AN ASSESSMENT OF INTEGRATED WEED MANAGEMENT STRATEGIES FOR PURPLE THREEAWN-DOMINATED RANGELANDS

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MASTER OF SCIENCE

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ABSTRACT

Purple threeawn (*Aristida purpurea* Nutt.) is a native bunch grass that is avoided by grazers. It is capable of dominating old cropland and overgrazed pastures, limiting livestock carrying capacity, and degrading wildlife habitat. Traditional management tools have had little impact on threeawn dominance in semiarid regions of the west. Our objectives were to: 1) assess fire and nitrogen treatment effects on threeawn forage quality at various phenological stages to test their potential as pretreatments in a grazing strategy and 2) examine a threeawn-dominated plant community's response to prescribed fire, nitrogen addition, and clipping. Fire improved threeawn forage quality with greater improvements in early phenological stages. Nitrogen had little effect on forage quality. Fire and nitrogen reduced threeawn while increasing cool season grasses. Light and moderate clipping following fire did not improve the efficacy of fire. Fire appears to an effective preliminary treatment to improve the chance of herbivory.

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DEDICATION

I dedicate this thesis to my lovely wife and life partner Kathryn Burton. I don't know if I could have done this without your love and understanding.

PREFACE

Chapters 2 and 3 of this thesis were written as manuscripts that will be submitted to peer-reviewed journals. Chapter 2, "Effects of fire and nitrogen addition on forage quality of *Aristida purpurea* (purple threeawn)" will be submitted to the *Journal of Animal Science*. Chapter 3, "Plant community response to clipping, fire and nitrogen addition in semiarid rangeland dominated by *Aristida purpurea* (purple threeawn)" will be submitted to *Rangeland Ecology and Management*. Both chapters follow the style and guidelines of the respective journal in which it intended to be submitted.

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Introduction

The degradation of grazing pastures and wildlife habitat by invasive plant species has become a major concern to rangeland managers in the western United States (Sheley and Petroff 1999). Invasive species on rangelands are characterized as plants spreading, without direct human assistance, that alter the structure and function of ecosystems, and threaten biological diversity (Olsen 1999; Frost and Launchbaugh 2003). For domestic livestock producers, the spread of invasive species threatens to crowd out desirable forage species, thus, lowering the carrying capacity and negatively affecting their economic incentives (Pimentel 2002). Purple threeawn (*Aristida purpurea* Nutt. and varieties) is a prime example of an invasive species that has come to dominate many western rangelands, challenging the sustainability of livestock production and wildlife habitat (Evans and Tisdale 1972; Hyder et al. 1975).

Purple threeawn is a C_4 perennial grass native to North America that is mostly found on hillsides and dry upland areas of semiarid rangelands (Evans and Tisdale 1972). As a small native component in many semiarid plant communities, threeawn may have a beneficial role in soil moisture retention and slope stability (Hyder et al. 1975). However, with intense soil disturbance, such as plowing and long-term overutilization of rangeland by domestic livestock, threeawn is capable of becoming an invasive and dominant component (Klipple and Costello 1960; Evans and Tisdale 1972). Threeawn's status as an undesirable species stems from characteristics that cause cattle to avoid grazing it when other, more palatable forage is available. These traits include sharp awns that protrude from the spikelets causing irritation to the eyes, nose, and mouth (Vallentine 1961). Due to this grazing avoidance, threeawn retains a high proportion of litter (Heitschmidt et al. 1990) leading to greater levels of fiber, lower digestibility, and overall lower nutritional value (Meyer and Brown 1985; Ramirez et al. 2004). Along with its grazing avoidance mechanisms, threeawn is well evolved to out-compete more desirable native species with prolific seed production and a deep robust root system that allows it to withstand drought (Evans and Tisdale 1972; Fowler 1984; Busso et al. 2001; Perkins and Owen 2003).

Threeawn-dominated communities present unique ecological challenges that traditional management strategies, like herbicide and prescribed fire alone, fail to address. Often, the goal of these strategies is the elimination of undesirable species, with little regard for promoting desirable species responses or reduction in potential reinvasion. Herbicide treatments may succeed in decreasing or eliminating the target species, however, desirable species may also be negatively affected (DiTomaso 2000). Since threeawn is a native component of these communities, generally the goal is not its elimination, but to reestablish the dominance of more desirable species. Prescribed fire has been utilized to decrease threeawn densities and enhance desirable species richness and diversity (Wright et al. 1978). However, this may be challenging in rangelands where desirable species densities have been reduced by threeawn dominance beyond a critical recovery threshold (Briske et al. 2005).

The use of domestic livestock grazing to negatively impact threeawn dominance seems counterintuitive given its grazing avoidance mechanisms. However, a grazing strategy that targets the plant when it is most palatable should be considered. Cattle have been observed grazing young threeawn leaves prior to the emergence of the seed head, although this has not been found to have any detrimental impact on threeawn density (Vallentine 1961). Grazing of new threeawn growth has also been observed in the early growing season following prescribed fire (Evans 1967). These observations offer clues to when herbivory, as a management tool, is possible and how the plant community can be manipulated to improve the chances of cattle selecting threeawn growing with common forage species.

A successful targeted grazing strategy should damage the target species and limit damage to desirable species (Frost and Launchbaugh 2003). For invasive grasses, rate and timing of the grazing prescription are key determinants in how much damage can be inflicted on the target species, as well as the surrounding species (Sternberg et al. 2003; Diamond et al. 2012). Threeawn, unlike many invasive perennial rangeland grasses, was not introduced to improve livestock production. Therefore, the focus with threeawn management is improving forage quality and production as well as increasing plant diversity. As one component in an integrated management approach, targeted grazing can improve the efficacy of other management strategies (Mosley and Roselle 2006).

The forage quality of most rangeland grasses improves following fire due to the removal of older less palatable plant material, thus increasing crude protein and digestibility (Norton 1982; Mbatha and Ward 2010). Threeawn forage quality following fire and changes throughout the growing season, relative to desirable forage species are important for assessing the likelihood of selection by cattle in a targeted grazing strategy. Domestic cattle and bison tend to select burned over non-burned patches where litter has accumulated from previous years (Tomer and Owen-Smith 2002; Fuhlendorf and Engle 2004; Vermeire et al. 2004). The short-term negative impacts of fire on threeawn have been well researched (Evans 1967; Trlica and Schuster 1969; Wright et al. 1978). However, few studies have presented data on threeawn forage quality following fire (Richarte-Delgado 2012).

The addition of nitrogen fertilizer has been researched as a management tool to improve the competitive abilities of desirable species in threeawn-dominated rangeland (Horn and Redente 1998). Increasing soil nitrogen has been shown to have a negative to neutral short-term effect on threeawn density (Hyder and Bement 1972; Horn and Redente 1998). Research suggests that early successional species, such as threeawn (Hyder and Bement 1972), are able to out-compete climax species in areas of limited soil available nitrogen (Roux and Warren 1963). Furthermore, soils in later successional stages have been shown to contain greater levels of nitrogen (Roux and Warren 1963). In examining the effects of treatments such as fire and grazing on forage quality and plant community response, it may be useful to also examine their interaction across a gradient of plant available nitrogen.

My research objective was to investigate the potential of a targeted grazing strategy in combination with prescribed fire and nitrogen amendment to reduce threeawn abundance and encourage a more desirable plant community for wildlife habitat and sustainable livestock production. My first experiment focused on changes in forage quality of purple threeawn throughout the growing season following fire and nitrogen additions. My second experiment assessed plant community response in a threeawn-dominated community following fire, nitrogen addition, and clipping. The results of these experiments should aid public and private landowners managing threeawn-dominated rangeland.

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CHAPTER 2. EFFECTS OF FIRE AND NITROGEN ADDITION ON FORAGE QUALITY OF *ARISTIDA PURPUREA* (PURPLE THREEAWN)[1]

Abstract

Purple threeawn (*Aristida purpurea*) is a native perennial bunchgrass with a limited forage value. It often dominates sites with disturbed soils and persists with continued severe grazing. Fire and nitrogen addition have each been used to reduce threeawn. However, they may also be used to increase grazing utilization of threea[1]wn by livestock. We evaluated the effects of fire, spring urea nitrogen addition, and phenological stage on purple threeawn forage quality one year post-fire in southeastern Montana on two similar sites during the 2011 (site 1) and 2012 (site 2) growing seasons. Season of fire (no fire, summer fire, fall fire) and rates of nitrogen addition (0, 46, 80 kg N/ha) were arranged in a completely randomized factorial design. Samples were collected at five phenological stages throughout each growing season. Forage quality was assessed using nutrient analysis (CP, NE_m, and TDN), anti-quality analysis (NDF, ADF, and silica), *in vitro* fermentation (IVOMD and IVNDFD), and gas production (asymptotic gas production, fractional rate of gas production, lag time, and average fermentation rate). In the vegetative phenological stages, CP was increased from 6.2 % in non-burned plots to 12.1 and 13.0 % in summer and fall plots ($P < 0.001$), respectively, and NDF decreased from 72.1% in non-burned plots to 69.4 and 68.2% in summer and fall fire plots ($P < 0.001$), respectively. Silica content decreased from 7.0 % in non-burned plots to 4.1 and 4.3 % in summer and fall fire plots ($P < 0.001$), respectively. Purple threeawn IVOMD increased by 14.0 and 13.0% in summer and fall fire plots ($P < 0.001$), respectively, *versus* non-burned plots. Nitrogen addition

[1] This chapter is co-authored by Nickolas Dufek, Lance Vermeire, Richard Waterman, and Amy Ganguli. Nickolas Dufek (graduate student) was the primary co-author responsible for collecting data, interpreting statistical outputs, and composing the information presented in this chapter.

increased CP from 7.5% in 0 kg N/ha plots to 8.0 and 8.4% in 46 and 80 kg N/ha plots ($P < 0.001$), respectively. *In vitro* fermentation and gas production variables did not change due to N-addition. Fire generally improved forage quality to a greater extent than did N addition. Our results indicate that fire shows a strong potential as a prerequisite treatment for improving the suitability of purple threeawn as a forage species.

