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RESEARCH ARTICLE

Promoting Native Vegetation and Diversity in Exotic Annual Grass Infestations

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Abstract

Exotic plant invasions are especially problematic because reestablishment of native perennial vegetation is rarely successful. It may be more appropriate to treat exotic plant infestations that still have some remaining native vegetation. We evaluated this restoration strategy by measuring the effects of spring burning, fall burning, fall applied imazapic, spring burning with fall applied imazapic, and fall burning with fall applied imazapic on the exotic annual grass, medusahead (*Taeniatherum caput-medusae* (L.) Nevski), and native vegetation at six sites in Oregon for 2 years post-treatment. Medusahead infestations included in this study had some residual native perennial bunchgrasses and forbs. Burning followed by imazapic application provided the best control of medusahead and resulted in the greatest increases in native perennial vegetation. However, imazapic application decreased native annual forb cover the first year post-treatment and density the first and second year post-treatment. The spring burn followed by imazapic application produced an almost 2-fold increase in plant species diversity compared to the control. The fall burn followed by imazapic application also increased diversity compared to the control. Results of this study indicate that native plants can be promoted in medusahead invasions; however, responses vary by plant functional group and treatment. Our results compared to previous research suggest that restoration of plant communities invaded by exotic annual grass may be more successful if efforts focus on areas with some residual native perennial vegetation. Thus, invasive plant infestations with some native vegetation remaining should receive priority for restoration efforts over near monocultures of invasive plant species.

Key words: herbicide, imazapic, invasion, medusahead, prescribed burning, *Taeniatherum caput-medusae*, weeds.

Introduction

Invasions by exotic annual grasses are a severe problem in arid and semiarid regions of western North America, Africa, Asia, and Australia (Purdie & Slatyer 1976; Mack 1981; Hobbs & Atkins 1988, 1990; D'Antonio & Vitousek 1992; Young 1992; Brooks et al. 2004; Milton 2004; Liu et al. 2006; Davies & Svejcar 2008). Invasion by exotic grasses are especially serious because they frequently increase the fire frequency, which negatively impacts native plant communities (Torell et al. 1961; Whisenant 1990; Hughes et al. 1991; D'Antonio & Vitousek 1992; Brooks et al. 2004; Milton 2004). The increase in fire frequency is an ecosystem-level change that often promotes self-perpetuation of the invading annual grass dominance of the plant community and ultimately facilitates invasion of adjacent areas (D'Antonio & Vitousek 1992). To compound the problem, efforts to control and revegetate invasive annual grass infestations are often unsuccessful (Young 1992; Rafferty & Young 2002; Milton 2004; Monaco et al. 2005).

Revegetation after annual grass control is often unsuccessful because climatic conditions rarely favor seedling establishment of native perennial species, and in the absence of competition, exotic annual grasses rapidly regain dominance of the site (Young 1992; Young et al. 1999). Exotic annual grasses often rapidly reestablish after control treatments because of abundant seed production and/or persistent seed banks (Milton 2004). Davies and Johnson (2008) suggested that restoration would be more successful in annual grass-invaded communities that still have enough native vegetation to eliminate the need for revegetation efforts. Efforts to restore exotic annual grass-invaded plant communities with residual native vegetation have not been tested and thus need to be evaluated. Treatments must be tailored to negatively impact annual grasses while minimizing undesirable effects on native vegetation. However, most research has focused on the most effective treatments to control annual grasses in near monocultures of exotic annual grasses (e.g., Monaco et al. 2005; Sheley et al. 2007).

