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Source: Rangeland Ecology & Management, 67(6):650-656. 2014.
Published By: Society for Range Management
DOI: http://dx.doi.org/10.2111/REM-D-14-00019.1
URL: http://www.bioone.org/doi/full/10.2111/REM-D-14-00019.1

Rangeland Ecol Manage 67:650–656 | November 2014 | DOI: 10.2111/REM-D-14-00019.1

#827

Can Imazapic and Seeding Be Applied Simultaneously to Rehabilitate Medusahead-Invaded Rangeland? Single vs. Multiple Entry

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Abstract

It has recently been proposed that the cost of rehabilitating medusahead (*Taeniatherum caput-medusae* [L.] Nevski)–invaded rangelands may be reduced by concurrently seeding desired vegetation and applying the preemergent herbicide imazapic. However, the efficacy of this "single-entry" approach has been inconsistent, and it has not been compared to the multiple-entry approach where seeding is delayed 1 yr to decrease herbicide damage to nontarget seeded species. We evaluated single- and multiple-entry approaches in medusahead-invaded rangelands in southeastern Oregon with seeding for both approaches occurring in October 2011. Before seeding and applying herbicide, all plots were burned to improve medusahead control with imazapic and prepare the seedbed for drill seeding–introduced perennial bunchgrasses. Both approaches effectively controlled medusahead during the 2 yr postseeding. However, almost no seeded bunchgrasses established with the single-entry treatment (< 0.5 individuals $\cdot$ m^{-2}), probably as a result of nontarget herbicide mortality. Perennial grass cover and density in the single-entry treatment did not differ from the untreated control. In contrast, the multiple-entry treatment had on average 6.5 seeded bunchgrasses $\cdot$ m^{-2} in the second year postseeding. Perennial grass (seeded and nonseed species) cover was eight times greater in the multiple-entry compared to the single-entry treatment by the second year postseeding. These results suggest that the multiple-entry approach has altered the community from annual-dominated to perennial grass–dominated, but the single-entry approach will likely be reinvaded and dominated medusahead without additional treatments because of a lack of perennial vegetation.

Key Words: annual grass control, invasive plants, preemergent herbicide, revegetation, sagebrush, *Taeniatherum caput-medusae*

INTRODUCTION

Medusahead (*Taeniatherum caput-medusae* [L.] Nevski) is an exotic annual grass that has invaded millions of hectares of rangeland in western North America and is continuing to spread at a rapid rate (Young 1992; Davies and Johnson 2008). Invasion by medusahead decreases biodiversity, reduces livestock forage, degrades wildlife habitat, and disrupts the ecological function of native plant communities (Davies and Svejcar 2008; Davies 2011). Medusahead is able to displace native vegetation because it is highly competitive (Hironaka and Sindelar 1975; Goebel et al. 1988; Young and Mangold 2008). The persistent litter layer that medusahead creates also increases the amount and continuity of fine fuels leading to more frequent fire, which favors medusahead over many native plants (Torell et al. 1961; Young 1992; Davies and Svejcar 2008) and creates a positive feedback cycle with fire (D'Antonio and Vitousek 1992). This annual grass–fire cycle can decrease the economic output of rangelands, increase wildfire suppression expenditures (Taylor et al. 2013), and furthers the risk to native wildlife, such as sage grouse (*Centrocercus urophasianus*), which are already a conservation concern (USFWS 2013). Thus, there is a critical need to rehabilitate medusahead-invaded rangelands to restore their productivity and to limit the spread of medusahead into uninfested areas.

Many efforts to rehabilitate medusahead-invaded rangeland have been unsuccessful because seeded vegetation has failed to establish after medusahead control (Young 1992; Monaco et al. 2005; Kyser et al. 2013). Davies (2010), however, found that prescribed burning followed by a fall application of the preemergent herbicide imazapic and then seeding bunchgrasses a year after application can successfully rehabilitate (establish perennial bunchgrasses) medusahead-invaded rangelands. However, this treatment strategy is expensive because several entries are required to control medusahead and seed perennial vegetation. In addition, waiting 1 yr after imazapic application to seed increases the probability that annual grasses will reinvade and subsequently reduce the establishment of seeded species (Madsen et al. 2014). Waiting a year after herbicide application to seed also delays a return on treatment investment for an additional year. An alternative approach is to simultaneously apply herbicide and seeding treatments; this may reduce the cost of rehabilitation and provide seeded species more time to establish before experiencing competition from reinvading medusahead. Sheley et al. (2001) developed such a single-entry revegetation approach that was effective in rehabilitating spotted knapweed (*Centaturea stoebe* L.)–invaded rangelands. Sheley et al. (2012a, 2012b) adapted this single-entry approach to revegetate medusahead-invaded rangelands

Research was funded in part by the Oregon Beef Council, Oregon Department of Fish and Wildlife, Oregon State University, and USDA–Agricultural Research Service.

