Weed Technology 2016 30:297–302

Spring Glyphosate Application for Selective Control of Downy Brome (*Bromus tectorum* L.) on Great Basin Rangelands

Christo Morris, Lesley R. Morris, and Cheryl Surface*

Downy brome has converted millions of hectares of Great Basin rangelands from shrubland to annual grass-dominated systems. Methods for removing downy brome from sites that already have perennial grasses established are especially needed because of the difficulty in re-establishing perennial species. In this study, early spring applications of glyphosate alone and glyphosate plus imazapic were monitored for 2 yr. Cover of downy brome was reduced from 45 to 10% by spring application of glyphosate alone and to approximately 1% with the addition of imazapic. Perennial grass cover was not affected by the spring application of glyphosate. The addition of imazapic reduced perennial grass cover in the first year; however, it recovered by the second year. The selective response to glyphosate may be due to differences in growth stage or dormancy characteristics between annual and perennial species. Our findings suggest spring application of glyphosate may provide an alternative approach for managing annual grasses on Great Basin rangelands.
Nomenclature: Glyphosate; imazapic; downy brome, *Bromus tectorum* L. BROTE.
Key words: Cheatgrass, dormancy, fire, restoration.

Bromus tectorum ha convertido millones de hectáreas del territorio de Great Basin de sistemas arbustivos a sistemas dominados por gramíneas anuales. Métodos que remuevan *B. tectorum* de sitios que ya tienen gramíneas perennes establecidas son especialmente requeridos debido a la dificultad de re-establecer especies perennes. En este estudio, aplicaciones de glyphosate solo y glyphosate más imazapic, temprano en la primavera, fueron monitoreadas durante 2 años. La cobertura de *B. tectorum* se redujo de 45 a 10% con la aplicación de glyphosate solo y a aproximadamente 1% con la adición de imazapic. La cobertura de gramíneas perennes no fue afectada por la aplicación de glyphosate en la primavera. La adición de imazapic redujo la cobertura de gramíneas perennes en el primer año, pero se recuperó en el segundo año. La respuesta selectiva a glyphosate podría deberse a diferencias en el estadio de desarrollo o las características de latencia entre especies anuales y perennes. Nuestros resultados sugieren que la aplicación de glyphosate en la primavera podría brindar una alternativa para el manejo de gramíneas anuales en los territorios de Great Basin.

Downy brome (also known as cheatgrass, Junegrass, bronco grass) was introduced into the Pacific Northwest region of the United States as a grain contaminant around 1889 (Knapp 1996). By 1894 it was present in Utah, and by 1906 was established across Nevada. By the late 1920s it was common throughout the Great Basin Desert region of the Western United States. Since then it has continued to spread in both extent and density, becoming the dominant vegetation across millions of hectares of former shrub-dominated rangeland (Duncan et al. 2004). The replacement of native vegetation by downy brome has resulted in reduced biodiversity, increased wildfire risk, difficulty reestablishing native vegetation, and reduction in livestock forage (Knapp 1996; Whisenant 1990; Young and Longland 1996).

Because of the difficulty in establishing desirable perennial species within established downy brome stands, emphasis for control has shifted toward protecting established perennial vegetation (Kyser et al. 2013). In stands where downy brome and perennial grasses coexist, treatments that selectively control downy brome while maintaining the perennial component are necessary. Herbicides such as imazapic and sulfometuron have been shown to control annual grasses selectively while causing minimal damage to perennial species (Kyser et al. 2013; Monaco et al. 2005; Sheley et al. 2007). However, results from imazapic have also been shown to vary depending on soil type, precipitation and thatch accumulation (Kyser et al. 2007; Morris

DOI: 10.1614/WT-D-15-00119.1
* Instructor and Assistant Professor, Department of Animal and Range Sciences, Oregon State University, La Grande, OR 97850 and Park Planner, Washoe County Parks and Open Space, Reno, NV 89520. Corresponding Author's E-mail: lesley.morris@oregonstate.edu.

