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Influence of Glufosinate Rate, Ammonium Sulfate, and Weed Height on Annual Broadleaf Weed Control

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Abstract

Weed control efficacy with contact herbicides can depend on weed height at application. Four field experiments were conducted at sites with multiple weed species at different heights to determine the effect of weed height, glufosinate rate, and the addition of ammonium sulfate (AMS) on annual broadleaf weed control in soybean in southwestern Ontario, Canada, during 2021 and 2022. Glufosinate was applied at 300 or 500 g ai ha^{-1} without or with 6.50 L ha^{-1} of AMS to 5, 10, and 15 cm tall common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), velvetleaf (*Abutilon theophrasti* Medik.), and redroot pigweed (*Amaranthus retroflexus* L.). Glufosinate provided excellent common ragweed control (> 98%) at both rates, without and with AMS, and at all three heights 4 weeks application (WAA). In contrast, glufosinate efficacy declined when applied to common lambsquarters, velvetleaf, and redroot pigweed > 5 cm in height. The addition of AMS to glufosinate improved common lambsquarters control. Increasing the rate of glufosinate to 500 g ai ha^{-1} and the addition of AMS improved control of velvetleaf and redroot pigweed. The results of this study demonstrate that the effect of glufosinate rate, AMS addition, and weed height at application timing is weed species-specific. In general, glufosinate (300 g ai ha^{-1}) controlled common annual broadleaf weeds if weeds were < 5 cm in height; otherwise, glufosinate needed to be applied at 500 g ai ha^{-1} with AMS for control of annual broadleaf weeds, especially common lambsquarters, velvetleaf and redroot pigweed.

Keywords: ammonium sulfate, biomass, density, glyphosate/glufosinate/2,4-D choline-resistant soybean, grain yield

1. Introduction

Glufosinate is a contact herbicide that provides broad-spectrum control of emerged young annual weeds. Applications of glufosinate to susceptible plants causes inhibition of glutamine synthesis through competitive inhibition of the active site on the glutamine synthetase (GS) enzyme (Takano et al., 2019; Takano & Dayan, 2020). Inhibition of GS induces an accumulation of reactive oxygen species, resulting in cell membrane peroxidation (Takano et al., 2019; Takano & Dayan, 2020). Plant response to glufosinate is rapid; foliar injury can occur within a few hours after treatment (Takano et al., 2019; Takano & Dayan, 2020). The mode of action of glufosinate is light dependent, resulting in a time-of-day at application effect on weed control efficacy. In general, greater efficacy is observed when glufosinate is applied during the warmest sunlit hours of the day (Martinson et al., 2005; Montgomery et al., 2017; Takano & Dayan, 2020). Higher temperatures and relative humidity can result in improved translocation (Anderson et al., 1993; Coetzer et al., 2001). The herbicide possesses no residual activity in the soil due to rapid degradation via soil microbes (Takano & Dayan, 2020). Across weed species, sensitivity to glufosinate can differ, with dicot species being generally more susceptible than monocot species (Takano & Dayan, 2020). Takano et al. (2019) reported dicot species produced greater amounts of reactive oxygen species compared to monocot species treated with glufosinate.

Weed control with contact herbicides is often dependent on weed height at application. Actively growing young weeds oftentimes have thinner, more permeable cuticles resulting in greater absorption of water-soluble herbicides (Steckel et al., 1997). Glufosinate is classified as a contact herbicide with limited translocation because of no efficient active transporter within the plant and the physiochemical characteristics of the herbicide (Takano et al., 2020). Maschhoff et al. (2000) reported improved glufosinate absorption and subsequent translocation in certain weed species when co-applied with ammonium sulfate (AMS). Inadequate herbicide coverage with contact herbicides often results in reduced control of large weeds (Steckel et al., 1997); therefore, glufosinate efficacy is influenced by weed height at application (Coetzer et al., 2001; Steckel et al., 1997). Research conducted by Steckel et al. (1997) reported greater control when glufosinate was applied to weeds 10 cm in height compared to either 5 or 15 cm weeds. Craigmyle et al. (2013) reported applications to larger waterhemp plants resulted in reduced control while applications to larger common cocklebur resulted in improved control. The influence of weed height on glufosinate efficacy is weed species-specific.

