RESEARCH ARTICLE

Effect of Imazapic on Cheatgrass and Native Plants in Wyoming Big Sagebrush Restoration for Gunnison Sage-grouse

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ABSTRACT: Imazapic has shown potential to control invasive weeds, such as cheatgrass (*Bromus tectorum* L.), during ecological restoration, but effects on non-target native plants are poorly known. In a replicated field experiment, as part of restoration for Gunnison sage-grouse (*Centrocercus minimus*) in Colorado, imazapic was applied in the fall at a high rate (175 g/ha) to control cheatgrass in mowed Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young). Cheatgrass was reduced, but only by 67%, and non-native forbs were reduced by 80% by the following summer. However, native forbs also declined (by 84%). Two native grasses declined, but others were not affected. Damage to native forbs would likely be detrimental to sage-grouse and other wildlife if it occurred over large areas. Perhaps application of imazapic just to cheatgrass plants or patches and application earlier in restoration would allow control with less adverse effects on native forbs.

Index terms: forbs, Gunnison sage-grouse, native plants, restoration

INTRODUCTION

Bromus tectorum L. (cheatgrass) is a non-native annual grass that can invade natural vegetation in the western United States, particularly after disturbance, and is capable of seriously disrupting restoration efforts. It can kill established or recovering native plants by competing for, and exhausting, spring moisture (Melgoza et al. 1990); it can also increase fire hazard, possibly leading to fires that favor more cheatgrass (Billings 1990). If these effects occur, they can hamper or prevent restoration of native plants. Where cheatgrass was present, but not dominant before disturbance, there may be a window of a few years after a disturbance during which cheatgrass re-establishes in patches from a surviving seed bank or by invasion from nearby areas (Shinneman 2006; Getz and Baker 2008). Initial patches may expand laterally, eventually coalescing and dominating across the matrix of vegetation (Shinneman 2006).

If cheatgrass control was applied and successful during the initial invasion window (Moody and Mack 1988), this could allow native plants time to re-establish. If so, an intensive initial cheatgrass control effort might allow successful native plant restoration. The best control method would kill cheatgrass, but not adversely affect native plants.

The herbicide imazapic has shown potential to control cheatgrass, while showing limited adverse effects on native plants, soil, or water (Shinn and Thill 2002, 2004; Kyser et al. 2007). Imazapic reduced some established native perennial grasses (e.g., western wheatgrass (*Pascopyrum smithii*) and bluebunch wheatgrass (*Pseudoroegneria spicata spicata*)) when applied directly in spring, but they recovered within one year after treatment (Shinn and Thill 2004). About 100 species survived post-emergence imazapic application in Kentucky (Barnes 2007), but vigor of native perennial grasses and forbs was reduced by spring or fall application of imazapic in California (Kyser et al. 2007). Imazapic also reduced height and biomass of seeded species when applied before planting (Shinn and Thill 2004).

Fall pre-emergence application of imazapic, followed by seeding of native species, led to reductions in cheatgrass seed production – but not in plant density one year after treatment (Bekedam 2005). Some seeded native species emerged less after imazapic application than without imazapic application (Bekedam 2005). However, relatively little is known about effects of imazapic on established native plants when applied in the fall to reduce cheatgrass emergence. The restoration objective was to experimentally test the effectiveness of fall application of imazapic in controlling cheatgrass, while not harming native plants during recovery after mowing in Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young).

METHODS

Study Site

The study site is part of the Colorado Division of Wildlife's Dry Creek Basin State Wildlife Area (SWA), at 38.04 N latitude and 108.56 W longitude; it lies in a semi-arid basin on the interface between

the San Juan Mountains and Colorado Plateau at about 2010 m elevation. Annual precipitation about 25 km to the northeast at Norwood, Colorado, averages 22.3 cm with a peak in July to September associated with the North American monsoon (National Climate Data Center, Asheville, N.C.). The basin serves as an important ungulate winter range and part of the occupied habitat of *Centrocercus minimus* Young, Braun, Oyler-McCance, Hupp & Quinn (Gunnison sage-grouse), a bird that, until April 2006, was listed as a Candidate Species under the U.S. Endangered Species Act. The SWA has Wyoming big sagebrush and *Artemisia nova* A. Nelson (black sagebrush) communities, both commonly in a degraded condition with low native forb and grass cover after about a century of domestic livestock grazing (USDI Bureau of Land Management 2007). Livestock grazing was removed from the study area in 1978, but grazing by native ungulates is ongoing, particularly in winter.

