Variable Impacts of Imazapic Rate on Downy Brome (*Bromus tectorum*) and Seeded Species in Two Rangeland Communities

Christo Morris, Thomas A. Monaco, and Craig W. Rigby*

The herbicide imazapic is registered for use on rangelands and provides effective short-term control of certain invasive annual grasses. However, details about optimal application rates for downy brome and susceptibility of simultaneously seeded species are lacking. Thus, we investigated downy brome and seeded species responses to variable rates of imazapic (0, 35, 70, 105, and 140 g ai/ha) in two plant communities (salt desert shrub and Wyoming big sagebrush). In autumn 2003, plots were treated with imazapic and seeded with one of five perennial plant materials (Siberian wheatgrass ['Vavilov' and the experimental source Kazak]; prostrate kochia ['Immigrant' and the experimental source 6X], and Russian wildrye ['Bozoisky II']). Downy brome cover and seeded species establishment were evaluated in spring 2004 and 2006. Downy brome cover in 2004 decreased with increasing imazapic rate at both sites, although more so at the Wyoming big sagebrush site. In 2006, no difference in downy brome cover existed among herbicide rates at the Wyoming big sagebrush site. At the salt desert shrub site, the high rate of imazapic reduced downy brome cover by about 25% compared to untreated plots. 'Vavilov' Siberian wheatgrass was the only seeded species with lower downy brome cover in 2006 than 2004. Seeded species establishment increased with imazapic rate in the salt desert shrub community, but in the Wyoming big sagebrush community it peaked at intermediate rates and declined at higher rates. Variation in downy brome control and seeded species establishment might have been associated with differences in precipitation, soil organic matter, and disturbance history between sites. Overall, imazapic was useful for helping establish desirable perennial species, but unless downy brome is reduced below a critical threshold, favorable precipitation can return sites to pretreatment levels within two years.

Nomenclature: Imazapic; downy brome, *Bromus tectorum* L. BROTE; Siberian wheatgrass, *Agropyron fragile* (Roth) P. Candargy; Russian wildrye, *Psathyrostachys juncea* (Fisch.) Nevski; prostrate kochia, *Bassia prostrata* (L.) A. J. Scott; Wyoming big sagebrush, *Artemisia tridentata* Nutt. var. *wyomingensis* (Beetle & Young) S. L. Welsh. Nomenclature of all plants follow the USDA–NRCS PLANTS database (http://plants.usda.gov/).

Key words: Assisted succession, integrated weed management, rangeland seeding, seedling establishment.

Grasses are considered one of the most invasive families of plants worldwide (Daehler 1998; Pysek 1998). Exotic grass invasion of wildlands occurs throughout the world, including: North America (Arriaga et al. 2004; Norton et al. 2007; Seabloom et al. 2006), South America (Deil et al. 2007; Hoffmann et al. 2004), Africa (Milton 2004; van der Putten et al. 2007), Asia (Khuroo et al. 2007; Xu et al. 2006), Australia (Rossiter et al. 2003), Hawaii (Mack et al. 2001), and even Antarctica (Gremmen et al. 1998). Impacts can include decreased species diversity (Gabbard and Fowler 2007; Thomson 2005), modified disturbance regimes (Mack and D'Antonio 1998), altered nutrient cycling (Mack et al. 2001), reduced livestock forage quality (Knapp 1996), and loss of wildlife habitat (Crawford et al. 2004). Control methods in wildlands consist of prescribed fire, prescribed grazing, herbicide application, or some combination of these techniques (Currie et al. 1987; DiTomaso et al. 2006; Harmoney 2007; Whitson and Koch 1998).

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Interpretive Summary

Combining herbicide application with seeding desirable perennial species has emerged as an effective technique for the restoration of weed-infested wildlands. The development of selective herbicides for fast-growing annual grasses has made this technique an option for the millions of acres dominated by downy brome within the Great Basin desert of North America. However, when selectivity is based on herbicide rate, success partially depends on the ability of the seeded species to tolerate the herbicide. Our results indicate that both communities experienced tradeoffs between downy brome control and injury/mortality of seeded species. Variation between communities can be attributed to differences in precipitation, which can affect herbicide effectiveness through a number of mechanisms, including foliar and root uptake of herbicide, soil organic matter, and resource competition between seeded species and downy brome. Downy brome began to recover within 2 yr after imazapic treatments, and this effect was more dramatic at the mesic Wyoming big sagebrush site than at the drier salt desert shrub site. It is not known at what level of downy brome cover combined with desirable species establishment is required in order to maintain low downy brome cover over the long term. Clearly, lower levels are required than what was achieved in this study, suggesting that at least one additional application of herbicide might be necessary. Although the use of imazapic herbicide combined with seeded perennial species shows promise in shifting downy brome-dominated sites to perennial species, proper dosage based on site-specific conditions is critical, as is follow-up treatment.