Herbicide-resistant crops offer increased herbicide application options for the control of emerged weeds. Soybean cultivars resistant to glufosinate have been genetically engineered to contain the PAT gene, coding for the *phosphinothricin acetyltransferase* enzyme resulting in enhanced glufosinate metabolism within the plant (Takano & Dayan, 2020). Soybean cultivars possessing multiple herbicide-resistant traits are increasing, which allows for more post-emergence (POST) herbicide options. The success of POST contact herbicides is dependent on weed height at application, oftentimes applications to larger weeds result in reduced control.

Currently, there is limited data on the effect of weed height at glufosinate application as influenced by the glufosinate rate and the addition of AMS under Ontario environmental conditions in glufosinate-resistant soybean. The objective of this research was to determine the effect of glufosinate rate, AMS addition, and weed height at application timing on glufosinate efficacy for the control of troublesome annual broadleaf weeds in Ontario.

2. Methods and Materials

A total of four field experiments were conducted during the 2021 and 2022 growing seasons. Trials were located at the University of Guelph, Ridgetown Campus in Ridgetown (42.45°N, 81.88°W), the Huron Research Station near Exeter (43.32°N, 81.50°W), and the BASF Research Farm near London, Ontario, Canada (42.87°N, 81.13°W) (Table 1). Five herbicide treatments were established and arranged in a randomized complete block design at each site. The study was arranged as a two-factor factorial. Factor A included five levels of herbicide treatment: nontreated control, glufosinate 300 g ai ha^{-1}, glufosinate 300 g ai ha^{-1} + ammonium sulfate (AMS) 6.50 L ha^{-1}, glufosinate 500 g ai ha^{-1}, and glufosinate 500 g ai ha^{-1} + AMS 6.50 L ha^{-1}. The 200 g L^{-1} formulation of glufosinate (Liberty® 200 SN, BASF Canada Inc. Mississauga ON) was used in this study. Factor B consisted of three weed heights at application: 5, 10, and 15 cm. Glufosinate efficacy is influenced by application time-of-day, therefore all herbicide treatments were applied between 9 am and 12 pm (Martinson et al., 2005; Montgomery et al., 2017; Takano & Dayan, 2020). A colored flag corresponding to weed species and height were placed behind each weed (relative to the direction of spraying) between the center of two soybean rows less than 24 hours before spray applications were made. Five weeds of each species and height (5, 10, and 15 cm) were identified in each plot when present. Herbicide treatments were applied from the front to the back of each plot to reduce flag-spray interference. Supplemental experiment information including soil characteristics, soybean planting and emergence dates, and application information was recorded for each site and experiment (Table 1).

Table 1. Year, location, soil characteristics, soybean planting and emergence dates, and herbicide application information for four field trials conducted in southwestern Ontario, Canada in 2021 and 2022

Year	Location	Soil Characteristics			Soybean		Herbicide Application	
		Texture	OM	pH	Planting Date	Emergence Date	Application Date	Soybean Development Stage
			%					
2021	Exeter	clay loam	2.9	7.6	May 14	May 22	Jun 17	V2
2021	Ridgetown	clay loam	4.2	7.6	May 20	May 26	Jun 30	V6
2022	Ridgetown	clay loam	5.5	6.6	May 24	May 31	Jul 8	V5
2022	London	loam	3.3	6.7	Jun 15	Jun 22	Jul 22	R1

Note. Abbreviations: OM, organic matter; V2, second trifoliate; V6, sixth trifoliate; V5, fifth trifoliate; R1, one open flower at any node on the main stem 1.

Soybean resistant to glyphosate, glufosinate, and 2,4-D choline was planted approximately 3.75 cm deep in rows spaced 75 cm apart at an approximate rate of 400,000 seeds ha^{-1}. Plots were 3 m wide, 10 m in length at Exeter, and 8 m in length at the Ridgetown and London locations. All herbicides were applied with a CO_2 pressurized backpack sprayer calibrated to deliver 200 L ha^{-1} water volume at 240 kPa. The sprayer consisted of a handheld boom equipped with four spray nozzles (ULD11002) set on 50 cm spacings producing a spray width of 2 m. Each site contained natural weed populations, except at London where small-seeded broadleaf weeds were seeded within the trial area. A cover spray of quizalofop-p-ethyl (36 g ai ha^{-1}) and Sure-Mix® (0.5% V/V) was applied to control monocot weed species.

