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Medusahead Control with Fall- and Spring-Applied Herbicides on Northern Utah Foothills[1]

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Abstract: Medusahead is an aggressive, nonnative, winter annual grass that infests rangelands in the western United States. Its ability to rapidly spread, outcompete native vegetation, and destroy forage potential is a primary concern for landowners and land managers exposed to this weed. Prescribed burns were conducted at a low- and high-litter site in northern Utah prior to conducting experiments to evaluate the effects of fall and spring applications of sulfometuron at 39 or 79 g ai/ha and imazapic at 70 or 140 g ai/ha on medusahead and associated perennial grasses, annual and perennial forbs, and bare ground cover. Large differences in pretreatment medusahead litter between the sites resulted in less surface area burning at the low-litter site (∼10%) compared to the high-litter site (∼80%). Higher herbicide rates significantly increased medusahead control and bare ground cover; however, this rate affect largely depended on site, season, and herbicide. The low- and high-litter sites did not differ significantly in perennial grass cover 2 yr after burning. Annual forb cover was greater, but perennial forb cover was lower at the low-litter site compared to the high-litter site. Several treatment combinations were identified as having the potential to maintain greater than 50% medusahead control in the second year after herbicide applications. These results collectively demonstrate that potential exists to successfully control medusahead and produce a window of opportunity to reintroduce a greater abundance of perennial species back into the plant community via seeding.

Nomenclature: Imazapic; sulfometuron; medusahead, *Taeniatherum caput-medusae* (L.) Nevski, #[3] ELYCM.

Additional index words: Prescribed fire, *Bromus tectorum* L., *Aegilops cylindrical* Host., invasive annual grass, Great Basin, revegetation, BROTE, AEGCY.

INTRODUCTION

Medusahead is an invasive winter annual grass that is listed as a noxious weed in numerous western U.S. states and is native to the Mediterranean region of Eurasia (Young 1992). It has nodding spikes, slender stems, and short, narrow leaf blades. Seeds are about 6 mm long, with a 5- to 10-cm awn. The rachis is continuous, which allows the spike and its empty glumes to remain intact after the seeds shatter. Tiny barbs on seeds and awns facilitate seed dispersal by livestock, wildlife, and humans. Awns are straight and closely grouped when green, but twist and spread erratically when dry, giving the spike its resemblance to the mythical Medusa's head.

Medusahead is known to have greater seed production, germination potential (Clausnitzer et al. 1999; Young et al. 1998), growth rate (Arredondo et al. 1998; Monaco et al. 2003), and competitive ability (Dakheel et al. 1993; Goebel et al. 1988; Harris and Wilson 1970) than the perennial shrub-steppe species it is currently replacing. Consequently, medusahead is a tremendous threat to biodiversity and the structure and function of plant communities in the Great Basin (Young 1992). Functionally, medusahead invasion reduces wildlife and livestock forage potential (Major et al. 1960) and other ecosystem-level processes such as increasing fire frequency and reducing fire return intervals (D'Antonio and Vitousek 1992). Structurally, medusahead dominance coupled with low grazing utilization facilitates the accumulation of a dense layer of leaf-litter on the soil surface (Hironaka and Tisdale 1956). This layer of insulation moderates temperature and moisture fluxes at the

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[3] Letters following this symbol are WSSA-approved computer codes from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

soil surface, producing a favorable microsite for germination and establishment of medusahead and other annual weed species (Evans and Young 1970).

Medusahead is most commonly managed with the following combination: burning accumulated litter, tillage, herbicides, and reseeding with perennial plant species. Burning appears to be necessary to effectively remove the litter layer, destroy some medusahead seeds, prepare a seedbed for reseeding perennials (McKell et al. 1962), and to improve herbicide contact with soil. Variable effects of prescribed burning alone for medusahead control is likely related to the amount of seed destroyed by fire (Christensen et al. 1974; Furbush 1953).