Medusahead (*Taeniatherum caput-medusae* (L.) Nevski) infestations with some remaining native perennial grasses and forbs provide an opportunity to evaluate if native vegetation

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can be promoted with various treatments without having to attempt expensive, high risk revegetation treatments (seeding native plants). Medusahead is one of the most problematic of the exotic annual grasses invading rangelands. It decreases biodiversity, reduces livestock forage production, and degrades ecological function of native plant communities (Davies & Svejcar 2008). Medusahead invasion negatively impacts native plant communities by competition, suppression, and increasing fire frequency. It has been demonstrated to effectively compete with desirable vegetation for resources (Hironaka & Sindelar 1975; Goebel et al. 1988; Young & Mangold 2008). Medusahead litter also facilitates its dominance of plant communities because it has a slow decomposition rate, allowing litter to accumulate and suppress other plants (Bovey et al. 1961; Harris 1965). Medusahead litter accumulation also increases the amount and continuity of fine fuel, which can increase the frequency of wildfires to the detriment of native vegetation (Torell et al. 1961; Young 1992; Davies & Svejcar 2008). Similar to other exotic annual grasses, revegetation of medusahead-invaded plant communities is often unsuccessful because seeded native vegetation rarely establishes (Young 1992; Young et al. 1999; Monaco et al. 2005).

The objective of this study was to determine if selective treatments could be applied that would promote native vegetation in invasive plant infestations. Specifically, we evaluated if prescribed burning, imazapic herbicide application, and their combination could be used to promote native vegetation remaining in medusahead infestations. Imazapic application has been demonstrated to be an effective short-term control treatment for medusahead and its effectiveness has been increased with prescribed burning (Monaco et al. 2005; Kyser et al. 2007; Sheley et al. 2007). Prescribed burning has been reported to be moderately successful to completely unsuccessful at reducing medusahead depending on site and fire characteristics (Murphy & Lusk 1961; Young et al. 1972; Kyser et al. 2008). We hypothesized that: (1) all treatments would reduce medusahead and promote native vegetation; and (2) combinations of imazapic application and prescribed burning would be the most effective treatments at reducing medusahead and increasing native vegetation. We speculated that controlling medusahead would produce a positive response in native vegetation because of a release from competition and/or suppression that would outweigh any negative impacts of the treatments on the native vegetation.

Methods

Study Sites

The study was conducted in the northwest and west foothills of Steens Mountain in southeast Oregon about 65 km southeast of Burns, OR. Elevation of the study sites ranges from 1,300 to 1,500 m above sea level. Slopes are 2 to 21° and aspect ranges from northeast to south. Topographical positions of the study sites include ridge tops, side slopes, shoulder slopes, and flats. Soils are a complex of different series with 20 to 35% clay content and moderate to high shrink–swell potential (Natural Resource Conservation Service 2008). Surface rock varies from less than 1 to 15%. Long-term average annual precipitation at study sites is between 250 and 300 mm (Oregon Climatic Service 2007). The study sites were formerly sagebrush (*Artemisia*)-bunchgrass steppe. Rangeland ecological sites for our study sites were Loamy 10-12PZ and Claypan 12–16PZ (Natural Resource Conservation Service 2008). Three study sites occurred on each of these rangeland ecological sites. Characteristic vegetation for the Loamy 10-12PZ rangeland ecological site is Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* [Beetle and A. Young] S. L. Welsh), bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve), and Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth) (Natural Resource Conservation Service 2008). Characteristic vegetation for the Claypan 12-16PZ rangeland ecological site is low sagebrush (*Artemisia arbuscula* Nutt.), Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass, and Sandberg bluegrass (*Poa secunda* J. Presl) (Natural Resource Conservation Service 2008). Prior to study initiation, livestock grazed the study sites every other year for the past 16 years. Once the study was initiated, livestock were excluded from the study sites with electric fences.

Experimental Design and Measurements

A randomized complete block design was used to evaluate the effects of treatments on native vegetation and medusahead. Six sites (blocks) with varying soils, potential natural vegetation, slope, and aspect were selected. Each block consisted of six 5×5–m plots randomly assigned the various treatments with 1-m buffers between treatments. Prior to treatment vegetation cover, composition, and density were similar among plots assigned the various treatments ($p > 0.05$) (Figs. 1-3), but differed among sites ($p < 0.05$). Treatments were (1) imazapic (IMAZAPIC); (2) spring prescribed burn and imazapic (SPRING BURN-IMAZAPIC); (3) fall prescribed burn and imazapic (FALL BURN-IMAZAPIC); (4) spring prescribed burn (SPRING BURN); (5) fall prescribed burn (FALL BURN); and (6) control (CONTROL).