Soybean injury was assessed 1, 2, and 4 weeks after application (WAA) on a scale of 0-100% where 0 was no visible injury and 100 was complete plant death. Visible weed control assessments were conducted 1, 2, and 4 WAA by estimating percent biomass reduction of each identified weed species at each height at application. As the presence of the five weed species and required sizes was not consistent, the number and type of flagged weeds was recorded for each plot. Density data are presented as the percent of flagged weeds controlled in each plot. Each flagged weed was cut at the soil surface, organized by height and species, placed in labeled paper bags, and dried at 60 ^{o}C in a kiln drier until the weed biomass reached a constant moisture. The dry weed biomass was then weighed on an analytical scale and recorded. Dry weed biomass was then calculated on a per plant basis by dividing the total biomass for each weed species at each height by the number of flagged weeds present in each plot to account for variation in the number of flagged weeds in each plot.

2.1 Statistical Analysis

The GLIMMIX procedure was utilized for the analysis of all data in SAS version 9.4. Variance was partitioned into the fixed effects of Factor A (herbicide treatment) and Factor B (weed height), and the interaction between the two factors. The random effects included the environment (differences in location and year of trials), replication within environment, and the interaction between both factors. All weed data were analyzed by weed species; there was no treatment by environment interaction, therefore, environments were pooled by weed species. Normality was tested using the Shapiro-Wilk statistic and visual analysis of the plotted residuals. An arcsine square root transformation was conducted to best fit the data to a normal distribution for common lambsquarters and common ragweed at all control assessment timings, and redroot pigweed at 1 WAA. Transformed means were back-transformed for the presentation of results. Dry biomass data for all weed species were analyzed using a lognormal distribution. A Gaussian distribution was used to analyze velvetleaf control at all assessment timings, redroot pigweed control at 2 and 4 WAA, and density data for all weed species evaluated. Least square means for herbicide or weed height (main effects) were compared when there was no statistically significant interaction between the factors. Least square means were compared using the Tukey Kramer multiple range test with a P-value of 0.05.

3. Results and Discussion

3.1 Soybean Injury

None of the herbicide treatments caused significant visible soybean injury (< 2%); data not presented.

3.2 Common Lambsquarters

At all environments common lambsquarters was present in weed communities consisting of multiple weed species at different heights; therefore, data were pooled from four environments. Herbicide treatment efficacy was not influenced by weed height ($P \geq 0.4842$ for all interactions), so the main effects are presented in Table 2. When averaged across weed heights, the addition of AMS to glufosinate improved common lambsquarters control by 17-25% across glufosinate rates and assessment timings ($P < 0.05$, Table 2). This is consistent with previous research conducted in Ontario by Soltani et al. (2011) who observed enhanced control of common lambsquarters with the addition of AMS to glufosinate. In contrast, Maschhoff et al. (2000) reported no improvement in common lambsquarters control when AMS was added to glufosinate. Averaged across all herbicide treatments, glufosinate provided greater common lambsquarters control across all weed assessment timings when applied to common lambsquarters at 5 cm (71% to 77%) compared to 10 cm (60% to 65%). There was an incremental decrease in common lambsquarters control when glufosinate was applied to 5, 10 and 15 cm common lambsquarters 2 and 4 WAA. Averaged across height at application, all glufosinate treatments reduced common lambsquarters density similarly at 31% to 45%. There was no impact of common lambsquarters height at time of glufosinate application on the reduction in lambsquarters density. Glufosinate alone (300 or 500 g ai ha^{-1}) did not reduce common lambsquarters biomass; however, the addition of AMS to glufosinate at 300 and 500 g ai ha^{-1} caused a biomass reduction relative to the non-treated control of 46% and 60%, respectively. Relative to glufosinate applied to 5 cm common lambsquarters, there was a 6- and 17-fold increase in biomass when the application was delayed to 10 and 15 cm, respectively. This study concludes that glufosinate provides improved common lambsquarters control when applied at 5 cm in height and with the addition of AMS.