Design and Analysis

In the summer of 2002, the Colorado Division of Wildlife mowed approximately 56 ha of Wyoming big sagebrush, in a mosaic with 55 patches about 1 ha each, to improve native forb and graminoid cover and increase habitat value for Gunnison sage-grouse. After mowing, a mix of native and non-native grasses and forbs was seeded with a rangeland drill. Our study began in 2006, four years after mowing and seeding, because by the spring of 2006, cheatgrass was evident at moderate densities throughout the vegetation.

The experiment was a replicated repeated measures experiment done with a single treatment factor having two levels: herbicide application and control; thus, the design is an improvement over before-after-control-impact (BACI) designs (Underwood 1994). Mowed patches were mapped from aerial photography and georectified in a GIS for use in identifying study sites. Preliminary study revealed vegetation differences along a gradual elevational gradient, so the set of patches was blocked into a lower and upper area. Soil in the lower area was a Barx fine sandy loam (Haplargid), and in the upper area was an Abra loam (Calciorthid) (USDA NRCS and USDI BLM 2001). Each treatment was replicated three times in each block for a total of 12 treatment units (six herbicide and six control). Treatments and replicates were randomly assigned to available units within each block. Before treatment, statistical power of the design was estimated, using G*Power (Erdfelder et al. 1996), to be 0.91 to detect even a small effect (0.0625 s.d. units change – after herbicide relative to before herbicide). Thus, the design was considered adequate to detect expected effects of imazapic on the response variables.

Response variables, measured identically before and after treatment, included mean percent cover of: (1) native shrubs, (2) native graminoids, (3) native forbs, (4) nonnative graminoids (cheatgrass), and (5) nonnative forbs. Percent cover was arcsine transformed for statistical analysis. The experiment lacked sufficient replicates or statistical power to test other variables. The null hypothesis was that mean change over time (before vs. after treatment) is not different between herbicide and control areas for each of the five response variables. This was evaluated by testing for a significant time-herbicide interaction using Wilks' Lambda as the test statistic (O'Brien and Kaiser 1985). Since the response variables are likely correlated (von Ende 2001), the SPSS general linear model program (SPSS 2007) was used to perform a repeated measures multivariate analysis of variance (MANOVA; O'Brien and Kaiser 1985; von Ende 2001). If the multivariate null hypothesis was rejected, it was followed by Bonferroni-corrected univariate F tests to determine where differences occurred (O'Brien and Kaiser 1985).

Field Methods

In early June 2006, prior to herbicide application, a permanent 50-m long sampling transect was oriented parallel to the long axis of each patch to be treated, beginning approximately 5 m from the northernmost and easternmost margin, to provide an unbiased location. The transect was made permanent by placing rebar at the origin and every 10 m. Geographical coordinates of the origin and end were recorded using a GPS, and a digital photograph was taken with the rebar at the origin in the foreground and the centerline of the transect in the background. Within the transect, sequential 1-m x 1-m quadrats (n = 50, except one transect with n = 25 because of accidental damage to part of transect) were sampled along the left side of the transect line viewed from the origin. Within each quadrat, percent canopy cover and maximum height of each live vascular plant, as well as percent cover of biological soil crust, bare ground, rocks, and dead and partially dead sagebrush, were visually estimated. The mean for each response variable was calculated among all the quadrats in each transect. Sample data are presented showing mean height and cover response by species, to aid in formulating future hypotheses, but statistical inferences are not possible.

On 12 October 2006, imazapic was applied at 175 g/ha (0.175 kg ai/ha), using a sprayer mounted on an all-terrain vehicle, to a 10-m wide swath centered on the transect in each of the six herbicide treatment units. The vehicle could have contributed to the observed effect, but only to a minor degree. Application occurred at the end of the growing season in a single pass and no damage to the vegetation was visible after application. The following spring, a distinct difference was evident between the spayed and unsprayed areas, but the track of the all-terrain vehicle was not visible at all. Moreover, the tires of the vehicle are about 0.15 m wide, but the sprayed swath is 10 m wide.