Spring burns were applied in mid-May of 2006 and fall burns were applied in mid-October of 2006. Burns were ignited as strip-head fires with drip torches. Fire spread at rates between 1 and 5 km/hr and maximum flame lengths were from 40 to 130 cm. Wind speeds varied between 1.6 and 8.0 km/hr, temperature ranged from 18 to 22°C, and relative humidity was between 28 and 35% during the spring burns. Fine fuels biomass ranged from 1,300 to 2,413 kg/ha depending on site and fuel moisture varied between 35 and 54% during the spring burns. Spring burning removed 89–94% of the medusahead litter and resulted in a 96–98% reduction in medusahead density for the rest of the growing season. Wind speeds ranged from 1.6 to 9.7 km/hr, temperature varied between 7 and 13°C, and relative humidity was 38–65% during the fall burns. Fine fuels biomass was 1,196–2,220 kg/ha and fuel moisture ranged from 11 to 16% during the fall burns. Fall burning removed 92–97% of the medusahead litter. Imazapic

(Plateau®) was applied at a rate of 87.5 g ai/ha in mid-October of 2006 after the fall prescribed burns were completed. This imazapic rate was selected by evaluating the success of previous local management and research projects using various rates (unpublished data). Imazapic was applied with a 10-foot handheld CO_2 sprayer (R&D Sprayers, Opelousas, LA, U.S.A.) with a tank pressure of 206.8 kPa. During imazapic application wind speeds varied from 1.2 to 5.6 km/hr and air temperatures ranged between 11 and 14°C. No precipitation occurred during application and the next precipitation event (4 mm) occurred 11 days post-application.

Vegetation measurements occurred in mid-June of 2007 and 2008. Herbaceous cover and density were measured by species in sixteen 40 × 50−cm frames (0.2 m^2) per plot. Cover was visually estimated in the 40 × 50−cm frames. Cover was estimated to the nearest 1% based on markings that divided the frame into 1, 5, 10, 25, and 50% segments. The 40 × 50−cm frames were located at 1-m intervals on four 5-m transects (starting at 1 m and ending at 4 m), resulting in four frames per transect. The 5-m transects were deployed at 1-m intervals in each plot. Herbaceous vegetation diversity was calculated from species density measurements using the Shannon diversity index (Krebs 1998). Litter and bare ground were also measured in each of the sixteen 40 × 50−cm frames per plot.

Statistical Analysis

Repeated measures analysis of variance (ANOVA) using the PROC MIX method in SAS v.9.1 (SAS Institute Inc., Cary, NC) was used to determine the effects of treatments on vegetation characteristics that were repeatedly measured. Fixed variables were treatments and random variables were sites and site by treatment interactions. The appropriate covariance structures were determined by using the Akaike's Information Criterion (Littell et al. 1996). Treatment means were separated using Fisher's protected least significant difference (LSD) ($p < 0.05$). Vegetation means are reported with standard errors (mean ± SE). For analyses, herbaceous cover and density were grouped into five functional groups: Sandberg bluegrass, large perennial bunchgrasses, perennial forbs, annual forbs, and medusahead. Sandberg bluegrass was classified as a separate functional group from other perennial bunchgrasses because of its relatively small stature and early development compared to other perennial grasses in these systems (Davies 2008; James et al. 2008). Functional groups are a common method of classifying plant species into groups based on physiological and morphological traits (Lauenroth et al. 1978). Functional groups are a useful and important method of classification for management and research (Davies et al. 2007).

Results

Large perennial bunchgrass density varied by treatment ($p < 0.01$) (Fig. 1). The FALL BURN-IMAZAPIC and SPRING BURN-IMAZAPIC treatments had greater perennial bunchgrass density than any of the other treatments ($p < 0.05$); however, the remaining treatments did not influence perennial

