
Glufosinate Rates, Timings, and Additives for Weed Control in Glufosinate-Resistant Sugarbeet

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ABSTRACT

Two experiments were conducted to evaluate weed control with glufosinate in glufosinate-resistant sugarbeet. The first experiment evaluated glufosinate rate, application timing, and combinations with ammonium sulfate (AMS). The second experiment examined glufosinate alone and in combination with postemergence (POST) or preplant incorporated (PPI) ethofumesate. In the first experiment in 1998, increasing glufosinate rate improved common lambsquarters control and redroot pigweed control was greater when glufosinate was initially applied mid-post (MP) compared to early-post (EP). In 1999, increasing glufosinate rate, beginning treatment at the EP application timing, and the addition of AMS, increased redroot pigweed control. Barnyardgrass control also was improved with the higher glufosinate rate and with the addition of AMS. Sugarbeet yield in 1998 was not significantly affected by glufosinate treatments. In 1999, the addition of AMS to low glufosinate rates and the addition of AMS to treatments applied beginning MP increased sugarbeet yield. In the second experiment, three applications of glufosinate and two applications of glufosinate following PPI ethofumesate resulted in weed control equal to a standard herbicide program consisting of PPI ethofumesate followed by a premix of ethofumesate, desmedipham, and phenmedipham (1:1:1

ratio) applied to cotyledonary weeds; followed by the premix plus triflusaluron applied EP; followed by the premix plus triflusaluron and sethoxydim applied MP. A single application of glufosinate followed by glufosinate applied in combination with ethofumesate controlled weeds less than or equal to the standard program. Sugarbeet yield from plots treated with glufosinate generally was equal to or greater than sugarbeet yield from standard programs. Among the glufosinate treatments, plots treated three times with glufosinate or twice following PPI ethofumesate had the greatest sugarbeet yield.

Additional index words: Herbicide-resistant, *Beta vulgaris*, ammonium sulfate, AMS, ethofumesate.

The development of glufosinate-resistant sugarbeet (*Beta vulgaris* L.) offers the potential to use glufosinate for weed control in sugarbeet (Dexter and Luecke 1997; Gasser 1989; Kishore et al. 1992; Wilson et al. 2002). Current herbicide programs require multiple applications of several herbicides to provide adequate weed control and the herbicides used often cause sugarbeet injury. Injury from current programs is often dependant on temperature (Starke and Renner 1996) and has the potential to reduce sugarbeet yield (Wilson 1999). No apparent sugarbeet injury has resulted from glufosinate applied to glufosinate-resistant sugarbeet (Dexter and Luecke 1997; Wilson et al. 2002). Glufosinate-resistant corn and canola are commercially available in the United States (Ritter and Menbere 1998; Culpepper and York 1999).

Glufosinate is a non-selective herbicide that controls a wide range of broadleaf and grass plant species (Hass and Müller 1987; Steckel and DeFelice 1995). In field experiments, glufosinate applied once, at rates from 0.42 to 0.56 kg/ha, provided greater than 80% control of giant foxtail (*Setaria faberi* Herrm.), Pennsylvania smartweed (*Polygonum pennsylvanicum* L.) and common cocklebur (*Xanthium strumarium* Wallr.) (Steckel et al. 1997b). Glufosinate applied sequentially at rates from 0.3 to 0.4 kg/ha, provided 90% or greater control of common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), velvetleaf (*Abutilon theophrasti* Medic.), wild proso millet (*Panicum miliaceum* Michx.) and fall panicum (*Panicum dichotomiflorum* Michx.) in glufosinate-resistant sweet corn (*Zea mays* L.) (Van Wychen et al. 1999). Glufosinate at rates ranging from 0.3 to 1.5 kg/ha, also controls a wide spectrum of perennial weeds and grasses (Hass and Müller 1987).

In greenhouse experiments, glufosinate reduced barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), common ragweed, fall panicum, giant foxtail and large crabgrass (*Digitaria sanguinalis* (L.) Scop.) biomass by 50% at rates ranging from 0.063 to 0.16 kg/ha (Tharp et al. 1999).