Variable medusahead control has also been observed with herbicides. Both postemergence and preemergence herbicide applications have been evaluated for control of medusahead in annual grasslands of California (Kay 1963; Kay and McKell 1963) and the Great Basin (Kay and McKell 1963; Young et al. 1971). However, the herbicides used in these reports have been discontinued or are no longer labeled for use on pastures and rangelands. More recently, the herbicides sulfometuron and imazapic have been registered for control of weeds on pastures, rangelands, and noncrop areas. Sulfometuron and imazapic are acetolactate synthase protein inhibitor herbicides. Sulfometuron is not registered for use on rangeland or any other grazing land by the Environmental Protection Agency.

The recent invasion of medusahead into foothill slopes in Utah necessitates the development of an effective management scenario incorporating the use of herbicides. Specifically, an understanding of the potential advantages of spring and fall applications of these new herbicides and their subsequent effects on medusahead, desirable nontarget species, and short-term changes in plant community composition is essential to land managers challenged with controlling this invasive species. In this paper, we present the results of a 2-yr experiment conducted at two sites in northern Utah to evaluate the effectiveness of two herbicides applied at different rates in either the fall or spring.

MATERIALS AND METHODS

Study Sites. Two sites in northern Utah (near Avon, Cache Co., UT) that differed in medusahead density and litter cover were selected for this study. The high-litter site had historically greater medusahead cover than the low-litter site. Both sites were located on the foothills of the Bear River Mountains on slopes ranging from 10 to 30%, roughly 2 km apart, with a south to southwest aspect, at ~1,590 m in elevation. Soils are of the McMurdie series (mesic Calcic Pachic Argixerolls), and include a clay horizon at about 17 cm in depth. Coordinates (UTM Zone 12 North) of the southeast corners of each site are: N 4598642 m, E 433172 m for the low-litter site, and N 4597702 m, E 434452 m for the high-litter site. The Cache County fire marshal and crew burned both sites on October 20, 2000, using drip torches and fusee ignition sticks to maximize the effectiveness of herbicide contact with the soil surface and living medusahead plants. Because the two sites differed greatly in litter cover, the estimated total surface area burned at the low- and high-litter sites was ~10 and ~80%, respectively.

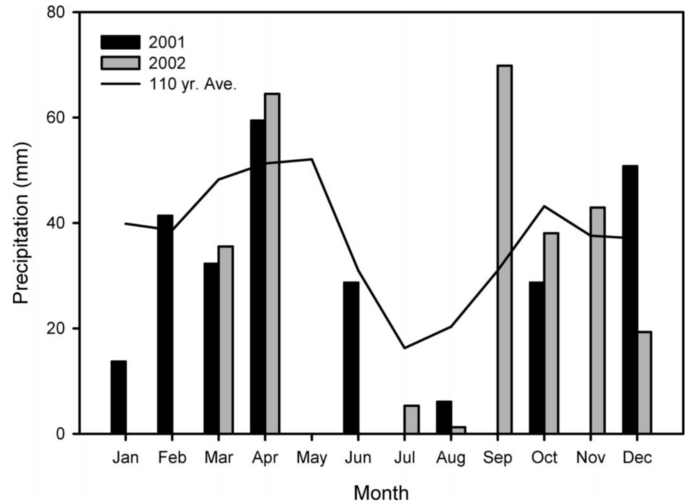

Figure 1. Monthly precipitation for Logan, UT in 2001, 2002, and the long-term average (110 yr).

The 110-yr annual precipitation average for Logan, UT, a city 25 km to the north with similar climate, is 430 mm. Over 40% of the annual precipitation comes as snow in winter (Figure 1). Both sites had previously been extensively grazed by cattle for over 50 yr but were fenced to prevent livestock grazing during our experiments. Plant species composition on the sites prior to establishing our experiment was dominated by medusahead (>75% plant cover). A list of the perennial grass and annual and perennial forb species that occur at this site are shown in Table 1.

Herbicide Treatments. Herbicide treatments consisted of imazapic applied at 70 and 140 g ai/ha and sulfometuron at 39.4 and 78.8 g ai/ha. Herbicides were applied with a 0.25% v/v nonionic surfactant.[4] Methylated seed oil was not used because of the label instructions not to use it when making applications to newly emerged seed-

[4] AG 98 surfactant, IFA, Salt Lake City, UT 84119.