et al. 2009). In addition, sulfometuron can move off-site with windblown soil, potentially damaging sensitive species (Hutchinson et al. 2007). Because of these types of concerns, researchers have continued to explore ways to utilize glyphosate, which is considered relatively easy to use, though not normally considered selective. As early as the mid-1990s researchers experimented with early-spring applications of glyphosate on shortgrass prairie and Conservation Reserve Program lands to control downy brome and other annual grasses selectively (Beck et al. 1995; Whitson and Koch 1998). More recently, Kyser et al. (2013) showed that an early-spring application of glyphosate was as effective as other herbicides for controlling downy brome and medusahead rye (*Teaniatherum caput-medusae*) on sagebrush rangelands with no damage to perennial grasses. Recent research has also shown that at low rates glyphosate can be effective for control of medusahead rye without causing damage to perennials on sagebrush-dominated rangelands (Kyser et al. 2012). Timing of application was also important for optimizing control and minimizing damage to perennials; applications made earlier in the spring caused less damage to perennials. These studies are all consistent with research in agriculture, forestry, and landscaping, where applications of glyphosate during winter or early spring resulted in selective control of the target species with minimal damage to desirable species (Frey et al. 2007; Johnson 1976; Neal et al. 1986; Willoughby 1996; Wilson et al. 1997). The objective of this study is to evaluate data from a site dominated by downy brome, with perennial species still present, where glyphosate was applied in early spring, and to discuss the mechanisms associated with the selective effect.

Materials and Methods

Site Description. The study site is located in the foothills of Peavine Mountain, northwest of Reno, NV, in a 25 to 30–cm precipitation zone at an elevation of 1,690 m. Soils are from 20 to 50 cm deep and described as a Koontz stony loam consisting of residuum and colluvium from meta-volcanic rock (U.S. Department of Agriculture–Natural Resources Conservation Service [USDA-NRCS] 2015). Historically, the site would have been dominated by perennial species, including desert needlegrass (*Achnatherum speciosum*), Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*), green ephedra (*Ephedra viridis*), purple sage (*Salvia dorii*) and Indian ricegrass (*Achnatherum hymenoides*) (USDA-NRCS 2003). However, because of multiple fires in the last two decades, the area is currently dominated by a matrix of downy brome ($> \sim 98\%$ cover; some medusahead rye [*Taeniatherum caput-medusae*] was present on the site, but did not intersect any of the transects), punctuated by perennial species, including species introduced with postfire reseeding. Perennial grasses currently include bottlebrush squirreltail (*Elymus elymoides*), hard fescue (*Festuca brevipila*), Sandberg bluegrass (*Poa secunda*), beardless wildrye (*Leymus triticoides*), and basin wildrye (*Leymus cinereus*). Shrubs include desert peach (*Prunus andersonii*), spineless horsebrush (*Tetradymia canescens*), mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*), rubber rabbitbrush (*Ericameria nauseosa*), and yellow rabbitbrush (*Chrysothamnus viscidiflorus*). Forbs currently consist of both introduced annual species and native perennial species, including silvery lupine (*Lupinus argenteus*), longleaf phlox (*Phlox longifolia*), Russian thistle (*Salsola kali*), skeletonweed (*Pleiacanthus spinosus*), and tall tumblemustard (*Sisymbrium altissimum*).

Experimental Design. In early April, 2011 0.8 ha of downy brome–dominated rangeland were mowed with hand-held weed whips to remove thatch from previous years' growth and then raked with an all-terrain-vehicle–mounted harrow and by hand around shrubs to remove cut material. This was done to ensure that dead thatch did not interfere with herbicidal activity (Monaco et al. 2005). Shrubs were avoided during mowing and weed whips were held 5–10 cm above the soil surface to avoid damage to both downy brome, which had emerged the previous fall, and to established perennial grasses. On April 4, 2011, the mowed and raked area was sprayed with glyphosate (Roundup Pro Max, 237 g ai ha^{-1}, Monsanto, St. Louis, MO 63137) combined with 90 g ai ha^{-1} of nonionic surfactant (Activator 90, Loveland Products, Loveland, CO 80538). Sixteen plots measuring 12 by 12 m were established at random locations within the sprayed area. On April 16, 2011, half of these plots were randomly selected and sprayed with imazapic herbicide (Panoramic 2SL, 24 g ai ha^{-1}, Alligare, LLC, Opelika, AL

36801) to provide a comparison to known methods. Eight control plots were also established in random locations adjacent to the perimeter of the sprayed and mowed area. Within each plot a 15-m transect was established running between the southeast and northwest corners. Transects were set back from each corner by 2 m to reduce edge effects. Cover values were measured in June of 2012 and 2013 with the use of the point-intercept method every 20 cm along the transect (Elzinga et al. 1998) for the following: annual grass, perennial grass, shrub, annual/biennial forb, perennial forb, bare soil, rock and litter. Despite numerous transformation techniques, none of the data were distributed normally. Analysis was completed with nonparametric comparisons for each pair with the use of the Wilcoxon method (Wilcoxon 1945). The threshold for mean separation was set at $\alpha \leq 0.05$. Data were analyzed with the use of JMP version 11.0 (SAS Institute, Cary, NC).

