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Ventenata and Other Coexisting Exotic Annual Grass Control and Plant Community Response to Increasing Imazapic Application Rates☆

Kirk W. Davies [a,]*, Erik Hamerlynck [b]

[a] Rangeland Scientist, US Department of Agriculture —Agricultural Research Service, Eastern Oregon Agricultural Research Center
[b] Ecologist, US Department of Agriculture —Agricultural Research Service, Eastern Oregon Agricultural Research Center

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ABSTRACT

Ventenata (*Ventenata dubia* [Leers] Coss.) is an exotic annual grass that can invade intermountain rangeland plant communities, where it can form monotypic stands, degrade wildlife habitat, and reduce livestock forage. There is limited information on ventenata control in rangelands as it has only recently been identified as a substantial problem. Imazapic is a pre-emergent herbicide commonly used to control other exotic annual grasses and, therefore, is likely to control ventenata in rangelands. We evaluated five application rates of imazapic ($0-175$ g ae$\cdot$ha^{-1}) on ventenata and other exotic annual grass control and plant community response at two rangeland sites in 2 yr (2014 and 2015). Imazapic reduced exotic annual grass (largely ventenata) cover and density, with greater control with increasing imazapic rates. Exotic annual grass density at the highest levels of control (82%−94%) was $184-299$ plants$\cdot$m^{-2} the first yr after imazapic application. Exotic annual grasses fully recovered in the second or third yr after imazapic application. Bare ground generally increased with imazapic application. However, density of perennial vegetation (grasses and forbs) did not vary among treatments. Perennial vegetation cover generally did not increase with imazapic control of ventenata and other exotic annual grasses. Imazapic can control ventenata; however, even at the highest rates, control was not enough to shift the dominance from exotic annual species to perennial species. Integrating other treatments with imazapic application may be a strategy to improve ventenata control and increase perennial vegetation and will require further investigation. The difficulty and likely expense of achieving substantial and lasting control of ventenata suggest, similar to other exotic annual grasses, that preventing ventenata invasion and dominance should be a high management priority.

Introduction

Exotic annual grass invasion and dominance is a serious management concern and causes substantial degradation of native ecosystems, especially in the western United States (Brooks et al., 2004; Davies et al., 2011; Chambers et al., 2014). Invasion by exotic annual grasses can increase wildfire frequency by increasing fine fuel amounts and continuity (D'Antonio and Vitousek, 1992; Davies and Nafus, 2013). Annual grass fuel also dries out earlier than native vegetation, potentially elongating the wildfire season (Brooks, 2008; Davies and Nafus, 2013). Exotic annual grass invasions are often an ecosystem-level change that converts native savannas, shrublands, and shrub-grasslands to near-monocultures of annual grasses (D'Antonio and Vitousek, 1992; Brooks et al., 2004). Conversion of native plant communities to exotic annual grasslands decreases biodiversity and ecosystem services (Belnap and Phillips, 2001; Davies, 2011).

Ventenata (*Ventenata dubia* [Leers] Coss.), also known as North Africa grass and wiregrass, is an exotic annual grass that is becoming of increasing concern across the western United States. Ventenata has rapidly spread in the Intermountain West and is especially problematic in grass-hay production systems, Conservation Reserve Program (CRP) lands, and rangelands (Wallace et al., 2015; Avert et al., 2016; Wallace and Prather, 2016). Ventenata is also expanding into sagebrush rangelands (Jones et al., 2018). In rangelands, ventenata dries out earlier than native perennial vegetation and increases the continuity of fine fuels, thereby increasing fire risk (Fryer, 2017). Ventenata appears to be generally unpalatable to cattle as they often consume substantial amounts of vegetation in and around infestation without any noticeable grazing of ventenata (personal observation). Hay infested with ventenata has low palatability to cattle (McCurdy et al., 2017). Ventenata is also competitive with

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* Correspondence: Kirk Davies, US Dept of Agriculture–Agricultural Research Service, Eastern Oregon Agricultural Research Center, 67826-A Hwy 205, Burns, OR 97720, USA. Tel.: +1 541 573 4074.
E-mail address: kirk.davies@ars.usda.gov (K.W. Davies).