Table 1. List of perennial grasses and annual and perennial forbs occurring at the research sites.

Common name	WSSA code	Scientific name
Perennial grasses		
Wheatgrass, bluebunch	—	*Pseudoroegneria spicata*
Bluegrass, bulbous	POABU	*Poa bulbosa*
Wheatgrass, tall	AGREL	*Thinopyrum ponticum*
Grass, timothy	PHLPR	*Phleum pratense*
Wheatgrass, western	—	*Pascopyrum smithii*
Annual forb		
Knotweed, erect	POLER	*Polygonum erectum*
Lettuce, prickly	LACSE	*Lactuca serriola*
Filaree, redstem	EROCI	*Erodium cicutarium*
Sunflower, common	HELAN	*Helianthus annuus*
Tarweed, cluster	MADGL	*Madia glomerata* Hook.
Mustard, tumble	SSYAL	*Sisymbrium altissimum* L.
Alyssum, yellow	AYSAL	*alyssum alyssoides* (L.) L.
Perennial forbs		
Alfalfa	MEDSA	*Medicago sativa* L.
Nightshade, bitter	SOLDU	*Solanum dulcamara* L.
Mallow, common	MALNE	*Malva neglecta* Wallr.
Gumweed, curlycup	GRNSQ	*Grindelia squarrosa* (Pursh) Dunal
Dock, curly	RUMCR	*Rumex crispus* L.
Dandelion	TAROF	*Taraxacum officinale* L.
Woad, dyer's	ISATI	*Isatis tinctoria* L.
Bindweed, field	CONAR	*Convolvulus arvensis* L.
Houndstongue	CYWOF	*Cynoglossum officinale* L.
Wormwood, Louisiana	ARTLU	*Artemisia ludoviciana* Nutt.
Lupine, tailcup	LUPCA	*Lupinus caudatus* Kell.
Onion, wild	ALLCA	*Allium canadense* L.
Ragweed, common	AMBEL	*Ambrosia artemisiifolia* L.
Salsify, western	TRODM	*Tragopogon dubius* Scop.
Lilly, sego	—	*Calochortus nuttallii*
Yarrow, western	ACHLA	*Achillea lanulosa* Nutt.

ling grasses or wild flowers. The experiment was arranged at both sites in a randomized complete block design with four blocks. Blocks were 30 by 49 m and herbicides were randomly assigned to 3 by 49 m plots within a block.

Fall herbicide treatments were applied on October 28 and 31, 2000, using an all-terrain vehicle (ATV)-mounted, five-nozzle boom sprayer, equipped with flat-fan nozzle tips[5] and a CO_2 backpack sprayer with a six-nozzle hand-held boom equipped with flat-fan nozzle tips at the low-litter and high-litter sites, respectively. The ATV spray system was calibrated to deliver 112 L/ha at 276 kPa over an effective spray width of ~3 m with a water carrier. The CO_2 backpack spray system was calibrated to deliver 142 L/ha at 276 kPa covering an effective spray width of ~3 m. All treatments were applied in the same direction, from east to west. Medusahead seedlings were approximately 2.5 to 5 cm tall at both sites. Air temperatures were 5 to 9 C, soil temperatures were 7 to 8.2 C, and relative humidities were 88 to 100%.

Spring herbicide treatments were applied at both sites on April 11, 2001, using the CO_2 backpack sprayer. Air temperature was 7.5 to 10.5 C, soil temperature was 4.5 to 6 C, and relative humidity was 38 to 51%. Medusahead seedlings were about 7 cm high at the time of herbicide applications. Although different methods were used to apply herbicides, it was assumed that the outcomes of using different methods would be overshadowed by the inherent differences in environmental characteristics associated with the different seasons.

Data Collection. Measurements of medusahead control were made by comparing visual estimates of the number, size, and abundance of medusahead in nontreated control plots and plots that had been treated with herbicides. Visual medusahead control evaluations were made between June 12 and June 26 in 2001, and June 17 and June 20 in 2002. The nontreated control was considered as 0% control and plots absent of medusahead were classified as 100% control. Thus, treatments were evaluated relative to the nontreated control.