Plants differ in sensitivity to glufosinate (Steckel et al. 1997a; Steckel et al. 1997b; Maschhoff et al. 2000). Differences in plant sensitivity to glufosinate are mainly related to differences in uptake and translocation of glufosinate, not metabolic degradation (Mersey et al. 1990, Maschhoff et al. 2000). Weed control efficacy with glufosinate has also been correlated with temperature and relative humidity around the time of application (Anderson et al. 1993; Coetzer et al. 2001).

Weed control in glufosinate-resistant sugarbeet has been examined in sugarbeet producing areas of the United States. Downard and Morishita (1998) reported that mixing ammonium sulfate with 0.3 kg/ha of glufosinate had the same effect on weed control as increasing the glufosinate rate to 0.4 kg/ha in Idaho. Wilson et al. (2002) reported that glufosinate applied three times to 3-cm weeds provided weed control comparable to desmedipham plus phenmedipham plus triflusaluron plus clopyralid applied three times in Western Nebraska. In Wyoming, glufosinate applied three times at rates ranging from 0.3 to 0.4 kg/ha, with and without ammonium sulfate, controlled kochia (*Kochia scoparia* (L.) Schrad), common lambsquarters, redroot pigweed (*Amaranthus retroflexus* L.), wild mustard (*Brassica kaber* (D.C.) L.C. Wheeler), hairy nightshade (*Solanum sarrachoides* Sendtner), and green foxtail (*Setaria viridis* (L.) Beauv.) 90 to 100% (Mesbah and Miller 1999). Norris and Roncoroni (1999) showed that glufosinate applied once did not provide season-long weed control in California due to lack of residual activity, whereas, glufosinate applied more than once provided over 95% control of weeds.

The objectives of this research were to (1) determine the effect of glufosinate rate, application timing, and combination with AMS and (2) to evaluate glufosinate alone, following PPI ethofumesate, or in combination with POST ethofumesate for weed control in glufosinate-resistant sugarbeet grown under furrow irrigation in Eastern Oregon.

MATERIALS AND METHODS

Field experiments were conducted at the Malheur Experiment Station near Ontario, OR. Fields were prepared in the fall by moldboard plowing and hilling the soil. The tops of the hills were leveled in the spring to provide a uniform seed bed for planting. The soil was a silt loam with 2.4% organic matter and pH 7.0 in 1998, and a silt loam with

1.4% organic matter and pH 7.9 in 1999. The glufosinate-resistant sugarbeet variety 'Beta 8757 LL' was planted on April 16, 1998 and April 7, 1999. Sugarbeet seed was spaced 5 cm within the row and 56 cm between rows. Terbufos (S-[[[1,1-dimethylethyl]thio]methyl] O,O-diethyl phosphorodithioate) was applied for insect control at 112 mg ai/m of row on April 17, 1998 and April 8, 1999. Plots were 2.23 m wide by 8.23 m long and treatments were arranged in a randomized complete block design with three replicates. Sugarbeet were furrow irrigated. After the sugarbeet reached the 4- to 6-leaf stage, the stand was thinned to a 20 cm spacing between plants. Sugarbeet was sidedressed with 235 kg N/ha in the form of urea June 5, 1998, and June 15, 1999. Herbicides were applied with a CO₂-pressurized backpack sprayer calibrated to deliver 187 L/ha at 207 kPa.

Weed control was evaluated visually 28 days after the final herbicide application (DAT) on June 29, 1998 and July 13, 1999, and 28 days prior to harvest (DPH) on September 14, 1998 and September 20, 1999. Sugarbeet injury was evaluated visually 14 and 28 days after the final herbicide application.

Sugarbeet was defoliated mechanically and harvested using a mechanical, single-row harvester October 15, 1998, and October 6 and 7, 1999. Roots from the center two rows of each plot were harvested and weighed. Sixteen sugarbeet roots from each plot were randomly sampled and taken to Syngenta Seeds for sucrose and purity determinations. Impurities measured were K, Na, and amino N in grams per 100 g of sucrose. Percent sucrose extraction was estimated using empirical equations (Carruthers et al. 1962). Parameters measured were sugarbeet root yield, sucrose content, percent sucrose extraction, kilograms of estimated recoverable sucrose per hectare, and grams of estimated recoverable sucrose per kilogram of sugarbeet.