In the eight months after application, precipitation at the closest weather station (25 km northeast) at Norwood, Colorado (2140 m elevation), was 27.8 cm, compared to a mean of 22.3 cm; and snowfall was 139 cm compared to a mean of 150 cm (National Climate Data Center, Asheville, N.C.). Thus, precipitation was nearly average after treatment. In June 2007, all transects were re-sampled as they were prior to treatment.

RESULTS

Time by itself, as expected, had a significant effect (Wilks' Lambda = 0.13, corresponding $F = 7.96$, $d.f. = 5$, $p = 0.013$ and observed power = 0.90), merely confirming that change occurred in response variables during the experiment. More important, the multivariate null hypothesis of no difference in change (2006 vs. 2007), in comparing herbicide and control for all response variables, can be rejected (Wilks' Lambda = 0.098, approximate $F = 10.99$, $d.f. = 5$, $p = 0.006$ and observed power = 0.97). Thus, a different change occurred in herbicide and control transects in at least one response variable. Means for the response variables and for individual species show the pattern of change (Table 1). Follow-up univariate tests of the time-herbicide interaction showed that change in all response variables, except native shrubs, differed significantly (< 0.05) between herbicide and control treatments (Table 2).

Cheatgrass was substantially reduced by fall application of imazapic. Cheatgrass almost doubled in percent cover in control transects, but declined 67% in transects treated with imazapic (Table 1). Non-native forbs increased by a factor of 4 in control transects, but declined 80% in transects treated with imazapic (Table 1). Unfortunately, cheatgrass still had an average 2% cover and non-native forbs 1.6% cover after treatment, probably sufficient to allow recovery of cheatgrass to higher levels without re-treatment.

Native forbs, shrubs, and graminoids also all increased in control transects from 2006 to 2007 (Table 1), likely reflecting ongoing recovery from the 2002 mowing and favorable growing conditions in 2006-2007. Native forbs more than doubled, on average, in control transects, but declined about 84% in transects treated with imazapic (Table 1). Native shrubs appeared to increase by about twice as much in transects treated with imazapic, relative to controls, because of a strong increase of *Gutierrezia sarothrae* Pursh (Britton & Rusby) (broom snakeweed) in transects treated with imazapic (Table 1), but this difference was not statistically significant (Table 2). Native graminoids more than doubled in percent cover in control transects and in transects treated with imazapic (Table 1), but observed power was only 0.6 (Table 2). Pre-treatment percent cover of native graminoids, by chance, was twice as high in control transects as in imazapic transects (Table 1). This suggests that the response of native graminoids to imazapic was likely not well determined by the experiment.

Sample means for percent cover suggest some plant species may be more sensitive to imazapic than are others (Table 1), but differences in population means could not be formally tested and the data suggest only potential patterns. Nearly all non-native plants, including cheatgrass, increased substantially in control transects, but were substantially reduced in transects treated with imazapic, as was the weedy native annual, *Lappula occidentalis* S. Watson (Greene) (flatspine stickseed). The most abundant native forbs (on average, before treatment), *Packera multilobata* (Torr. & A. Gray ex A. Gray) W.A. Weber & A. Löve (lobeleaf groundsel) and *Sphaeralcea coccinea* Nutt. (Rydb.) (scarlet globemallow), both declined strongly in transects treated with imazapic. Among native graminoids, *Poa secunda* J. Presl (Sandberg bluegrass) and *Elymus trachycaulus* Gould ex Shinners (slender wheatgrass) appeared most reduced by imazapic. The only common native species not reduced by imazapic were *Elymus elymoides* Ref. (Swazi) (squirreltail) and broom snakeweed. Most other species had low pre-treatment cover and their response is likely not well measured.

Height data also could not be formally tested statistically, but suggest potential patterns. In control transects, 24 of 26 plant species increased on average in mean height from 2006 to 2007 (Table 1). In contrast, in imazapic transects only 16 of 26 species increased in mean height from 2006 to 2007, height increases were less in imazapic transects than in controls for 24 of 26 species, and 10 of 26 species declined in height in imazapic transects (Table 1). Most species that declined in height also declined in cover, suggesting an overall decrease in size.