To evaluate treatment effects on the perennial grasses, annual and perennial forbs, and bare ground cover, we used a standard frame and quantitative method frequently used in rangeland inventories (Interagency Technical Team 1996). Cover (ground) evaluations were made between June 19 and July 5 at both sites in 2002. Cover measurements were taken using the "nested plot square frame" (0.25 by 0.25 m) that had eight points: two within the frame interior, and six on the exterior of the frame. The frame was placed in 16 regularly spaced locations within each plot, and cover was categorized below each point. Point data were tallied by cover category, divided by total number of points taken, and then multiplied by 100 to express data as percentage cover for each category.

Statistics. To test the effects of site, season, herbicide, and rate on medusahead control and cover of the other plant community entities, data were analyzed with a mixed-model analysis of variance (ANOVA) as a complete factorial experiment using a randomized complete block design. Data met the assumptions of ANOVA and did not require any transformations. Fisher's protected LSD (least significant difference) test was used for multiple pairwise comparisons to distinguish significant differences between treatment combinations at the $P = 0.05$ level.

RESULTS AND DISCUSSION

Medusahead Control. In 2001, fall-applied herbicides had significantly greater medusahead control than

[5] TeeJet 8002, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189.

Table 2. Results of the factorial ANOVA to evaluate the effects of two herbicides (sulfometuron and imazapic) applied at two rates, in two seasons (fall and spring), and at two sites (low and high litter). Analysis is shown for percentage medusahead control in 2001 and 2002 and for percentage cover of perennial grasses, annual and perennial forbs, and bare ground in 2002.[a]

	Percentage medusahead control		Percentage cover			
Source of variation	2001	2002	Perennial grass	Annual forb	Perennial forb	Bare ground
Site[b]	*	NS	NS	*	*	NS
Season	***	NS	NS	NS	NS	*
Season by site	NS	*	NS	NS	NS	*
Herbicide	***	NS	*	NS	NS	NS
Herbicide by site	*	NS	NS	NS	NS	NS
Herbicide by season	***	*	*	NS	NS	**
Herbicide by season by site	NS	NS	*	NS	NS	NS
Rate	***	*	NS	NS	NS	**
Rate by site	NS	NS	NS	NS	NS	NS
Season by rate	NS	NS	NS	NS	NS	NS
Season by rate by site	*	NS	NS	NS	NS	NS
Herbicide by rate	*	NS	NS	NS	NS	NS
Herbicide by rate by site	NS	NS	*	NS	NS	NS
Herbicide by season by rate	NS	*	NS	*	NS	NS
Herbicide by season by rate by site	NS	*	NS	NS	NS	NS

[a] Abbreviation: NS, not significant.

[b] *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

spring-applied herbicides (Tables 2 and 3). Greater medusahead control in fall than in spring was more pronounced for sulfometuron than for imazapic (Table 4). In contrast, medusahead control in 2002 was not significantly influenced by the main effects of season or site (Table 5). Lower medusahead control from spring applications than from fall applications in 2001 may have been a result of less time available for herbicides to damage medusahead seedlings with spring applications. Fall-germinated medusahead seedlings tend to be smaller than spring-germinated seedlings and may have been more vulnerable to herbicide effects. Alternatively, it is also likely that fall applications provide the opportunity to reduce actively growing medusahead plants in the fall as well as the young emerging seedlings in the spring because this species frequently germinates in both the fall and spring depending on the distribution of precipitation (Young and Evans 1970). From a management perspective, fall herbicide applications may be more desirable than spring applications because favorable soil conditions for using mechanical equipment on steep foothill slopes in the Great Basin are most likely to occur in the fall when the soil is less saturated from spring snowmelt.

Medusahead control was significantly greater at the high- than the low-litter site for all spring applications and for fall applications at the low rate (Table 3). In addition, both sulfometuron and imazapic had significantly greater medusahead control at the high-litter site compared to the low-litter site (Table 4). A plausible explanation for the trend of greater herbicide control at the high-litter site than the low litter site in 2001 may be associated with more complete burning of litter at the

Table 3. Mean percentage control of medusahead at the low- and high-litter sites in 2001. Data are displayed to interpret the season-by-rate-by-site interaction. Means followed by the same letter are not significantly different at $P < 0.05$.