Results and Discussion

Cover of annual grasses was significantly reduced by the application of glyphosate as compared to the control, from approximately 40 to 10% across both sample years (Figure 1). The addition of imazapic significantly reduced annual grasses even further to approximately 1% across both years. In contrast, the only significant difference for perennial grasses was between the glyphosate treatment and the glyphosate plus imazapic treatment for the first sample year. However, by 2013, there was no longer any significant difference in perennial grass cover between the two treatments. Annual forbs were also significantly lower than the control for the first year in the glyphosate plus imazapic treatment, though not from the glyphosate-alone treatment. In 2013, there was a significant increase in annual forbs within the control plots, but not within the plots treated by either herbicide. There were no significant differences in cover of perennial forbs for the first sample year, but cover increased from about 1 to about 5% in plots treated with either herbicide in 2013. Shrub cover was similar between treatments for the first sample year, but by 2013 plots treated with glyphosate plus imazapic had significantly higher shrub cover than the control, though both were statistically similar to the glyphosate-alone treatment. Lastly, bare ground increased from approximately 5 to 20% the first year for both herbicide treatments and bare ground for the imazapic plus glyphosate treatment significantly increased to 30% in 2013.

Selectivity in herbicides can occur through multiple mechanisms, including differences in leaf surfaces, height, translocation, physiology, and phenology (Ross and Lembi 1999). Downy brome is a winter annual, with germination occurring in fall and continuing through the winter months and into spring, if conditions allow (Mack and Pyke 1983). The decrease in cover of annual grasses with no change in cover of perennial grasses or forbs with the application of glyphosate can be attributed to two potential mechanisms. The selective response may be due to differences in growth stage, because plants at the seedling stage (including winter annuals) are often more susceptible to herbicide damage than established perennial plants (Ross and Lembi 1999). However, another reason may be related to differences in dormancy characteristics between winter annuals and perennials. Research has shown that downy brome is able to emerge from soil at faster rates and also to continue growth at temperatures colder than perennial grasses (Aguirre and Johnson 1991; Hardegree et al. 2010; Harris 1967, 1977; Morris and Schupp 2009; Nasri and Doescher 1995). Although this adaptation to cold temperatures may provide an advantage for cheatgrass over perennials in terms of early growth, it may also provide an opportunity for increased selectivity in herbicide application. Application of glyphosate during winter or early spring has provided selective control of winter annuals in a variety of environments, with minimal damage to dormant desirable species (Beck et al. 1995; Frey et al. 2007; Johnson 1976; Kyser et al. 2013; Neal et al. 1986; Whitson and Koch 1998; Willoughby 1996; Wilson et al. 1997). Little information is available regarding growth of perennial species in the Great Basin at low temperatures, compared to downy brome, which has been found to grow at temperatures as low as 2 C (Evans and Young 1972). Germination of bottlebrush squirreltail does occur at 2 C (Young and Evans 1977), suggesting that it may have a similar minimum temperature growth threshold as downy brome, but other factors may also be important for breaking winter dormancy of established plants (Vegis 1964). For instance, at a slightly higher elevation site situated much further south in Arizona, growth measure-

https://doi.org/10.1614/WT-D-15-00119.1 Published online by Cambridge University Press