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native perennial grasses (McKay et al., 2017). Similar to other exotic annual grasses, ventenata invasion of rangelands is expected to decrease biodiversity, decrease forage production, and degrade wildlife habitat (Fryer, 2017).

Though ventenata has been present since the 1950s in the Intermountain West, it has only been identified as a significant issue in the past decade (Wallace and Prather, 2016). Subsequently, there are substantial knowledge gaps about its ecology and management, especially in rangelands. Ventenata invasion can produce near-monotypic stands (Wallace and Prather, 2016) requiring development of management approaches that both control ventenata and promote perennial vegetation. Preemergent herbicides have been used in such approaches in rangelands for controlling other invasive annual grasses, including cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* [L.] Nevski) (Kyser et al., 2007; Elseroad and Rudd, 2011; Mangold et al., 2013). Preemergent herbicides demonstrate potential for controlling ventenata (Sebastian et al., 2016; Wallace and Prather, 2016) but have not been evaluated in rangelands.

Imazapic is a preemergent herbicide commonly used to control exotic annual grasses in noncultivated lands. Ventenata has been controlled with imazapic in a greenhouse study (Sebastian et al., 2016) and in grasslands (Wallace and Prather, 2016). Ventenata in rangelands, therefore, can likely be controlled with imazapic. Imazapic control of other annual grasses generally increases with increasing application rates; however, full control is often achieved before the highest rates (Kyser et al., 2007; Sheley et al., 2007). Imazapic can cause injury to perennial grasses, dependent on rates, timing of application, and species (Shinn and Thill, 2004; Kyser et al., 2007). Therefore, evaluating different imazapic application rates is critical to determine ventenata control efficiency, as well as plant community response in rangeland systems.

The objective of this study was to evaluate varying rates of imazapic application on control of ventenata and coexisting exotic annual grasses and plant community response. We hypothesized that 1) increasing imazapic application rates would improve exotic annual grass (primarily ventenata) control and 2) perennial grasses and forbs would increase with exotic annual grass control.

Methods and Materials

Study Area

The study was conducted in two ventenata-invaded sites in Grant County south and southeast of John Day, Oregon at 1 111 and 1 320 m above sea level and separated by 21 km. Slopes were relatively flat (< 4°). In this region, most precipitation occurs in the winter and early spring and summers are typically hot and dry. Long-term (1981 − 2010) average annual precipitation was 353 mm and 441 mm at Site 1 and Site 2, respectively (PRISM, 2018). Crop year (Oct.−Sept.) precipitation at Site 1 was 85%, 101%, 83%, and 104% of the long-term average in 2013 − 2014, 2014 − 2105, 2015 − 2016, and 2016 − 2017, respectively (PRISM, 2018). Crop year precipitation at Site 2 was 86%, 99%, 87%, and 104% of the long-term average in 2013 − 2014, 2014 − 2105, 2015 − 2016, and 2016 − 2017, respectively (PRISM, 2018). Soils were shallow clayey and loamy at Site 1 and Site 2, respectively. The potential natural vegetation at these study sites was shrub steppe with an understory dominated by Idaho fescue (*Festuca idahoensis* Elmer) and bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve). The overstory included antelope bitterbrush (*Purshia tridentata* [Pursh] DC.) and low sagebrush (*Artemisia arbuscula* Nutt.) before ventenata dominance. Shrubs had been lost from the study sites from previous wildfires. Livestock were excluded from both sites for the duration of the study with four-strand barbwire fencing. Wildlife were not excluded from study sites.