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Manuscript received 10 February 2014; manuscript accepted 23 June 2014.

by simultaneously applying imazapic and seeding perennial grasses. The results from Sheley et al. (2012a, 2012b) showed some promise with at times increases in seeded species at some of their study sites, but results were inconsistent. The limited success and inconsistent results with using this single-entry approach may be because imazapic can cause high levels of nontarget damage to seeded species (Shinn and Thill 2004) and the response of seeded species to imazapic can be highly variable (Sheley et al. 2007). Therefore, further evaluation of the single entry approach is needed. Furthermore, the single- and multiple-entry approach to rehabilitating medusahead-invaded rangelands needs to be compared to better understand their advantages and disadvantages.

The objective of this medusahead rehabilitation research project was to compare concurrent herbicide and seeding approach (single-entry approach) to an approach where seeding is delayed until 1 yr after herbicide application to decrease injury and mortality risks to seeded species (multiple-entry approach). With both approaches, plots were burned prior to imazapic application because prescribed burning increases medusahead control and revegetation success (Davies 2010; Sheley et al. 2012a). We recognize that burning prior to imazapic application constituted another management entry, but we were interested in whether or not imazapic and seeding can be applied together in a "single entry" to successfully rehabilitate medusahead-invaded rangelands. We hypothesized that 1) perennial grass density and cover would be higher in the multiple-entry approach compared to the single-entry approach and 2) that perennial grass cover and density would be greater in the single-entry treatment compared to the untreated control.

METHODS

Study Area

The study was conducted in southeastern Oregon in the northern Great Basin. Five study sites (blocks) were located between Crane and Juntura, Oregon, in medusahead-invaded rangelands. The sites were up to 33 km apart. Elevation of the study sites ranged from 972 to 1 052 m above sea level with slopes that were relatively flat to 12° with aspects of northeast, southwest, and west. In this region, most precipitation occurs in the winter and early spring, and the summers are typically hot and dry. Long-term average annual precipitation was between 250 and 300 mm (Oregon Climatic Service 2011). Crop year (October–September) precipitation was 62% and 74% of the long-term average in 2011–2012 and 2012–2013, respectively (Eastern Oregon Agricultural Research Center, unpublished data). Soils ranged from clay loam to loam among the blocks. The sites were formerly shrub–bunchgrass steppe. At the initiation of the study the sites were near-monocultures of medusahead. For the duration of the study, livestock were excluded with a four-strand barbwire fence. Wildlife species were not excluded from the study sites.

Experimental Design and Measurements

A randomized complete block design with five blocks was used to compare treatment effects on vegetation and soil nutrient response variables. Treatments were 1) untreated control (control), 2) fall prescribed burned and imazapic application (in the same year) with seeding occurring in the fall 1 yr later (multiple entry), and 3) prescribed burned and imazapic application and seeding occurring simultaneously in the fall (single entry). Each treatment was applied to one of three 30 m×50 m plots at each block separated by a 2-m buffer. Prescribed burning occurred in the fall 2010 and 2011 in the multiple- and single-entry treatments, respectively. Burning treatments were conducted as strip-head fires ignited using drip torches. In 2010 wind speed varied from 0 $km \cdot hr^{-1}$ to 5 $km \cdot hr^{-1}$, relative humidity ranged from 21% to 48%, and air temperature varied from 14°C to 29°C during the burns applied to the multiple-entry plots. In 2011 wind speed varied from 0 $km \cdot hr^{-1}$ to 5 $km \cdot hr^{-1}$ with the exception of one plot being burned with wind speeds up to 15 $km \cdot hr^{-1}$, relative humidity was between 35% and 76%, and air temperature ranged from 8°C to 20°C during the burns applied to the single-entry plots. Burns were nearly complete across the plots with 90–95% of the medusahead litter and other fuels being consumed. Imazapic was applied at 87.5 g ai $\cdot ha^{-1}$ using a UTV-mounted seven-nozzle boom spray with a nozzle height of 0.6 m from the ground and a tank pressure of 207 kPa. In 2010 wind speed varied from 0 $km \cdot hr^{-1}$ to 5 $km \cdot hr^{-1}$, and air temperatures ranged from 7°C to 16°C during the imazapic application. In 2011 wind speed ranged from 3 $km \cdot hr^{-1}$ to 13 $km \cdot hr^{-1}$, and air temperatures varied from 15°C to 21°C during imazapic application. Perennial grasses were drill seeded in early October 2011 in the multiple- and single-entry treatments at 21.6 $kg \cdot ha^{-1}$ pure live seed with equal proportions by weight of crested wheatgrass (*Agropyron desertorum* [Fisch. Ex Link] Schult) and Siberian wheatgrass (*A. fragile* [Roth] P. Candargy) using a Versa-Drill (Kasco, Shelbyville, IN). Seeds from both species were mixed together and seeded in common drill rows spaced 23 cm apart.