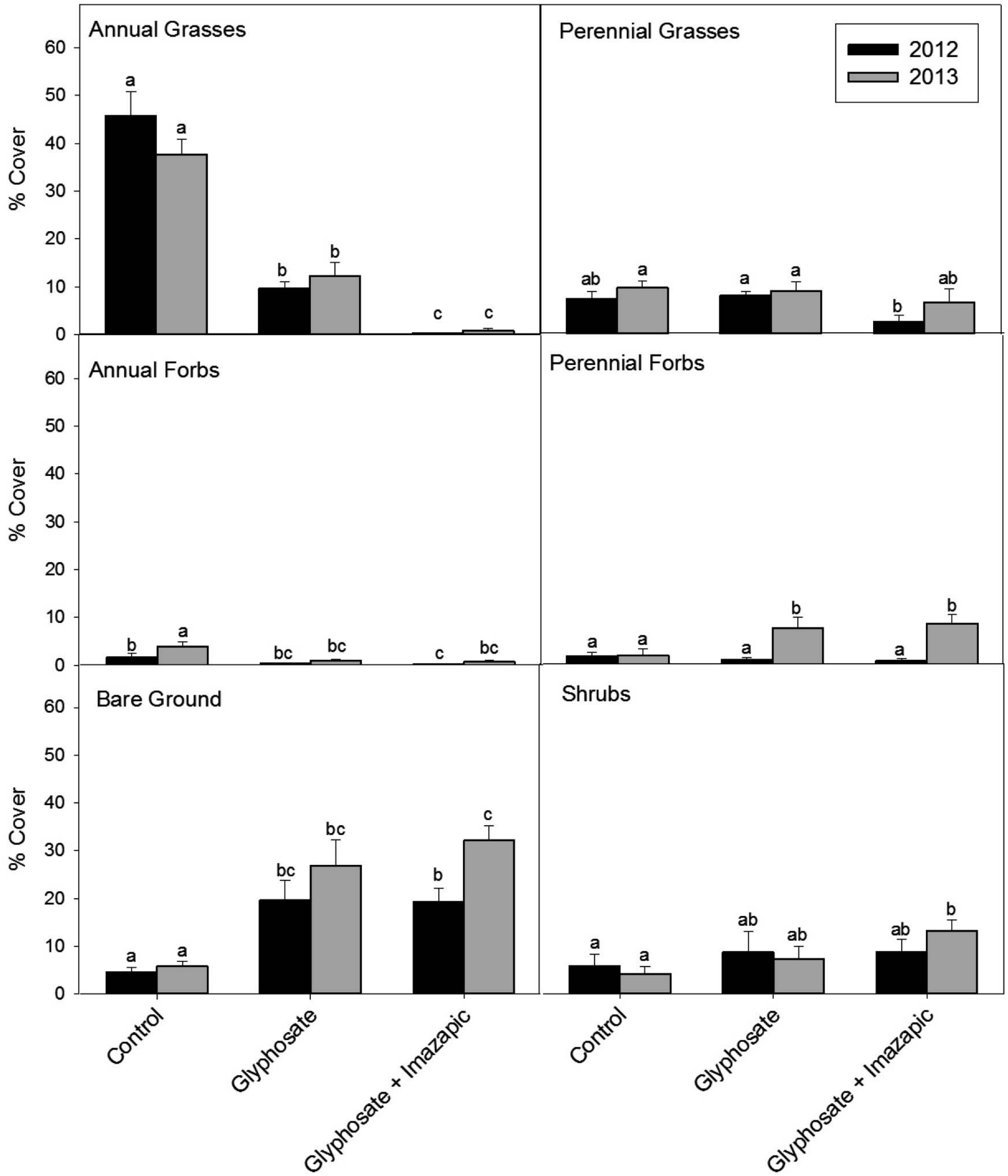

Figure 1. Mean cover values plus standard error based on the point-line intercept method for 2 yr of monitoring after a spring application of glyphosate and imazapic in 2011. Differences in letters indicate a significant difference (≤ 0.05) between values within each panel based on nonparametric comparisons for each pair with the use of Wilcoxon methods.

ments for bottlebrush squirreltail were not even initiated until mid-April (Clary 1975). More research on differences in active growth periods between annuals and perennials would improve the effectiveness and the applicability of using spring application of glyphosate to control winter annuals.

The differences between the glyphosate alone and the glyphosate plus imazapic treatments on annual grasses can best be explained in terms of the differences in soil activity between the two herbicides. Glyphosate is foliar active, because it binds tightly to soil particles, making it unavailable for root uptake (Senseman 2007). This means that it is only effective on downy brome that germinated during fall or winter. Because a small percentage of downy brome germinates in the spring (Mack and

Pyke 1983), the plots that were only sprayed with glyphosate could have had a second cohort germinate after the application of herbicide. Imazapic, on the other hand, is soil active (Sensemen 2007) and may have more effectively controlled downy brome that germinated after the application of glyphosate. For the plots that were treated with glyphosate only, it is likely that (given adequate precipitation) they could return to pretreatment cover of downy brome within several years (Morris et al. 2009). A subsequent spring application of glyphosate the following year could potentially provide similar control as the glyphosate plus imazapic treatment; however, a small percentage of spring germinates may escape control relying on this method and allow downy brome to persist on the site.