Prescribed fire can be effective against both annual and perennial grasses (DiTomaso et al. 2006). Burns should be timed to maximize damage to seeds, because annual plants rely on seed production to regenerate each year. Fire is particularly effective on plants whose seeds are animal-dispersed, because their seeds remain attached to inflorescences, making them more susceptible to damage from fire than seeds that have fallen to the soil surface. Fire can be effective at reducing reproductive output, but a subsequent burn and/or other treatments generally are required for adequate control. Fire also can be used to remove accumulated plant litter and improve herbicide contact with emerging target plants and the soil surface (Sheley et al. 2007; Shinn and Thill 2003).

Herbicide use, especially when combined with other treatments, is the most common approach to control wildland weeds (DiTomaso 2000; DiTomaso et al. 2006; Jacobs et al. 2006; Sheley et al. 2004). A variety of herbicides have been developed for control of invasive grasses, ranging from broad spectrum to selective (Currie et al. 1987; Monaco et al. 2005; Whitson and Koch 1998), and control is improved when their use is combined with establishing desirable species (Benz et al. 1999; Pokorny et al. 2005; Sheley et al. 2005; Whitson and Koch 1998). Seeding desirable species reduces opportunities for invasive plant recolonization and provides competition for individuals that survive herbicide treatments. When the two are combined, proper herbicide dosage must be applied in order to avoid damaging seeded species (Shinn and Thill 2004).

The cool-season annual grass downy brome (*Bromus tectorum* L.) has invaded over 8.9 million ha (22 million acres) in the western United States, and is estimated to spread at a rate of 14% each year (Duncan et al. 2004). Since its accidental introduction to the Pacific Northwest in the late 1800s from agricultural seed originating from Eurasia, it has spread throughout the Snake River Plain and Great Basin (Mack 1981). Downy brome increases size, intensity, and frequency of fires in the Great Basin region (Knick and Rotenberry 1997), and recovers well after fire if seed banks are present (Humphrey 2001; Young and Evans 1978). Its success across these ecosystems is attributed to positive feedbacks between production of continuous fine fuels and wildfire (Mack and D'Antonio 1998). Expenses associated with fire suppression, including post-fire revegetation, can be as high as $20 million each year (Knapp 1996). Additional costs associated with downy brome invasion include the loss of forage for livestock and wildlife, and other hidden costs associated with the displacement of native vegetation (Crawford et al. 2004; Knapp 1996; Mack 1981).

Downy brome control in semiarid ecosystems of the Snake River Plain and Great Basin typically includes herbicide application and reseeding (Thompson et al. 2006). Prescribed fire alone is ineffective because downy brome inflorescences shatter early in the season and temperatures at the soil surface are not usually high enough to damage seeds during fires (DiTomaso et al. 2006). However, carefully-timed prescribed livestock grazing to reduce fine fuels and suppress downy brome seed production might be a viable option for control (Hempy-Mayer and Pyke 2008; Mosley 1996). A variety of herbicides are effective for downy brome; including glyphosate (Whitson and Koch 1998), atrazine (Currie et al. 1987), and paraquat (Park and Mallory-Smith 2005). Herbicides that provide selective control with less nontarget injury and are soil-active show promise in wildland settings (Monaco and Creech 2004). In particular, the selective herbicide imazapic has recently been labeled and approved for landscape-level application on federal wildlands. Several studies showcase reductions of the annual grass medusahead [*Taeniatherum caput-medusae* (L.) Nevski] between 66 and 90% (Kyser et al. 2007; Monaco et al. 2005; Sheley et al. 2007; Shinn and Thill 2002). However, only a few peer-reviewed studies have evaluated imazapic control of downy brome or other annual bromes (Davison and Smith 2007; Shinn and Thill 2002). In addition, response of seeded species to variable imazapic application rates is only addressed in a few studies (Kyser et al. 2007; Sheley et al. 2007). Consequently, we conducted rangeland seedings in representative salt desert shrub and Wyoming big