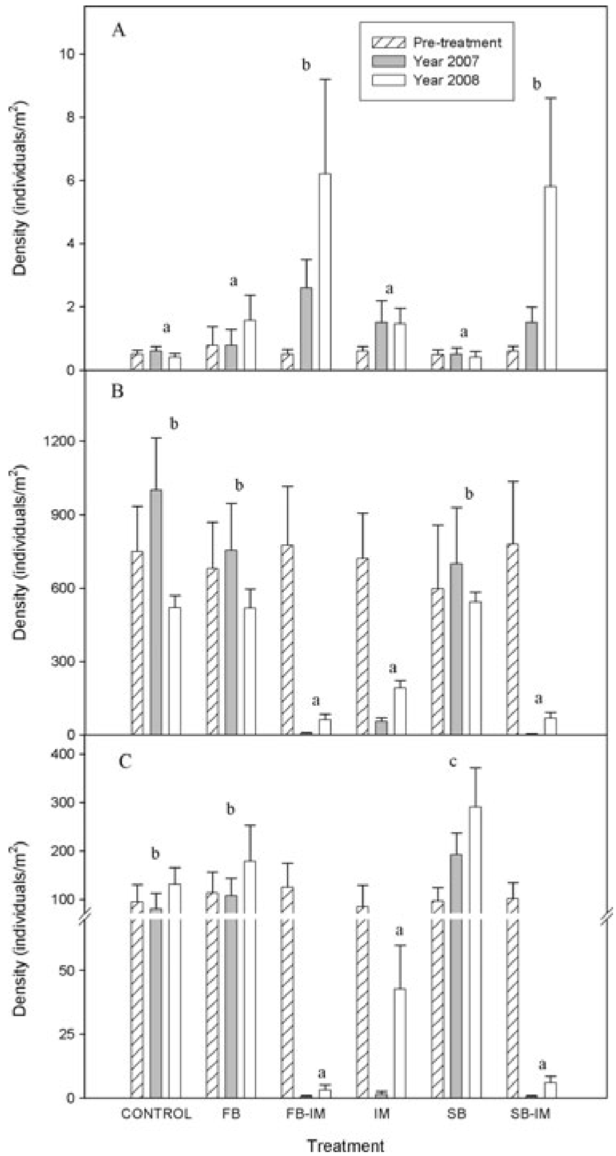

Figure 1. Large perennial bunchgrass (A), medusahead (B), and annual forb (C) densities (mean + SE) in the various medusahead control treatments prior to treatment and in 2007 and 2008. Comparisons of treatment effects were only made on post-treatment data. Pre-treatment data are reported to demonstrate that prior to treatment applications plots were similar. Treatments are CONTROL, control; FB, prescribed fall burn; FB-IM, prescribed fall burn followed with fall imazapic application (87.5 g ai/ha); IM, fall imazapic application; SB, prescribed spring burn; and SB-IM, prescribed spring burn followed with fall imazapic application. Different lower case letters indicate differences between treatments after treatment application ($p < 0.05$).

bunchgrass density ($p > 0.05$). Medusahead density was greater in the CONTROL, SPRING BURN, and FALL BURN treatments compared to the SPRING BURN-IMAZAPIC, FALL BURN-IMAZAPIC, and IMAZAPIC treatments ($p < 0.05$). However, medusahead density increased in SPRING BURN-IMAZAPIC, FALL BURN-IMAZAPIC, and IMAZAPIC treatments in 2008 compared to 2007 ($p < 0.05$), while it decreased or remained the same in the other treatments. Annual forb density was the least in the SPRING BURN-IMAZAPIC, FALL BURN-IMAZAPIC, and IMAZAPIC treatments ($p < 0.05$). Annual forb density was greatest in the SPRING BURN treatment ($p < 0.05$), but did not differ between the FALL BURN and CONTROL treatments ($p = 0.30$). Perennial forb and Sandberg bluegrass densities did not vary by treatment ($p = 0.52$ and 0.09, respectively).

Plant species diversity was influenced by treatment ($p < 0.01$). The SPRING BURN-IMAZAPIC treatment (0.80 ± 0.07) had greater diversity than the other treatments ($p < 0.05$), except it was not different from the FALL BURN-IMAZAPIC treatment (0.68 ± 0.10) ($p = 0.14$). SPRING BURN, FALL BURN, and IMAZAPIC treatments (0.60 ± 0.07, 0.56 ± 0.11, and 0.54 ± 0.08, respectively) did not differ from the CONTROL treatment (0.46 ± 0.08) ($p > 0.05$). The FALL BURN-IMAZAPIC treatment was also not different from IMAZAPIC and SPRING BURN treatments ($p > 0.05$).