Experimental Design and Measurements

A randomized complete block design at two sites was used to evaluate different imazapic application rates replicated four times at each site. The entire experiment was repeated in 2014 and 2015. Treatments were imazapic applied at 0 (nontreated control), 70, 105, 140, and 175 g ae·ha^{-1}, with application treatments randomly assigned to 5 × 10 m plots in each block at each site in each year. A 2-m buffer was placed between treatment plots. Imazapic was applied in 2014 on 2 and 3 October and in 2015 on 29 and 30 September. In 2014, winds speeds ranged from 0.6 to 6.2 km·hr^{-1}, relative humidity varied from 20% to 40%, and temperatures were between 11°C and 21°C during imazapic application. In 2015, winds speeds ranged from 1.0 to 6.5 km·hr^{-1}, relative humidity varied from 17% to 20%, and temperatures were between 21°C and 24°C during imazapic application. Imazapic treatments were applied with water at a rate of 140 L·ha^{-1} (15 gallons·ac^{-1}) using a manual pump backpack sprayer with a fan nozzle.

Vegetation measurements were conducted in June in 2015, 2016, and 2017 and June in 2016 and 2017 for the 2014 and 2015 applications, respectively. Two 10-m transects spaced 2 m apart and located parallel to the long edge of the plot were used to sample each treatment plot. Vegetation foliar cover by species was estimated in ten 0.2 m^2 (40 × 50 cm) quadrats located at 2-m intervals along the two 10-m transects. Biological soil crust, bare ground, and litter cover were also estimated in the 0.2-m^2 quadrats. Herbaceous density for perennial species was measured by counting all individuals rooted inside the 0.2-m^2 quadrats. Annual grass and annual forb density were measured by counting all individuals rooted inside a corner (10%) of the 0.2-m^2 quadrats. Shrubs were not present in any treatment plot, so shrub cover and density were not measured.

Statistical Analyses

Repeated measures analysis of variances (ANOVAs) with sampling year as the repeated factor using the PROC MIXED method in SAS v. 9.4 (SAS Institute Inc., Cary, NC) were used to compare vegetation characteristics among treatments. The 2014 and 2015 applications were analyzed individually because they differed in the number of post-treatment sampling years. There was not a site • treatment interaction for any response variable; thus, data from both sites were analyzed together. The appropriate covariance structure for each analysis was selected using the Akaike's Information Criterion (Littell et al., 1996). When needed, data were log transformed before analysis to meet ANOVA data distribution assumptions. Treatment means were reported as original, nontransformed data and with standard errors (mean + S.E.). Post-hoc treatment means were separated using the Tukey method ($P < 0.05$). Herbaceous vegetation was grouped into four groups for analyses: perennial grass, exotic annual grass, perennial forb, and annual forb. The exotic annual grass group was primarily composed of ventenata but also included medusahead and cheatgrass. Ventenata comprised 81 − 96% and 88 − 99% of the density and cover of the exotic annual grass group in test plots in each year.

Results

2014 Application

Exotic annual grass density showed a treatment • year interaction (Fig. 1A; $P < 0.001$). In the first 2 yr post treatment, exotic annual grass density generally decreased with increasing imazapic application rate, but by the third yr exotic annual grass density was similar among all treatments. Perennial grass density was not influenced by the treatment • year interaction ($P = 0.882$) and did not vary among treatments ($P = 0.258$) but was greater in 2016 than 2015 and 2017 ($P = 0.039$). Perennial grass density averaged 14.8 ± 3.3, 12.9 ± 2.0, 15.7 ± 2.1, and 16.4 ± 2.4 plants·m^{-2} in the 0, 70, 105, 140, and 175 g ae·ha^{-1}