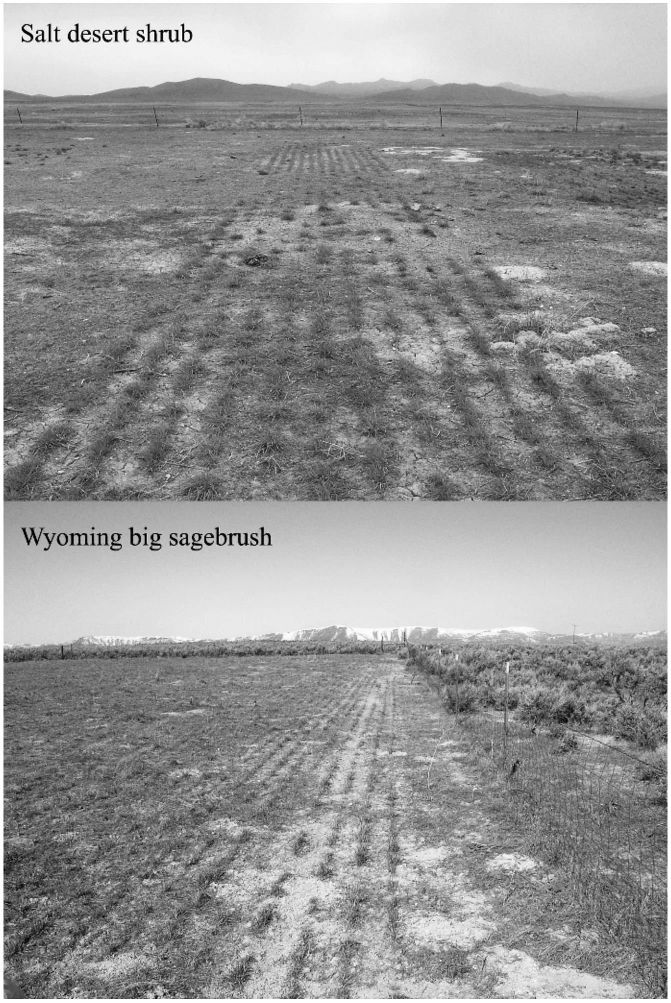

Figure 1. Salt desert shrub and Wyoming big sagebrush sites used for this study.

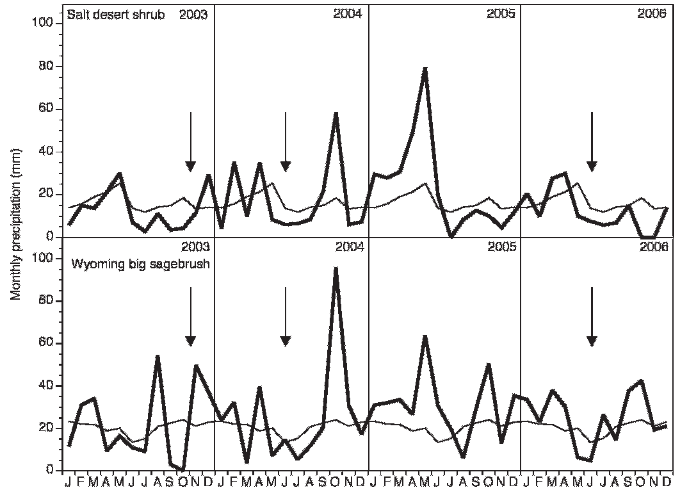

Figure 2. Monthly precipitation at the salt desert shrub and Wyoming big sagebrush sites used for this study. Thin lines are the 45-yr monthly average. Arrows in 2003 indicate dates for herbicide application, and arrows in 2004 and 2006 indicate dates for data collection.

sagebrush (*Artemisia tridentata* Nutt. spp. *wyomingensis* Beetle and Young) communities treated with variable rates of imazapic. Our study evaluates the effects of imazapic on downy brome and five seeded plant materials as well as the potential for plant materials to prevent reinvasion of downy brome over a 3-yr period.

Methods

Two sites in central Utah differing in climate, vegetation state, and disturbance history were chosen for this study. The first site was a salt desert shrub community (Figure 1; 40°19′37.13″N, 112°46′56″W) situated at 1,452 m (4,763 ft). It has fine sandy loam soils from eolian, lacustrine, and alluvial deposits derived from mixed parent materials and has 0.52% organic matter (NRCS 2008). Total annual precipitation at the nearest weather station, located 11.1 km (6.9 mi) away, for the years 2003 to 2006 were: 135 mm (5.31 in), 208 mm, 284 mm, and 119 mm (Figure 2; WRCC 2008). The 45-yr average for annual precipitation is 195 mm. It is classified as a desert loam Ecological Site (NRCS 2008). The reference plant community is composed of 45% perennial grasses, 40% shrubs and 15% forbs, by weight. Dominant species include indian ricegrass [*Achnatherum hymenoides* (Roem. & Schult.) Barkworth], bottlebrush squirreltail [*Elymus elymoides* (Raf.) Swezey], James' galleta (*Pleuraphis jamesii* Torr.), shadscale saltbush [*Atriplex confertifolia* (Torr. & Frém.) S. Watson], winterfat [*Krascheninnikovia lanata* (Pursh) A. Meeuse & Smit], and bud sagebrush (*Picrothamnus desertorum* Nutt.). A vegetation assessment conducted at the site during the late 1950s described it as consisting of 85% shrubs, 10% grasses, 5% forbs, and dominated by shadscale saltbush and bottlebrush squirreltail (Page et al. 1994). Fires in the early 1960s converted the site to downy brome and other annual weeds, and wildfire has burned the site three additional times since, thus preventing the reestablishment of a perennial plant community.

Our second site was a Wyoming big sagebrush community (Figure 1; 39°30′36.27″N, 111°31′51.07″W), situated at an elevation of 1,739 m. This site has gravelly loam alluvial soils derived from limestone and sandstone with 1.5% organic matter (NRCS 2008). Total annual precipitation at the nearest weather station, located 4.8 km from the site for the years 2003 to 2006 were: 218 mm, 302 mm, 316 mm, and 272 mm (Figure 2; WRCC 2008). The 45-yr average is 240 mm. The Ecological Site classification for this site is a semidesert loam (NRCS 2008). The reference community is described as consisting of 50% shrubs, 45% perennial grasses, and 5% forbs, by weight. Potential perennial grasses include indian ricegrass, needle and thread grass [*Hesperostipa comata* (Trin. & Rupr.) Barkworth], purple threeawn (*Aristida purpurea* Nutt.), bottlebrush squirreltail, and Sandberg bluegrass (*Poa secunda* J. Presl). Following a fire in 1978, the perennial forage grass crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.] was seeded and cattle and sheep have variably grazed year-round or during winter. Over time the site transitioned back to dominance by Wyoming big sagebrush, with an understory of downy brome and crested wheatgrass until spring 2003, when it was disked to a depth of 15 cm to remove all shrubs, and cultivated with a spike-toothed harrow to prepare the seedbed.