DISCUSSION

As expected from past research (e.g., Kyser et al. 2007), cheatgrass was reduced by fall application of imazapic as a pre-emergent. However, other studies have shown higher cheatgrass control, near 100%, with both lower and higher rates of fall application (e.g., 53-140 g/ha--Kyser et al. 2007; 280 g/ha--Shinn and Thill 2002). Incomplete control in our study occurred while control areas had a doubling of cheatgrass and a quadrupling of non-native forb cover (Table 1). Thus, where non-natives were increasing, imazapic reduced the increase.

Previous studies showed tolerance to imazapic varied among species, with members of the Hordeae grass tribe particularly tolerant, but other species more vulnerable to injury (Kyser et al. 2007). The Hordeae grass, squirreltail, was also tolerant of imazapic in this study, but another Hordeae grass, slender wheatgrass, appeared reduced, as were other native perennial grasses, particularly *Poa secunda* (Table 1).

This study showed large reductions, about 84% on average, in nearly all native perennial forbs (Table 1), a larger suite of forbs than evaluated in previous studies of cheatgrass control. Four native forbs were tolerant to imazapic in another study of fall application of imazapic, at somewhat lower application rates (< 140 g/ha--Kyser et al. 2007) than the 175 g/ha used here, but vigor of the four native forbs was substantially reduced at 280 g/ha (Kyser et al. 2007). In our study, both cover and height reductions occurred in many species in imazapic-treated areas (Table 1), suggesting a decline in biomass similar to that found previously (Shinn and Thill 2004). Further study is needed to determine whether affected species will recover from these reductions.

The substantial reduction in native forbs in this study from fall application at 175 g/ha, without achieving full control of non-natives, indicates that fall application of imazapic to control cheatgrass can also significantly damage native forbs. More research is needed on effects on native plants at lower application rates. Unfor-

Table 1. Response of species groups (e.g., native shrubs) and individual species to herbicide and control. Table entries are mean percent canopy cover and mean height, in cm. Omitted are species without at least a single percent cover value ≥ 0.10. Values in bold are from the SPSS repeated measures multivariate analysis of variance. Diff. is the 2007 value minus the 2006 value.

	CONTROL			IMAZAPIC			CONTROL			IMAZAPIC		
	2006	2007	Diff.	2006	2007	Diff.	2006	2007	Diff.	2006	2007	Diff
Species	%Cover						Height (cm)					
NATIVE SHRUBS	**8.87**	**11.27**	**2.40**	**8.42**	**12.63**	**4.21**						
Artemisia tridentata ssp. *wyomingensis: < 75% alive*	0.26	0.23	-0.03	0.47	0.47	0.00	0.83	0.30	-0.53	0.49	0.73	0.24
Artemisia tridentata ssp. *wyomingensis: > 75% alive*	0.29	0.71	0.42	0.42	0.93	0.51	1.77	3.58	1.81	1.67	2.69	1.02
Artemisia tridentata ssp. *wyomingensis: 0% alive*	6.73	7.08	0.35	6.47	6.86	0.39						
Gutierrezia sarothrae	1.55	3.15	1.60	1.01	4.23	3.22	0.60	6.29	5.69	3.92	8.77	4.85
NATIVE GRAMINOIDS	**14.67**	**32.90**	**18.23**	**7.80**	**16.32**	**8.52**						
Achnatherum hymenoides	0.19	1.32	1.13	0.22	0.25	0.03	1.48	8.18	6.70	2.59	1.31	-1.28
Bouteloua gracilis	0.02	0.10	0.08	0.01	0.09	0.08	0.22	0.48	0.26	0.09	0.24	0.15
Elymus elymoides	6.02	14.10	8.08	3.62	11.77	8.15	17.84	27.49	9.65	13.39	20.59	7.20
Elymus trachycaulus	3.74	8.54	4.80	1.77	1.66	-0.11	13.94	26.20	12.26	6.83	4.79	-2.04
Pascopyrum smithii	1.36	3.00	1.64	0.49	1.67	1.18	7.20	11.04	3.84	4.12	5.57	1.45
Poa secunda	3.30	5.83	2.53	1.54	0.76	-0.78	9.32	14.83	5.51	6.51	2.26	-4.25
NATIVE FORBS	**5.35**	**13.80**	**8.45**	**10.18**	**1.63**	**-8.55**						
Achillea millefolium var. *occidentalis*	0.01	0.25	0.24	0.02	0.09	0.07	0.06	0.49	0.43	0.26	0.34	0.08
Chaetopappa ericoides	0.14	0.32	0.18	0.27	0.50	0.23	0.14	0.25	0.11	0.30	0.30	0.00
Erigeron concinnus	0.21	1.17	0.96	0.03	0.10	0.07	0.74	2.02	1.28	0.27	0.52	0.25
Eriogonum microthecum	0.00	0.19	0.19	0.01	0.11	0.10	0.00	0.25	0.25	0.19	0.22	0.03
Lappula occidentalis	0.25	4.32	4.07	1.50	0.00	-1.50	2.82	11.91	9.09	3.40	0.02	-3.38
Packera multilobata	2.21	1.60	-0.61	4.14	0.12	-4.02	0.02	2.60	2.58	0.18	0.66	0.48
Penstemon strictus	0.07	1.31	1.24	0.06	0.10	0.04	0.55	3.73	3.18	0.51	0.23	-0.28
Schoenocrambe linifolia	0.14	0.51	0.37	0.29	0.09	-0.20	1.47	9.52	7.95	2.87	1.40	-1.47
Sphaeralcea coccinea	2.25	3.81	1.56	3.84	0.40	-3.44	1.91	5.08	3.17	2.83	1.20	-1.63