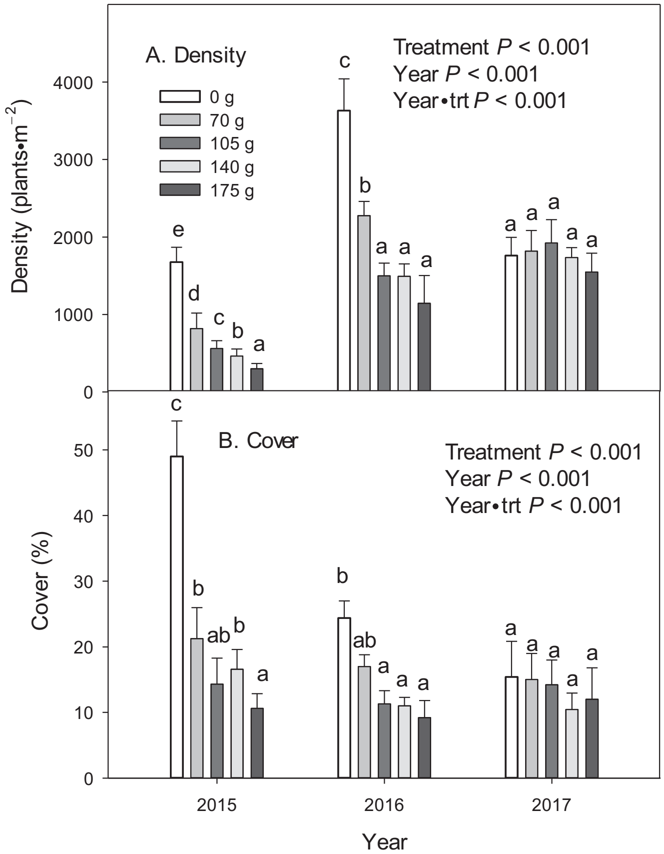

Figure 1. Exotic annual grass (primarily ventenata) density (**A**) and cover (**B**) (mean + S.E.) across five rates of imazapic application (0 − 175 g ae·ha^{-1}) in the three post-treatment growing seasons following the 2014 application. Year • trt = treatment • year interaction. Different lowercase letter indicates difference between treatment means (P < 0.05) for that growing season.

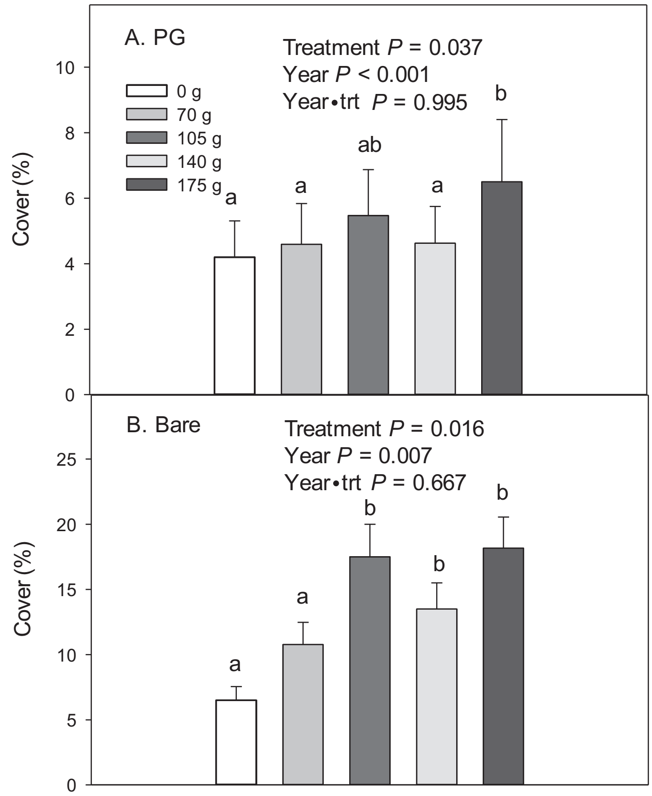

Figure 2. Perennial grass (**A**) and bare ground (**B**) cover (mean + S.E.) across five rates of imazapic application (0 − 175 g ae·ha^{-1}) in the three post-treatment growing seasons after the 2014 application. Year • trt = treatment • year interaction. Different lowercase letter indicates difference between treatment means (P < 0.05) for that growing season.

treatments, respectively. Perennial forb and annual forb density were not influenced by the treatment • year interaction (P = 0.776 and 0.930, respectively; data not shown) and did not vary among treatments (P = 0.193 and 0.126, respectively). Perennial and annual forb density differed among years (P < 0.001) with greater densities in 2016 than 2015 or 2017.