The experiment was set up with a split-plot design (Lentner and Bishop 1993) by randomly assigning the five imazipic rates to 4.5 m (15 ft) by 15 m (50 ft) whole plots and the five seeded species to 3 m by 4.5 m split plots with three replications of each whole plot. Imazapic[1] was sprayed at rates of 0, 35, 70, 105, and 140 g ai/ha (0, 0.5, 1, 1.5, and 2 oz ai/ac) on October 28, 2003 at the salt-desert shrub community and October 29, 2003 at sagebrush community. Herbicide was combined with a nonionic surfactant[2] (0.25% v/v) and applied with a custom-built sprayer mounted on bicycle wheels. The boom was 4.1 m in length and had eight flat-fan nozzles[3] spaced 51 cm apart. The system was pressurized with air to 276 kPa (40 psi) and pushed at a speed of 1.3 m/s (3 mi/h). The system was calibrated to spray each plot at the rate of 94 L/ha (10 gal/ac) in one pass. Applications were made in midmorning with negligible wind. No rain events occurred at either site within the critical time period after application.

Five perennial plant materials were seeded perpendicular to herbicide applications to create random combinations of herbicide rate by seeded material plots. Seeded plant materials included two sources of Siberian wheatgrass [*Agropyron fragile* (Roth) P. Candargy; 'Vavilov' and the experimental line, Kazak], two sources of prostrate kochia [*Bassia prostrata* (L.) A. J. Scott; 'Immigrant' and the experimental line, 6X], and 'Bozoisky II' Russian wildrye [*Psathyrostachys juncea* (Fisch.) Nevski]. These five species were selected for evaluation based on their successful establishment on similar ecological sites (Asay et al. 2003; Monaco et al. 2003; Newhall et al. 2004). Grasses were seeded with a lightweight plot drill[4] on 11 November 2003 at a rate of 1.2 pure live seeds/cm to a depth of 1.3 cm. Prostrate kochia was similarly seeded, except that the disks were lifted so that the seeds were pressed into the soil surface by a brillion compactor, rather than being buried. Each plot consisted of eight seeded rows, spaced 25.4 cm (10 in) apart.

Plant material establishment was determined using a frequency grid that contained 42, 11 cm squares arranged in seven rows and six columns (Vogel and Masters 2001). Thus, the grid sampled only 24 squares because drill rows were spaced 25.4 cm apart. To avoid areas with border effects or where overlap might have occurred during herbicide application, we sampled only the four central rows in every plot by placing the grid 2 m and 4 m from the top of each plot. Establishment frequency was calculated as the proportion (%) of squares that contained seeded plant material. We also made visual estimates of downy brome ground cover (%) within the same area sampled for seeded plant material establishment. Establishment and cover percentages were evaluated in mid-June of 2004 and 2006. Data from the two grid measurements were averaged for each plot and analyzed as a factorial ANOVA experiment with statistical software (Sall et al. 2005) to determine significant main- and interaction-effects between site, year, plant material, and herbicide rate ($\alpha = 0.01$). The mean square for experimental error was used as the error term for all effects. When significant effects were found, differences between means were compared using Fisher's Protected LSD procedure ($\alpha = 0.05$).

Results and Discussion

Substantiating cause and effect between downy brome and seeded material establishment is challenging because of the dynamic and indirect interactions influencing this relationship. For example, the ultimate effect of herbicide application depends not only on inherent tolerance and resistance of plants, but also on direct and indirect effects of additional biotic and abiotic environmental factors (Radosevich et al. 2007).

Understanding how herbicide application affects the potential trade-off between herbicide control of downy brome and herbicide damage to nontarget seeded species as the rate of application increases is of particular importance to this study.

Downy Brome Cover. As imazapic rate increased, downy brome cover declined to nearly 10% for the middle imazapic rate in the big sagebrush community in 2004; however, by 2006 this invasive species entirely rebounded and no differences in downy brome cover existed among imazapic rates (Table 1; Figure 3). In contrast, downy brome cover was only reduced to about 25% at the highest herbicide rate in the salt desert shrub community, and increased to 55% in 2006 at the highest herbicide rate. The initial differences in response of downy brome cover at the two sites might be attributed to precipitation differences prior to and after herbicide application. The effect of precipitation on downy brome emergence *after* herbicide application or the higher levels of soil organic matter at the Wyoming big sagebrush site do not help to explain the results. Instead, the greater reduction of downy brome in the Wyoming big sagebrush community in 2004 than in the salt desert shrub community was likely a consequence of greater-than-average precipitation in summer and autumn *prior* to applying herbicide (Figure 2). In addition, a four-fold greater than average precipitation in November 2003 at the Wyoming big sagebrush site prior to freezing soil temperatures might have provided ideal conditions for synchronized favorable downy brome germination and herbicide uptake by susceptible seedlings. Conversely, at the salt desert shrub community, extremely low precipitation during autumn of 2003 created less opportunity for downy brome to germinate and absorb imazapic before freezing temperatures. Disking to remove sagebrush also might be partially responsible for greater downy brome reduction in 2004 by disrupting seed production and removing thatch, which can intercept herbicide and prevent uptake (Sheley et al. 2007; Shinn and Thill 2003).