Key words: *Aristida*, digestibility, gas production, *in vitro* fermentation, prescribed fire, silica.

Introduction

Aristida purpurea (purple threeawn) is a warm-season (C_4) perennial bunchgrass native to North America. Purple threeawn and varieties are mostly found on hillsides and dry upland areas of rangelands (Evans and Tisdale 1972), but can also be found in pastures where it is often considered to be undesirable for forage and wildlife habitat (Hyder et al. 1975). In the western US, purple threeawn has been shown to dominate overgrazed rangelands and disturbed areas like roadsides (Klipple and Costello 1960; Evans and Tisdale 1972). Purple threeawn is generally unpalatable to grazing animals due to sharp awns that may cause injury to the mouth, nostrils, and eyes (Vallentine 1961). Purple threeawn also has high fiber content and low levels of protein relative to most forage grasses (Rauzi et al. 1969; Cogswell and Kamstra 1976; Meyer and Brown 1985; Ramirez et al. 2004). Purple threeawn reproduces vegetatively and is capable of producing abundant seeds which enter the ground quickly and have a high probability of germination (Evans and Tisdale 1972; Fowler 1984). Seedlings rapidly develop a deep, robust root system, making this species very competitive with desirable native grasses and increasing its ability to withstand drought and herbivory (Evans and Tisdale 1972; Fowler 1984; Busso et al. 2001).

Purple threeawn is of poor to fair forage quality in most regions (Dittberner and Olsen 1983; Ramirez et al. 2004). It is generally accepted that fire improves the forage quality of grasses by removing older, less palatable plant material, thus increasing crude protein and digestibility (Norton 1982; Mbatha and Ward 2010). Fire may also improve forage quality indirectly by creating more optimal conditions for nitrogen mineralization through the combustion of litter, thus increasing plant available nitrogen (Seastedt and Knapp 1993). Large herbivores will select burned areas over non-burned areas where biomass has accumulated from previous years (Tomer and Owen-Smith 2002; Vermeire et al. 2004). Although fire effects on purple threeawn density and competitive ability are well documented (Evans 1967; Trlica and Schuster 1969; Wright et al. 1978), there are few data describing how fire affects its forage quality. Altering forage quality of purple threeawn relative to other forage species in the plant community is a key component in evaluating the potential of improved herbivory on this species in a targeted grazing strategy.

Soil nitrogen availability is one factor that can limit forage quality and productivity, especially in semi-arid rangelands (Wilman 1975; Seastedt et al. 1991). Soil nitrogen addition as an invasive species management tool is mostly directed at improving the competitive abilities of desirable species (Sheley and Jacobs 1997). The application of ammonium nitrate has been shown to decrease threeawn cover when it was a dominant component of rangeland (Hyder and Bement 1972). However, the mechanism by which high levels of soil available nitrogen adversely affects threeawn is not clear. Evaluating the effects of fire, nitrogen addition, and their interaction on purple threeawn forage quality will help us determine the role of each tool as potential prerequisite treatments for targeted grazing.

When considering grazing as a tool to manage undesirable species, the potential impacts the species will have on the animal must be evaluated (Launchbaugh and Walker 2006). The objectives of this research were to evaluate changes in forage quality characteristics of purple threeawn during the first growing season following fire and nitrogen addition. We evaluated three aspects of purple threeawn forage quality to elucidate fire and N-addition effects on animal productivity and health. First, we evaluated for changes in crude protein (CP), net energy for maintenance (NE_m), and total digestible nutrients (TDN) to allow comparisons with common forage species of acceptable forage quality. Second, we analyzed change in neutral detergent fiber (NDF), acid detergent fiber (ADF), and silica content as anti-quality factors that can inhibit forage selection as well as digestibility. Third, we assessed *in vitro* fermentation and gas production to predict the rumen degradation of purple threeawn. We hypothesized that purple threeawn; 1) CP, NE_m, TDN would increase following fire and N-additions, 2) NDF, ADF, and silica would decrease following fire and be unaffected by N-addition, and 3) *In vitro* fermentation and gas production would increase following fire and N-additions.

Materials and methods

The Fort Keogh Livestock and Range Research Laboratory (LARRL) Institutional Animal Care and Use Committee approved all animal handling and experimental procedures used in this study (IACUC No 021308-1).

For these experiments, data were collected on United States Department of Interior, Bureau of Land Management property near Terry, Montana (46°69’N 105°3’W) at an average elevation of 687 m. The climate is semi-arid with average annual precipitation of 298 mm and less than 250 mm of rainfall occurring in one out of every seven yr. Spring and fall seasons are cool with temperature rarely exceeding 32^0 C. Summers are typically hot and dry with daily temperatures averaging 21 ± 3 C° (WRCC 2012). Average precipitation from April to June is about 47 mm, and July to September is about 34 mm (WRCC 2012).

Purple threeawn collection and preparation

This experiment was repeated during two consecutive years on different study sites to account for annual variation. Within each study site, fire and nitrogen amendment treatments were randomly assigned to 27 plots, (20X20 m) in a 3 X 3 factorial design (Fire X Fertilizer) with 3 replications for each treatment combination. Fire treatments were: 1) summer fire, 2) fall fire, and 3) no fire. Summer fire treatments were applied on 12 August 2010 and 7 September 2011 following purple threeawn summer senescence. Fall fire treatments were applied 17 October 2010 and 31 October 2011 following the season's first killing frost (< -2 °C). Nitrogen addition treatments were: 1) 0 kg N/ha, 2) 46 kg N/ha, and 3) 80 kg N/ha applied on 26 April 2011 and 5 April 2012. The timing of N-addition treatments coincided with cool spring temperatures and predicted precipitation to minimize volatilization and maximize incorporation into soil. Plants were sampled (approximately) every two weeks from June through August 2011 at site 1 and May through July 2012 at site 2 by randomly hand-clipping approximately 70 g of purple threeawn from each plot. Plants were clipped above the crown (approximately 3 cm from soil surface) to minimize soil in samples. Average plant phenology was described for each experimental plot to allow a qualitative description of plant condition and its relation to forage quality throughout the growing season. Phenological stages were: 1) vegetative, 2) boot, 3) flowering, 4) maturity, and 5) senescence. Samples were promptly transported in a cooler with ice to the LARRL and frozen at -4 °C. Frozen samples were then lyophilized for 72 h and ground (Thomas-Wiley Laboratory Mill, Model 4, Arthur H Thomas Company, Philadelphia, PA, USA) to pass a 2-mm sieve.

Ground samples for each experimental plot along with hay and alfalfa standards were analyzed for dry matter (DM), organic matter (OM; A.O.A.C 1990), *in vitro* organic matter disappearance (IVOMD), neutral detergent fiber (NDF; Goering and Van Soest 1970), *in vitro* neutral detergent fiber disappearance (IVNDFD), gas production , and silica content (Galyean, 1997). Approximately 10 g of ground sample from each treatment plot were packaged and sent to an independent commercial laboratory for analyses of crude protein (combustion method), acid detergent fiber (Ankom filter bag technique), total digestible nutrients, and net energy for maintenance.

Animals and management

Rumen liquor for IVOMD, IVNDFD, and gas production was collected from two ruminally-cannulated beef cows (8 and 5 yr of age). Cows were fed a standard hay diet and allowed *ad libitum* access to water for 14 d prior to the first *in vitro* experiment and between all subsequent experiments. Rumen liquor was collected from the interface between the mat and liquid layer. Extrusa samples were placed into a collection Dewar (Nalgene 4150-200- StevenJo & Steph, Rochester, NY, USA) that had been previously warmed to 39° C for 12 h. Rumen liquor samples were transported to the lab immediately after collection and strained through four layers of cheese cloth into a 4 L beaker which was continuously under CO_2 bubbling. Each donor animal provided approximately 350 mL of rumen liquor at each collection. A 250 mL sample of rumen liquor from each animal was measured and then combined to make a 500 mL sample. Rumen liquor was then combined with 1,000 mL of McDougal’s buffer (Tilley and Terry 1963), and placed in a pre-warmed 39 °C water bath under continuous CO_2 bubbling. This mix will subsequently be referred to as inoculum.

In vitro substrate fermentation and gas production

In vitro organic matter disappearance (IVOMD) was measured using the Tilly and Terry laboratory technique (Tilly and Terry 1963). Previously weighed *in vitro* tubes containing 0.5 g substrate (six tubes per treatment plot) were placed in a 39 °C water bath, then filled with 30 mL inoculum using a Brinkman dispenser (5–25 mL bottle top dispenser; Brinkman Instruments, Westbury, NY, USA), flushed with CO_2, and tightly sealed with plastic screw caps. Tubes were randomly placed in one of four metal racks, inserted into an incubator (39 °C), and manually agitated five times. *In vitro* racks were agitated every 2 h for the first 12 h, then every 4 h for the second 12 h, and every 6 h throughout the last 24 h until being removed at 48 h. The plastic screw caps were then loosened and tubes were then frozen at -4 C° for 24 h. The frozen samples were then lyophilized for 72 h before removal from the tubes for OM and NDF disappearance assessment procedures.

Gas production was measured using the technique described by Menke et al. (1979). *In vitro* gas production syringes (100 mL) containing 0.25 g of substrate (3 syringes per treatment plot) were filled with 20 mL of inoculum that was under continuous CO_2 bubbling using a Brinkman dispenser (5–25 mL bottle top dispenser; Brinkman Instruments). Excess air was released before sealing and placing syringes into two 60-syringe water baths maintained at 39° C. Gas measurements were recorded at 0, 2, 4, 6, 8, 10, 12, 14, 16, 24, 30, 36, 48, 54, 60, 72 and 96 h by measuring gas displacement. Gas was released from syringes when gas displacement exceeded 90 mL and syringes were reset to 80 mL.

