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Research

Selective Control of Medusahead (*Taeniatherum caput-medusae*) in California Sagebrush Scrub using Low Rates of Glyphosate

Guy B. Kyser, J. Earl Creech, Jimin Zhang, and Joseph M. DiTomaso*

Although glyphosate is typically used as a nonselective herbicide, low rates have the potential to provide selective control of seedling annuals in the understory of established perennial plants. In a repeated experiment on two adjacent sites at a single location near Alturas, CA (2009 and 2010), we evaluated the efficacy of glyphosate at several different rates on medusahead and nontarget species in northern California sagebrush scrub. We applied glyphosate at 10 rates ranging from 0 to 709 g ae ha^{-1} (0 to 18 oz product acre^{-1}) at three separate timings in each trial: mid-March (medusahead in early seedling stage), late April to early May (tillering), and late May to early June (boot to early head). Plots measured 3 m by 9 m (10 ft by 30 ft) and were arranged in randomized complete blocks with four replications for each rate and timing. We visually estimated vegetative cover for all dominant species in July before medusahead seed drop using three 1-m^2 quadrats per plot. Medusahead cover declined with increasing rates of glyphosate, and the middle application timing (at tillering) was the most effective. In rate series regression models, we achieved 95% control of medusahead with 160 g ae ha^{-1} glyphosate in midseason 2009, compared with 463 g ae ha^{-1} in early season and 203 g ae ha^{-1} in late season. In 2010, we achieved 95% control with 348 g ae ha^{-1} in midseason, compared with $>$ 709 g ae ha^{-1} in early season. Medusahead seed production reflected changes in cover, though individual plants tended to produce more seed at low densities. We attribute reduced control early in the season and poorer overall control in 2010 to greater tolerance of medusahead to glyphosate at lower temperatures. Treatment effects on big sagebrush, as indicated by shoot tip vigor, were minor, although the midseason timing caused a slight reduction in vigor. These results show that low rates of glyphosate (158 to 315 g ae ha^{-1}) at a treatment timing corresponding to medusahead tillering can give economical and effective control of medusahead without long-term damage to big sagebrush.

Nomenclature: Glyphosate; medusahead, *Taeniatherum caput-medusae* (L.) Nevski; big sagebrush, *Artemisia tridentata* Nutt.

Key words: *Taeniatherum caput-medusae*, glyphosate, chemical weed control, invasive rangeland, sagebrush.

Medusahead (*Taeniatherum caput-medusae* (L.) Nevski) is one of the most problematic invasive annual grasses in California (Kyser et al. 2007) and other western rangelands and grasslands (Torell et al. 1961), often forming near-monotypic stands. The high silica content in its foliage retards decomposition, often resulting in a persistent thatch, which suppresses germination and establishment of other rangeland species. In addition, high silica content makes medusahead less palatable to livestock and can reduce rangeland grazing capacity by as much as 80% (Hironaka 1961). Medusahead is highly competitive with other herbaceous species, and severe infestations have been shown to reduce the population densities of a number of native functional groups (Davies and Svejcar 2008; Young and Mangold 2008).

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Management Implications

In a Great Basin sagebrush community, low rates of glyphosate applied at the medusahead tillering stage in late April to early May provided the best control of medusahead. At this timing, we achieved at least 95% control of medusahead cover and a corresponding reduction in seed production with 160 g ae ha^{-1} (4.1 oz product acre^{-1}) in 2009 and 348 g ae ha^{-1} (8.8 oz product acre^{-1}) in 2010. Generic glyphosate products have a lower concentration of glyphosate (3 lb ae gal^{-1}) compared to *Roundup ProMax* used in this study (4.5 lb ae gal^{-1}) and, thus, would require 6 to 13 oz product acre^{-1} to provide effective control of medusahead at the optimum timing. These rates are far lower than those required to control perennial species and provide a more cost effective option to ranchers and land managers compared to other herbicide treatments. Earlier applications required significantly higher rates to achieve equivalent control. Later applications (close to heading) also gave excellent control at slightly higher rates than applications at tillering. However, late application timing not only provided less competitive release and increased injury of desirable understory species, but also left a cover of standing dead medusahead, increasing the risk of wildfire. A potential negative aspect to the middle application timing is the overlapping timing with big sagebrush bud break. This level of injury did not cause plant death, but did suppress the current-year shoot tip growth. Although a single year of timely glyphosate treatment can provide excellent control in the year of application, medusahead seedbanks are capable of reestablishing invasive populations the following year. As such, a multi-year commitment will be required to deplete the soil seedbank and prevent new seed production.