Perennial forb cover was influenced by treatment and treatment by year interaction ($p < 0.01$) (Fig. 2). Perennial forb cover was similar between treatments in 2007, but in 2008 it varied among treatments. In 2008, perennial forb cover appears to have increased in the SPRING BURN-IMAZAPIC, FALL BURN-IMAZAPIC, and IMAZAPIC treatments while it appears relatively unchanged in the SPRING BURN, FALL BURN, and CONTROL treatments. Large perennial bunchgrass and Sandberg bluegrass cover differed among treatments ($p < 0.01$) and were generally greater in 2008 than 2007 ($p < 0.01$). FALL BURN-IMAZAPIC treatment increased perennial bunchgrass cover more than the other treatments ($p < 0.05$). SPRING BURN-IMAZAPIC and IMAZAPIC treatments had greater perennial bunchgrass cover than the SPRING BURN, FALL BURN, and CONTROL treatments ($p < 0.05$). Perennial bunchgrass cover did not differ among the SPRING BURN, FALL BURN, and CONTROL treatments ($p > 0.05$). Sandberg bluegrass cover was greater in the FALL BURN treatment than all the other treatments ($p < 0.05$), except the FALL BURN-IMAZAPIC treatment ($p = 0.75$). The only other difference in Sandberg bluegrass cover was that it was greater in FALL BURN-IMAZAPIC compared to the SPRING BURN-IMAZAPIC treatment ($p < 0.01$).

Medusahead cover varied among treatments and by the interaction between treatment and year ($p < 0.01$) (Fig. 3). The SPRING BURN-IMAZAPIC and FALL BURN-IMAZAPIC treatments decreased medusahead cover more than the other treatments ($p < 0.05$). The IMAZAPIC treatment decreased medusahead cover compared to the SPRING BURN, FALL BURN, and CONTROL treatments ($p < 0.01$). The SPRING BURN, FALL BURN, and CONTROL treatments did not differ in medusahead cover ($p > 0.05$). Medusahead cover increased between 2007 and 2008 in the SPRING BURN-IMAZAPIC, FALL BURN-IMAZAPIC, and IMAZAPIC treatments and decreased in the CONTROL, FALL BURN, and SPRING BURN treatments. Annual forb cover varied among treatments and by the interaction between treatment and year ($p < 0.01$). The SPRING BURN-IMAZAPIC, FALL BURN-IMAZAPIC, and IMAZAPIC treatments reduced annual forb