Precipitation also is important for explaining increases in downy brome cover at both sites 2 yr after treatment (Figure 3). Both plant communities had highly favorable precipitation patterns in autumn/spring of 2004/2005, which promoted downy brome growth. However, there were distinct differences in seasonal precipitation in autumn/spring of 2005/2006 (Figure 2) between the two sites. Minor reductions in downy brome cover at the salt desert shrub site relative to the control rate in 2006 is a consequence of particularly low autumn precipitation, similar to the conditions that prevented a dynamic herbicide response in autumn 2003. In contrast, at the Wyoming big sagebrush site, the opportunity for downy brome seed production and growth was augmented by two-fold greater precipitation during October 2005 and May 2006, resulting in no difference between control and treated plots in 2006, and greater downy brome cover than in control plots from 2004. Rapid recovery of downy brome after disturbance, even when seed banks were depleted by prescribed burning, can occur within 2 yr (Humphrey 2001). It appears that the effects of high precipitation can quickly overshadow the effects of herbicide, because of the ability of downy brome to respond quickly to favorable conditions. Previous research similarly highlights the importance of precipitation for establishment of downy brome (Chambers et al. 2007).

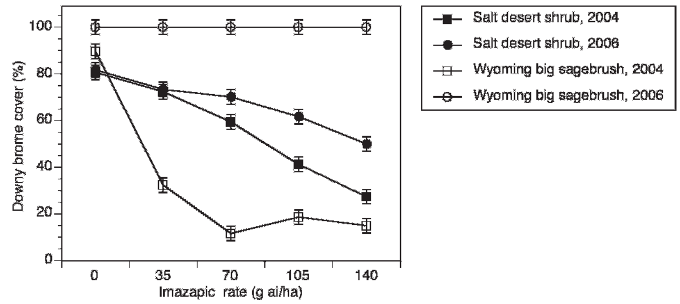

Figure 3. Mean downy brome cover for the significant interaction between site, year, and herbicide rate. Error bars are one standard error.

Downy brome cover also depended on how site and year interacted with seeded plant materials (Table 1; Figure 4). Although seeded plant materials failed to influence downy brome cover at the Wyoming big sagebrush site, the two Siberian wheatgrasses experienced respectively similar (Kazak) or decreased ('Vavilov') downy brome cover between 2004 and 2006 at the salt desert shrub site. In contrast, Russian wildrye and both prostrate kochia

Table 1. ANOVA results for downy brome cover and establishment frequency of seeded plant material. Significant effects in bold are discussed in text.

Effect	df	Downy brome cover (%) P value	Establishment frequency (%) P value
Site	1	0.0005	< 0.0001
Year	1	< 0.0001	< 0**.0001**
Site·year	1	< 0.0001	0.1742
Plant material (pm)	4	< 0.0001	< 0.0001
Site·pm	4	< 0.0001	< 0**.0001**
Year·pm	4	< 0.0001	0.0162
Site·year·pm	4	< 0**.0001**	0.0692
Rate	4	< 0.0001	< 0.0001
Site·rate	4	< 0.0001	< 0**.0001**
Year·rate	4	< 0.0001	0.3094
Site·year·rate	4	< 0**.0001**	0.615
Pm·rate	16	**0.0049**	< 0**.0001**
Site·pm·rate	16	0.0188	0.0124
Year·pm·rate	16	0.9319	0.9977
Site·year·pm·rate	16	0.8092	0.5572