Consistent with density data, exotic annual grass cover was influenced by the treatment • year interaction (Fig. 1B; P < 0.001) and generally declined with increasing imazapic rates in the first 2 yr after treatment, but by the third yr there was not a difference among treatments. Perennial grass cover varied among treatments (Fig. 2A; P = 0.037). Perennial grass cover was greatest in the 175 g ae·ha^{-1} treatment (P < 0.02) but did not differ from the 105 g ae·ha^{-1} treatment (P = 0.095). Perennial grass cover did not differ among the other treatment comparisons (P > 0.05). Perennial grass cover was greater in 2016 than 2015 and 2017 (P < 0.001). Perennial forb and annual forb cover (data not shown) were not influenced by the treatment • year interaction (P = 0.779 and 0.942, respectively) and were similar between treatments (P = 0.193 and 0.126, respectively). Perennial and annual forb cover were greater in 2016 than 2015 and 2017 (P < 0.001). Bare ground varied among treatments (Fig. 2B; P = 0.016) with it being greater at the three highest rates of imazapic application. Bare ground decreased over time (P = 0.007) but was not influenced by the treatment • year interaction (P = 0.667). Litter and biological soil crust cover (data not shown) were not influenced by the treatment • year interaction (P = 0.153 and 0.796, respectively) and did not vary among treatments (P = 0.534 and 0.130, respectively) but varied among years (P < 0.001). Litter was greater in 2017 than 2015 and 2016. Biological soil crust cover was greater in 2016 than 2015 and 2017.

2015 Application

Exotic annual grass density was influenced by the treatment • year interaction (Fig. 3A; P < 0.001). In the first yr post treatment, annual grass density generally decreased with increasing imazapic application rate. However, by the second yr, exotic annual grass density was similar among treatments. Perennial grass density was not influenced by the treatment • year interaction (P = 0.077) and did not differ among treatments (P = 0.271) or between years (P = 0.117). Perennial grass density averaged 9.6 ± 1.8, 10.3 ± 1.8, 15.5 ± 2.5, 13.8 ± 2.0, and 11.0 ± 2.0 plants·m^{-2} in the 0, 70, 105, 140, and 175 g ae·ha^{-1} treatments, respectively. Perennial forb and annual forb densities (data not shown) were not influenced by the treatment • year interaction (P = 0.750 and 0.347, respectively) and did not vary among treatments (P = 0.506 and 0.318, respectively). Perennial forb density was similar between years (P = 0.997); however, annual forb density was greater in 2017 compared with 2016 (P < 0.001).

Exotic annual grass cover was influenced by the treatment • year interaction (Fig. 3B; P = 0.009). In the first yr post treatment, annual grass cover generally decreased with increasing imazapic application rate. By the second yr, exotic annual grass cover was similar among treatments. Perennial grass cover did not vary among treatments (Fig. 4; P = 0.374) but was greater in 2016 compared with 2017 (P < 0.001). Perennial forb and annual forb cover (data not shown) did not vary by the treatment • year interaction (P = 0.734 and 0.360, respectively), were similar among treatments (P = 0.807 and 0.651, respectively), and were greater in 2016 than 2017 (P < 0.001). Bare ground varied by the treatment • year interaction (Fig. 5; P = 0.040). Bare ground was similar among treatments in 2016. In 2017, bare ground generally increased