Vegetation was sampled the first and second growing seasons after seeding in June 2012 and 2013, respectively. Four 45-m transects spaced 5 m apart were used to sample each treatment plot. Herbaceous canopy cover was estimated by species inside 0.2-m^2 quadrats located at 3-m intervals on each transect, resulting in 15 quadrats per transect and 60 quadrats per plot. Biological soil crust cover, litter cover, and bare ground were also estimated using the 0.2-m^2 quadrats. Herbaceous density by species was measured by counting all plants rooted inside the 0.2-m^2 quadrats.

Plant available soil nutrient concentrations of total nitrogen (NO_3^- and NH_4^+), magnesium, potassium, and phosphorus were estimated using four cation and anion ion exchange probes (PRS-probes, Western Ag Innovations, Saskatoon, Saskatchewan, Canada) in each plot. PRS-probes attract and absorb ions on an ion exchange membrane that is buried in the soil to estimate the availability of soil nutrients to plants (Jowkin and Schoenau 1998). The PRS-probes were buried vertically in the upper 20 cm of the soil profile from 1 April through 30 July 2012 and 2013.

Statistical Analysis

We estimated effects of treatments on vegetation and soil nutrient concentrations with repeated measure ANOVAs with years as the repeated factor using the PROC MIX method in

SAS v. 9.2 (SAS Institute, Cary, NC). The appropriate covariance structure for each analysis was determined using the Akaike's Information Criterion (Littell et al. 1996). When assumptions of ANOVA were violated, we log transformed data prior to analysis. Treatment means were reported as original, nontransformed data and with standard errors (mean+SE). Treatment means were separated using LSMEANS method in SAS v. 9.2 ($P < 0.05$). The split-by-year function was used in the repeated measures ANOVA to determine differences among treatments in each year. Herbaceous cover and density were grouped into six groups for analyses: introduced bunchgrass (seeded bunchgrasses), total perennial grass, Sandberg bluegrass (*Poa secunda* J. Presl), annual grass, perennial forb, and annual forb. The total perennial grass group included seeded and nonseeded perennial grasses, except Sandberg bluegrass was excluded. Sandberg bluegrass was treated as a separate group from the other perennial grasses because it is much smaller in stature and matures considerably earlier in the growing season. The annual grass group was comprised solely of exotic annual grasses and was predominately medusahead.