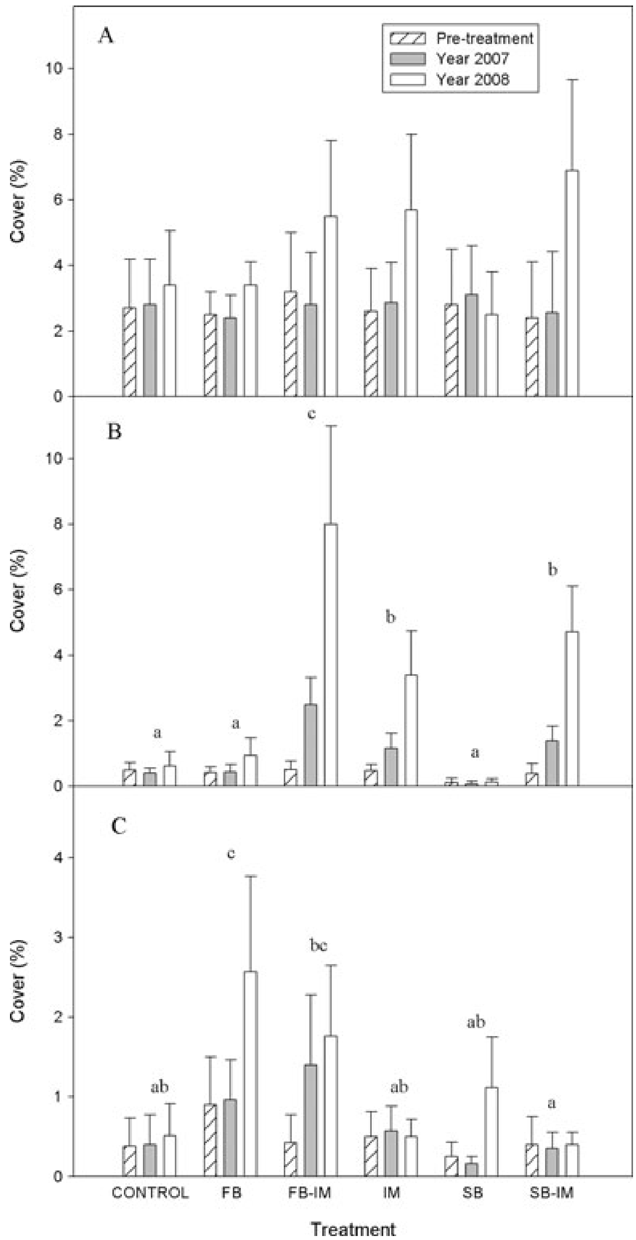

Figure 2. Perennial forb (A), large perennial bunchgrass (B), and Sandberg bluegrass cover values (mean + SE) in the various medusahead control treatments prior to treatment and in 2007 and 2008. Comparisons of treatment effects were only made on post-treatment data. Pre-treatment data are reported to demonstrate that prior to treatment applications plots were similar. Treatments are CONTROL, control; FB, prescribed fall burn; FB-IM, prescribed fall burn followed with fall imazapic application (87.5 g ai/ha); IM, fall imazapic application; SB, prescribed spring burn; and SB-IM, prescribed spring burn followed with fall imazapic application. Different lower case letters indicate differences between treatments after treatment application ($p < 0.05$).

cover in 2007, but became relatively similar to the CONTROL and FALL BURN treatments in 2008. The SPRING BURN was the only treatment to have more annual forb cover in 2007 and 2008 than the CONTROL treatment ($p < 0.01$).

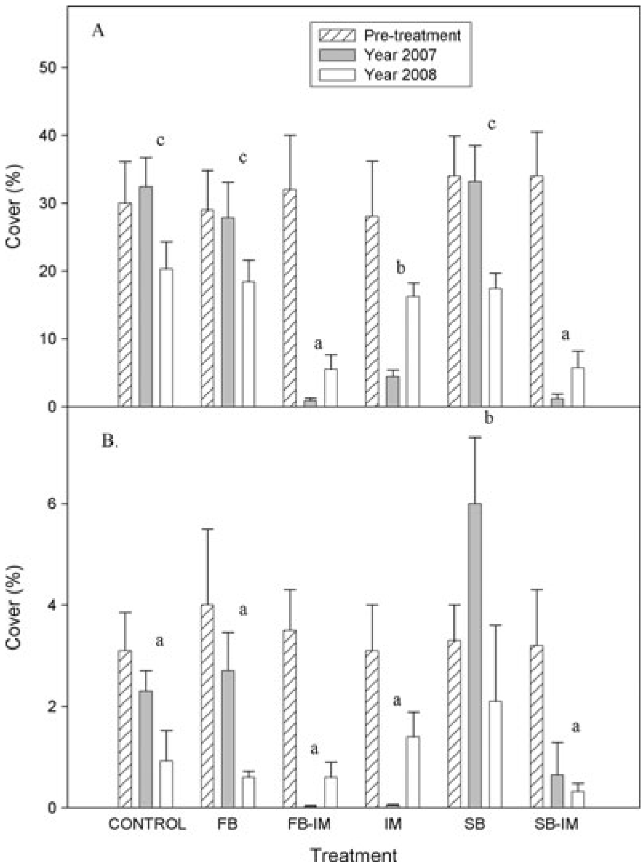

Figure 3. Medusahead (A) and annual forb (B) cover values (mean + SE) in the various medusahead control treatments prior to treatment and in 2007 and 2008. Comparisons of treatment effects were only made on post-treatment data. Pre-treatment data are reported to demonstrate that prior to treatment applications plots were similar. Treatments are CONTROL, control; FB, prescribed fall burn; FB-IM, prescribed fall burn followed with fall imazapic application (87.5 g ai/ha); IM, fall imazapic application; SB, prescribed spring burn; and SB-IM, prescribed spring burn followed with fall imazapic application. Different lower case letters indicate differences between treatments after treatment application ($p < 0.05$).