Glufosinate Rate, Timing, and Combinations with AMS

Glufosinate was applied three times at 0.3 or 0.4 kg/ha alone or in combination with AMS at 3.4 kg/ha, beginning at either an early-post timing (0.5 to 2.5 cm weeds) (EP) or a mid-post timing (2.5 to 10 cm weeds) (MP). Application dates, sugarbeet and weed stages, and environmental conditions on each application date are listed in Table 1.

Treatments were arranged in a two (glufosinate rate) by two (application timing) by two (plus or minus AMS) factorial design. Data were subjected to analysis of variance (ANOVA) at the 0.05 probability level to identify main effects and interactions.

Table 1. Application dates, sugarbeet and weed size, and environmental conditions on the day of application for the glufosinate rate, timing, and combination with AMS experiments in 1998 and 1999.

Application timing	Date	Plant height at application					Average air temperature [†]	Max air temperature	Relative humidity [†]
		Sugarbeet	Redroot pigweed	Common lambsquarters	Hairy nightshade	Barnyard-grass			
		cm						C	%
<u>1998</u>									
Early-post (EP)	May 4	1.9	0.6	1.9	1.3	1.3	16	25	65
Mid-post (MP)	May 11	6.4	2.5	3.8	2.5	4.3	13	18	87
Late-post (LP)	May 18	_____					11	18	64
Late-late-post (LLP)	May 24	_____					16	22	79
<u>1999</u>									
Early Post (EP)	May 10	2.5	0.6	-	2.5	2.5	7	14	42
Mid-post (MP)	May 26	10.0	2.5	7.6	5.0	4.6	19	28	27
Late-post (LP)	June 4	_____					16	23	75
Late-late-post (LLP)	June 15	_____					26	36	47

[†]Air temperature and relative humidity are averaged over the 24-hour period.

Glufosinate Combinations with Ethofumesate

Glufosinate was applied three times alone, twice following preplant incorporated (PPI) ethofumesate, or twice with ethofumesate applied in combination with the second glufosinate application. Treatments without PPI ethofumesate were applied beginning at EP or MP application timings. In each of the treatments, glufosinate was applied at 0.3 and 0.4 kg/ha. The glufosinate treatments were compared to a standard program consisting of PPI ethofumesate followed by a premix of ethofumesate, desmedipham, and phenmedipham (1:1:1 ratio) applied to cotyledonary weeds; followed by the premix plus triflurosulfuron applied EP; followed by the premix plus triflurosulfuron and sethoxydim applied MP. Treatment application dates, sugarbeet and weed size, and environmental conditions on the day of application are listed in Table 2. Data were analyzed using ANOVA at the 0.05 probability level. Means were separated using Fisher's protected LSD ($P=0.05$).

RESULTS AND DISCUSSION

Sugarbeet plants were defoliated by hail on July 4, 1998. The sugarbeet canopy reformed approximately two to four weeks after the hailstorm. Weed control comparisons were still valid since the hail damage was uniform across the trial. Data for both experiments are presented individually by year because of significant year by treatment interactions. These interactions could be related to the hail damage or to differences in environmental conditions when treatments were applied in each year.

Glufosinate Rate, Timing, and Combinations with AMS.

All treatments in 1998 gave 89% or more control of redroot pigweed, common lambsquarters, and hairy nightshade at 28 days after treatment (DAT) and greater than 84% control at 28 days prior to harvest (DPH). Barnyardgrass control was 83% or more at 28 DPH (Table 3). Glufosinate treatments initiated at the MP timing increased redroot pigweed and barnyardgrass control from 84 and 83% to 96 and 91%, respectively, 28 DPH compared to those initiated at the EP timing. Common lambsquarters control 28 DAT was improved by increasing the glufosinate rate from 0.3 to 0.4 kg/ha. Other main effects were not significant. All herbicide treatments controlled all species 72% or greater 28 DAT and 81% or greater at 28 DPH in 1999. In contrast to 1998, redroot pigweed and barnyardgrass control in 1999 was increased by increasing the glufosinate rate or by the addition of AMS. In 1999, redroot pigweed control 28 DAT and 28 DPH and common lambsquarters control

Table 2. Application dates, sugarbeet and weed size, and environmental conditions on the day of application for the glufosinate alone and in combinations with ethofumesate in 1998 and 1999.