RESULTS

The difference in introduced bunchgrass (seeded bunchgrasses) and total perennial grass (seeded and nonseeded perennial grasses) cover between the multiple entry treatment and the other two treatments increased as introduced bunchgrasses grew larger from the first to second year (Figs. 1A and 1B; $P=0.033$ and 0.042, respectively). Introduced bunchgrass cover was 11- and 17-fold greater in the multiple-entry treatment compared to the single-entry treatment in 2012 and 2013, respectively. The control treatment had no measured introduced bunchgrass cover. Total perennial grass cover was 6- to 8-fold and 31- to 22-fold greater in the multiple-entry compared to the single-entry and control treatments in 2012 and 2013, respectively. Introduced bunchgrass and total perennial grass cover did not differ between the control and single-entry treatments ($P=0.832$ and 0.709, respectively). Annual grass cover was less in the multiple entry and single entry compared to the control (Fig. 1C; $P < 0.001$), but did not differ between the multiple- and single-entry treatments ($P=0.443$). The control treatment had 21 and 6 times greater annual grass cover compared to the multiple-entry treatment in 2012 and 2013, respectively. Annual grass cover was 920- and 215-fold greater in the control compared to single-entry treatment in 2012 and 2013, respectively. Sandberg bluegrass cover did not differ among treatments (Fig. 1D; $P=0.325$). Perennial forb cover varied by the interaction between treatment and year ($P=0.049$). In 2012 perennial forb cover was less in the single entry than the other treatments ($P < 0.001$), but in 2013 there was no difference among treatments (Fig. 1E; $P=0.297$). There was a significant interaction between treatment and year effects on annual forb cover ($P=0.002$). In 2012 there was no difference between treatments (Fig. 1F; $P=0.761$), but in 2013 annual forb cover was greater in the control compared to the other treatments ($P < 0.001$). Biological soil crust cover did not differ among treatments (data not presented; $P=0.370$). Bare ground was less, and litter was greater in the control compared to the other treatments (Figs. 1G and 1H; $P < 0.001$), but did not differ between the single- and multiple-entry treatments ($P=0.445$ and 0.544, respectively). In 2013 bare ground was more than 30 times greater in the single- and multiple-entry treatments compared to the control. Litter was 9- to 10-fold greater in the control treatment compared to other treatments in 2013.

Introduced bunchgrass and total perennial grass density was greater in the multiple-entry compared to single-entry and control treatments in both years (Figs. 2A and 2B; $P < 0.001$) but did not differ between the single-entry and control ($P > 0.05$). Introduced bunchgrass density was 22- and 13-fold greater in the multiple-entry compared to the single-entry treatment in 2012 and 2013, respectively. Introduced bunchgrasses were not detected in the control. Total perennial grass density was 6- and 4-fold and 30- and 17-fold greater in the multiple entry compared to the single-entry and control treatments in 2012 and 2013, respectively. Annual grass density was greater in the control compared to the multiple- and single-entry treatments (Fig. 2C; $P < 0.001$), but did not differ between the multiple- and single-entry treatments ($P=0.640$). Annual grass density averaged 1.5, 37, and 877 plants $\cdot$ m^{-2} in the single-entry, multiple-entry, and control treatments, respectively. Sandberg bluegrass density did not differ among the treatments (Fig. 2D; $P=0.427$). Perennial forb density differed by treatment in 2012 (Fig. 2E; $P=0.019$), but in 2013 there was no difference among treatments ($P=0.462$), resulting in a significant treatment-by-year interaction ($P=0.027$). Annual forb density was greater in the control compared to the multiple- and single-entry treatments (Fig. 2F; $P < 0.001$), but did not differ between the multiple- and single-entry treatments ($P=0.509$). Averaged over both years, annual forb density was 12- and 291-fold greater in the control compared to the multiple- and single-entry treatments, respectively.

Total plant available nitrogen (N) soil concentrations showed a significant treatment-by-year interaction (Fig. 3A; $P=0.033$). In 2012 total N was 1.4-fold greater in the multiple-entry compared to the single-entry treatment ($P=0.05$). In 2013 total N was 1.7-fold greater in the single-entry treatment compared to the multiple-entry treatment ($P < 0.001$). The control had less total N than the other treatments ($P < 0.001$). Plant available magnesium, potassium, and phosphorus soil concentrations did not vary among treatments (Fig. 3B–3D; $P=0.812$, 0.139, and 0.092, respectively).

DISCUSSION

Our results suggest that medusahead-invaded sagebrush rangeland can be effectively revegetated with a multiple-entry approach where infested land is prescribed burned and treated with imazapic in the fall and then seeded with Siberian and crested wheatgrass the next fall. Comparing results from this approach to the single-entry approach suggests that seeding should be postponed for 1 yr after imazapic application to reduce nontarget herbicide damage to Siberian and crested wheatgrass. Though there would be significant cost savings with a single-entry approach where imazapic application and seeding occur simultaneously (Sheley et al. 2012a, 2012b), the magnitude of difference in seeded perennial bunchgrass density and cover between the single- and multiple-entry approaches