In semiarid big sagebrush (*Artemisia tridentata* Nutt.) scrub, medusahead acts as a fire promoter (Brooks et al. 2004) in a manner similar to downy brome (*Bromus tectorum* L.) in more arid parts of the Great Basin (Brooks and Pyke 2001; D'Antonio and Vitousek 1992; Torell et al. 1961). Like downy brome, medusahead fills the interstices of the sagebrush understory, creating a continuous fuel corridor that accelerates the fire cycle from a historical average of 50 to 100 yr to once every 2 to 5 yr (Peters and Bunting 1994; Young 1992). Unlike medusahead or downy brome, sagebrush is unable to regenerate from more frequent fires. This change in fire frequency quickly leads to type conversion from a native scrub community to predominantly nonnative annual grassland. As a secondary impact, this is contributing to the decline of sagebrush-dependent wildlife species such as sage grouse (Davies and Johnson 2008).

Options for medusahead control in rangelands are limited, particularly in low-productivity Great Basin systems. Although medusahead can be controlled by burning in high-productivity, low-elevation grasslands, this technique is less effective in semiarid sites where insufficient fuel loads generally prevent fires from reaching temperatures hot enough to kill medusahead seed (Kyser et al. 2008; Sweet et al. 2008). Furthermore, even in ecosystems where prescribed burning is effective for medusahead control, it can severely damage native shrubs and is counterproductive to sagebrush system management goals. Intense timely grazing by sheep has also been shown to provide medusahead control (DiTomaso et al. 2008), but this technique is difficult to scale up and requires a large number of animal units in a short time frame. The herbicides imazapic and sulfometuron can give effective control of medusahead (Monaco et al. 2005; Sheley et al. 2007), but results with imazapic are often variable depending on thatch and soil texture (Kyser et al. 2007), and sulfometuron can create environmental issues related to off-site movement to sensitive crops from contaminated windblown soil (Hutchinson et al. 2007). Burning followed by treatment with imazapic has been reported effective in some situations (Davies and Sheley 2011; Kyser et al. 2007; Sheley et al. 2007), but this strategy is subject to the limitations of both burning and imazapic. Using any of these control options in sagebrush scrub can result in management costs that quickly exceed the capability of ranchers to implement large-scale control efforts.

Glyphosate has been the most widely used pesticide in the United States since its introduction in the 1970s (USDA Economic Research Service 2011). It is applied as a foliar spray and is generally considered nonselective, although a few plant species are relatively tolerant and others have developed resistance through repeated exposure (Heap et al. 2011). Typical glyphosate application rates range between 840 and 3,362 g ae ha^{-1} (0.75 to 3 lb ae acre^{-1}) for control of herbaceous weeds, including perennials. Labels recommend higher rates of 3,362 to 8,406 g ae ha^{-1} for controlling brush. Labels also suggest lower rates, i.e., 420 to 1,261 g ae ha^{-1}, for controlling seedling annual grasses in established perennial grass pasture. Various researchers have used glyphosate at rates even lower than 420 g ae ha^{-1} to control seedling annual weedy grasses in perennial systems. For example, glyphosate rates between 110 and 370 g ae ha^{-1} controlled *Vulpia*, *Hordeum*, *Bromus*, and *Lolium* species in hardinggrass (*Phalaris aquatica* L.) pasture (Campbell and Nicol 1991); ripgut brome (*Bromus diandrus* Roth) (Tozer et al. 2008), jointed goatgrass (*Aegilops cylindrica* Host), and downy brome (Beck et al. 1995) in mixed perennial grass pasture; and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] and broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster] in bermudagrass [*Cynodon dactylon* (L.) Pers.] pasture (Butler et al. 2005). Comparison of the rates of glyphosate used to control seedling annual weedy grasses and woody plants suggests that seedling grasses may be controlled with rates much lower than those likely to cause damage to native shrubs. In this study, we used a series of low rates of glyphosate at three spring timings to determine the potential for efficient and economical management of emerged medusahead seedlings in a sagebrush scrub community.

Table 1. Times of application and evaluation.