Application timing	Date	Plant height at application					Average air temperature [†]	Max air temperature	Relative humidity [†]
		Sugarbeet	Redroot pigweed	Common lambsquarters	Hairy nightshade	Barnyard-grass			
<u>1998</u>									
PPI	April 14	-	-	-	-	-	6	12	69
Cotyledon	April 27	1.3	-	1.3	1.3	-	14	24	50
Early-post (EP)	May 4	1.9	0.6	1.9	1.3	1.3	16	25	65
Mid-post (MP)	May 11	5.0	2.5	3.8	3.8	6.3	13	18	87
Late-post (LP)	May 18	-----					11	18	64
Late-late-post (LLP)	May 28	-----					13	22	69
<u>1999</u>									
PPI	April 7	-	-	-	-	-	8	17	53
Cotyledon	April 24	0.6	-	-	0.6	-	15	22	36
Early Post (EP)	May 5	1.9	0.6	1.3	1.3	1.3	8	16	53
Mid-post (MP)	May 18	3.8	1.3	5.0	2.5	3.8	16	23	65
Late-post (LP)	June 4	-----					16	23	75
Late-late-post (LLP)	June 15	-----					26	36	47

[†]Air temperature and relative humidity are averaged over the 24-hour period.

Table 3. Main effects of glufosinate rate, application timing, and addition of AMS on weed control in 1998 and 1999.

Treatment [†]	Weed control [‡]														
	1998							1999							
	Redroot pigweed		Common lambsquarters		Hairy nightshade		Barnyard-grass [§]	Redroot pigweed		Common lambsquarters		Hairy nightshade		Barnyardgrass	
	28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH
	-----%-----														
Glufosinate Rate															
0.3 kg ai/ha	93	90	89	97	93	97	87	87	86	90	94	97	100	81	83
0.4 kg ai/ha	95	89	93	97	94	97	87	96	95	92	96	96	100	90	89
P-value	0.1262	0.7537	0.0064	0.8419	0.5395	0.6904	0.9620	0.0010	0.0008	0.5728	0.4937	0.7531	-	0.0096	0.0535
Application timing															
EP, MP, LP	94	84	90	96	93	97	83	95	93	89	91	98	100	86	87
MP, LP, LLP	94	96	93	98	94	98	91	88	88	93	99	95	100	86	86
P-value	-	0.0002	0.0760	0.1744	0.5395	0.4288	0.0301	0.0053	0.0214	0.3149	0.0132	0.3507	-	0.9156	0.8340
Additive															
- AMS	93	91	91	97	93	97	89	88	87	88	94	94	100	72	81
+ AMS	95	88	92	97	95	98	85	95	94	94	96	100	100	92	91
P-value	0.1262	0.2669	0.5360	0.4291	0.0769	0.4288	0.2624	0.0023	0.0042	0.1020	0.4937	0.0383	-	0.0009	0.0060

[†]Main effect treatment means are averaged across the other two main effects. Timings are as follows: EP, early-postemergence; MP, mid-postemergence; LP, late-postemergence; LLP, late-late-postemergence. AMS, ammonium sulfate (3.4 kg/ha)

[‡]Ratings were taken 28 days after the final application (DAT), June 29, 1998 and July 13, 1999 and 28 days prior to harvest (DPH), September 14, 1998 and September 20, 1999.

[§]Barnyardgrass was only evaluated in September 1998.

28 DPH were affected by application timing. Redroot pigweed control was improved when treatment began EP while common lambsquarters control was increased when treatment began MP. The effect of timing on redroot pigweed control was opposite of what was observed in 1998 where treatments initiated MP were more effective. Others have documented similar common lambsquarters control from glufosinate and glufosinate plus AMS (Pline et al. 1999, Maschhoff et al. 2000). Glufosinate absorption by barnyardgrass was increased with the addition of AMS (Maschhoff et al. 2000). Downard and Morishita (1998) showed that ammonium sulfate improved the consistency of weed control from glufosinate in sugarbeet production systems. The main effects were not consistent across years, which may be related to environmental conditions at application. Relative humidity in 1998 was 23 to 60% higher at three of the four application dates compared to 1999. Weed control with glufosinate has been demonstrated to be dependent on environmental factors including temperature and relative humidity (Anderson et al. 1993; Coetzer et al. 2001). The contradictory response of redroot pigweed to glufosinate application timing in 1998 and 1999 is not explained by weed size since redroot pigweed plants were similar in size at the EP and MP timings in both years.