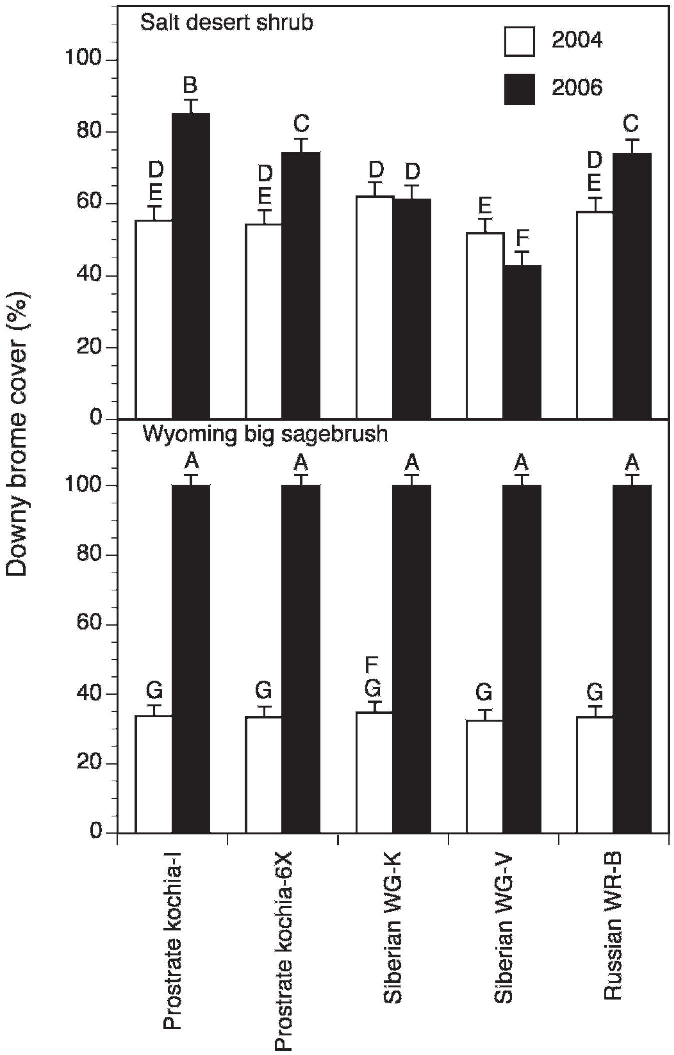

Figure 4. Mean downy brome cover for the significant interaction between sampling year and plant material (prostrate kochia ['Immigrant' and 6X]; Siberian wheatgrass [Kazak and 'Vavilov']; and Russian wildrye ['Bozoisky II']). Error bars are one standard error. Values followed by the same letter are not different (Fisher's Protected LSD procedure; $\alpha = 0.05$).

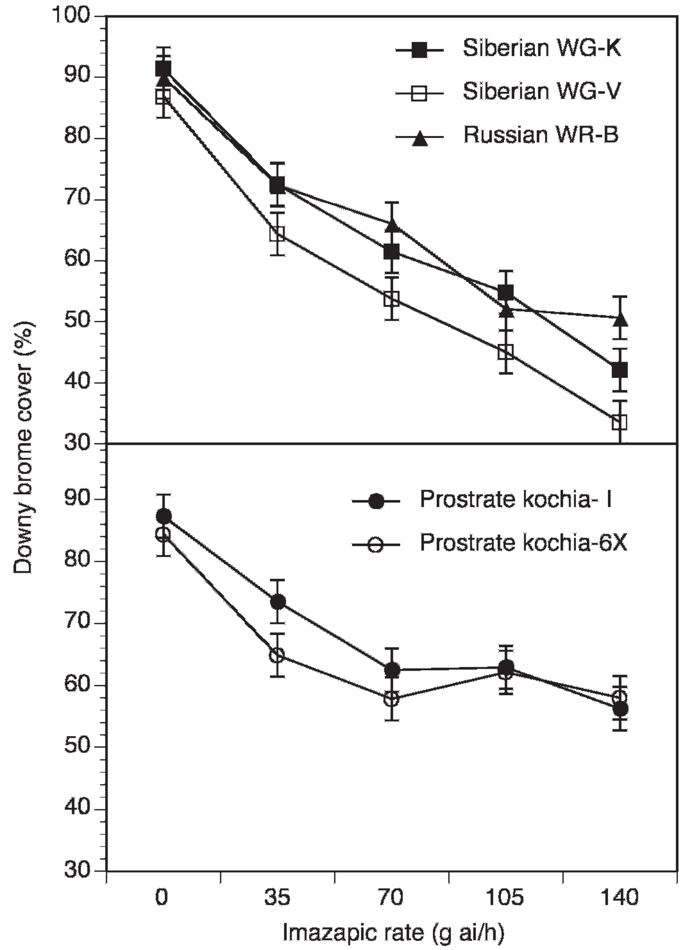

Figure 5. Mean downy brome cover for the significant interaction between herbicide rate and plant material (prostrate kochia ['Immigrant' and 6X]; Siberian wheatgrass [Kazak and 'Vavilov']; and Russian wildrye ['Bozoisky II']). Error bars are one standard error.

materials experienced significant increases in downy brome cover between 2004 and 2006. Successful establishment of Siberian wheatgrass and favorable competition with weeds following rangeland seedings have also been documented by others (Asay et al. 2003; Waldron et al. 2005). It also is likely that weed control in prostrate kochia plots will improve over time, because young stands are known to provide poor initial control of downy brome, but control improves after 5 to 10 yr (Monaco et al. 2003). Thus, the biotic effects of seeded species on downy brome only were apparent when abiotic conditions (e.g., precipitation) were limiting (e.g., salt desert shrub community). Although the importance of competition in stressful, low-productivity sites has been questioned (Grime 1977), theories developed for semiarid systems that experience temporally distinct pulse and interpulse resource periods indicate that competition can be intense even under low resource availability (Goldberg and Novoplansky 1997). Variable effects of seeded plant materials on downy brome cover also appear to depend on herbicide rate (Table 1; Figure 5). For example, plant materials had similar effects on downy brome cover up to the 70 g ai/ha rate; however, perennial grasses provided greater additional control than prostrate kochia materials at the two higher rates. These results emphasize that herbicide rate might indirectly influence target weed cover, depending on how it affects the establishment of seeded species.