For perennial grasses, the decrease in cover in the glyphosate plus imazapic plots for the first year is related to dose-specific selectivity that can change based on site-specific conditions, including soil moisture (Morris et al. 2009). Precipitation for the 2 mo after herbicide was applied was about 15% of normal and precipitation over the course of the entire study was about 68% of normal (Western Regional Climate Center [WRCC] 2015). Because of low precipitation levels, uptake of imazapic from the soil may have actually been reduced, thus reducing overall damage to both annual and perennial grasses (Morris et al. 2009). Regardless, damage to the perennials by imazapic may have been offset by the increased water availability from reduced competition for soil moisture by downy brome (Melgoza et al. 1990), allowing them to recover within 1 yr. It is unknown what caused the delay in increased cover by perennial forbs. The increase in bare ground was related to the decrease in thatch production in plots treated by herbicide. There was also considerable movement of thatch by surface flow of water, which caused it to concentrate on the uphill side of standing vegetation (personal observation) in plots where herbicide was applied.

Although no single method of controlling downy brome will be suitable for all situations, the use of a spring application of glyphosate shows promise as an alternative approach to management of this invasive species where conservation of established native perennials is desired. It has certainly been shown to be effective in other situations (Beck et al. 1995; Frey et al. 2007; Johnson 1976; Neal et al. 1986; Willoughby 1996; Wilson et al. 1997), and results in our study suggest that it may be useful in the Great Basin. Limitations to this method might include recently seeded sites where perennial grasses had not fully established, thus eliminating any selectivity due to growth stage. On the other hand, selectivity may be due to differences in timing of dormancy. In this case, it would be encouraging to see that cold tolerance, which appears to be a trait that confers an advantage for downy brome against perennial species, may also provide unique opportunities for control.

Acknowledgments

This project was partially funded by the American Recovery and Reinvestment Act, through a grant to Washoe County Department of Parks and Open Space. The USDA-ARS Great Basin Rangelands Research Unit also contributed materials and labor. We would also like to thank Julie Etra of Western Botanical Services, Inc. for assistance with data collection.

Literature Cited

Aguirre L, Johnson DA (1991) Influence of temperature and cheatgrass competition on seedling development of two bunchgrasses. J Range Manage 44:347–354

Beck, KG, Sebastian JR, Chapman PL (1995) Jointed goatgrass (*Aegilops cylindrica*) and downy brome (*Bromus tectorum*) control in perennial grasses. Weed Technol 9:255–259

Clary WP (1975) Ecotypic adaptation in *Sitanion hystrix*. Ecology 56:1407–1415

Duncan CA, Jachetta JJ, Brown ML, Carrithers VF, Clark JK, DiTomaso JM, Lym RG, McDaniel KC, Renz MJ, Rice PM (2004) Assessing the economic, environmental, and societal losses from invasive plants on rangeland and wildlands. Weed Technol 18:1411–1416

Elzinga CL, Salzer DW, Willoughby JW (1998) Measuring and Monitoring Plant Populations: U.S. Bureau of Land Management Technical Reference 1730-1. Denver, CO: BLM National Business Center. 477 p

Evans RA, Young JA (1972) Microsite requirements for establishment of annual rangeland weeds. Weed Sci 20:350–356

Frey MN, Herms CP, Cardina J (2007) Cold weather application of glyphosate for garlic mustard (*Alliaria petiolata*) control. Weed Technol 21:656–660

Hardegree SP, Moffet CA, Roundy BA, Jones TA, Novak SJ, Clark PE, Pierson FB, Flerchinger GN (2010) A comparison of cumulative-germination response of cheatgrass (*Bromus tectorum* L.) and five perennial bunchgrass species to simulated field-temperature regimes. Environ Exp Bot 69:320–327

https://doi.org/10.1614/WT-D-15-00119.1 Published online by Cambridge University Press

Harris GA (1967) Some competitive relationships between *Agropyron spicatum* and *Bromus tectorum*. Ecol Monogr 37:89–111

Harris GA (1977) Root phenology as a factor of competition among grass seedlings. J Range Manage 30:172–177

Hutchinson PJ, Morishita DW, Price WJ (2007) Season-long dose-response of potato to sulfometuron. Weed Sci 55:521–527

Johnson BJ (1976) Glyphosate for weed control in dormant bermudagrass. Weed Sci 24:140–143