Table 2. Least square means and significance of main effects and interaction for common lambsquarters control (1, 2, and 4 weeks after application), density, and dry biomass from four field trials conducted in Ontario, Canada in 2021 and 2022

Main effects	Rate	Control[a]			Density	Dry Biomass
		1 WAA	2 WAA	4 WAA		
Herbicide	g ai ha^{-1} or L ha^{-1}	---------------- % ----------------			% controlled	mg plant^{-1}
Non-treated	-				3 b	1977 b
Glufosinate	300	49 b	50 b	46 b	33 a	1621 ab
Glufosinate + AMS	300 + 6.50	66 a	74 a	71 a	42 a	1072 a
Glufosinate	500	56 b	60 b	57 b	31 a	1354 ab
Glufosinate + AMS	500 + 6.50	74 a	78 a	74 a	45 a	799 a
Standard error		2.3	2.3	2.4	2.4	157.4
Herbicide P-value		<0.0001	<0.0001	<0.0001	<0.0001	0.0007
Weed Height						
5 cm	-	71 a	77 a	77 a	37	248 a
10 cm	-	60 b	65 b	60 b	30	1805 b
15 cm	-	54 b	57 c	48 c	25	4563 b
Standard error		2.3	2.3	2.4	2.4	157.4
Weed height P-value		<0.0001	<0.0001	<0.0001	0.1663	<0.0001
Interaction						
Herbicide × Weed Height P-value		0.8984	0.4842	0.9809	0.8683	0.9801

Note. Abbreviations: WAA, weeks after application.

[a] Means followed by the same lowercase letter within the same column are not statistically different according to the Tukey-Kramer test ($P < 0.05$).

3.3 Common Ragweed

At the Ridgetown in 2021 and 2022 environments, common ragweed was present in weed communities consisting of multiple weed species at different heights; therefore, data were pooled from these two environments. The effect of herbicide treatment was not influenced by common ragweed height ($P \geq 0.2441$ for all interactions), therefore the main effects are presented in Table 3. Averaged across all common ragweed heights, glufosinate 300 g ai ha^{-1} + AMS, and glufosinate 500 g ai ha^{-1} applied with or without AMS, provided greater common ragweed control compared to glufosinate applied at 300 g ai ha^{-1} at 1 WAA. Averaged across all glufosinate treatments, glufosinate provided improved common ragweed control when applied to 5 cm plants versus 10 or 15 cm plants 1 WAA, control of 10 and 15 cm plants was similar. Glufosinate provided excellent common ragweed control (≥ 97%) across all glufosinate treatments regardless of plant height 2 and 4 WAA. This is consistent with Corbett et al. (2004) who observed 100% control of common ragweed at 2-5 cm and ≥ 95% of 8-10 cm when glufosinate was applied at 291 or 409 g ai ha^{-1}. Glufosinate reduced common ragweed density 87% to 94% and biomass 99% to 100%. There was no impact of common ragweed height on common ragweed density or biomass. Glufosinate has excellent activity on common ragweed; generally, there was little impact of glufosinate rate, AMS addition, and common ragweed height on common ragweed control.

Table 3. Least square means and significance of main effects and interaction for common ragweed control (1, 2, and 4 weeks after application), density, and dry biomass from two field trials conducted in Ontario, Canada in 2021 and 2022

Main effects	Rate	Control[a]			Density	Dry Biomass
		1 WAA	2 WAA	4 WAA		
Herbicide	g ai ha^{-1} or L ha^{-1}	---------------	%	---------------	% controlled	mg plant^{-1}
Non-treated	-				8 b	3465 b
Glufosinate	300	78 b	97	99	92 a	3 a
Glufosinate + AMS	300 + 6.50	85 a	98	99	94 a	4 a
Glufosinate	500	84 a	99	99	93 a	15 a
Glufosinate + AMS	500 + 6.50	84 a	98	99	87 a	21 a
Standard error		1.9	4.1	5.0	3.7	124.6
Herbicide P-value		0.0086	0.2172	0.8547	<0.0001	<0.0001
Weed Height						
5 cm	-	87 a	98	99	79	40
10 cm	-	82 b	98	99	74	394
15 cm	-	78 b	98	99	71	3477
Standard error		1.9	4.1	5.0	3.7	124.6
Weed height P-value		0.0006	0.8245	0.6719	0.4768	0.1783
Interaction						
Herbicide × Weed Height P-value		0.7625	0.4819	0.2441	0.6163	0.3260

Note. Abbreviations: WAA, weeks after application.

[a] Means followed by the same lowercase letter within the same column are not statistically different according to the Tukey-Kramer test ($P < 0.05$).