	2009	2010
Early – seedlings to 5 cm tall	March 18	March 19
Middle – seedlings up to 10 cm tall, first tillers	May 8	April 30
Late – established plants in boot (2009) to early heading (2010)	May 27	June 8
Evaluation	June 22	July 8

Materials and Methods

Site Description. In 2009 and 2010, we established glyphosate rate and timing trials on two sites at a single location approximately 12 km (7.5 mi) south of Alturas, Modoc County, CA (41°23′N, 120°30′W, 1,410 m [4,626 ft] elevation). Although the two sites were adjacent to each other, the first-year site had almost no big sagebrush and the second-year site had mean mountain big sagebrush [*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle] cover of approximately 6%. The local soil was in the Karcal-Ninekar complex of cobbly clay to stony silt loam. Typical annual precipitation at this location is approximately 36 cm (14 in), but during the 2 yr of the study it received approximately 23 cm each year. In addition to medusahead and big sagebrush, other species at the sites included the introduced annual grass downy brome, the native perennial grass *Elymus elymoides* (Ref.) Swezey (squirreltail), native broadleaves *Epilobium brachycarpum* C. Presl (tall annual willowherb) and *Crepis* sp. (hawksbeard), and a number of species that represented a minor component of the plant community.

Experimental Design. Plots were 3 m by 9 m, with each site having three treatment timings (Table 1; early seedling stage, tillering stage, and boot to early heading), 10 rates of glyphosate (*Roundup ProMax*® herbicide, Monsanto Company, St. Louis, MO) (0, 79, 158, 236, 315, 394, 473, 552, 630, and 709 g ae ha^{-1}), and four replications per treatment (total of 120 plots per site). Time and rate combinations were randomized in complete blocks. Applications were made using a CO_2 backpack sprayer at 207 kpa (30 psi) and 3 m boom with six 8002 nozzles. Treatments were in 140 L ha^{-1} (15 gal $acre^{-1}$) total spray solution, with 2.5% liquid ammonium sulfate (*Bronc*®, 38% ammonium sulfate, Wilbur-Ellis Company, San Francisco, CA) added to prevent precipitation of glyphosate in hard water.

Evaluation. In each year we evaluated the plots about 1 mo after the final treatment (Table 1), before medusahead seed drop. Three 1-m^2 quadrats were randomly placed along the center line of each plot, and cover was visually estimated for all species. In addition, we estimated big sagebrush cover (%) and vigor in 2010. We interpreted reduced vigor in sagebrush as a slightly reduced and desiccated appearance in new shoot growth. Three 0.1-m^2 quadrats were also randomly placed, and samples were clipped at ground level for biomass measurements. Samples were dried at 60 C (140 F) for 1 wk and weighed; medusahead stems were then counted. In late summer 2009 we revisited the site after medusahead maturation to collect seedhead samples to determine the number of filled seed. In 2010, medusahead was mature at the time of initial data collection, so we used the initial biomass samples to estimate the number of filled seed. Nearly all filled seeds tested germinated (data not shown).

Analysis. Medusahead cover, stem density, and filled seed production; cumulative cover of broadleaf species; and sagebrush vigor (2010 only) were plotted against rate of glyphosate for each time of application. We fitted regressions to the medusahead cover rate series plots using SigmaPlot (SigmaPlot for Windows v. 10.0, Systat Software Inc., San Jose, CA); responses were modeled as exponential decay with two parameters [cover $= a \times \exp(-b \times \text{rate})$, where $a =$ cover in untreated plots and b $=$ decay constant]. The regression models were used to estimate glyphosate rates for 90 and 95% control of medusahead at each time of application. For each variable in each year, we compared rate series responses using multiple response permutation procedures (MRPP) in PC-ORD (PC-ORD for Windows v. 5.10, MjM Software, Gleneden Beach, OR.) to determine whether responses differed by time of application. Comparisons were made pairwise using Euclidean distance measures.

Results and Discussion

Overview of Medusahead Cover Results. Cover of medusahead in untreated plots was approximately twice as high in 2010 as in 2009 (Figures 1A and 1B). Year-to-year cover differences were not due to precipitation, as the rainfall totals and pattern were similar in both years. Moreover, when the 2009 untreated plots were reevaluated in 2010, medusahead cover was similar to untreated plots in the adjacent 2010 site (data not shown), so year-to-year differences in medusahead cover were not due to a site effect. We speculate that the cooler spring in 2010 (Figure 2) favored medusahead survival and growth, owing to enhanced germination (Young et al. 1968), direct temperature effects on phenology, or reduced evapotranspiration and greater soil moisture retention later into the growing season (Mangla et al. 2011).