	Medusahead control	
	Low litter	High litter
	%	
Fall-low[a]	55 b	73 a
Fall-high	78 a	81 a
Spring-low	19 c	41 b
Spring-high	24 c	56 b

[a] Sulfometuron applied at 39 and 79 g/ha. Imazapic applied at 70 and 140 g/ha. Fall and spring applications made on October 28, 2000 and April 11, 2001, respectively.

Table 4. Mean percentage control of medusahead in 2001 in response to herbicide treatments. Data are displayed to interpret the herbicide-by-site, herbicide-by-season, and the herbicide-by-rate interactions. Means within an interaction followed by the same letter are not significantly different at $P < 0.05$.

	Medusahead control	
	Sulfometuron[a]	Imazapic
	%	
Low-litter site	54.3 b	29.3 c
High-litter site	68.2 a	57.0 a
Fall	90.7 a	48.0 b
Spring	31.8 c	38.3 bc
Low rate	56.2 b	33.0 c
High rate	66.3 a	53.2 b

[a] Sulfometuron applied at 39 and 79 g/ha. Imazapic applied at 70 and 140 g/ha. Fall and spring applications made on October 28, 2000 and April 11, 2001, respectively.

Table 5. Mean percentage control of medusahead at the low- and high-litter sites in 2002. Data are displayed to interpret the herbicide-by-season-by-rate-by-site interaction. Means followed by the same letter are not significantly different at P < 0.05.

	Medusahead control			
	Low litter		High litter	
	Fall	Spring	Fall	Spring
	%			
Sulfometuron-low[a]	40 b	19 b	24 b	48 b
Sulfometuron-high	56 ab	20 b	55 ab	56 ab
Imazapic-low	26 b	35 b	37 b	41 b
Imazapic-high	53 ab	54 ab	45 b	90 a

[a] Sulfometuron applied at 39 and 79 g/ha. Imazapic applied at 70 and 140 g/ha. Fall and spring applications made on October 28, 2000 and April 11, 2001, respectively.

high- than the low-litter site. Burning may remove the dense litter layer (Facelli and Pickett 1991) that may obstruct herbicide contract with medusahead seedlings and destroy some medusahead seeds (Furbish 1953; McKell et al. 1962). Although burning may remove appreciable amounts of seed, some studies have shown that these effects are only temporary (Maret and Wilson 2000) and may facilitate medusahead productivity in following years (Blank et al. 1996; Hironaka 1994).

Medusahead control was greater in the high than the low rate for fall applications at the low-litter site in 2001 (Table 3). In addition, spring-applied imazapic at the high rate had nearly twofold greater control than any other treatment combination (Table 4). Sulfometuron more effectively controlled medusahead than imazapic at the low-litter site, for fall applications, and at both the low and high application rate (Table 4).

Perennial Grass Cover. Overall, the low- and high-litter sites did not differ significantly in perennial grass cover

Table 6. Mean percentage cover of perennial grasses in 2002 at the low- and high-litter sites. Data are displayed to interpret the herbicide-by-season-by-site interaction and the herbicide-by-rate-by-site interaction. Means within an interaction followed by the same letter are not significantly different at P < 0.05.

	Perennial grass cover	
	Low litter	High litter
	%	
Sulfometuron-fall[a]	1.0 c	2.1 bc
Sulfometuron-spring	9.7 ab	3.3 bc
Imazapic-fall	15.8 a	4.1 bc
Imazapic-spring	8.2 abc	4.1 bc
Sulfometuron-low	6.0 b	3.5 b
Sulfometuron-high	4.7 b	2.0 b
Imazapic-low	15.9 a	2.9 b
Imazapic-high	8.1 b	4.8 b

[a] Sulfometuron applied at 39 and 79 g/ha. Imazapic applied at 70 and 140 g/ha. Fall and spring applications made on October 28, 2000 and April 11, 2001, respectively.