continued

Table 1. Continued.

Species	CONTROL 2006	CONTROL 2007	CONTROL Diff.	IMAZAPIC 2006	IMAZAPIC 2007	IMAZAPIC Diff.	CONTROL 2006	CONTROL 2007	CONTROL Diff.	IMAZAPIC 2006	IMAZAPIC 2007	IMAZAPIC Diff
	%Cover						Height (cm)					
NON-NATIVE GRAMINOIDS	**11.37**	**22.22**	**10.85**	**7.15**	**2.33**	**-4.82**						
Bromus tectorum	11.36	22.21	10.85	7.10	2.33	-4.77	12.05	24.62	12.57	12.54	6.16	-6.38
NON-NATIVE FORBS	**1.43**	**6.22**	**4.79**	**1.55**	**0.33**	**-1.22**						
Ceratocephala testiculata	0.00	0.93	0.93	0.00	0.00	0.00	0.00	0.41	0.41	0.00	0.00	0.00
Erodium cicutarium	0.00	0.53	0.53	0.00	0.01	0.01	0.00	0.31	0.31	0.00	0.07	0.07
Lactuca serriola	0.03	0.45	0.42	0.10	0.02	-0.08	0.20	1.51	1.31	0.09	0.17	0.08
Marrubium vulgare	0.14	0.26	0.12	0.30	0.02	-0.28	0.23	0.68	0.45	0.90	0.07	-0.83
Salsola tragus	0.19	0.00	-0.19	0.00	0.02	0.02	0.90	0.03	-0.87	0.10	0.13	0.03
Sanguisorba minor	0.88	2.84	1.96	1.09	0.04	-1.05	0.95	8.92	7.97	2.08	0.16	-1.92
Sisymbrium altissimum	0.00	0.60	0.60	0.00	0.00	0.00	0.00	3.89	3.89	0.00	0.00	0.00
Tragopogon dubius	0.12	0.52	0.40	0.04	0.18	0.14	0.07	5.12	5.05	0.20	1.61	1.41
GROUND COVERS												
Bare ground	26.54	33.43	6.89	33.65	46.84	13.19						
Biological soil crust	0.05	0.02	-0.03	0.00	0.02	0.02						
Litter-covered ground	36.28	30.61	5.67	41.39	34.18	-7.21						
Rock-covered ground	0.03	0.04	0.01	0.25	0.35	0.10						

tunately, longer term studies are needed as well, since it is unclear from this first-year study which species will recover after documented reductions and whether the longer term outcome will be beneficial or detrimental to restoration.