Medusahead cover showed a strong rate response at all times of application in both years. In addition, application timing resulted in response differences. In 2009, the middle (May 8) timing produced a greater reduction in cover overall than the early (March 18) timing (P =

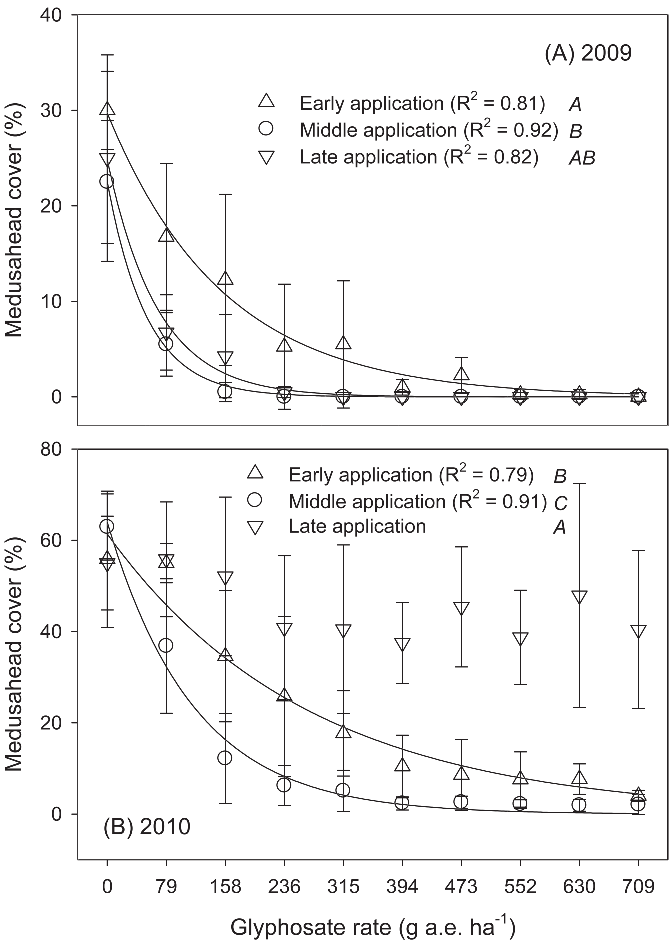

Figure 1. Cover of medusahead in (A) 2009 and (B) 2010. Application timings followed by different italic letters are different at $\alpha = 0.05$ (separated using multiple response permutation procedures [MRPP]). Probabilities (P) and chance-corrected within-group agreements (A) for MRPP were as follows: for 2009, early vs. middle, P = 0.019 and A = 0.207; early vs. late, P = 0.105, A = 0.074; middle vs. late, P = 0.628, A = −0.035. For 2010, early vs. middle, P = 0.009, A = 0.179; early vs. late, P = 0.007, A = 0.288; middle vs. late, P = 0.006, A = 0.454. Regressions were performed on all data, but only means (± SD) are shown. Regression parameters are indicated in Table 2. In late application treatments in 2010, plants that were controlled by the treatments could not be distinguished from naturally senesced plants.

0.0186 using MRPP). The late (May 27) timing was not significantly different than the early or middle treatment times. In 2010, overall medusahead cover was significantly different for each timing ($P < 0.01$), with the middle timing again resulting in the greatest reduction in cover.

Regressions fitted to each timing/rate series were consistently strong (R^2 approximately 0.8 to 0.9, $P < 0.0001$ for all relationships), with the exception of the late timing in 2010, owing to difficulties in separating naturally

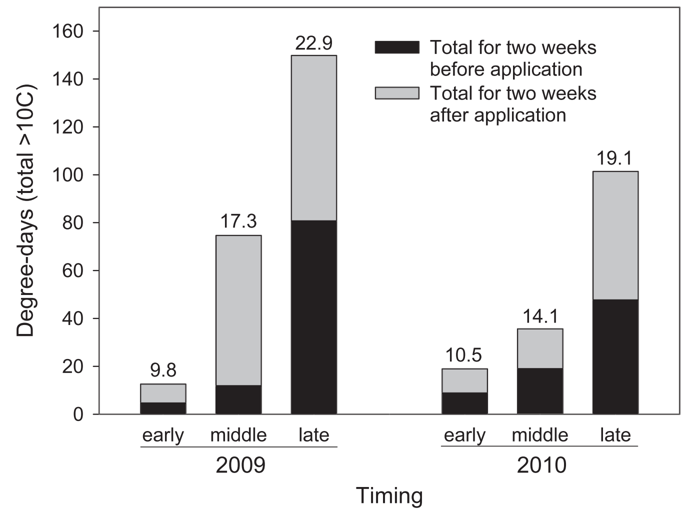

Figure 2. Cumulative degree-days (10 C baseline, no upper limit) for the 2 wk before and after each application, showing overall cooler temperatures in middle and late treatments in spring 2010. Numbers indicate average maximum temperatures (C) during 2 wk before and after application.

senesced individuals from plants that had been controlled by the treatments. Using the exponential decay model, the rates of glyphosate required to achieve 90 and 95% reduction in medusahead cover were higher in 2010 than in 2009 (Table 2). The midseason treatment consistently gave the best control of medusahead, with 90% and 95% lethal dose (LD_{90} and LD_{95}) values of 123 and 160 g ae ha^{-1}, respectively, for 2009, and 268 and 348 g ae ha^{-1}, respectively, for 2010. LD_{90} and LD_{95} values for early season treatments were two to three times higher compared to midseason treatments. Late season treatments were nearly as effective in controlling medusahead as midseason treatments, although they resulted in high levels of residual fine fuels remaining on the site, a potential wildfire hazard.