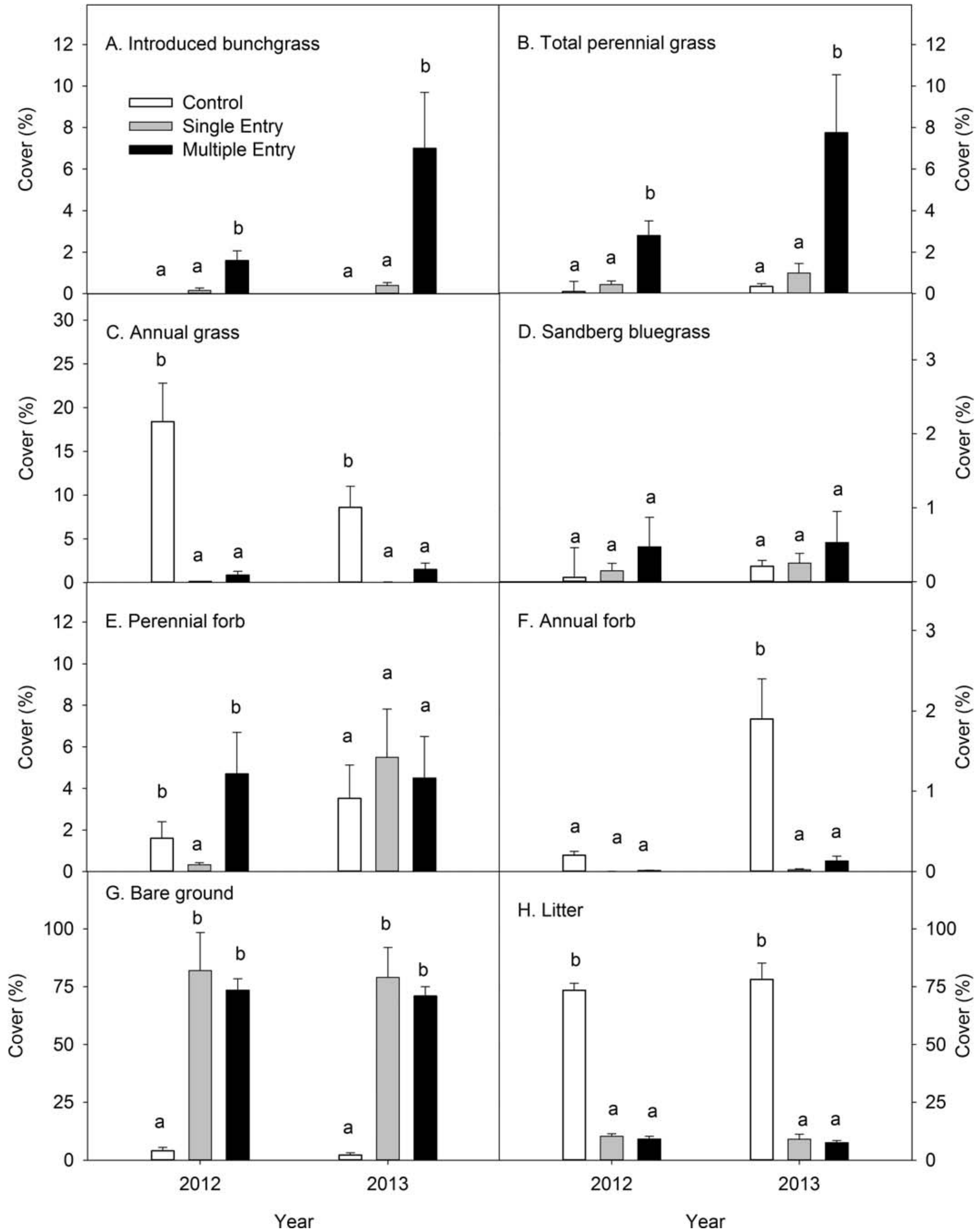

Figure 1. Cover (mean+SE) of plant groups, bare ground, and litter in the untreated control (control), simultaneous application of imazapic and seeding (single entry), and application of imazapic and then seeding 1 yr later (multiple entry) treatments. Differing lower case letters indicated a significant difference ($P \leq 0.05$) between treatments in that year.