3.4 Velvetleaf

At the Ridgetown in 2021 and 2022 environments velvetleaf was present in weed communities consisting of multiple weed species at different heights; therefore, the presented velvetleaf results are pooled from two environments. No interaction effect was detected between the two factors for velvetleaf control 1, 2, and 4 WAA, density, and dry biomass ($P \geq 0.1946$ for all interactions, Table 4). Averaged across all velvetleaf heights, glufosinate 500 g ai ha^{-1} + AMS provided greater velvetleaf control compared to all other glufosinate treatments 1 and 2 WAA. The addition of AMS to glufosinate applied at 500 g ai ha^{-1} improved velvetleaf control 1, 2 and 4 WAA. The addition of AMS to glufosinate enhanced velvetleaf control by improving foliar absorption and translocation (Maschhoff et al., 2000). Averaged across glufosinate treatments velvetleaf control was reduced when applied to 15 cm compared to 10 cm velvetleaf; control of 5 cm tall was intermediate and similar to both at 1 WAA. At 2 WAA, glufosinate controlled 5 cm tall velvetleaf better than 15 cm tall velvetleaf; control of 10 cm tall velvetleaf was intermediate and similar to both. Glufosinate efficacy decreased as velvetleaf height increased 4 WAA; the glufosinate treatments applied to 5, 10, and 15 cm velvetleaf resulted in 82%, 70%, and 50% control, respectively. Glufosinate applied at 500 g ai ha^{-1} + AMS reduced velvetleaf density and dry biomass relative to the non-treated control. There was no difference in velvetleaf density among the glufosinate treatments evaluated when averaged across all velvetleaf heights. The glufosinate treatments applied to 5 cm velvetleaf reduced density 52%; when applied to 10 or 15 cm velvetleaf density was reduced 26% and 10% respectively. The greatest reductions in dry biomass plant^{-1} were observed when glufosinate treatments were applied to 5 cm velvetleaf plants; there was a 3- and a 9-fold increase in biomass plant^{-1} when glufosinate was applied to 10 and 15 cm plants, respectively. Glufosinate efficacy has been shown to be influenced by the velvetleaf growth stage (Tharp et al., 1999). Glufosinate applied at 500 g ai ha^{-1} with AMS to 5 cm tall velvetleaf resulted in the greatest control.

Table 4. Least square means and significance of main effects and interaction for velvetleaf control (1, 2, and 4 weeks after application), density, and dry biomass from two field trials conducted in Ontario, Canada in 2021 and 2022

Main effects	Rate	Control[a]			Density	Dry Biomass[b]
		1 WAA	2 WAA	4 WAA		
Herbicide	g ai ha^{-1} or L ha^{-1}	----------------- % -----------------			% controlled	mg plant^{-1}
Non-treated	-				10 b	1697 b
Glufosinate	300	42 b	44 b	63 b	35 ab	1790 b
Glufosinate + AMS	300 + 6.50	41 b	56 b	65 ab	30 ab	1288 ab
Glufosinate	500	41 b	53 b	64 b	25 ab	1257 ab
Glufosinate + AMS	500 + 6.50	48 a	76 a	78 a	46 a	574 a
Standard error		2.8	2.8	2.4	3.2	187
Herbicide P-value		0.0135	0.0029	0.0202	0.0367	0.0070
Weed Height						
5 cm	-	43 ab	69 a	82 a	52 a	257 a
10 cm	-	45 a	59 ab	70 b	26 b	1063 b
15 cm	-	40 b	45 b	50 c	10 b	2550 c
Standard error		2.8	2.8	2.4	3.2	187
Weed height P-value		0.0411	0.0045	<0.0001	0.0003	<0.0001
Interaction						
Herbicide × Weed Height P-value		0.4033	0.8432	0.4638	0.6548	0.1946

Note. Abbreviations: WAA, weeks after application.

[a] Means followed by the same lowercase letter within the same column are not statistically different according to the Tukey-Kramer test ($P < 0.05$).

[b] Dry biomass means presented are untransformed with separation based on analysis with a lognormal distribution.