One possible explanation for reduced effectiveness in early season treatments is that the persistent thatch of medusahead may have intercepted much of the glyphosate spray solution, preventing deposition on seedlings under the thatch canopy. Likewise, it has been shown that medusahead thatch can interfere with application of imazapic to the soil, reducing its effectiveness (Kyser et al. 2007). Another compatible possibility is that medusahead absorbed and translocated less glyphosate during the cooler early season timing, when its growth rate was slower. Similarly, glyphosate has been shown to have reduced activity in low-temperature applications to a number of species including quackgrass [*Elymus repens* (L.) Gould] (Harker and Dekker 1988), potato (*Solanum tuberosum* L.) (Masiunas and Weller 1988), and horsenettle (*Solanum carolinense* L.) (Whitwell et al. 1980). In addition, accumulation of degree days for the periods before and

Table 2. Medusahead cover regression parameters and modeled values for control. Model is exponential decay with two parameters (*cover* = a * exp (−b * *rate*)).

		Regression parameters		Glyphosate rate for 90% control		Glyphosate rate for 95% control	
Trial year	Application timing	a	b	g ae ha^{-1}	oz product $acre^{-1}$	g ae ha^{-1}	oz product $acre^{-1}$
2009	early	29.73	0.254	355	9.0	463	11.7
	middle	22.54	0.739	123	3.1	160	4.1
	late	24.85	0.581	156	4.0	203	5.2
2010	early	61.39	0.146	646	16.4	>709	>18
	middle	63.99	0.342	268	6.8	348	8.8

after applications shows that spring temperatures were considerably cooler in 2010 compared to 2009 (Figure 2). This would account for generally better medusahead control during the warmer spring of 2009 compared to 2010, as indicated by lower LD_{90} and LD_{95} rates in 2009 (Table 2).

Early Season Treatments Caused Phenological Delay. Medusahead plants that survived early season treatments with moderate to high rates of glyphosate were still green at the time of evaluation and had not yet reached senescence. These plants eventually matured and produced viable seed 2 to 3 wk later than untreated plants. In contrast, medusahead in the untreated plots had reached senescence by the time of evaluation; the seedheads on these plants had turned red to brown and some had just begun to drop seed. Late maturation in early-treated plots was not due to subsequent germination of medusahead after the treatment. If new seedlings had germinated after application, they should have filled in at some baseline cover value without respect to rates of glyphosate, which does not have soil activity (Senseman 2007). Instead, the high rates of glyphosate (394 to 709 g ae ha^{-1} in 2009; 709 g ae ha^{-1} in 2010) gave nearly 100% control. We hypothesize that there were either few additional germinants or little survival of seedlings that germinated after the early season treatment timing in mid-March.

The delayed maturation of surviving medusahead plants in some treated plots was probably due to the reduction in plant density. Owing to the lower density, survivors had higher resource availability, particularly soil moisture later into the season. This allowed individual plants more time to develop and produce additional tillers. In effect, this resulted in an extension of the growing season, rather than a slowing in the growth rate. Previous studies have shown that desert annuals flower in response to depletion of soil moisture (e.g., Tevis 1958). Young et al. (1970) also found that medusahead matured earlier when in competition with other weeds.

In support of the hypothesis that density reduction resulted in an extended growing season, we performed an exploratory analysis of the 2009 data and found that medusahead growth compensated strongly for reduced densities. Although overall medusahead cover (Figure 1A) and number of flowering stems per square meter (Figure 3A) declined with increasing glyphosate rates in the early-treated plots, the rate of seed production per unit area of cover (Figure 3B) increased. Thus, the delay in maturation in the early season treatments corresponded with an apparent increase in seed production per plant. In a