(Fig. 4) suggests that the cost savings are unlikely worth the reduction in revegetation success. Additionally, in our study seeding using a single-entry approach did not statistically increase perennial grass density relative to the unseeded control. Similarly, Sheley et al. (2012b) found that at one site seeded species density (measured as tillers) was not different between the single-entry treatment and the unseeded plots, but, in contrast, the other site included in their study had greater density of seeded species with the single-entry strategy. Though seeded perennial bunchgrasses generally failed to establish with the single-entry approach in our study, using a lower rate of imazapic than applied in our study may have resulted in greater bunchgrass establishment (Sheley et al. 2012a, 2012b). However, using a lower rate of imazapic would likely reduce its weed control effectiveness and may necessitate follow-up treatments to reduce competition of medusahead with seeded species (Sheley et al. 2012a).

The multiple-entry approach has likely changed the trajectory of the plant community from continued annual dominance to dominance by the seeded perennial bunchgrasses. Similar to Davies (2010), we found that seeding perennial bunchgrasses 1 yr after prescribed burning and imazapic application generally resulted in more than six established bunchgrasses $\cdot$ m^{-2}. Davies (2008) reported a strong negative correlation between mature

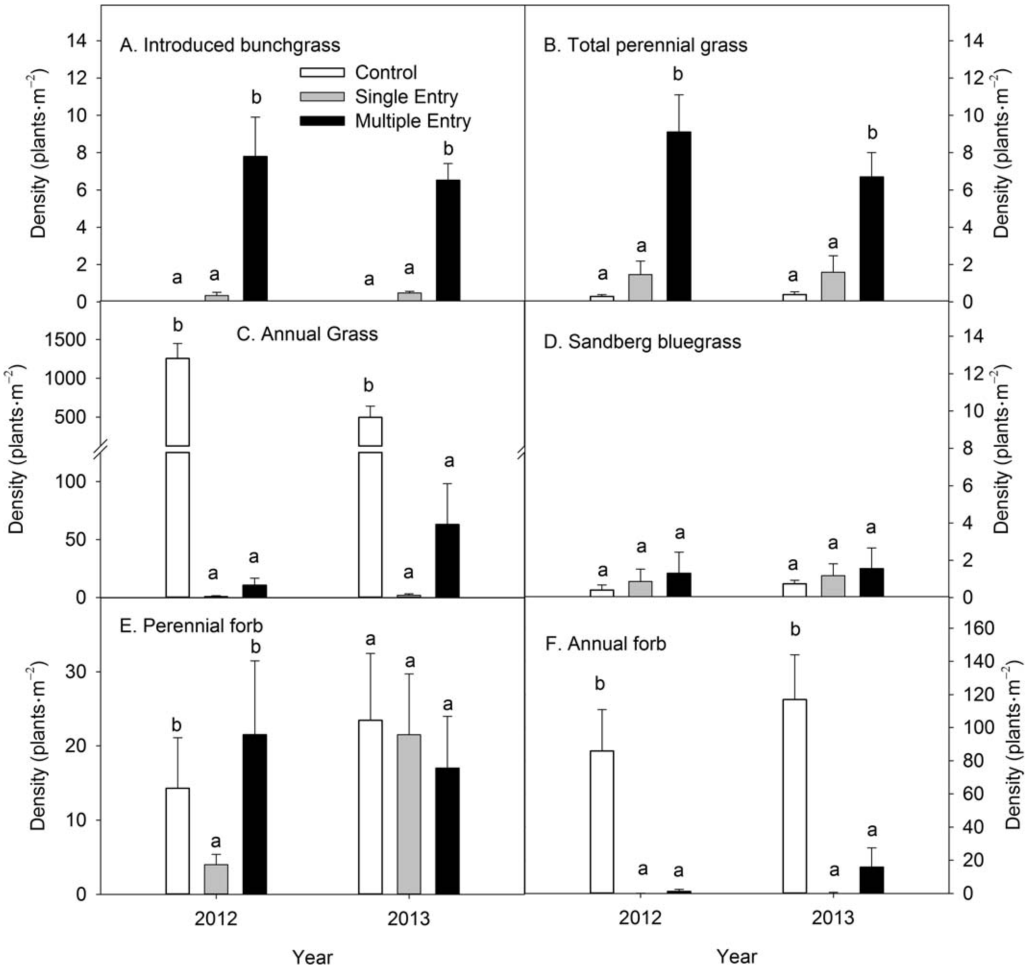

Figure 2. Density (mean+SE) of plant groups in the untreated control (control), simultaneous application of imazapic and seeding (single-entry), and application of imazapic and then seeding 1 yr later (multiple-entry) treatments. Differing lower case letters indicated a significant difference ($P \leq 0.05$) between treatments in that year.

bunchgrass density and medusahead establishment and found that medusahead establishment declined markedly when bunchgrass density exceeded 6 plants $\cdot$ m^{-2}. In addition, the multiple-entry plots were seeded with bunchgrass species that can effectively limit medusahead invasion. In southeastern Oregon, Davies et al. (2010) found that seeding crested wheatgrass in areas at risk of invasion limited medusahead establishment and spread. Therefore, the plant communities revegetated using the multiple entry approach in our study should be fairly resistant to medusahead reinvasion.