Seeded Plant Material Establishment. Herbicide rate not only significantly impacted downy brome cover, but also had pronounced effects on seeded plant material establishment. Seeded plant establishment steadily improved with

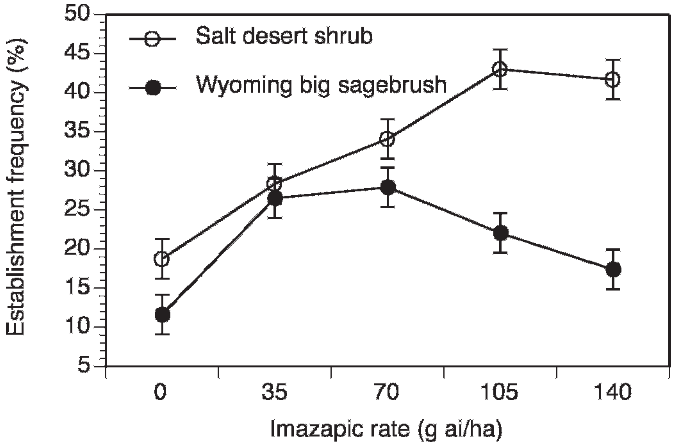

Figure 6. Mean seeded plant material establishment for the significant interaction between site and herbicide rate. Error bars are one standard error.

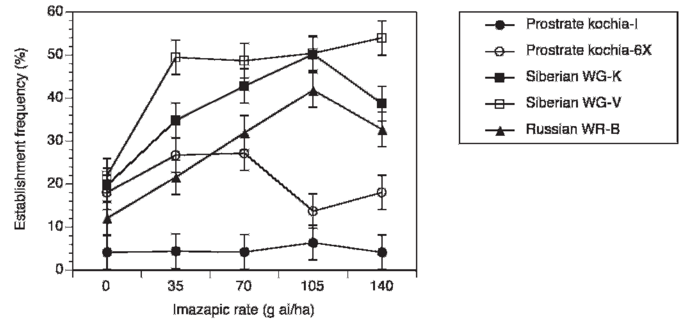

Figure 7. Mean seeded plant material establishment for the significant interaction between herbicide rate and plant material (prostrate kochia ['Immigrant' and 6X]; Siberian wheatgrass [Kazak and 'Vavilov']; and Russian wildrye ['Bozoisky II']). Error bars are one standard error.

imazapic rate up to the second highest rate at the salt desert shrub site (Table 1; Figure 6). In contrast, at the Wyoming big sagebrush site, establishment was barely improved and/or declined beyond the 35 g ai/ha rate. Differences in establishment between sites can be attributed to differential effectiveness of the herbicide and precipitation, as discussed earlier in relation to downy brome cover.

Imazapic rate also differentially impacted individual seeded plant materials (Table 1; Figure 7). Establishment of Kazak Siberian wheatgrass and 'Bozoisky' Russian wildrye was greatly improved by increasing imazapic rate up to the 105 g ai/ha rate, after which it was reduced. 'Vavilov' Siberian wheatgrass generally had the highest establishment, even though it did not improve above the 35 g ai/ha rate. Both prostrate kochia materials had poor seedling establishment, and establishment of the 6X experimental material declined at the 105 and 140 g ai/ha rates. Our results confirm reports indicating that high rates of imazapic can hinder establishment of some seeded and pre-existing perennial species (Monaco et al. 2005; Shinn and Thill 2004). Reduced establishment might compromise their ability to affect downy brome cover. Collectively, our results suggest that if seeded perennial species were not negatively impacted by imazapic at higher rates, downy brome cover would be reduced even more. This general increase in establishment with herbicide rate for the perennial grasses likely explains the consistent decrease in cover for downy brome as herbicide rate increased with perennial grasses (Figure 5), as compared to the leveling-off for the prostrate kochias at the higher rates. The overall high establishment of 'Vavilov' Siberian wheatgrass likely explains the decrease in downy brome cover from 2004 to 2006 (Figure 4). Likewise, greater establishment of Kazak Siberian wheatgrass than 'Bozoisky II' Russian wildrye, and differences in their response to imazapic rate (Figure 7) clarify why the former did not experience significant increases in downy cover during the study (Figure 4). These results corroborate previous rangeland reseeding observations of lower seedling establishment of Russian wildrye than Siberian wheatgrass, and 'Vavilov' outperforming establishment of Kazak (Palazzo et al. 2005; Waldron et al. 2005). We view poor establishment of prostrate kochia as one of the factors responsible for downy brome cover leveling-off at the two highest rates (Figure 5). Interestingly, superior establishment of 6X compared to 'Immigrant' kochia also might be responsible for the former material having greater impact on downy brome cover at lower imazapic rates in Figure 5. Poor establishment of prostrate kochia reflects its difficulty of establishment (Sheley et al. 2007) and extremely poor seed viability, even when stored in temperature-controlled facilities (Kitchen and Monsen 2001).