Table 7. Mean percentage cover of annual forbs in 2002 in response to herbicide treatments in fall or spring. Data are displayed to interpret the herbicide-by-season-by-rate interaction. Means followed by the same letter are not significantly different at P < 0.05.

	Annual forb cover	
	Fall	Spring
	%	
Sulfometuron-low[a]	11.6 ab	5.6 b
Sulfometuron-high	16.0 a	10.6 ab
Imazapic-low	10.7 ab	13.8 a
Imazapic-high	17.4 a	12.7 a

[a] Sulfometuron applied at 39 and 79 g/ha. Imazapic applied at 70 and 140 g/ha. Fall and spring applications made on October 28, 2000 and April 11, 2001, respectively.

2 yr after burning (Table 2), even though perennial grass cover was generally greater at the low- than the high-litter site for seven of the eight comparisons shown in Table 6. Specific examples where perennial grass cover was significantly greater at the low-litter site than at the high-litter site include fall-applied imazapic and imazapic at the low application rate. Differential responses between the low- and high-litter sites may be reflective of the fact that the high-litter site historically had high medusahead cover and few perennial grass plants. Fall applications of imazapic at the low-litter site had significantly greater perennial grass cover than all herbicide-by-season combinations at the high-litter site. Perennial grass cover was also significantly greater for fall-applied imazapic than for fall-applied sulfometuron. In addition, the low rate of imazapic produced significantly greater perennial grass cover than the high rate of imazapic and sulfometuron treatments at the low-litter site.

Annual and Perennial Forb Cover. The main effect of site was significant for both annual and perennial forb cover (Table 2). Annual forb cover was greater at the low- than at the high-litter site (16.9 vs. 7.5%); whereas perennial forb cover was lower at the low- than at the high-litter site (5.2 vs. 17.9%). The two herbicides had

Table 8. Mean percentage cover of bare ground in 2002 in response to herbicide treatments in fall or spring. Data are displayed to interpret the herbicide-by-season and the season-by-site interactions. Means within an interaction followed by the same letter are not significantly different at P < 0.05.

	Bare ground cover	
	Fall	Spring
	%	
Sulfometuron[a]	18.3 a	10.2 b
Imazapic	14.1 ab	14.8 ab
Low litter	15.8 a	8.9 b
High litter	16.6 a	15.9 a

[a] Sulfometuron applied at 39 and 79 g/ha. Imazapic applied at 70 and 140 g/ha. Fall and spring applications made on October 28, 2000 and April 11, 2001, respectively.

similar effects on annual forb cover in the fall; however, the low rate of imazapic had significantly greater annual forb cover than the low rate of sulfometuron in the spring (Table 7). High productivity of perennial forbs at the high-litter site may be associated with greater initial control of medusahead in 2001 and fire effects that may have consumed a larger portion of annual forb seeds at the high-litter than at the low-litter site (Lamont et al. 1993). Alternatively, these patterns of cover in annual and perennial forbs following medusahead control may also be associated with differences in pretreatment densities of these groups of species.

Bare Ground Cover. Bare ground cover was significantly greater at the high than the low herbicide rate (16.5 vs. 12.0%; Table 2). Interestingly, the significant decrease in medusahead cover with herbicide rate resulted in parallel significant increases in bare ground cover. A significant herbicide-by-season interaction was the result of greater bare ground cover in fall than spring applications for sulfometuron, but not for imazapic (Table 8). For spring-applied herbicides, bare ground cover was significantly greater at the high- than at the low-litter site.

In conclusion, a critical requirement for successful medusahead control is the use of herbicides to create a window of opportunity when medusahead emergence can be reduced long enough to successfully reestablish perennial species into plant communities via seeding (Horton 1991; Robocker and Schirman 1976). We suggest that this window of opportunity would be most pronounced in treatments that maintain greater than 50% medusahead control in the second year after herbicide application. Several of the treatment combinations evaluated in this study provided this management opportunity. Our results suggest that medusahead control programs for foothill slopes in the Great Basin should be aware of the importance of application rates, season of treatment, and litter characteristics of the site when using these sulfonylurea herbicides.

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