Calculations and statistical analysis

In vitro gas production variables were derived using GraphPad Prism (GraphPad Software Inc. 2003), from the exponential equation $G = A\{1 - \exp[-K(t - Lag)]\}$ where G (mL g^{-1} OM) represents total gas production, A (mL g^{-1} OM) represents the asymptotic gas production (AGP), K (h^{-1}) is the fractional fermentation rate, lag time (h) is the initial delay in the onset of gas production and t (h) is the gas reading time (France et al. 2000). The average fermentation rate (AFR; mL gas h^{-1}), defined as the average gas production rate between the start of incubation and the time at which the cumulative gas production was half of its asymptotic value, was calculated as AFR = A × K/[2(ln 2 + K × Lag

Data were analyzed using the MIXED analysis of variance procedure of SAS (SAS Institute Inc., Cary, NC, USA) with phenological stage within a year as a repeated measure and plot as the experimental unit. The models for each response variable included the effects of phenological stage, fire treatment, nitrogen addition rate, and their interactions. Year of study was the random effect. Significant interactions ($P \leq 0.05$) were followed by tests of simple effects at $\alpha = 0.05$.

Results

Climatic conditions

Growing season temperatures (April through July) were slightly cooler (6%) during 2011 and warmer (12%) during 2012 than the recorded 63-yr average (Figure 2.1). Growing season precipitation following N additions (April through July) was 54% greater (2011) and 8% less

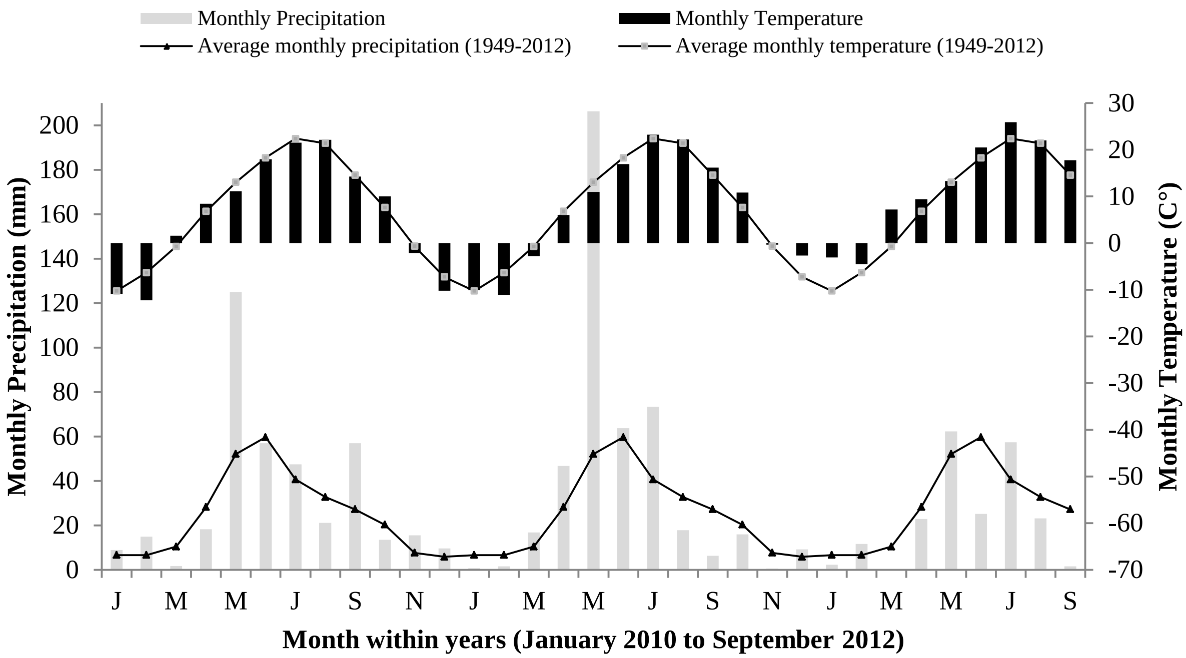

Figure 2.1. Monthly precipitation (mm) and temperature (°C) from January 2010 to September 2012 (bars) and their corresponding 63-yr averages (lines; ▲ precipitation, ■ temperature) for Terry, Montana, are provided. Weather data were obtained from Western Regional Climate Center (WRCC 2012).

(2012) than the 63-yr recorded average, with 2011 being the wettest spring on record. Fall through spring precipitation (October through June) following fires were 47% greater (2010-11) and 13% less (2011-12) than the 63-yr recorded average.

Phenological stage

Changes in nutritional and anti-quality variables with phenological progression of purple threeawn were apparent in this study (Table 2.1). Net energy for maintenance and TDN decreased with advancing phenological stage. Acid detergent fiber increased with advancing phenology. There was no clear pattern that emerged in silica measurements with advancing phenology. However, the boot and senescence stages showed increased silica content compared to the flowering and maturity stages and the vegetative stage was similar to all but the boot stage.

Table 2.1. Least squares means ± SEc for net energy for maintenance (NE_m; Mcal/kg), total digestible nutrients (TDN; % DM), acid detergent fiber (ADF; % DM), silica (% DM), asymptotic gas production (AGP; mL/g OM), lag time (h), and *in vitro* organic matter disappearance (IVOMD; % OM) of purple threeawn samples collected at different phenological stages one year post-treatment in 2011 and 2012 (n = 54).

	Phenological Stage						
Measurement	Vegetative	Boot	Flowering	Maturity	Senescence	SEc	*P*-value
NE_m	1.14[a]	1.08[b]	1.06[b]	1.03[c]	1.00[c]	0.01	<0.01
TDN	53.89[a]	51.65[b]	51.01[b]	49.67[c]	48.52[c]	0.61	<0.01
ADF	42.67[c]	44.64[b]	45.20[b]	46.38[a]	47.37[a]	0.54	<0.01
Silica	5.2[bc]	5.8[a]	4.9[c]	5.1[c]	5.6[ab]	0.2	<0.01
AGP	67.0[a]	65.7[a]	61.9[bc]	62.8[b]	60.3[c]	0.8	<0.01
Lag	2.13[a]	1.50[c]	1.33[c]	0.68[d]	1.90[b]	0.10	<0.01
IVOMD	59.5[bc]	68.8[a]	61.1[b]	58.8[c]	47.4[d]	0.9	<0.01

[a-d] Means with common superscripts are similar (p<0.05).

Gas production and *in vitro* fermentation measurements generally decreased with advancing phenology of purple threeawn plants (Table 2.1). Asymptotic gas production was greater in the vegetative and boot stages compared to all other stages and was greater during the maturity stage than the senescence stage, with no difference for either compared to the flowering stage. Lag time decreased with advancing phenology with the exception of the senescence stage, which was less than the vegetative stage and greater than the boot, flowering, and maturity stages. *In vitro* OM disappearance decreased from the boot stage through senescence with the vegetative stage only differing from the boot and senescence stages.

Fire effects

Net energy for maintenance and TDN varied by fire treatment (Table 2.2) and CP varied by fire treatment and phenological stage (Figure 2.2a). Fire increased NE_m and TDN, with fall fire showing the most improvement. Crude protein concentrations increased ($P < 0.001$) with fire compared to controls in all phenological stages. Fall fire had greater CP *versus* summer fire in the vegetative stage (P < 0.001). However, summer fire increased CP compared to fall fire within the flowering stage (P < 0.001). No differences in CP were detected between summer and fall fire for the boot, maturity, or senescence stages (P > 0.05).

Table 2.2. Least squares means ± SEc for net energy for maintenance (NE_m; Mcal/kg), total digestible nutrients (TDN; % DM), acid detergent fiber (ADF; % DM), silica (% DM), asymptotic gas production (AGP; mL/g OM), lag time (h), and *in vitro* organic matter disappearance (IVOMD; % OM) of purple threeawn samples collected throughout the growing season from two sites one year following fire treatments (n = 54).

	Burn Treatment				
Measurement	No Fire	Summer Fire	Fall Fire	SEc	P-value
NE_m	0.97^c	1.09^b	1.12^a	0.01	<0.01
TDN	47.50^c	52.02^b	53.34^a	0.47	<0.01
ADF	48.28^a	44.32^b	43.16^c	0.41	<0.01
Silica	7.0^a	4.7^b	4.3^c	0.2	<0.01
AGP	57.7^b	66.4^a	66.5^a	0.6	<0.01
Lag	1.84^a	1.36^b	1.33^b	0.08	<0.01
IVOMD	53.6^b	62.3^a	61.4^a	0.9	<0.01

$^{a\text{-}c}$ Means with common superscripts are similar (p<0.05).

Silica and ADF varied by fire treatment (Table 2.2) and NDF varied with interacting effects of fire treatment and phenological stage (Figure 2.2b). Acid detergent fiber and silica were reduced by fire, with fall fire showing the greatest reductions. Fire also reduced (P < 0.001) NDF in the vegetative stage compared to the control. However, fall and summer fire effects were similar. Fire did not affect NDF during the boot, flowering, or maturity stages. Fall fire increased NDF during the senescence stage compared to summer fire. However, neither fall nor summer fire differed from the control.