Knapp PA (1996) Cheatgrass (*Bromus tectorum*) dominance in the Great Basin Desert. Global Environ Chang 6:37–52

Kyser GB, Creech JE, Zhang J, DiTomaso JM (2012) Selective control of medusahead (*Taeniatherum caput-medusae*) in California sagebrush scrub using low rates of glyphosate. Invasive Plant Sci Manage 5:1–8

Kyser GB, DiTomaso JM, Doran MP, Orloff SB, Wilson RG, Lancaster DL, Lile DF, Porath ML (2007) Control of medusahead (*Taeniatherum caput-medusae*) and other annual grasses with imazapic. Weed Technol 21:65–75

Kyser GB, Wilson RG, Zhang J, DiTomaso JM (2013) Herbicide-assisted restoration of Great Basin sagebrush steppe infested with medusahead and downy brome. Rangeland Ecol Manage 66:588–596

Mack RN, Pyke DA (1983) The demography of *Bromus tectorum*: Variation in time and space. J Ecol 71:69–93

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

Monaco TA, Osmond TM, Dewey SA (2005) Medusahead control with fall- and spring-applied herbicides on northern Utah foothills. Weed Technol 19:653–658

Morris C, Monaco TA, Rigby CW (2009) Variable impacts of imazapic rate on downy brome (*Bromus tectorum*) and seeded species in two rangeland communities. Inv Plant Sci Manage 2:110–119

Morris C, Schupp EW (2009) Comparison of emergence speed and sterility in two sterile annual hybrid cereal grasses developed for use in restoration. Restor Ecol 17:678–685

Nasri M, Doescher PS (1995) Effect of temperature on growth of cheatgrass and Idaho fescue. J Range Manage 48:406–409

Neal JC, Skroch WA, Monaco TJ (1986) Effects of plant growth stage on glyphosate absorption and transport in ligustrum (*Ligustrum japonicum*) and blue pacific juniper (*Juniperus conferta*). Weed Sci 34:115–121

Ross MA, Lembi CA (1999) Applied Weed Science. 2nd edn. Upper Saddle River, NJ: Prentice Hall. 452 p

Senseman SA, ed. (2007) Herbicide Handbook. 9th edn. Lawrence, KS: Weed Science Society of America. Pp 82–84, 243–246

Sheley RL, Carpinelli MF, Morghan RJ (2007) Effects of imazapic on target and nontarget vegetation during revegetation. Weed Technol 21:1071–1081

[USDA-NRCS] U.S. Department of Agriculture–Natural Resources Conservation Service (2003) Rangeland Ecological Site Description: 026XY011NV. Reno, NV: USDA Natural Resources Conservation Service

[USDA-NRCS] U.S. Department of Agriculture–Natural Resources Conservation Service (2015) Web Soil Survey. http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm. Accessed January 1, 2015.

Vegis A (1964) Dormancy in higher plants. Annu Rev Plant Physiol 15:185–224

Whisenant SG (1990) Changing fire frequencies on Idaho's Snake River plains: Ecological and management implications. Pages 4–10 *in* McArthur ED, Romney EM, Smith SD, Tueller PT, eds. Proceedings of the Symposium on Cheatgrass Invasion, Shrub Die-Off, and Other Aspects of Shrub Biology and Management, General Technical Report INT-GTR-276. Ogden, UT: USDA Forest Service, Intermountain Research Station

[WRCC] Western Regional Climate Center (2015) http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?nv6779. Accessed September 28, 2015

Whitson TD, Koch DW (1998) Control of downy brome (*Bromus tectorum*) with herbicides and perennial grass competition. Weed Technol 12:391–396

Wilcoxon F (1945) Individual comparisons by ranking methods. Biom Bull 1:80–83

Willoughby I (1996) Dormant season application of broad spectrum herbicides in forestry. Aspects Appl Biol 44:55–62

Wilson RG (1997) Downy brome (*Bromus tectorum*) control in established alfalfa (*Medicago sativa*). Weed Technol 11:277–282

Young JA, Evans RA (1977) Squirreltail seed germination. J Range Manage 30:33–36

Young JA, Longland WS (1996) Impact of alien plants on Great Basin rangelands. Weed Technol 10:384–391

Received July 29, 2015, and approved October 13, 2015.

Associate Editor for this paper: Randy L. Anderson, USDA-Northern Grain Insects.