Litter and bare ground varied by treatment and the interaction between treatment and year ($p < 0.01$). Treatments compared to the control generally decreased litter and increased bare ground in 2007, except the IMAZAPIC treatment. However, the IMAZAPIC treatment had less litter and more bare ground than the CONTROL treatment in 2008. The SPRING BURN-IMAZAPIC and FALL BURN-IMAZAPIC treatments had the least litter and greatest amount of bare ground of all the treatments ($p < 0.05$). The SPRING BURN-IMAZAPIC and FALL BURN-IMAZAPIC treatments had more than 10-fold the amount of bare ground and less than one-fifth the litter cover of the CONTROL in 2008.

Discussion

Restoration may be successful without seeding in areas with some native plants growing in association with annual grass infestations; however, additional treatments may be needed to expedite vegetation recovery. Our results demonstrate that native vegetation can be promoted in exotic plant infestations by applying treatments that selectively negatively impacted exotic plants. Minimizing nontarget vegetation impacts by using a selective herbicide proved effective at promoting desired vegetation. Imazapic, used as a pre-emergence herbicide, controlled annual species and thus favored native perennial vegetation. Differences in phenology, physiology, and life cycles between native and exotic vegetation can provide opportunities to apply selective treatments to control exotics while minimizing negative impacts to native plants. However, not all treatments will selectively control exotic invaders and favor native vegetation.

In our study, not all treatments were successful at promoting native vegetation and controlling medusahead. Prescribed burn treatments without imazapic application were ineffective as medusahead control treatments and generally did not promote native vegetation. However, the spring burn treatment did increase annual forb cover and density. Control of medusahead with imazapic was improved when used with prescribed burning. Similarly, Monaco et al. (2005), Kyser et al. (2007), and Sheley et al. (2007) reported that burning prior to imazapic application increased its effectiveness. Fire may increase the effectiveness of herbicide applications by removing litter to provide better contact between the herbicide and target (DiTomaso et al. 2006). Prescribed burning treatments combined with imazapic application generally produced the most successful control of medusahead and the greatest positive response from native functional groups. However, imazapic, either as the sole treatment or in combination with prescribed burning, reduced annual forb cover in the first post-treatment year and density in both years post-treatment. Annual forbs were negatively impacted by applying this herbicide because it reduced their establishment from seed. The similarity in life cycles between annual forbs and the exotic annual grass resulted in nontarget impacts with the use of a pre-emergence herbicide. This reduction in annual forbs may be short-lived, but presents a potential risk with using imazapic. Similarities between native plant functional groups and exotic invaders must be carefully evaluated prior to applying treatments to minimize negative nontarget impacts.

The level of response of functional groups to imazapic application differed with seasonality of the burn. If the desired outcome was to maximize the increase in large perennial bunchgrass, than the most effective treatment would be fall burning followed with a fall application of imazapic. However, if a perennial forb increase was more important to management than promoting large perennial bunchgrasses, prescribed spring burning with a fall application of imazapic would be the preferred treatment. Seasonality of burn is important because it could directly and indirectly affect desired species. Spring burning prior to herbicide application probably did not promote perennial bunchgrasses as much as fall burning, because the perennial bunchgrasses were actively growing when burned in the spring. Burning early in the season when bunchgrasses are actively growing compared to fall prescribed burning can increase mortality and decrease the size of native perennial bunchgrasses (Wright & Klemmedson 1965; Britton et al. 1990; Davies & Bates 2008). Indirect impacts could be the influence of the season of burn on competition between invasive and native plants. In our study, the spring burn almost completely removed all the medusahead (96–98% decrease in density) for the remainder of the growing season allowing native perennial vegetation an extra period of growth with minimal medusahead competition.