Glufosinate did not injure sugarbeet regardless of rate, timing, or the addition of AMS in 1998 or 1999 (data not shown). Sucrose extraction ranged from 90.1 to 90.4% in 1998 and 92.0 to 93.0% in 1999, with no significant main effects or interactions (data not shown). Sugarbeet root yield (Table 4) and sucrose extraction (data not shown) were not influenced by any of the main effects in 1998. Estimated recoverable sucrose yield was greater from plots where glufosinate treatments began EP compared to plots where glufosinate treatments were not applied until MP. This is the opposite of what was expected based on the weed control data because redroot pigweed and barnyardgrass control was greater from treatments initiated MP compared to those initiated EP. It is possible that early weed competition reduced sugarbeet yields in plots where glufosinate treatments were not applied until MP. Sugarbeet sucrose content and estimated recoverable sucrose in grams per kilogram of sugarbeet root were slightly increased by the addition of AMS to glufosinate. In 1999, sugarbeet sucrose content, percent extraction, and estimated recoverable sucrose per kilogram of sugarbeet root were not influenced by glufosinate treatments (Table 4). Root yield and estimated recoverable sucrose per hectare were significant for glufosinate rate by AMS and application timing by AMS interactions (Table 5). In the case of both yield components, the addition of AMS to glufosinate at 0.3 kg/ha increased yield, but not when added to glufosinate

Table 4. Main effects of glufosinate rate, application timing, and AMS on sugarbeet yield and quality in 1998 and 1999.

Treatment [†]	Sugarbeet							
	1998				1999			
	Root yield kg/ha	Sucrose content %	Estimated recoverable sucrose kg/ha	Estimated recoverable sucrose g/kg	Root yield kg/ha	Sucrose content %	Estimated recoverable sucrose kg/ha	Estimated recoverable sucrose g/kg
Glufosinate rate								
0.3 kg ai/ha	93,393	16.40	13,816	148.0	- [‡]	17.9	- [‡]	166.3
0.4 kg ai/ha	92,521	16.35	13,650	147.5	-	18.1	-	168.5
P-value	0.2765	0.5976	0.2081	0.6566		0.1626		0.1635
Application timing								
EP, MP, LP	93,576	16.44	13,872	148.3	-	18.1	-	167.2
MP, LP, LLP	92,338	16.31	13,594	147.2	-	18.0	-	167.7
P-value	0.1293	0.1652	0.0427	0.2693		0.7704		0.7491
Additive								
- AMS	93,486	16.27	13,721	146.8	-	18.0	-	167.3
+ AMS	92,427	16.48	13,746	148.7	-	18.0	-	167.6
P-value	0.1903	0.0287	0.8453	0.0476		0.8662		0.8655

[†]Main effect treatment means are averaged across the other two main effects. Timings are as follows: EP, early-postemergence; MP, mid-postemergence; LP, late-postemergence; LLP, late-late-postemergence. AMS, ammonium sulfate (3.4 kg/ha).

[‡]Application rate by AMS and application timing by AMS interactions were significant for root yield and estimated recoverable sucrose in 1999. Those data are presented in Table 5.

Table 5. Effect of glufosinate rate by AMS and application timing by AMS interactions on sugarbeet root yield and estimated recoverable sucrose in 1999.