Variation in seeded material establishment was not only influenced by herbicide rate, but by year main-effects and an interaction between sites (Table 1). In contrast to downy brome cover, seeded material establishment frequency (%) significantly declined between 2004 and 2006 (Mean $\pm$ 1 SE, n = 150; 35.5 $\pm$ 1.1 vs. 18.8 $\pm$ 1.1). Three plant materials had greater establishment at the salt desert shrub site, whereas the other two were equal between sites (Figure 8). We suggest that greater seedling establishment in the salt desert shrub community, even under less favorable precipitation, might be attributed to the combined effects of downy brome interfering more with seedling establishment in 2006 in the Wyoming big sagebrush community (Figure 4), and the two higher rates of imazapic facilitating seedling establishment at the salt desert shrub community (Figure 7). Variable imazapic control of target weeds and seeded species injury similarly have been attributed to site characteristics in other studies, including various management conditions, i.e., amount of ground litter and extent of prescribed burning (Kyser et al. 2007; Monaco et al. 2005; Sheley et al. 2007).

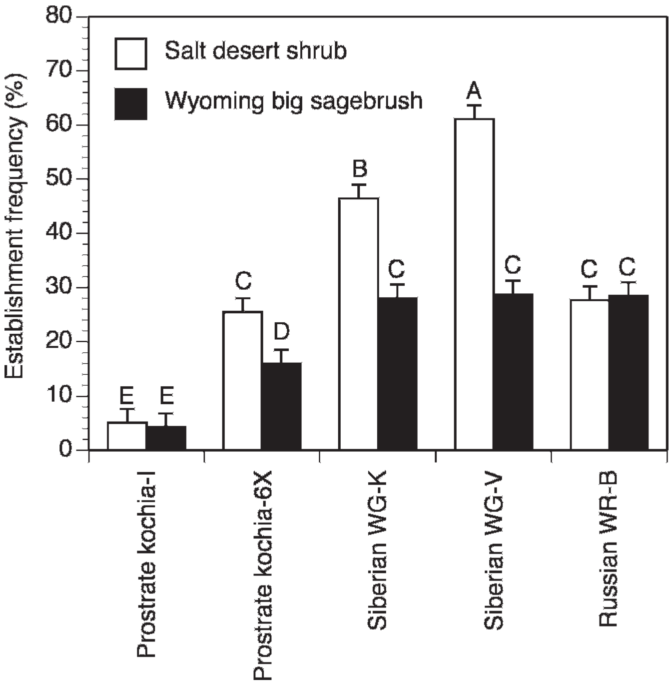

Figure 8. Mean seeded plant material establishment for the significant interaction between site and plant material (prostrate kochia ['Immigrant' and 6X]; Siberian wheatgrass [Kazak and 'Vavilov']; and Russian wildrye ['Bozoisky II']). Error bars are one standard error. Values followed by the same letter are not different (Fisher's Protected LSD procedure (α = 0.05).

Due to time and financial constraints, land managers are more likely to pursue weed management if success can be achieved without requiring follow-up actions (Sheley 2007). Combining herbicide application with simultaneous seeding of appropriate, competitive perennial grasses is considered a viable management option for controlling some undesirable weeds in one pass; e.g., spotted knapweed (*Centaurea stoebe* L.), Russian knapweed [*Acroptilon repens* (L.) D.C], and green rabbitbrush [*Ericameria teretifolia* (Durand & Hilg.) Jeps.] (Sheley 2007; Sheley et al. 2001). However, the difficulty of reestablishing desirable species within communities infested with invasive annual grasses, combined with the ability of annual grasses to recover after disturbance, suggests that follow-up actions or alternative management approaches should be explored. In the two plant communities evaluated in our study, downy brome cover significantly increased between 2004 and 2006, even when it was reduced to as low as 12% in the Wyoming big sagebrush community. These results are not surprising given the well-recognized ability of downy brome to rapidly recover from existing seed banks under favorable precipitation (Humphrey 2001; Mack and Pyke 1983). Consequently, downy brome has a low threshold for acceptable plant density posttreatment, because even a few surviving plants can quickly repopulate a site and reverse reseeding efforts (Evans 1961; Young and Evans 1978). Acceptable densities of perennial weeds might be higher because their population levels do not track resource pulses as closely as annuals species (Sheley and Jacobs 1997). Therefore, the primary challenge for rangeland managers and researchers is to identify and quantify sources of failure and successful establishment of perennial grasses and develop strategies that directly counterbalance the ability of downy brome to reinvade from existing seed banks. We might be stating the obvious, but if rangeland seedings fail and control methods do not include some level of depletion of downy brome seedbanks, downy brome will quickly reinvade. The necessity to deplete downy brome seed banks thus will require land managers to consider a management strategy that accommodates multiple, repeated treatments (Dewey et al. 1995).

Sources of Materials

[1] Imazapic, Plateau®, BASF Corp., Research Triangle Park, NC 27709.

[2] S-90 Surfactant, IFA-S90, Intermountain Farmers Association, Salt Lake City, UT 84119.

[3] 8001 E flat fan nozzle, Teejet® Technologies, Wheaton, IL 60189-7900.

[4] HEGE 80, lightweight plot drill, Wintersteiger Inc., Salt Lake City, UT 84116–2876.

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