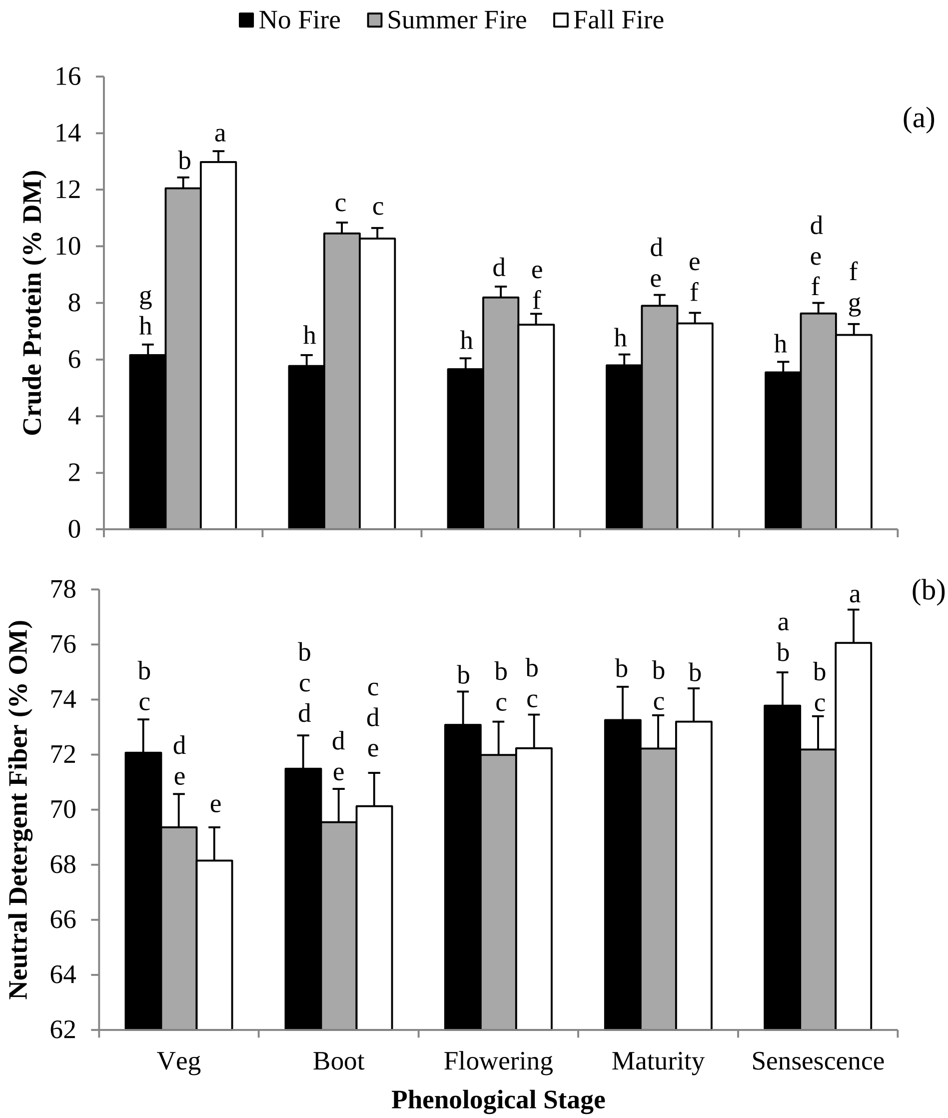

Figure 2.2. Least squares means ± standard error of the mean for fire treatment × phenological stage for (a) crude protein (% DM) and (b) neutral detergent fiber (% OM) for purple threeawn samples collected the growing season following year of the fire treatments. Means with different superscripts differ (p<0.05).

Fire increased asymptotic gas production about 15% ($P < 0.001$), with no difference between summer and fall fire (Table 2.2). Similarly, summer and fall fire reduced lag time 0.48 h. Fire effects on K and AFR varied by fire treatment and phenological stage, with increases due to fire measured during all phenological stages ($P < 0.001$) (Figure 2.3a, b). Summer and fall fire did not differ in the vegetative, boot, or senescence stages for K. However, summer fire increased K in the flowering and maturity stages compared to fall fire ($P < 0.001$). Fall fire increased AFR within the vegetative stage compared to summer fire and the opposite was observed in the maturity stage. Average fermentation rate did not differ between fall and summer fire in the boot, flowering, or senescence stages. Fire increased IVOMD at least 7.8% relative to controls, with no difference between summer and fall fire (Table 2.2). Fire effects on IVNDFD varied by fire treatment and phenological stage (Figure 2.3c). Fall and summer fire increased IVNDFD in the vegetative, boot, and flowering stages compared to controls and both seasons of fire produced similar effects at each phenological stage. Only summer fire increased IVNDFD in the maturity stage compared to controls and all treatments were similar at senescence.

Nitrogen addition effects

Nitrogen addition affected all nutrient and anti-quality variables of purple threeawn (Table 2.3). Crude protein, NE_m, and TDN improved with both 46 and 80 kg N/ha rates compared to controls, with 80 kg N/ha showing the greatest improvements. Both 46 and 80 kg N/ha rates similarly reduced NDF relative to controls. Acid detergent fiber content decreased with increasing N-addition. Nitrogen addition effects were absent in all gas production measurements (AGP; $P > 0.535$, lag time; $P > 0.264$, K; $P > 0.141$, and AFR; $P > 0.470$). Nitrogen addition effects were also not detected for IVOMD ($P > 0.964$) or IVNDFD ($P > 0.753$).

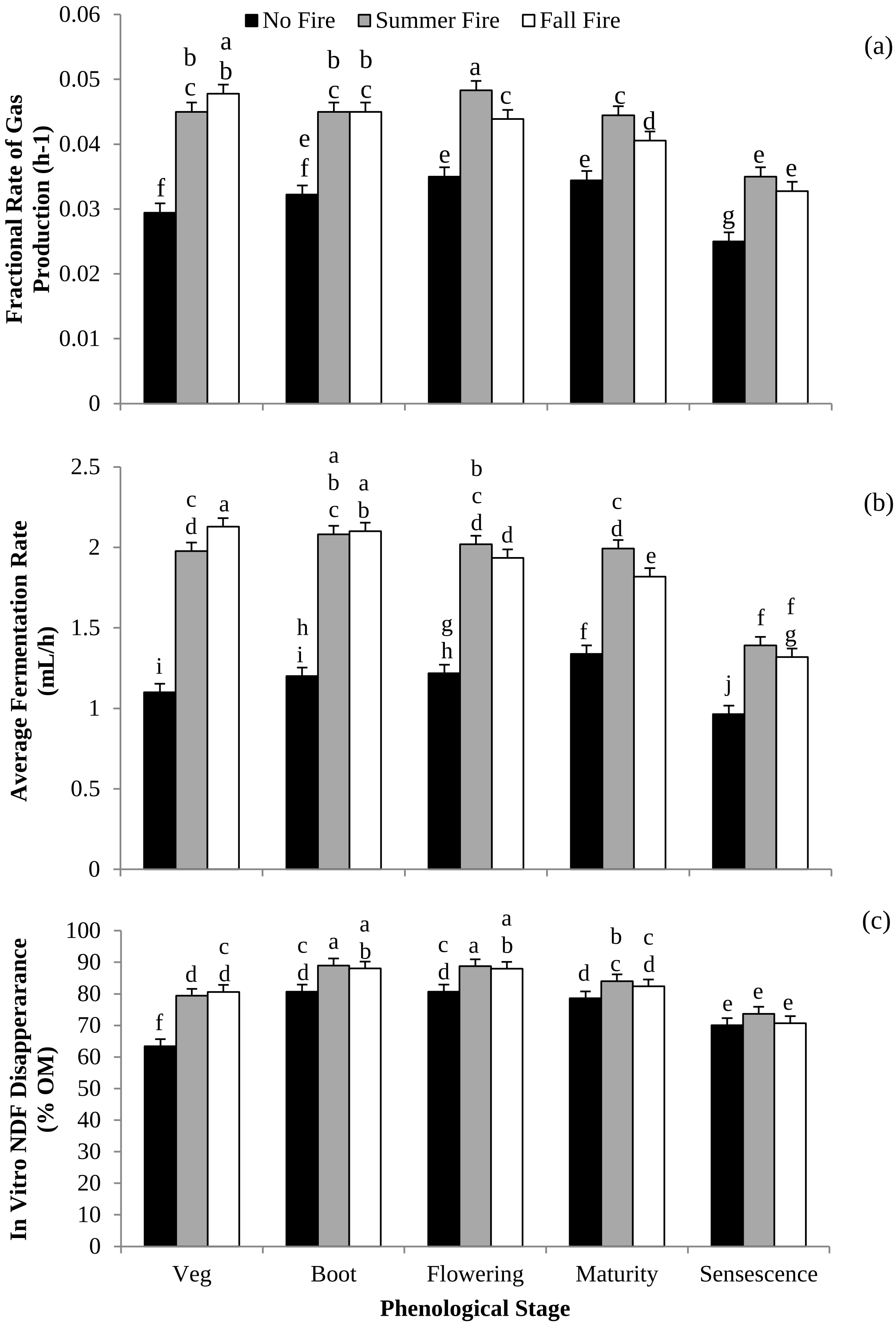

Figure 2.3. Least squares means ± standard error of the mean for fire treatment × phenological stage for (a) fractional rate of gas production (h^{-1}), (b) average fermentation rate (mL/h), and (c) *in vitro* NDF disappearance (% OM) for purple threeawn samples collected the growing season following yr of the fire treatments. Means with different subscripts differ (p<0.05).

Table 2.3. Least squares means ± SEc for crude protein (CP; % DM) net energy for maintenance (NE_m; Mcal/kg), total digestible nutrients (TDN; % DM), neutral detergent fiber (NDF; % OM) acid detergent fiber (ADF; % DM), and silica (% DM) of purple threeawn samples collected the growing season following nitrogen addition treatments (n = 54).

	Nitrogen Addition Treatment				
Measurement	0 kg N/ha	46 kg N/ha	80 kg N/ha	SEc	P-value
CP	7.5^{c}	8.0^{b}	8.4^{a}	0.2	<0.01
NE_m	1.04^{c}	1.05^{b}	1.09^{a}	0.01	<0.01
TDN	50.24^{c}	50.65^{b}	51.95^{a}	0.47	<0.01
NDF	72.9^{a}	71.72^{b}	71.13^{b}	0.54	<0.01
ADF	45.8^{a}	45.5^{b}	44.4^{c}	0.4	<0.01
Silica	5.9^{a}	5.2^{b}	5.0^{c}	0.2	<0.01

$^{a\text{-}c}$Means with common superscripts are similar (p<0.05)

Discussion

In this study, the effects of fire on forage quality vary across phenological stages and season of fire, whereas the effects of N-addition vary by rate of application. As expected, forage quality of purple threeawn tended to be greater the early part of the growing season, with or without fire. Fire generally improved forage quality to a greater extent than did nitrogen addition. Of particular importance in fire’s effect on forage quality is the improvement relative to standard measurements of forage quality in common forage grasses (Rauzi et al. 1969; Cogswell and Kamstra 1976; NRC 2000).