Treatment [†]	Sugarbeet			
	Root yield		Estimated recoverable sucrose	
	- AMS	+ AMS	- AMS	+ AMS
	-----kg/ha-----			
Glufosinate rate				
0.3 kg ai/ha	70,126	83,905	11,749	13,854
0.4 kg ai/ha	81,097	80,746	13,557	13,693
LSD (0.05)	-----4,141-----		-----766-----	
Application timing				
EP, MP, LP	78,902	82,676	13,246	13,816
MP, LP, LLP	72,320	81,974	12,060	13,731
LSD (0.05)	-----4,141-----		-----766-----	

[†]Glufosinate by AMS interaction means are averaged over application timings. Application timing by AMS interaction means are averaged over glufosinate rate. Timings are as follows: EP, early-postemergence; MP, mid-postemergence; LP, late-postemergence; LLP, late-late-postemergence. AMS, ammonium sulfate (3.4 kg/ha).

at 0.4 kg/ha. The addition of AMS to glufosinate applied beginning at the MP timing increased sugarbeet yield parameters while addition of AMS to glufosinate applied beginning at the EP timing had no effect.

Glufosinate Combinations with Ethofumesate.

Glufosinate applied three times at 0.4 kg/ha and PPI ethofumesate followed by glufosinate twice at 0.4 kg/ha controlled weeds similar to the standard program in 1998 and similar or greater than the standard program in 1999 (Tables 6 and 7). In 1998, the standard treatment provided greater redroot pigweed control 28 DAT compared to all treatments except glufosinate (0.4 kg/ha) applied three times alone beginning at either EP or MP, glufosinate (0.3 kg/ha) applied three times beginning EP, and glufosinate (0.4 kg/ha) applied twice following PPI ethofumesate. In 1999, the standard treatment controlled redroot pigweed less than glufosinate applied three times at 0.4 kg/ha beginning EP or PPI ethofumesate followed by glufosinate twice at 0.4 kg/ha. In 1998, glufosinate at 0.3 kg/ha applied three times beginning MP provided less

Table 6. Weed control with glufosinate applied alone, in combination with, or following ethofumesate, 1998.

Treatment ¹	Rate kg ai/ha	Timing ²	Weed control ³							
			Redroot pigweed		Common lambsquarters		Hairy nightshade		Barnyardgrass	
			28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH
Ethofumesate fb	1.12	PPI	73	93	87	96	95	97	-	86
Glufosinate	0.3	MP + LP								
Ethofumesate fb	1.12	PPI	88	97	92	97	95	98	-	93
Glufosinate	0.4	MP + LP								
Glufosinate	0.3	EP + MP + LP	87	87	82	85	88	92	-	79
Glufosinate	0.4	EP + MP + LP	92	89	92	96	95	97	-	92
Glufosinate	0.3	MP + LP + LLP	73	82	77	87	95	98	-	88
Glufosinate	0.4	MP + LP + LLP	92	95	92	96	92	98	-	94
Glufosinate fb	0.3	EP	30	89	50	88	50	94	-	68
Glufosinate + etho	0.3 + 1.12	MP								
Glufosinate fb	0.4	EP	75	93	88	93	92	95	-	75
Glufosinate + etho	0.4 + 1.12	MP								

¹Abbreviations: etho, ethofumesate; EDP, commercial premix of ethofumesate + desmedipham + phenmedipham; trif, triflurosulfuron; seth, sethoxydim.

²Herbicide application timings: PPI, preplant incorporated; COT, cotyledon stage weeds; EP, 0.5 to 2.5 cm weeds; MP, 2.5 to 10 cm weeds or 7 to 10 days after EP; LP 7 to 10 days after LP; LLP, 7 to 10 days after LP.

³Weed control Ratings were taken 28 days after the final application (DAT), June 29 and 28 days prior to harvest (DPH), September 14.

(continued)

Table 6 (continued). Weed control with glufosinate applied alone, in combination with, or following ethofumesate, 1998.

Treatment [†]	Rate kg ai/ha	Timing [‡]	Weed control [§]							
			Redroot pigweed		Common lambsquarters		Hairy nightshade		Barnyardgrass	
			28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH
Glufosinate fb	0.3	MP	37	87	73	89	77	94	-	58
Glufosinate + etho	0.3 + 1.12	LP								
Glufosinate fb	0.4	MP	61	85	80	91	87	94	-	83
Glufosinate + etho	0.4 + 1.12	LP								
Ethofumesate fb	1.12	PPI	95	98	95	98	95	98	-	95
EDP fb	0.3	COT								
EDP + trif fb	0.37 + 0.0175	EP								
EDP + trif + seth	0.37 + 0.0175 + 0.34	MP								
Untreated			0	0	0	0	0	0	-	0
LSD (0.05)			11	10	13	NS	11	NS	-	NS

[†]Abbreviations: etho, ethofumesate; EDP, commercial premix of ethofumesate + desmedipham + phenmedipham; trif, triflusalufuron; seth, sethoxydim.