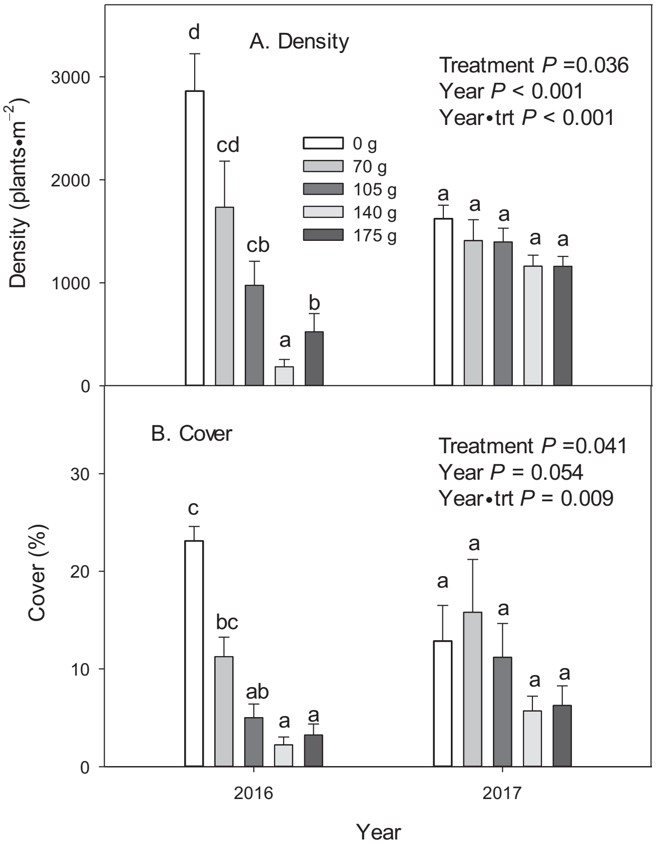

Figure 3. Exotic annual grass (primarily ventenata) density (**A**) and cover (**B**) (mean + S.E.) across five rates of imazapic application ($0-175$ g ae·ha^{-1}) in the two post-treatment growing seasons following the 2015 application. Year • trt = treatment • year interaction. Different lowercase letter indicates difference between treatment means ($P < 0.05$) for that growing season.

with increasing imazapic application rate. Litter (data not shown) was not influenced by the treatment • year interaction ($P = 0.623$) and did not differ among treatments ($P = 0.077$) but was greater in 2017 than 2016 ($P < 0.001$). Biological soil crust cover (data not shown) was not influenced by the treatment • year interaction ($P = 0.932$) and was similar among treatments ($P = 0.559$), but it was greater in 2016 than 2017 ($P = 0.041$).

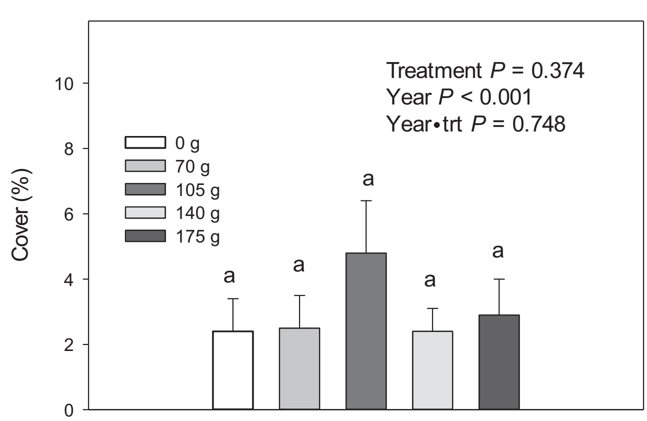

Figure 4. Perennial grass cover (mean + S.E.) across five rates of imazapic application ($0-175$ g ae·ha^{-1}) after the 2015 application. Year • trt = treatment • year interaction. Different lowercase letter indicates difference between treatment means ($P < 0.05$).