In semi-arid grasslands, precipitation is the most limiting factor to plant productivity (Gutierrez and Whitford 1987; Huxman et al. 2004). In rangeland management planning, it is difficult to predict the post-treatment precipitation. The vast difference in climate between years, in this study, allows us to examine the average effects of our treatments on purple threeawn forage quality between wet and dry growing seasons. Our results present what could be expected within a broad range of years with less extreme levels of precipitation.

Effects of plant phenology

As the growing season progresses in semiarid grasslands, forage quality tends to decline with increasing temperatures, less precipitation, and an increasing proportion of senesced plant tissue (Grings et al. 2004; Waterman et al. 2007; Mbatha and Ward 2010). Greater NE_m and TDN values in the early phenological stages are evidence that purple threeawn adheres to this trend. The seasonal trend in ADF concentration indicates that the proportion of more digestible plant tissue is reduced with advancing phenology in purple threeawn. Acid detergent fiber concentration remained higher than most common forage species throughout the growing season (Hart et al. 1983; Shewmaker et al. 1989; Jefferson et al. 2004). The lack of discernible pattern in silica concentration with advancing phenology may be due to the high proportion of standing dead litter in non-burned plants throughout the growing season. As a chemically inert mineral, silica may be less prone to reductions by weathering than other structural components like hemicelluloses, cellulose, and lignin (Shewmaker et al. 1989). Similar to most rangeland forage species (Kirby and Parman 1986; Olsen et al. 1994), purple threeawn digestibility tends to decline with advancing phenology as indicated by our results for AGP, IVOMD, and lag time.

Effects of fire

Improvements in CP, NE_m, and TDN following fire were clear. Post-fire levels of CP throughout the growing season are comparable to common rangeland grass of high forage quality (Rauzi et al. 1969; Cogswell and Kamstra 1976). Both NE_m and TDN following fire exceed diet nutrient density requirements for beef cows (NRC 2000). Increased nutrient concentrations in post-fire grass may be attributed to a number of factors. For example, ash leaching into the soil following fire may be one direct cause for increases in certain nutrients (Frost and Robertson

1987). However, in a grassland setting, these increases have been considered negligible (Boerner 1982; Van Der Vijver et al. 1999), are predominantly minerals, and would not account for our increase in CP and NE_m. In tallgrass prairie, fire enhanced nutrient content has been attributed to increased mineralization near the soil surface due to increased soil surface temperature (Knapp and Seastedt 1986). Mineralization also depends on adequate soil moisture (Haynes and Seastedt 1989). It would be challenging to draw any conclusion regarding mineralization from this study, given the extreme temperature and moisture differences between study years. Enhanced CP, NE_m, and TDN were most likely due to the increased proportion of young plant tissue in burned plots (Van Der Vijver et al. 1999; Mbatha and Ward 2010). Non-burned plots contained nearly 50% previous year's growth while burned plots contained very little (N. Dufek, unpublished data). Differences between fall and summer fire treatments for NE_m and TDN were small, but consistently greater with the fall fire. Given the longer chance for regrowth in the growing season of the fire, summer fire treatments may have contained a slightly higher proportion of less nutritious, standing dead tissue than fall plots.

Fire consistently reduced NDF, ADF, and silica concentration in purple threeawn. A direct effect of fire is the removal of older plant material leaving mostly young growth in the following growing season, consequently, young growth contains less cell wall constituents such as NDF, ADF, and silica (Griffin and Jung 1983; Shewmaker et al. 1989). This is also evident in our fire × phenological stage interaction for NDF, with post-fire regrowth in the early stages showing the lowest levels of NDF concentration relative to later stages. The level of NDF concentration in the vegetative and boot stages and mean ADF values following fire are comparable to many common forage species of fair to high forage quality (Hart et al. 1983; Jefferson et al. 2004). It is also interesting to note the reduction, due to fire, from what is considered near dangerous levels of silica for cattle health to levels of acceptable tolerance (Parker 1957; Smith et al. 1971; Walker et al. 1978).

Fire effects on *in vitro* fermentation are consistent with previous work in post-fire digestibility. Fire reduced the proportion of previous years' growth relative to non-burned plants, leaving more young leaves. Digestibility tends to be greater in young, green leaves compared to older more mature leaves (Norton 1982; Mbatha and Ward 2010). Studies examining post-fire gas production for single grass species are lacking. However, Brown et al. (2002) found a strong relationship between gas production and fermentation patterns in grass silage. Our findings confirm this with increased gas production as well as increased *in vitro* OM and NDF disappearance in post-fire purple threeawn.

Effects of nitrogen addition

Consistent improvements in CP, NE_m, TDN and reductions in NDF, ADF, and silica due to N-addition were evident in this study. Similar studies involving forage quality response to nitrogen addition support our results of increasing CP, NE_m, and TDN (Allen et al. 1976; Mitchell et al. 1994; Cohen et al. 2004; Mbatha and Ward 2010). Decreases in NDF, ADF, and silica content with N-addition may be an indication of nitrogen limiting productivity in purple threeawn. As plant productivity increases, so does the proportion of young leaves, thus decreasing the proportion of less digestible plant tissue components (Norton 1982) like NDF, ADF, and silica. On the contrary, this is not reflected in our gas production or *in vitro* fermentation results. Although differences in nutrient concentrations and anti-quality factors are statistically significant, the biological differences may not be great enough to translate into increased animal productivity with N-addition.

Conclusions

Forage quality of purple threeawn one growing season following fire treatment showed marked improvement compared to non-burned plots, whereas N-addition effects were not as substantial. In terms of potential effects on animal production and health, post-fire purple threeawn forage quality is comparable to that of most commonly utilized rangeland forage (Rauzi and Dobrenz 1969; Cogswell and Kamstra 1976; NRC 2000; Waterman and Vermeire 2011). It would be difficult to justify N-addition as a prerequisite treatment to grazing from this study. Decisions about grazing management following fire to reduce purple threeawn density should be based on a number of factors including timing and intensity, *in situ* animal preference and performance, and plant community response to integrated management tools (Frost and Launchbaugh 2003). Our data include changes in forage quality factors throughout the growing season for fire and N-addition but, due to the avoidance of purple threeawn following seed head emergence, early season grazing would be essential in order to delay flowering. Prescribed fire shows strong potential as a prerequisite treatment for increasing the suitability of purple threeawn as a forage species.

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CHAPTER 3. PLANT COMMUNITY RESPONSE TO CLIPPING, FIRE, AND NITROGEN ADDITION IN SEMIARID RANGELAND DOMINATED BY *ARISTIDA PURPUREA* (PURPLE THREEAWN)[1]

Abstract

Aristida purpurea (purple threeawn) is a bunch grass, native to the western United States and often avoided by grazers. It is capable of dominating old cropland and overgrazed pastures, limiting livestock production, and degrading wildlife habitat. Fire and nitrogen addition have been effective tools for reducing *Aristida spp.*-dominance in the short term. However, little is known about long-term treatment efficacy. Cattle grazing following these treatments may extend the longevity of their effectiveness, allowing more time for managers to integrate other management tools, like seeding. We evaluated the effects of fire (no fire, summer fire, and fall fire) and nitrogen addition (0, 46, and 80 kg ha^{-1}) followed by clipping on a purple threeawn-dominated plant community in southeastern Montana. We applied four clipping treatments based on combinations of light, moderate and no clipping of the target species (purple threeawn) and non-target species. Plant community response was evaluated using biomass production, canopy composition, and basal cover measurements. In non-burned plots, total biomass was reduced by 25 and 29% with 46 and 80 kg N ha^{-1}, respectively. However, this reduction due to nitrogen addition was not seen in burned plots. Purple [2]threeawn production was reduced by 51 and 20% with summer and fall fire, respectively, while cool-season grass production was increased by 62 and 48 % with fall and summer fire, respectively. Purple threeawn was not decreased by clipping and total annual production was unaffected by clipping. Summer fire

[1] This chapter is co-authored by Nickolas Dufek, Lance Vermeire, and Amy Ganguli. Nickolas Dufek (graduate student) was the primary co-author responsible for collecting data, interpreting statistical outputs, and composing the information presented in this chapter.

decreased purple threeawn composition by 25% and increased *Agropyron cristatum* (crested wheatgrass) by 38 %. Other functional groups were unaffected by treatments. Our results confirm short-term reductions in purple threeawn due to fire and nitrogen addition. However, light and moderate early summer grazing may be an ineffective tool for prolonging treatment efficacy.

Introduction

Aristida purpurea (Purple threeawn) and varieties are C_4 perennial bunchgrasses native to North America that are mostly found on hillsides and dry upland areas of semiarid rangelands (Evans and Tisdale 1972). Purple threeawn is capable of dominating rangelands that have experienced intense soil disturbance in practices such as tilling and long-term overgrazing (Klipple and Costello 1960; Evans and Tisdale 1972). It is considered an undesirable species when found in rangeland being utilized for livestock production and wildlife habitat (Hyder et al. 1975). Purple threeawn is generally avoided by grazing animals when other, more palatable forage is available. Grazing animals tend to avoid purple threeawn due to sharp awns that may cause injury to eyes, nostrils, and mouth (Vallentine 1961) and retention of large proportion of litter (Heitschmidt et. al. 1990) leading to high fiber content, low digestibility, and low nutritional value (Meyer and Brown 1985; Ramirez et al. 2004). These avoidance mechanisms coupled with prolific seed production and a deep root system makes threeawn very competitive with more desirable species and able to withstand drought and herbivory (Evans and Tisdale 1972; Fowler 1984; Busso et al. 2001; Perkins and Owen 2003).