[‡]Herbicide application timings: PPI, preplant incorporated; COT, cotyledon stage weeds; EP, 0.5 to 2.5 cm weeds; MP, 2.5 to 10 cm weeds or 7 to 10 days after EP; LP 7 to 10 days after LP; LLP, 7 to 10 days after LP.

[§]Weed control Ratings were taken 28 days after the final application (DAT), June 29 and 28 days prior to harvest (DPH), September 14.

Table 7. Weed control with glufosinate applied alone, in combination with, or following ethofumesate, 1999.

Treatment [†]	Rate kg ai/ha	Timing [‡]	Weed control [§]							
			Redroot pigweed		Common lambsquarters		Hairy nightshade		Barnyardgrass	
			28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH
Ethofumesate fb	1.12	PPI	70	80	100	100	88	100	77	83
Glufosinate	0.3	MP + LP								
Ethofumesate fb	1.12	PPI	88	90	100	100	78	97	80	90
Glufosinate	0.4	MP + LP								
Glufosinate	0.3	EP + MP + LP	74	83	82	100	93	100	75	87
Glufosinate	0.4	EP + MP + LP	83	85	97	97	95	100	90	87
Glufosinate	0.3	MP + LP + LLP	75	82	92	100	78	100	85	87
Glufosinate	0.4	MP + LP + LLP	78	80	92	93	83	100	87	88
Glufosinate fb	0.3	EP	50	73	90	83	78	100	67	73
Glufosinate + etho	0.3 + 1.12	MP								
Glufosinate fb	0.4	EP	75	83	100	100	78	100	72	83
Glufosinate + etho	0.4 + 1.12	MP								

[†]Abbreviations: etho, ethofumesate; EDP, commercial premix of ethofumesate + desmedipham + phenmedipham; trif, triflurosulfuron; seth, sethoxydim.

[‡]Herbicide application timings: PPI, preplant incorporated; COT, cotyledon stage weeds; EP, 0.5 to 2.5 cm weeds; MP, 2.5 to 10 cm weeds or 7 to 10 days after EP; LP 7 to 10 days after LP; LLP, 7 to 10 days after LP.

[§]Weed control Ratings were taken 28 days after the final application (DAT), July 13 and 28 days prior to harvest (DPH), September 20.

(continued)

Table 7 (continued). Weed control with glufosinate applied alone, in combination with, or following ethofumesate, 1999.

Treatment [†]	Rate kg ai/ha	Timing [‡]	Weed control [§]							
			Redroot pigweed		Common lambsquarters		Hairy nightshade		Barnyardgrass	
			28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH	28 DAT	28 DPH
Glufosinate fb	0.3	MP	63	80	92	100	52	100	75	78
Glufosinate + etho	0.3 + 1.12	LP								
Glufosinate fb	0.4	MP	73	80	97	100	70	97	73	78
Glufosinate + etho	0.4 + 1.12	LP								
Ethofumesate fb	1.12	PPI	68	79	95	100	73	100	92	93
EDP fb	0.3	COT								
EDP + trif fb	0.37 + 0.0175	EP								
EDP + trif + seth	0.37 + 0.0175 + 0.34	MP								
Untreated			0	0	0	0	0	0	0	0
LSD (0.05)			12	NS	NS	10	20	NS	13	8

[†]Abbreviations: etho, ethofumesate; EDP, commercial premix of ethofumesate + desmedipham + phenmedipham; trif, triflurosulfuron; seth, sethoxydim.

[‡]Herbicide application timings: PPI, preplant incorporated; COT, cotyledon stage weeds; EP, 0.5 to 2.5 cm weeds; MP, 2.5 to 10 cm weeds or 7 to 10 days after EP; LP 7 to 10 days after LP; LLP, 7 to 10 days after LP.