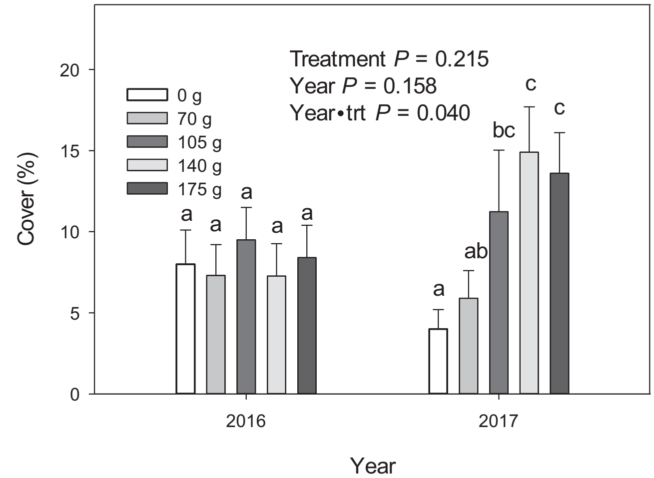

Figure 5. Bare ground cover (mean + S.E.) across five rates of imazapic application ($0-175$ g ae·ha^{-1}) in the two post-treatment growing seasons after the 2015 application. Year • trt = treatment • year interaction. Different lowercase letter indicates difference between treatment means ($P < 0.05$) for that growing season.

Discussion

Imazapic application at all rates generally reduced exotic annual grass, primarily ventenata, cover, and density in both the 2014 and 2015 applications compared with the nontreated control, except the 70 g ae·ha^{-1} imazapic rate was similar to the nontreated control in the 2015 application. Ventenata and coexisting exotic annual grass control was generally more successful with increasing rates of imazapic; however, in the 2015 application there was not an advantage of increasing the application rate from 140 g ae·ha^{-1} to 170 g ae·ha^{-1}. Similarly, increasing imazapic application rates, up to a point, generally increased control of other exotic annual grasses (Kyser et al., 2007; Sheley et al., 2007). The 2014 applications appeared more effective than the 2015 applications at controlling ventenata and other coexisting exotic annual grasses. This suggests that there likely will be variability in ventenata control when using imazapic, depending on interannual climatic variation and other factors.

Exotic annual grass control was not complete in the first yr after treatment in either application at any imazapic application rate. At the best control levels, annual grass density averaged 299 and 184 plants·m^{-2} the first yr after imazapic application in the 2014 and 2015 applications, respectively. This is probably not adequate control for dealing with exotic annuals with high seed production that can rapidly redominate a site. Better control may have been achieved by reducing the accumulated annual grass litter before imazapic application, as has been found in controlling medusahead where litter removal results in better contact between the herbicide and target (Monaco et al., 2005; Kyser et al., 2007; Davies, 2010).

Density of perennial vegetation did not increase with imazapic application, regardless of application rate. Thus, it seems unlikely that short-term control of ventenata with imazapic will promote substantial long-term changes in plant community composition. We did detect a slight increase in perennial grass cover in the 2014 application at the highest imazapic application rate, but an increase in total perennial grass cover of 1.3% is probably not biologically significant. Though bare ground cover increased with ventenata control in both the 2014 and 2015 applications, it did not correspond to increases in plant groups, in particular annual forbs. If more resources were available for other plant groups, we would have expected to see increases in annual forbs in the second yr after imazapic toxicity had abated or increases in perennial vegetation. Variation in perennial grass, perennial forb, and annual forb cover were probably related to interannual climatic differences, not imazapic application rates. The general lack of response from perennial species to imazapic application suggests there is limited value in applying imazapic to these ventenata-dominated communities without also including revegetation efforts. However, a second herbicide application to control ventenata and other exotic annual grasses may release perennial grasses and may also improve revegetation efforts. Enhancing perennial vegetation establishment is critical to increasing resistance to exotic annual grass dominance (Davies, 2008; Chambers et al., 2014; Davies and Johnson, 2017) and, therefore, ventenata control should be followed with seeding or planting perennial vegetation to provide lasting reductions in exotic annuals.