In contrast, the limited establishment of seeded bunchgrasses with the single-entry approach suggests that these areas will be reinvaded and dominated by medusahead in the future. Perennial grass density of 1.6 plants $\cdot$ m^{-2} in plots treated with the single-entry approach may not be sufficient to exploit soil resources enough to limit medusahead reinvasion (Davies 2008). The perennial grass density in the single-entry plots was also not statistically different than the untreated control further suggesting perennial grasses will not prevent medusahead from reinvading. Without successful establishment of seeded species after control, medusahead regains dominance of the plant community (Young 1992; Monaco et al. 2005). To be successful, the single-entry plots will probably need to be seeded a second time, thus eliminating any cost savings. In agreement, Sheley et al. (2012a) acknowledged that additional treatments may be necessary when using the single-entry approach to rehabilitate medusahead-invaded rangelands.

The response of plant available total N suggests that the multiple-entry approach was already decreasing the susceptibility of the plant community to medusahead reinvasion by the second year after seeding, as medusahead establishment decreases with decreasing N (Young et al. 1998). The first year after seeding the multiple-entry approach had more plant available total N in the soil than the single-entry approach, but by the second year after seeding total N was 1.7-fold higher in the single-entry approach compared to the multiple-entry approach. The greater total N in the multiple-entry approach in the first year was probably a fallowing effect because the plots had almost no live vegetation (other than a few remnant bunchgrasses) during the 2011 growing season. Fallowing is the practice of controlling weeds but not planting a crop in the field that year to increase resources, often soil water and N, for a crop the next year (Smika and Wicks 1968; Elliott et al. 1984). The fallowing effect may be, in part, why this treatment combination has been effective for revegetation of medusahead-invaded rangelands. By the second year after seeding, the seeded bunchgrasses in the multiple entry