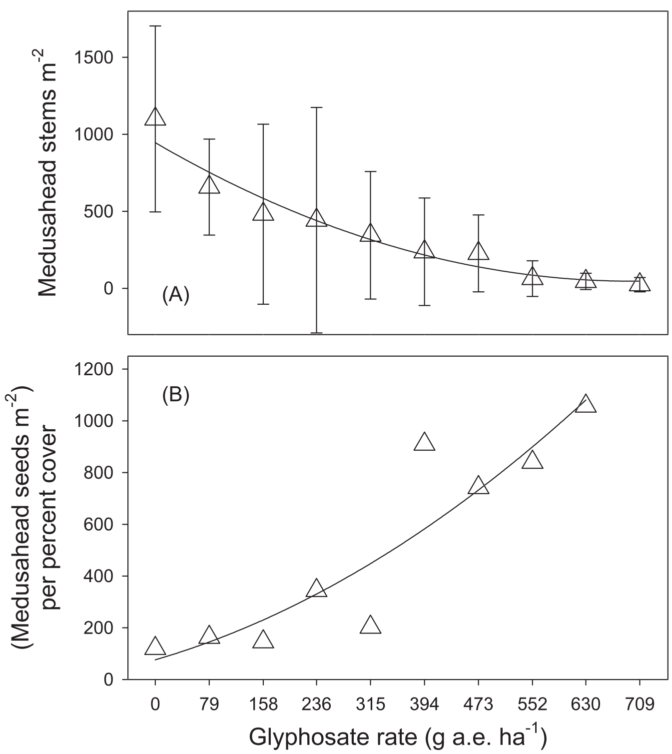

Figure 3. (A) Medusahead flowering stems per area and (B) seed production relative to cover for early season treatments in 2009, demonstrating compensatory seed production with reduced plant densities. In (A), means are shown with standard deviation but regression is performed on all data ($y = 946.02 - 2.58x + 0.002x^2$, $R^2 = 0.39$, $P = 0.0001$). In (B), some biomass samples recovered seeds from plots rated at 0% cover, so regression is performed on means ($y = 76.19 + 0.7671x + 0.001x^2$, $R^2 = 0.84$, $P = 0.004$).

rangeland management situation, this compensatory increase in seed production would tend to partially negate the effect of cover reduction in early treatments.

Late Season Treatments Resulted in Standing Biomass. Late treatments were applied after shoot elongation, when medusahead was nearly mature. In 2009 the late season application was made at the boot stage of medusahead (preflower), and during the summer evaluation it was possible to distinguish plants controlled by the treatments from plants that escaped herbicide injury. However, in 2010 the late season treatment was made when medusahead was at the early heading stage. During evaluation it was difficult to determine whether plants had been killed by glyphosate or had naturally senesced. In both years, the residual dry material from late season treatments was sufficient to constitute a potential fire hazard.

Evaluation of Medusahead Seed Production. To provide another measure of medusahead control—and to compensate for the loss of cover data from the 2010 late season treatments—we also evaluated the number of filled medusahead seeds per square meter. Filled seed have been previously shown to be closely correlated to viable seed (Sweet et al. 2008), and we similarly found close correlation in germination tests (data not shown).

The results in both years were similar in trend. In 2009, the middle and late application timings provided significantly better control of seed production compared to the early season treatments ($P = 0.009$ and $P = 0.034$, respectively, using MRPP) (Figure 4A). In 2010, seed production in middle and late application plots was generally, though not significantly, lower than in early season application plots (Figure 4B). In addition to confirming the efficacy of mid- to late season applications, these results indicate that medusahead cover measured in late season treatments in 2010 generally comprised standing dead plants controlled by the treatments. Overall we estimated much higher seed production per unit area in 2010 compared to 2009, probably because in 2009 seedheads were collected after senescence and had begun to drop seed.