A concerning result from our study was the rapid redominance of the treated areas by ventenata. In fact, the untreated control and areas treated with the highest imazapic application rates were similar in exotic annual grass density and cover in the third or second yr after treatment in the 2014 and 2015 applications, respectively. Most invasive annuals produce large seed banks, though these rarely persist over multiple growing seasons (Pyke, 1994). Only a small fraction (< 1%) of ventenata seed remains viable up to 3 yr in a grassland (Wallace et al., 2015). Invasive annual grasses have considerable phenological plasticity to support consistent high seed production (Rice and Mack, 1991). Thus, ventenata survivors were likely able to adjust to the reduction in ventenata abundance and rapidly redominate imazapic-treated areas. This is a management issue because seeding of desirable vegetation is often postponed for a year after imazapic application to allow the herbicide toxicity to abate; otherwise, imazapic causes high mortality of seeded vegetation (Davies et al., 2014). There has been some limited success in medusahead-invaded rangelands with a single-entry approach of simultaneous seeding and low rate application of imazapic, but results have not been consistent (Sheley et al., 2012). Furthermore, our results suggest low rates of imazapic application will not provide effective control of ventenata. Exotic annual grasses are competitive with perennial grasses, especially at the seedling stage (Clausnitzer et al., 1999; Young and Mangold, 2008; Schantz et al., 2016), so it is unlikely that perennial grasses and other plant groups can be successfully seeded into these communities when exotic annual grass control is largely limited to the first yr post treatment.

Our results do not suggest that a single application of imazapic creates a long enough window of reduced ventenata for the establishment of perennial grasses or other desired vegetation. An integrated treatment approach may be more effective at controlling ventenata in rangelands. Mackey (2014) found integrated treatments achieved greater control of ventenata in Conservation Reserve Program lands and timothy hay fields. Revegetation of medusahead-dominated rangelands were much more effective with combined burning and imazapic application (Davies, 2010). Integrated treatments have repeatedly demonstrated to be more effective for controlling exotic species than single-treatment approaches (Lym, 2005; DiTomaso et al., 2006; Herrera-Reddy et al., 2012). Alternatively, because there is substantial control of exotic annual grasses in the first growing season after imazapic application, there may be an opportunity to seed simultaneously with imazapic application if imazapic induced nontarget mortality can be prevented. To overcome imazapic-induced mortality of simultaneously seed species (Davies et al., 2014), imazapic would need to be deactivated in the immediate vicinity of the seeded seeds through activated carbon seed coatings (Madsen et al., 2014) or pellets (Davies et al., 2017; Davies, 2018).

Management Implications

One- to 2-yr reductions in ventenata and other coexisting exotic annual grasses can be accomplished with imazapic, but longer-term and substantial reductions will likely be challenging and expensive. Imazapic applied as the sole treatment to control ventenata does not appear to be a viable strategy to manage this exotic annual grass as control was not complete and ventenata fully recovered in two to three growing seasons after herbicide treatment. Perennial vegetation did not respond substantially to even the highest levels of ventenata and coexisting exotic annual grass control, and there is no window of time to establish perennial vegetation from seed when herbicide toxicity has diminished and exotic annual grass competition has been sufficiently limited. Thus, research is necessary to develop more complete and longer-term control of ventenata and coexisting exotic annual grasses. Integrated control treatments and possibly other preemergent herbicides, such as indaziflam (Sebastian et al., 2016), may offer better control than solely applying imazapic. However, integrated and other herbicide control of ventenata and coexisting exotic annual grasses will need further evaluations and likely be expensive. This suggests that prevention of ventenata dominance should be a research and management priority to reduce the need for costly control and revegetation efforts that may have a high probability of failure.

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