58
CP	p = .00 r^2 = .89 y =3.48+(60.87/x)	p = .00 r^2 = .67 y = -.34x + 12.17	p = .00 r^2 = .33 y = .06x + 2.64	p = .00 r^2 = .47 y = -.29x + 11.79	p = .005 r^2 = .17 y = .05x + 2.79
Ca	p = .00 r^2 = .66 y = .03x + .26	p = .00 r^2 = .63 y = .04x + .28	p = .00 r^2 = .35 y = .02x + .26	p = .00 r^2 = .68 y = .04x + .28	p = .00 r^2 = .51 y = .02x + .26
P	p = .00 r^2 = .77 y = .06+(1.67/x)	p = .03 r^2 = .11 y = -.004x + .24	p = .00 r^2 = .50 y = .004x + .06	p = .01 r^2 = .14 y = -.005x + .25	p = .00 r^2 = .31 y = .004x + .07
Ash	p = .39	p = .48	p = .053	p = .02 r^2 = .11 y = .04x + 5.09	p = .03 r^2 = .10 y = .05x + 3.07
IVOMD	p = .00 r^2 = .51 y = -1.22x + 71.74	p = .00 r^2 = .48 y = -.73x + 67.07	p = .02 r^2 = .12 y = .46x + 20.73	p = .00 r^2 = .42 y = -.56x + 66.35	p = .00 r^2 = .38 y = .52x + 19.20
IVDMD	p = .00 r^2 = .52 y = -1.17x + 73.43	p = .00 r^2 = .48 y = -.70x + 68.88	p = .00 r^2 = .41 y = .55x + 20.94	p = .000 r^2 = .439 y = -.55x + 68.27	p = .00 r^2 = .37 y = .53x + 21.11