Declines in forbs documented in this study, however, would likely be detrimental to sage-grouse and other wildlife if applied over a large area. However, our study did not begin until four years after mowing when cheatgrass was already extensive. Perhaps if imazapic was applied to individual cheatgrass plants or cheatgrass patches sooner after restoration actions (mowing in this case), cheatgrass control could be achieved without adverse effects on forbs over the whole restoration area. Our study suggests that aerial or ground application over large areas could damage or delay native forb recovery.

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LITERATURE CITED

Barnes, T.G. 2007. Using herbicides to rehabilitate native grasslands. Natural Areas Journal 27:56-65.

Bekedam, S. 2005. Establishment tolerance of six native sagebrush steppe species to imazapic (Plateau®) herbicide: implications for restoration and recovery. M.S. thesis, Oregon State University, Corvallis.

Billings, W.D. 1990. Bromus tectorum, a biotic

Table 2. Univariate *F* tests of time-herbicide interaction for individual percent-cover response variables..

Response variable	*F*	*p*	Observed power
Native shrubs	0.99	0.342	0.15
Native graminoids	6.17	0.032	0.61
Native forbs	27.65	0.000	1.00
graminoids	40.59	0.000	1.00
Non-native forbs	11.83	0.006	0.87

cause of ecosystem impoverishment in the Great Basin. Pp. 301-322 in G.M. Woodwell, ed., The Earth in Transition: Patterns and Processes of Biotic Impoverishment. Cambridge University Press, Cambridge, U.K.

Erdfelder, E., F. Faul, and A. Buchner. 1996. GPOWER: a general power analysis program. Behavior Research Methods, Instruments, & Computers 28:1-11.

Getz, H.L., and W.L. Baker. 2008. Invasion of cheatgrass into burned piñon-juniper woodlands in western Colorado. American Midland Naturalist 159:489-497.

Kyser, G.B., J.M. DiTomaso, M.P. Doran, S.B. Orloff, R.G. Wilson, D.L. Lancaster, D.F. Lile, and M.L. Porath. 2007. Control of medusahead (*Taeniatherum caput-medusae*) and other annual grasses with imazapic. Weed Technology 21:66-75.

Melgoza, G., R.S. Nowak, and R.J. Tausch. 1990. Soil water exploitation after fire: competition between *Bromus tectorum* (cheatgrass) and two native species. Oecologia 83:7-13.

Moody, M.E., and R.N. Mack. 1988. Controlling the spread of plant invasions: the importance of nascent foci. Journal of Applied Ecology 25:1009-1021.

O'Brien, R.G., and M.K. Kaiser. 1985. MANOVA method for analyzing repeated measures designs: an extensive primer. Psychological Bulletin 97:316-333.

Shinn, S.L., and D.C. Thill. 2002. The response of yellow starthistle (*Centaurea solstitialis*), annual grasses, and smooth brome (Bromus inermus) to imazapic and picloram. Weed Technology 16:366-370.

Shinn, S.L., and D.C. Thill. 2004. Tolerance of several perennial grasses to imazapic. Weed Technology 18:60-65.

Shinneman, D.J. 2006. Determining restoration needs for piñon-juniper woodlands and adjacent ecosystems on the Uncompahgre Plateau, western Colorado. Ph.D. diss., University of Wyoming, Laramie.

SPSS. 2007. Statistical Package for the Social Sciences. SPSS, Chicago, Ill.

Underwood, A.J. 1994. On beyond BACI: sampling designs that might reliably detect environmental disturbances. Ecological Applications 4:3-15.

USDA NRCS and USDI BLM. 2001. Soil survey of San Miguel Area, Colorado, Parts of Dolores, Montrose, and San Miguel Counties. U.S. Government Printing Office, Washington, D.C.

USDI Bureau of Land Management. 2007. Environmental assessment—livestock grazing use on seven BLM allotments in the vicinity of Dry Creek Basin, Colorado. Dolores Public Lands Office, Dolores, Colo.

von Ende, C.N. 2001. Repeated-measures analysis: growth and other time-dependent measures. Pp. 134-157 in S.M. Sheiner and J. Gurevitch, eds., Design and Analysis of Ecological Experiments. Oxford University Press, New York.