The increase in plant species diversity with prescribed burning combined with imazapic suggest that ecosystem functions and resiliency may be improved with invasive plant control in plant communities with some residual native vegetation. Greater diversity can prevent ecosystem nutrient loss, altered nutrient cycling, and reduced carbon storage, and decreased ecosystem productivity (Tilman et al. 1997; Hooper & Vitousek 1998). The almost 2-fold increase in plant diversity with the spring burning and imazapic treatment compared to the control was similar to the difference in diversity between medusahead-invaded and noninvaded Wyoming big sagebrush steppe communities reported by Davies and Svejcar (2008). Thus, effective exotic plant control in infestations with some residual native vegetation may produce plant species diversity similar to noninvaded plant communities. The increase in large perennial bunchgrasses, which has been demonstrated to be the most important native plant functional group to impede exotic annual grasses invasion (Davies 2008; James et al. 2008), and diversity with prescribed burning and imazapic treatments suggest that these plant communities can be restored, at least partially, when sufficient native vegetation remains in exotic annual grass infestations. However, long-term evaluation of these treatments at larger scales will be needed to accurately determine the effectiveness of this restoration strategy.

The significant increase in perennial bunchgrass density in the first and second years of the study was surprising considering the reported difficultly in establishing perennial bunchgrasses in annual grass infestations (e.g., Young 1992; Rafferty & Young 2002; Milton 2004; Monaco et al. 2005). Medusahead was probably suppressing some of the large perennial bunchgrasses to the point that they were not detected in the pre-treatment sampling. The increase in large perennial bunchgrass density in the first post-treatment year would probably not be from seed because of the application of a pre-emergence herbicide. However, the increase in perennial bunchgrass density between the first and second year post-treatment suggests that at least part of the overall increase in perennial bunchgrass density was from recruitment from seed. Based on our results and the general failure of annual grass control and restoration projects that required seeding (e.g., Rafferty & Young 2002; Monaco et al. 2005), it appears that resources may be best assigned to restoring infestations that support some residual native perennial vegetation. Thus, by controlling invasive annual grasses and potentially other invasive plant species in plant communities with some native vegetation remaining, the likelihood of failure can be minimized and the high cost of seeding native species can be avoided. Furthermore, rarely are more than the dominant perennial grasses seeded after invasive plant control, because of the lack of availability or the expense of obtaining adequate quantities of native forb seeds (Davies & Svejcar 2008). Efforts to control invasive species prior to the need for a post-control seeding treatment may preserve plant species diversity. However, the gradual increase in medusahead in the second year post-treatment in even the most effective control treatments suggests that further treatments may be needed to ensure continued increases in native vegetation. Although seeding native species appears to not be required, it may improve and hasten recovery. However, additional treatments or seeding native species will greatly increase the cost.

Conclusion

Plant communities invaded by exotic annual grass that have some residual native perennial vegetation can be at least partially restored with appropriate annual grass control. Prescribed burning prior to imazapic application provides the best control of medusahead and facilitates a generally positive response from the native plant functional groups with the exception of annual forbs. However, prescribed burning increases the cost of restoration. Considering the numerous failed attempts to reestablish native plants following exotic annual grass control, resources may be more effectively allocated to controlling exotic annual grass infestations with enough native vegetation remaining to eliminate the need for exhaustive restoration, including seeding. Determining at what quantities native plant functional groups must be present in plant communities to respond positively to annual grass and other invasive plant species control without needing to be seeded would assist in prioritizing restoration efforts and improve restoration success.

Implications for Practice

- Invasive plant infestations with some native vegetation remaining should receive priority for restoration efforts over near monocultures of invasive plant species.
- Prescribed spring and fall burning followed by imazapic application provided the best control of medusahead and the greatest increases in the native perennial functional groups.
- Effective control of medusahead with imazapic application will negatively affect native annual forbs.
- Retreatment of medusahead infestations a couple of years post-treatment, probably with imazapic or other herbicides, may be needed to ensure that these plant communities continue to progress toward a plant community dominated by native species.
- The expense of and difficulty in restoring wildlands invaded by medusahead and other exotic annual grasses suggests that more efforts should be directed at preventing these invasions.

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