Rangeland managers have used a variety of tools to restore rangeland dominated by undesirable species, including fire (Willson and Stubbendieck 1997; DiTomaso et al. 2006), grazing (Johnston and Peake 1960; Sheley et al. 1996; Wallace et al. 2008; Diamond et al. 2012), and combinations of the two (Cummings et al. 2007; McGranahan et al. 2012). Nitrogen addition has also been utilized as a method for enhancing the competitive ability of more desirable species in dryland prairie where nitrogen is often a limiting factor to production (Jacobsen et al. 1996; Sheley and Jacobs 1997). When considering grazing, fire, and nitrogen addition as restoration strategies, it is important to understand the effects on the target species as well as the plant community (Sheley et al. 1996).

Prescribed fire is a management tool used to maintain and restore rangelands throughout the western US. In the northern Great Plains, a common use of prescribed fire is suppression of invasive cool-season perennial grass and promotion of warm-season perennial grasses (Robocker and Miller 1955; DiTomaso et al. 2006). As a warm-season perennial grass, purple threeawn presents a unique challenge to prescribed fire strategies in the northern Great Plains. In other regions, purple threeawn and purple threeawn-dominated communities' response to fire varies. Initially, fire may reduce threeawn cover by burning accumulated litter around the bunches and damaging or killing the plant by heating the root crowns that are close to the soil surface (Trlica and Schuster 1969; Wright 1974; Wright et al. 1978). Small bunches may be killed by repeated fire, but large bunches typically split into several small bunches (Evans 1967). Additionally, fire may stimulate seed stalk production, adversely effecting long-term reduction in cover (Trlica and Schuster 1969). With regards to long-term plant community response, we lack sufficient data to understand the role of fire in purple threeawn-dominated systems.

Without periodic fire, plant productivity in prairie ecosystems can be limited by shading effects of accumulating litter (Knapp and Seastedt 1986). Prairie that is burned following an extended period without fire tends to have increased production in subsequent years (Seastedt et al. 1991). One explanation for this pulse of plant productivity is removal of shading plant material causes an increase in available energy (temperature and light) at the soil surface, thus increasing the soil available nitrogen through increased mineralization of organic nitrogen (Seastedt and Knapp 1993). This trend is important when considering short-term plant community response following fire in purple threeawn-dominated rangelands. With livestock avoidance of purple threeawn, litter continues to accumulate even with grazing. This litter may limit site availability for establishment and expansion of desirable species and also resource availability (Horn and Redent 1998).

Targeted grazing is developed for the application of a specific kind of livestock at a determined season, duration, and intensity to accomplish defined vegetation and landscape goals (Launchbaugh et al. 2006). The primary goal of an invasive species-targeted grazing strategy is to give desirable species in the plant community the competitive edge over the target species (Launchbaugh et al. 2006). The focus of targeted grazing strategies for most invasive grasses is on the rate and timing with which animals are deployed in order to induce the most damage to the target species and avoid hurting the competitive abilities of desirable species (Frost and Launchbaugh 2003). Unlike other invasive perennial grasses of the northern Great Plains (e.g. crested wheatgrass, smooth brome, etc.), purple threeawn is not a species introduced to improve forage production. Therefore, the focus of purple threeawn management, in comparison to introduced forages, is improving forage production and plant diversity. It seems counterintuitive to suggest using grazing to improve the forage production and plant diversity of a community dominated by a species that is mostly unpalatable to livestock. However, as one of the tools in an integrated management approach, a measured application of grazing can add to the efficacy of the other management strategies (Mosley and Roselle 2006). Relative to non-burned purple threeawn, regrowth following fire should have increased forage quality, thus improving the likelihood of selection by grazers (Van Der Vijver et al. 1999; Mbatha and Ward 2010). Purple threeawn's vulnerability to fire, improved forage quality of surviving plants, and the neutral or positive response of fire tolerant neighboring species in the northern Great Plains (Vermeire et al. 2011) indicate fire and grazing may be effective management strategies for purple threeawn-dominated plant communities.

Plant community response to nitrogen addition can vary considerably based on site, initial species present, and other management techniques being applied such as, grazing or burning (Gillen et al. 1987). On purple threeawn-dominated abandoned croplands, nitrogen addition resulted in a reduction of purple threeawn while increasing the production of annual forbs (Hyder and Bement 1972). In the northern Great Plains, nitrogen addition has resulted in increased yields for many common perennial forage grasses during years of favorable precipitation (Power 1985; Jacobsen et al. 1996). Early successional species, such as purple threeawn, are able to out-compete climax species in areas of low plant available nitrogen (Roux and Warren 1963). Also, soils of plant communities in later successional stages have been shown to contain higher levels of nitrogen (Roux and Warren 1963). In examining the effects of treatments such as fire and grazing on plant community response, N-addition allows us to examine their effects across a gradient of plant-available N.

The objective of this research was to evaluate short-term effects of light to moderate clipping following prescribed fire, nitrogen additions, and their combination on plant functional group composition and production in purple threeawn-dominated rangelands. We hypothesize that 1) fire, nitrogen addition, and their combination will have negative short-term impact on purple threeawn composition and production while enhancing non-threeawn composition and production, and 2) light and moderate clipping following fire and nitrogen treatments will have negative to neutral effects on purple threeawn composition and production while increasing composition and production of non-threeawn species.

Methods

Study site

This study was conducted on semiarid mixed grass prairie near Terry, Montana, USA (lat 46°69’N, long 105°3’W; 687 m above sea level). Average annual precipitation is 298 mm, with approximately half occurring during the April-September growing season. Mean annual temperature is 6.6 °C with average monthly extremes ranging from 22.4 °C in July to -10.2 °C in January (WRCC 2012). Snowfall can be expected as late as May and as early as September (NOAA 2012). The study site is characterized as a sandy ecological site with flat, upland plains and is situated over the Degrand soil series, a fine-loamy over sandy or sandy-skeletal, mixed, superactive, frigid Aridic Argiustolls (USDA-NRCS 2011). The research plots were established in 2009 and fenced with barb-wire to exclude large herbivore grazing. The study site was given one year’s rest from grazing before fire treatments were applied in 2010.

The plant community was dominated by purple threeawn and the perennial introduced cool-season (C_3) bunchgrass, crested wheatgrass (*Agropyron cristatum* (L.) Gaertn). These two species comprised 80-90% of the biomass composition. Other warm-season (C_4) perennial grasses present included sand dropseed (*Sporobolus cryptandrus* (Torr.) A. Gray), blue grama (*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths), buffalograss (*B. dactyloides* (Nutt.) Engelm.), and tumblegrass (*Schedonnardus paniculatus* (Nutt.) Trel.). Other cool-season perennial grasses included needle and thread (*Hesperostipa comata* (Trin. & Rupr.) Barkworth), western wheatgrass (*Elymus smithii* (Rydb.) Gould), Sandberg bluegrass (*Poa secunda* Presl), and bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) A. Love). Cool-season (C_3) annual grasses were sixweeks fescue (*Vulpia octoflora* (Walt.) Rydb.), Japanese brome (*Bromus arvensis* L.), and cheatgrass (*B. tectorum* L.). The sub-shrub green sage (*Artemisia campestris* L.) was present, in addition to, the perennial legume silverleaf Indian breadroot (*Pediomelum argophyllum* (Pursh.) J. Grimes) and the perennial forb yellow salsify (*Tragopogon dubius* Scop.). Annual forbs included field cottonrose (*Logfia arvensis* (L.) Holub) and rough false pennyroyal (*Hedeoma hispida* Pursh.). Plant nomenclature follows the USDA PLANTS database (USDA, NRCS 2012).

Experimental design

Plant community response to clipping, fire, and N-addition was evaluated on experimental plots in a 3 X 3 X 4 factorial design (fire X N-addition X clipping) with 3 replications. Fire and N-addition treatments were randomly assigned to 27, 20 X 20 m plots. Clipping treatments, to simulate grazing, were assigned to four, 1 X 1 m subplots within each of the 27 plots with >1 m buffer around each subplot to minimize edge effects. Clipping subplots were selected to include purple threeawn, C_3 grasses, and other C_4 grasses. Fire treatments were comprised of 1) summer fire, 2) fall fire, and 3) no fire. Nitrogen addition treatments were comprised of 1) 0 kg N ha^{-1}, 2) 46 kg N ha^{-1}, and 3) 80 kg N $ha^{-1}$of granular urea nitrogen fertilizer. Clipping treatments were comprised of four different clipping regimes based on clipped height above ground, with stubble heights of 10 and 5 cm representing light to moderate and moderate to heavy grazing for the region, depending on plant species (Holscher and Woolfolk 1953). Clipping regimes were: 1) no clipping of purple threeawn and clipping to 10 cm of non- purple threeawn (NL), 2) clipping of purple threeawn to 10 cm and non- purple threeawn to 5 cm (LM), 3) clipping of purple threeawn and non- purple threeawn to 5cm MM, and 4) no clipping of any species (NN). Summer and fall fires were applied on 12 August and 17 October 2010 and N-addition treatments were applied on 26 April 2011. Pre-treatment measurements and clipping treatments of subplots were conducted 9-11 July 2011 (approximately 305, 239, and 48 d following fall fire, summer fire and N-addition, respectively) to simulate early summer grazing. Post-clipping treatment measurements were conducted 16-19 July 2012.

Response variables included basal cover, relative species composition, and biomass. One, centrally-located, $0.25 m^2$ quadrat was used to measure basal and canopy cover by species, bare ground, and litter in each subplot using the point intercept method, with 15 randomly placed points per quadrat. Post-treatment measurements also included plant biomass, which were collected by clipping the $0.25 m^2$ quadrat and sorting by the functional groups; purple threeawn, cool-season perennial grasses (CSPG), other warm-season perennial grass (WSPG), annual grasses, and forbs. Biomass samples were dried at 60 °C for 48 h, weighed, then sorted by standing dead and current-year plant tissue, dried again, and reweighed.