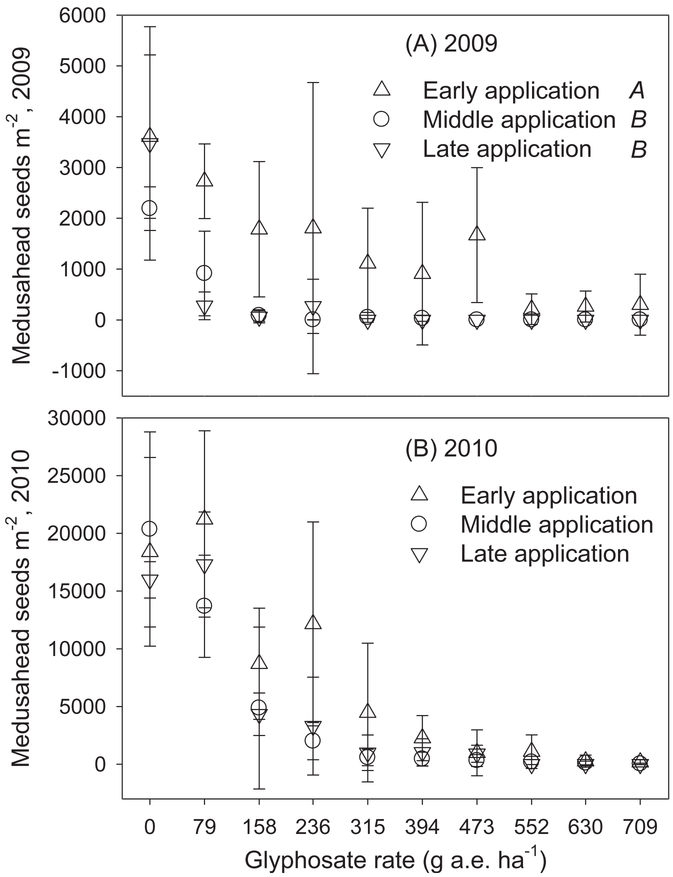

Figure 4. Medusahead seed production in seeds per square meter for (A) 2009 and (B) 2010. Error bars indicate standard deviation. Application timings followed by different italic letters are different at $\alpha = 0.05$ (separated using multiple response permutation procedures [MRPP]). Probabilities (P) and chance-corrected within-group agreements (A) for MRPP were as follows: for 2009, early vs. middle, $P = 0.009$ and $A = 0.216$; early vs. late, $P = 0.034$, $A = 0.118$; middle vs. late, $P = 0.320$, $A = 0.033$. For 2010, early vs. middle, $P = 0.157$, $A = 0.058$; early vs. late, $P = 0.099$, $A = 0.064$; middle vs. late, $P = 0.394$, $A = 0.009$.

Effects on Nontarget Species. Although herbaceous broadleaf plants were sparse in these sites, we evaluated effects of treatments on broadleaf cover. There were no statistical differences among treatment timings in 2009, but broadleaf species tended to have higher cover in early-treated plots than in other treatment timings (Figure 5A). Similarly, in 2010 broadleaf cover was higher overall in plots treated early or midseason than in plots treated at the late timing ($P = 0.019$ and 0.012, respectively, using MRPP) (Figure 5B). These data suggest that a portion of the broadleaf flora emerged after the early and midseason applications, or that earlier emerged broadleaf plants were less susceptible to glyphosate, perhaps owing to cooler temperatures early in the season, as discussed earlier.

Big sagebrush shoot tip vigor was only evaluated in 2010, as the 2009 site did not contain big sagebrush. Shoot tip vigor was significantly lower in plots treated midseason compared to plots treated early ($P = 0.0066$) or late ($P = 0.0099$) (Figure 6). Big sagebrush also demonstrated differences in response to late treatments compared to early treatments ($P = 0.022$), but this response was not consistent. The early application occurred during shoot dormancy, whereas the midseason application coincided with typical times for big sagebrush bud break and rapid shoot growth (Hyder et al. 1962). In other studies, bud break was similarly found to be the most sensitive timing