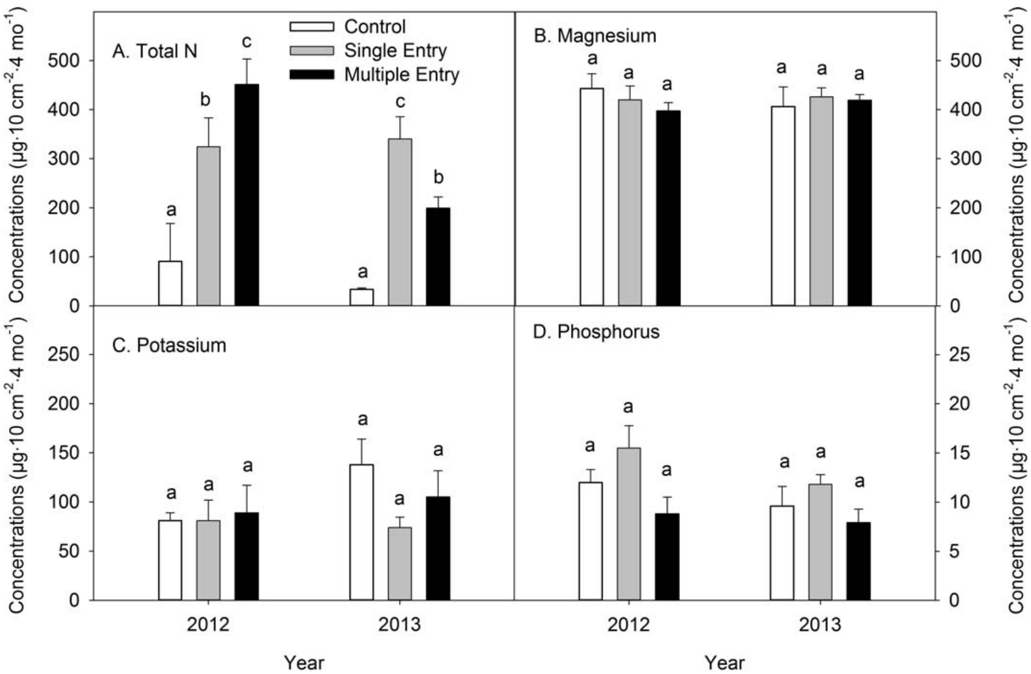

Figure 3. Plant available nutrients (mean + SE) in the untreated control (control), simultaneous application of imazapic and seeding (single-entry), and application of imazapic and then seeding 1 yr later (multiple-entry) treatments. Differing lower case letters indicated a significant difference ($P \leq 0.05$) between treatments in that year.

treatment plots had greatly increased in size and likely their associated acquisition of plant available N and thereby probably increased community resistance to medusahead reinvasion. We expect to see this trend of decreasing N availability continue as seeded bunchgrasses increase in size and likely increase their resource acquisition.

The economic advantages of a single-entry approach that is successful are apparent (Sheley 2007; Sheley et al. 2012a, 2012b); however, to be a practical treatment for rehabilitating medusahead-invaded rangelands with imazapic, a substantial increase in the success of seeded vegetation is needed. One potential method to increase the success of seeded species may be to use activated carbon to deactivate imazapic in the immediate vicinity of seeded species. Activated carbon has a high surface area allowing it to bind to and deactivate various herbicides (Coffey and Warren 1969). In a greenhouse study, incorporating activated carbon into seed coats and pellets greatly decreased the negative effects of imazapic on seeded bunchgrass (Madsen et al. 2014). However, this method cannot be recommended at this time because it has not yet been validated with field trials.

Though the single entry approach was not successful in our study, there may be other opportunities to reduce the cost of rehabilitating medusahead-invaded rangelands. Wildfires in medusahead-invaded rangelands may provide an opportunity to reduce the cost of integrated programs to rehabilitate these rangelands by eliminating the need to conduct prescribed burning prior to applying imazapic (Davies et al. 2013). The single-entry approach is a valuable method to reduce the cost of programs to rehabilitate exotic plant-invaded rangelands (Sheley et al. 2001; Sheley 2007), but its utility appears limited when imazapic is used in efforts to rehabilitate medusahead-invaded rangelands or at least requires significant refinement. The multiple-entry approach was successful at establishing a plant community that

Figure 4. Photograph of the multiple entry approach (left) and the single entry approach (right) to rehabilitate medusahead-invaded rangelands. Photographs were taken after the second growing season postseeding.

will likely resist medusahead reinvasion; however, longer-term evaluations of both treatments would be valuable for determining treatment effects on plant community succession.

MANAGEMENT IMPLICATIONS

Our results suggest that the multiple entry approach of waiting 1 yr to seed perennial grasses after postburn imazapic application to control medusahead is more effective than the single-entry approach of simultaneously applying imazapic and seeding perennial grasses. Clearly the idea of a single-entry approach is appealing, but the general lack of seeded bunchgrass establishment we observed in this study suggests additional treatments may be needed to establish sufficient perennial grasses. Any benefit of a single-entry approach will be lost if reentry proves necessary. However, as research refines the use of activated carbon in seed coats and pellets there may be opportunities in the future to successfully rehabilitate medusahead-invaded rangelands using a single-entry approach with imazapic. There may also be the possibility to use lower rates of imazapic or alter the timing of its application to control medusahead and allow the establishment of seeded species with a single-entry approach, but to date no effective prescription has been developed. The success of multiple and single entry approaches when using imazapic likely also varies substantially with site characteristics and climatic conditions. However, our results suggest that revegetation of medusahead-invaded rangelands will be most successful when perennial bunchgrasses are seeded 1 yr after imazapic application. Our results also provide further evidence that medusahead-invaded rangelands can be successfully rehabilitated by fall burning followed with imazapic application and seeding introduced perennial bunchgrasses the following fall.

ACKNOWLEDGMENTS

The authors thank Urban "Woody" Strachan and summer students for assistance with data collection. The authors sincerely thank the Ott Ranch, Second Oregon Ranch, and Oregon Department of State Lands for allowing this research to be conducted on lands they own or administer. The authors also appreciate the thoughtful reviews provided by Drs Erik Hamerlynck and Brenda Smith.

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