Data analysis

Data were analyzed using the MIXED analysis of variance procedure of SAS (SAS Institute Inc., Cary, NC, USA). The models for each response variable included the fixed effects of fire treatment, N-addition rate, clipping intensity, and their interactions with subplot as the experimental unit ($n = 108$). Significant interactions ($P \leq 0.05$) were followed by tests of simple effects at $\alpha = 0.05$.

Results

Spring (April through June) precipitation was 56% greater than average (1949-2012) following fire and N-addition treatments in 2011 and 21% less than average prior to composition and biomass measurements in 2012 (Fig. 3.1). Total precipitation following clipping treatments (July, 2011 through June. 2012) was 17 % less than average (WRCC 2012). Dry conditions in 2012 may have contributed to the near absence of annual grasses and forbs in our measurements. For this reason, only results for purple threeawn, CSPG, and WSPG current year production are reported.

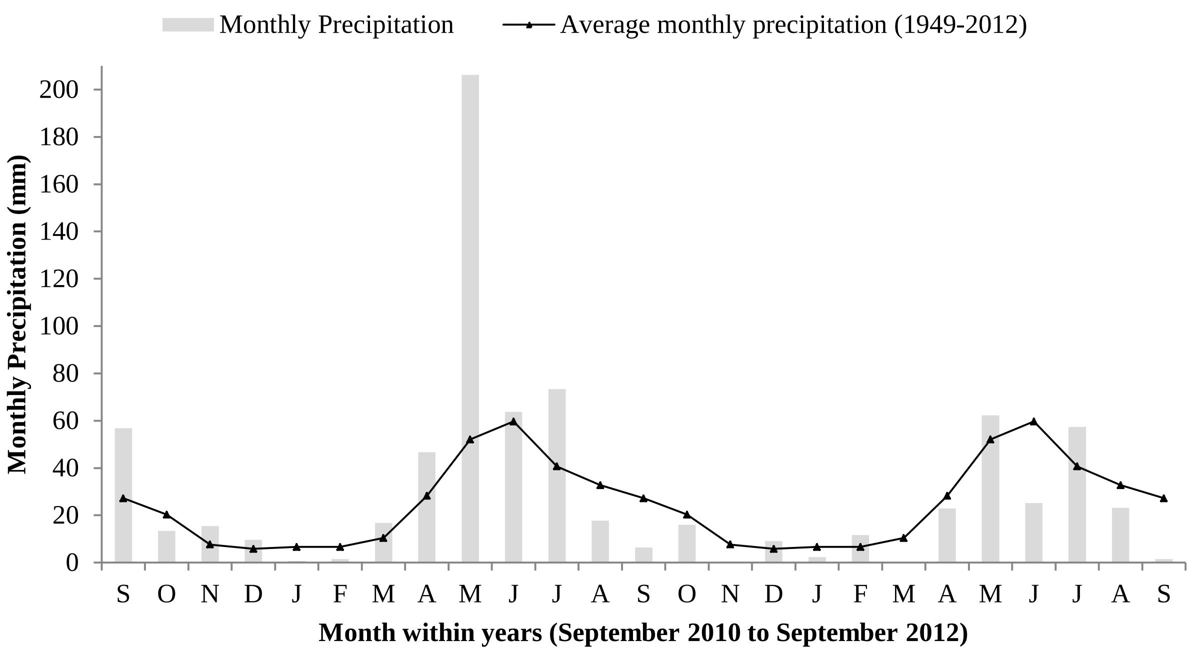

Figure 3.1. Monthly precipitation (mm) from September 2010 to September 2012 (bars) and their corresponding 63-yr average (line) for Terry, Montana are provided. Weather data were obtained from Western Regional Climate Center (WRCC 2012).

Biomass

Total biomass was greater in subplots that did not receive fire or N-addition treatments ($P < 0.05$) compared to all other fire and N-addition treatment combinations with the exception of the fall fire and 46 kg ha^{-1} combination (Fig. 3.2). As expected, NN subplots contained more total biomass ($P < 0.01$; 1565 ± 111 kg ha^{-1}) than all other clipping treatments. Total biomass was similar for NL (1225 kg ha^{-1}) and MM (1113 kg ha^{-1}) subplots and greater than LM subplots (866 ± 111 kg ha^{-1}).

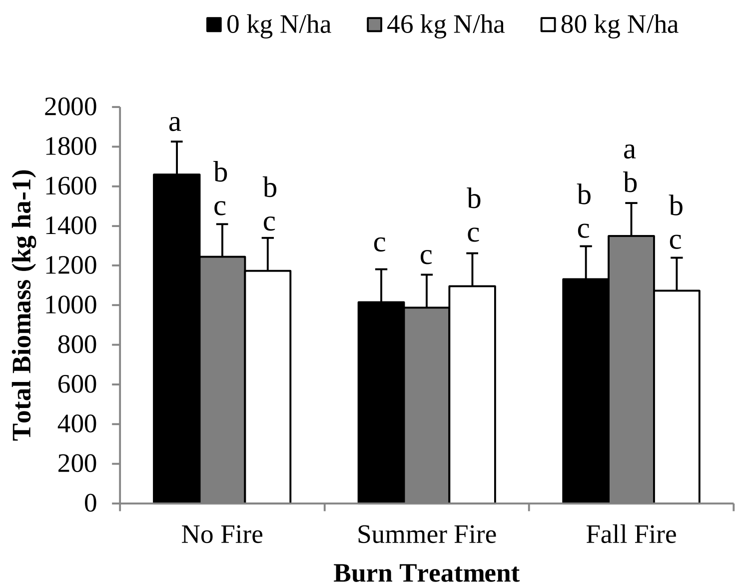

Figure 3.2. Means of total biomass ± standard error of the mean (kg ha-1) for fire × N-addition treatments collected the second growing season following fire and N-addition treatments. Means with common superscripts do not differ at P<0.05.

Fire and N had interacting effects on current year production of purple threeawn ($P <$ 0.01; Fig. 3.3). Within 0 kg ha^{-1}N addition treatments, both summer and fall fire reduced purple threeawn production. Purple threeawn production decreased with increasing N-addition when plots were not burned. Only 80 kg N ha^{-1}decreased purple threeawn production after summer fire. In the fall fire treatment, there was no difference between 46 and 80 kg N ha^{-1}. Clipping did not affect purple threeawn production (198 ± 20 kg ha^{-1}; $P > 0.61$). Only fire affected CSPG current year production. Fire increased CSPG production ($P < 0.01$) in the second season following fire treatment compared to the control (summer fire: 275 kg ha^{-1} = fall fire: 200 kg ha^{-1} > no fire: 105 ± 38 kg ha^{-1}). Production of CSPG was similar across nitrogen addition rates (P > 0.07). There were no treatment effects on WSPG production (P > 0.13).

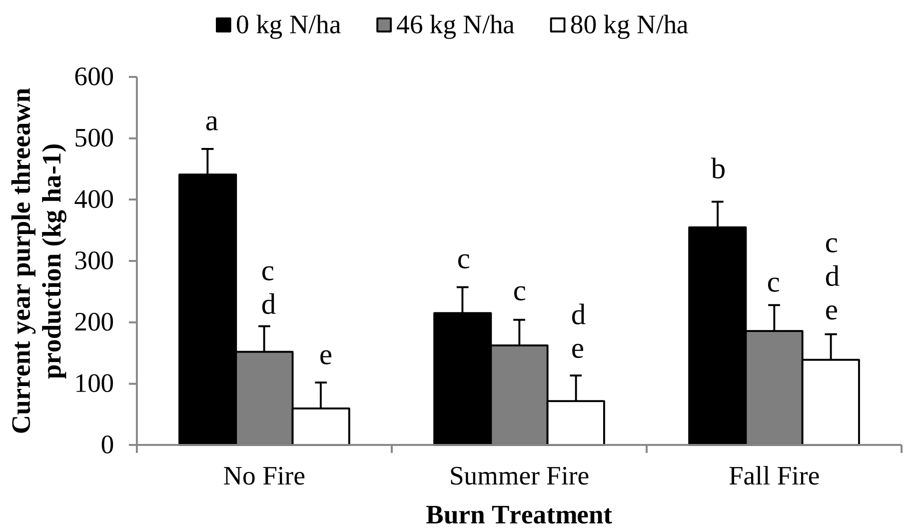

Figure 3.3. Means of current yr purple threeawn production ± standard error of the mean (kg ha-1) for fire × N-addition treatment collected the second growing season following fire and N-addition treatments. Means with common superscripts do not differ at P<0.05.

Relative composition

Control plot canopy composition was dominated by purple threeawn, and the cool-season grasses, crested wheatgrass, and needle and thread. Warm-season grasses (blue grama, buffalograss, and sand dropseed), annual grasses, and forbs, combined, totaled no more than 10%. Canopy composition for both purple threeawn and crested wheatgrass were affected by fire, N-addition, and clipping (Table 3.1). Summer fire reduced purple threeawn canopy composition (P < 0.01) and increased crested wheatgrass canopy composition (P < 0.05). Fall fire effects on relative composition did not differ for purple threeawn or crested wheatgrass *versus* controls. Both 46 and 80 kg ha^{-1} N-addition rate reduced purple threeawn canopy composition (P < 0.01) and only the 80 kg ha^{-1} N-addition increased crested wheatgrass composition (P < 0.01). Clipping increased purple threeawn canopy composition (P < 0.01) regardless of intensity. However, the opposite effect was measured for crested wheatgrass, with all clipping intensities reducing canopy composition (P < 0.01). N-addition was the only treatment to have an effect on needle and thread, with 46 kg N ha^{-1}increasing canopy cover (P < 0.01). Annual grasses were affected only by fire with near complete elimination on summer and fall fire plots (P < 0.05) (control: 1.5% > summer: 0.3% = fall: 0 ± 0.6 %). No treatment effects were detected for any warm-season grasses or forbs.