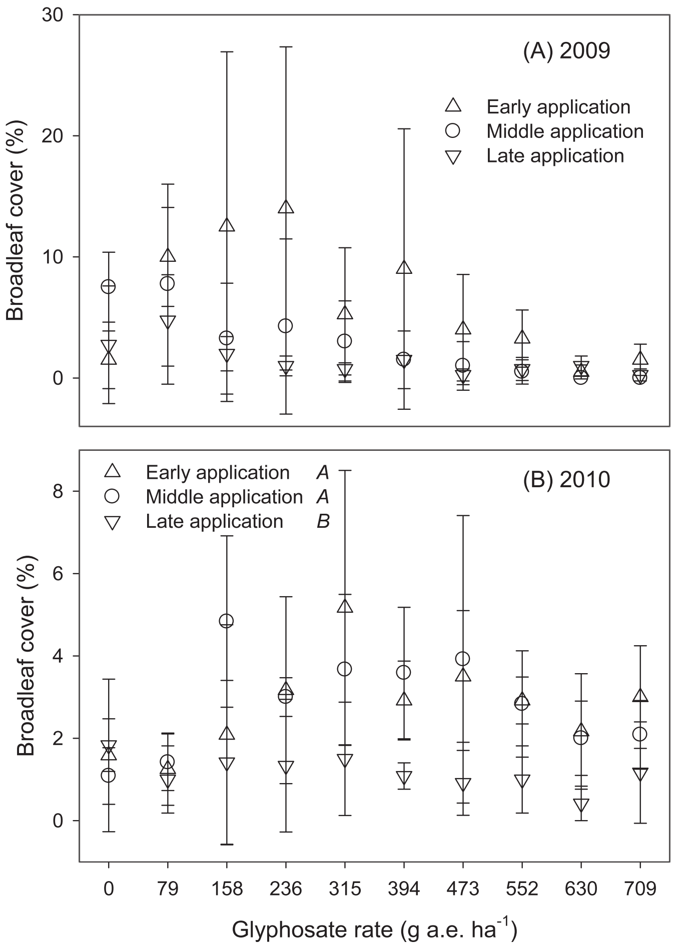

Figure 5. Cover of all broadleaf species in (A) 2009 and (B) 2010. Error bars indicate standard deviation. Application timings followed by different italic letters are different at $\alpha = 0.05$ (compared using multiple response permutation procedures [MRPP]). Probabilities (P) and chance-corrected within-group agreements (A) for MRPP were as follows: for 2009, early vs. middle, P = 0.221 and A = 0.054; early vs. late, P = 0.082, A = 0.127; middle vs. late, P = 0.341, A = 0.012. For 2010, early vs. middle, P = 0.590, A = −0.013; early vs. late, P = 0.019, A = 0.127; middle vs. late, P = 0.012, A = 0.180.

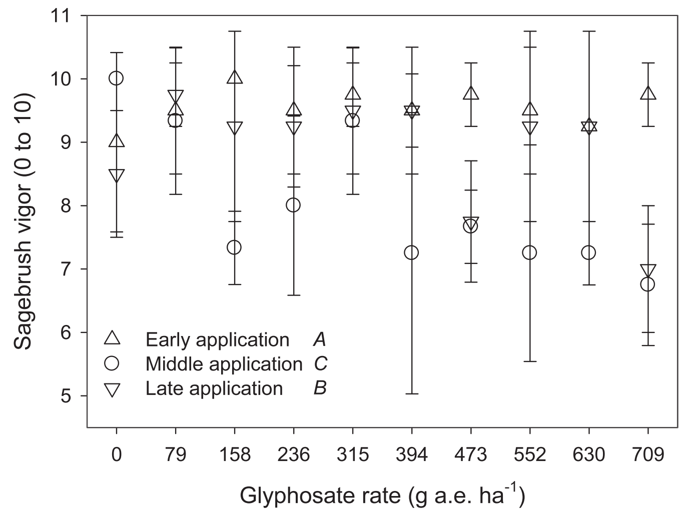

Figure 6. Vigor of sagebrush in 2010 (0 to 10 scale where 0 = dead and 10 = high vigor; error bars indicate standard deviation). All application times were significantly different from each other at $\alpha = 0.05$ (separated using multiple response permutation procedures [MRPP]). Probabilities (P) and chance-corrected within-group agreements (A) for MRPP were as follows: early vs. middle, P = 0.007 and A = 0.261; early vs. late, P = 0.022, A = 0.090; middle vs. late, P = 0.010, A = 0.132.

for 2,4-D applications to big sagebrush (Hyder et al. 1962; McDaniel et al. 1991) and for glyphosate applications to conifers (Willis et al. 1989), *Ligustrum japonicum* Thunb., and *Juniperus conferta* Parl. (Neal et al. 1986). Midseason treatment effects appeared to be limited to shoot tips and were unlikely to threaten the long-term health of big sagebrush. By the late season treatment timing, new shoot growth may have begun to slow down and harden off, reducing the impact of glyphosate on sagebrush vigor.

Conclusions. Low rates of glyphosate applied in spring show potential for selectively controlling medusahead in big sagebrush scrub ecosystems. At the optimal timing in this study (late April to early May, medusahead at tillering), glyphosate at 160 g ae ha^{-1} (2009) to 348 g ae ha^{-1} (2010) achieved 95% reduction in medusahead cover, with a corresponding reduction in production of filled seed. Applications in mid-March (seedling stage of medusahead) and in late May to early June (after initiation of flowering) required higher rates for equivalent control. Applications at the optimal timing were successful using rates of glyphosate far lower than those required to control perennial species, thus in a safe rate range for overspraying big sagebrush. This treatment provides a cost effective option to ranchers and land managers compared to other herbicide treatments. For example, an equivalent rate of generic 3 lb ae gal^{-1} glyphosate would be approximately 950 ml ha^{-1} (342 g ae ha^{-1}), or 13 oz $acre^{-1}$ of product. Although a single year of timely glyphosate treatment can provide excellent control in the year of application, medusahead seedbanks are capable of reestablishing populations the following year. As such, a multi-year commitment will be required to deplete the soil seedbank and prevent new seed production.

Acknowledgments

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