3.5 Redroot Pigweed

At the Ridgetown 2021, Exeter 2021, and London 2022 environments redroot pigweed was present in weed communities consisting of multiple weed species at different heights; therefore, results are pooled from three experiments. No significant interaction effect was detected for any assessments of redroot pigweed ($P \geq 0.5095$); therefore, the main effects will be discussed (Table 5). Averaged across heights, glufosinate 500 g ai ha^{-1} + AMS provided 10% greater redroot pigweed control compared to glufosinate 300 g ai ha^{-1} 1 WAA. The addition of AMS to glufosinate at 300 g ai ha^{-1} improved redroot pigweed control 11% 2 WAA. Compared to glufosinate at 300 g ai ha^{-1}, the application of glufosinate 500 g ai ha^{-1} + AMS improved redroot pigweed control by 14 and 18 percentage points at 2 and 4 WAA, respectively. By applying the glufosinate treatments to 5 or 10 cm redroot pigweed control was improved by 12 and 9 percentage points compared to applications made to 15 cm plants, respectively 1 WAA. When glufosinate treatments were applied to 5 cm plants control was improved by 9 and 18 percentage points compared to applications made to 15 cm redroot pigweed plants 2 WAA and 4 WAA, respectively; control of redroot pigweed when glufosinate was applied to 10 cm plants resulted in intermediate control and was similar to both other heights. When glufosinate was applied to 2-5 cm redroot pigweed, Corbett et al. (2004) reported an improvement of 13 percentage points compared to glufosinate applied to 8-10 cm plants. Similar to this study, Coetzer et al. (2001) observed 73% control of 15-18 cm redroot pigweed with glufosinate 4 WAA; however, in contrast to this study control of 2-5 and 7-10 cm plants was 65 and 68%, respectively. Poor control was attributed to the regrowth of treated plants and the second flush of redroot pigweed which was not observed in this study. All glufosinate treatments resulted in decreased plant density and dry biomass compared to the non-treated control. There was a 5 and 46-fold increase in redroot pigweed biomass plant^{-1} when glufosinate was applied to 10 and 15-cm plants compared to 5-cm plants, respectively. Glufosinate efficacy was optimized when applied at 500 g ai ha^{-1} with AMS to 5 cm tall redroot pigweed.

Table 5. Least square means and significance of main effects and interaction for redroot pigweed control (1, 2, and 4 weeks after application), density, and dry biomass from three field trials conducted in Ontario, Canada in 2021 and 2022

Main effects	Rate	Control[a] 1 WAA	Control[a] 2 WAA	Control[a] 4 WAA	Density	Dry Biomass
Herbicide	g ai ha^{-1} or L ha^{-1}		--------------- % --------------		% controlled	mg plant^{-1}
Non-treated	-				3 b	2088 b
Glufosinate	300	84 b	79 b	70 b	57 a	2013 a
Glufosinate + AMS	300 + 6.50	93 ab	90 a	84 ab	62 a	533 a
Glufosinate	500	90 ab	85 ab	81 ab	54 a	557 a
Glufosinate + AMS	500 + 6.50	94 a	93 a	88 a	74 a	504 a
Standard error		1.1	1.3	2.1	2.1	132
Herbicide P-value		0.0202	0.0054	0.0309	<0.0001	<0.0001
Weed Height						
5 cm	-	95 a	92 a	90 a	59	160 a
10 cm	-	92 a	86 ab	80 ab	51	984 b
15 cm	-	83 b	83 b	72 b	41	7569 b
Standard error		1.1	1.3	2.1	2.1	132
Weed height P-value		0.0006	0.0492	0.0071	0.0763	<0.0001
Interaction						
Herbicide × Weed Height P-value		0.5095	0.8288	0.8229	0.9685	0.9707

Note. Abbreviations: WAA, weeks after application.

[a] Means followed by the same lowercase letter within the same column are not statistically different according to the Tukey-Kramer test ($P < 0.05$).

4. Conclusions

This study demonstrates that the effect of glufosinate rate, the addition of AMS, and weed height at application is weed species-specific. Glufosinate provided excellent common ragweed control at both rates and at all weed heights; there was no improvement in control with the addition of AMS. Control was reduced as common lambsquarters, velvetleaf, and redroot pigweed height increased at the time of glufosinate application. The addition of AMS provided improved control of common lambsquarters when averaged across all weed heights. Greater velvetleaf and redroot pigweed control was observed when glufosinate rate was increased from 300 to 500 g ai ha^{-1} and AMS was included in the application. Previous research has determined that the benefit of the addition of AMS to glufosinate varies among weed species (Maschhoff et al., 2000). Results from this study are in agreement with Coetzer et al. (2001), Craigmyle et al. (2013), and Steckel et al. (1997), who reported that glufosinate efficacy is influenced by rate and weed height at application and the response was weed species-specific. In general, weed control efficacy with glufosinate was improved when applied at the high rate, with the addition of AMS, and when applied to smaller weeds.

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