Table 3.1. Relative composition (%) response of purple threeawn, crested wheatgrass, and needle and thread in the second yr following fire and nitrogen addition and one yr following clipping (NN: no clipping of purple threeawn /no clipping of other species, NL: no clipping of purple threeawn/light clipping of other species, LM: light clipping of purple threeawn /moderate clipping of other species, MM: moderate clipping of purple threeawn /moderate clipping of other species) by treatment and species[1].

	Relative Composition		
Treatment	**Purple threeawn**	**Crested wheatgrass**	**Needle and thread**
No fire	61.8 a	20.3 b	5.8 a
Summer fire	46.1 b	32.5 a	9.8 a
Fall fire	59.7 a	23.3 b	7.0 a
0 kg N•ha^{-1}	65.7 a	20.2 b	7.4 b
46 kg N•ha^{-1}	54.5 b	21.8 b	13.1 a
80 kg N•ha^{-1}	47.4 b	34.1 a	2.1 b
NN	44.4 b	39.4 a	4.4 a
NL	58.2 a	21.6 b	10.5 a
LM	60.7 a	19.6 b	5.6 a
MM	60.2 a	20.7 b	9.7 a

[1]Means marked with the same letter within effect and species are similar (P < 0.05)

Ground cover

Cover in control plots was dominated by litter, followed by purple threeawn, and crested wheatgrass, with bare ground, other perennial grasses, forbs and annuals comprising no more than 5% of the total. As expected, both summer and fall fire reduced litter cover ($P < 0.01$; Table 3.2). Also, LM and MM clipping treatments reduced litter compared to the control ($P < 0.01$), with NL treatments having intermediate litter. Consequently, increases in bare ground were measured in both fall and summer fire plots compared to controls ($P < 0.01$), with summer fire plots showing more bare ground than fall fire plots. Bare ground also decreased from controls ($P < 0.05$) with 46 and 80 kg ha^{-1}N-addition. Of our dominant grasses, purple threeawn and crested wheatgrass, only purple threeawn showed any treatment effects. Purple threeawn basal cover was reduced by summer fire ($P < 0.01$) compared to fall fire and controls. Both 46 and 80 kg ha^{-1} N-addition had a small negative impact on purple threeawn basal cover ($P < 0.05$) compared to controls. There were no treatment effects on basal cover for any other species.

Discussion

The effects of grazing or clipping and fire on plant community composition and productivity vary considerably due to site-specific differences in climate, dominant species present, nitrogen availability, and timing and intensity of grazing and fire (Coppedge et al. 1998; Engle and Bidwell 2001; Harris et al. 2008). Wet conditions in 2011 following fire treatments, coupled with increased plant available nitrogen via N-additions, may have created optimum conditions for post-fire plant productivity and recovery of surviving plants (Smart et al. 2007; Vermeire et al. 2008). In contrast, dry conditions in 2012 may have prevented seedling establishment of less desirable annual grasses, annual forbs, and purple threeawn. This is evident in our lack of annual grass and forb production and reduced basal cover of purple threeawn in fire plots where increased bare ground may have increased site availability under wetter growing condition.

Table 3.2. Ground cover (%) response of purple threeawn, crested wheatgrass, bare ground, and litter in the second yr following fire and nitrogen addition and one yr following clipping (NN: no clipping of purple threeawn /no clipping of other species, NL: no clipping of purple threeawn /light clipping of other species, LM: light clipping of purple threeawn /moderate clipping of other species, MM: moderate clipping of purple threeawn /moderate clipping of other species) by treatment and species[1].

Treatment	Purple threeawn	Crested wheatgrass	Bare ground	Litter
No fire	14.5 a	1.3 a	5.4 c	74.4 a
Summer fire	9.3 b	4.0 a	31.7 a	50.2 b
Fall fire	18.5 a	2.6 a	17.2 b	57 b
0 kg N•ha^{-1}	17.8 a	1.7 a	22.4 a	55.6 a
46 kg N•ha^{-1}	12.6 b	2.2 a	15 b	64.4 a
80 kg N•ha^{-1}	11.9 b	3.9 a	16.9 b	61.7 a
NN	9.4 a	2.2 a	14.8 a	69.1 a
NL	15.8 a	3.0 a	16.0 a	60.7 ab
LM	16.5 a	1.5 a	18.5 a	58.8 b
MM	14.6 a	3.7 a	23.0 a	53.6 b

[1]Means marked with the same letter within effect and species are similar ($P < 0.05$).

Effects on target species: purple threeawn

Clipping increased relative composition of purple threeawn, but had no effect on production or basal cover. The increase in purple threeawn relative composition was likely driven by the decrease in crested wheatgrass. Crested wheatgrass grows to several times the height and canopy width of purple threeawn. Therefore, light and moderate clipping removed a greater percentage of standing biomass in crested wheatgrass relative to purple threeawn. Dry conditions in the 2012 growing season may have contributed to the lack of clipping effect on purple threeawn production and basal cover. However, previous research has also shown that clipping has no effect on purple threeawn root mass, shoot mass, or root: shoot ratio over a gradient of soil moisture (Perkins and Owen 2003). This lack of above-ground production response has been attributed to purple threeawn's reallocation of energy to root production following defoliation (Briske et al. 1996). Dry site conditions following clipping may have also prevented tillering of purple threeawn plants as well as establishment of seedlings.

Summer fire had the greatest negative impact on purple threeawn relative composition, basal cover, and production, two years following fire treatments. These results support prior research on the short-term effects of fire on purple threeawn abundance (Trlica and Schuster 1969; Wright 1974; Wright et al. 1978). The negative impact of summer fire on purple threeawn basal cover, relative to fall fire, illustrates the importance of timing in prescribed fire planning. The greatest negative impact that fire will have on the target species will be when that species is most vulnerable to heat and defoliation (Trlica and Cook 1971; DiTomaso et al. 2006). Purple threeawn's increased sensitivity to summer fire may be attributed to its hemicryptophyte (bunchgrass) growth form (Raunkiaer 1934) and its elevated meristems in the crown of the plant as the growing season progresses (Ewing and Engle 1988). Higher fuel loads in the bunchgrass growth form result in greater heating duration and heat dosage, increasing the probability of fire damage to the elevated meristems (Wright 1971). Summer fire may also act to prevent more below ground carbohydrate allocation relative to fall fire, thus, reducing energy storage for the following growing season.

Nitrogen addition reduced purple threeawn relative composition, basal area, and annual production relative to controls. However, decreases in annual production did not vary within 46 and 80 kg ha^{-1} N-addition rates across fire treatments. Reductions in *Aristida var. longisetta* two years following N-addition were reported in an *Aristida*-dominated abandoned cropland in the central Great Plains (Hyder and Bement 1972). However, the mechanisms by which the reduction occurred are not clear. In our study, the negative impact of N-addition on purple threeawn may be related to the early spring application of urea nitrogen and differences in timing of growth stages between purple threeawn and crested wheatgrass. As a cool-season grass, crested wheatgrass begins vegetative growth earlier in the season relative to purple threeawn. This may have allowed crested wheatgrass to utilize the increased plant available N for production prior to purple threeawn in the growing season following N application. This early increase in production for crested wheatgrass may have contributed to a competitive advantage over purple threeawn into the second growing season following N-addition.

Effects on non-target plant community

Clipping treatments had no effect on the non-target plant community with the exception of purple threeawn relative composition, which was reduced. As previously mentioned, the percentage of biomass removed with light and moderate clipping of purple threeawn was much higher than all other species clipped. Dry conditions following the clipping treatment likely prevented recovery of crested wheatgrass canopy cover to levels comparable to control plots where grazing had been prevented for three years prior.

Fire effects on the non-target plant community were limited to the CSPG functional group which was overwhelmingly comprised of crested wheatgrass. The positive effect of summer fire on crested wheatgrass relative composition was likely due to the negative effect of summer fire on purple threeawn as well as crested wheatgrass's tolerance of fire (Lodge 1960). The increase in CSPG production in fire treatment plots may indicate that the reduction of purple threeawn, relative to controls, improved the ability of crested wheatgrass to exploit more resources. Fire's positive effect on CSPG production supports previous work in the northern mixed-grass prairie (Steuter 1987; Vermeire et al. 2011). The neutral effect of fire on WSPG may be attributed to the inconsistent occurrence of the two species that were included in this group, blue grama and sand dropseed, and their opposing responses to fire. Blue grama is considered a fire tolerant species (Dwyer and Pieper 1967) and fire tends to have negative short-term effects on sand dropseed (Trlica and Schuster 1969). We must also take into account the rare initial occurrence of these species in this study.

The lack of increase in CSPG production with increasing N-addition rates and the lack of increase in relative composition at 46 kg ha^{-1}may be due to the fact that production measurements were taken in the year after N-addition treatments were applied. Nitrogen effects would have to be from N that remained available into the second growing season or through improved resistance or recovery during the first growing season. A previous study found that with 112 kg N ha^{-1} applied to crested wheatgrass plots, production was reduced in the second year relative to the first year following treatment (Jacobsen et al. 1996). Lack of adequate precipitation in the second year following N-addition may have also contributed to the lack of production response in CSPG. Precipitation following N-addition and subsequent years has been found to influence the production response in many C_3 rangeland grass species including crested wheatgrass (McGinnies 1960; Power 1985; Jacobsen et al. 1996).

Management implications

There was no evidence, in this study, to suggest that clipping following fire increases the efficacy of fire for reducing short-term purple threeawn abundance. However, there was also no evidence of negative effects on the non-target plant community. The ineffectiveness of the post-fire clipping intensities in early summer should highlight the need for further research to include more intensive grazing strategies at various times during the growing season. Fire's negative effects on purple threeawn and positive to neutral effects on cool-season and warm-season grass production and relative composition offer support for its use as a management tool to reduce purple threeawn dominance on semiarid rangelands in the short-term. The use of N-addition to enhance the positive effects of fire on the non-target plant community was less evident. As such, effectiveness of N in improving desirable species production may be contingent on adequate growing season precipitation. Moreover, long-term effects of fire, N-addition, and clipping on plant production and composition may differ from the short-term response observed in this study.

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