[§]Weed control Ratings were taken 28 days after the final application (DAT), July 13 and 28 days prior to harvest (DPH), September 20.

redroot pigweed control 28 DAT and 28 DPH and less common lambsquarters control 28 DAT compared to glufosinate at 0.4 kg/ha. No differences between rates were observed when treatments were initiated at the EP timing. In 1998, glufosinate at 0.3 kg/ha applied MP and late-post (LP) following PPI ethofumesate provided greater redroot pigweed, common lambsquarters, and hairy nightshade control 28 DAT compared to glufosinate (0.3 kg/ha) applied twice with the second application combined with ethofumesate beginning at either an EP or MP timing. When glufosinate was applied EP and was followed by glufosinate tank mixed with ethofumesate MP, increasing glufosinate from 0.3 kg/ha to 0.4 kg/ha increased redroot pigweed, common lambsquarters, and hairy nightshade control 28 DAT in 1998. This same trend was apparent for redroot pigweed control 28 DAT and common lambsquarters and barnyardgrass control 28 DPH in 1999. In general, glufosinate at 0.4 kg/ha more consistently controlled weeds compared to 0.3 kg/ha across various timings and combinations. Ethofumesate applied PPI followed by glufosinate applied twice controlled weeds similar to glufosinate applied three times regardless of glufosinate rate. The exception was redroot pigweed control 28 DAT in 1998, which was less from glufosinate (0.3 kg/ha) applied twice following PPI ethofumesate compared to glufosinate (0.3 kg/ha) applied three times beginning at EP.

Glufosinate applied alone did not significantly injure sugarbeet. Significant crop injury was observed with the standard program in 1998 and treatments in which glufosinate (0.4 kg/ha) plus ethofumesate were applied LP in 1998 and 1999 (Tables 8 and 9). Injury from ethofumesate was greater when applied to larger sugarbeet later in the growing season. Sugarbeet root yield with PPI ethofumesate followed by glufosinate applied twice and three of four treatments with glufosinate applied three times was equal to the standard program. Sugarbeet root yield was less than the standard program for glufosinate applied three times at 0.3 kg/ha beginning MP in 1998, but not in 1999. In 1998, all treatments in which glufosinate was applied postemergence in combination with ethofumesate had lower sugarbeet root yield than the standard program. In 1999, sugarbeet root yield from all treatments containing glufosinate were equal to or greater than the standard program. Greatest sugarbeet root yield resulted from glufosinate applied three times at 0.4 kg/ha when initially applied EP to 1.0 to 2.5 cm weeds. Sucrose content was not significantly different among any of the treatments.

This research demonstrates that glufosinate can effectively control weeds in glufosinate-resistant sugarbeet. Variable weed control with glufosinate between years shows that efficacy can be influenced by environmental conditions. In general, higher glufosinate rates or the

Table 8. Sugarbeet injury and yield with glufosinate applied alone, in combination with, or following ethofumesate, 1998.

Treatment [†]	Rate kg ai/ha	Timing [‡]	Sugarbeet	Sugarbeet [§]				
			Injury 14 DAT ---- % ----	Root yield kg/ha	Sucrose content %	Extraction %	Estimated recoverable sucrose kg/ha g/kg	
Ethofumesate fb	1.12	PPI	10	90,944	16.18	89.99	13,224	145
Glufosinate	0.3	MP + LP						
Ethofumesate fb	1.12	PPI	10	94,080	16.17	90.08	13,634	145
Glufosinate	0.4	MP + LP						

Glufosinate	0.3	EP + MP + LP	0	91,168	16.46	90.45	13,493	149
Glufosinate	0.4	EP + MP + LP	0	93,408	16.28	90.12	13,649	147
Glufosinate	0.3	MP + LP + LLP	5	88,032	16.24	90.41	12,970	147
Glufosinate	0.4	MP + LP + LLP	2	94,080	16.06	90.00	13,552	144

[†]Abbreviations: etho, ethofumesate; EDP, commercial premix of ethofumesate + desmedipham + phenmedipham; trif, triflurosulfuron; seth, sethoxydim.

[‡]Herbicide application timings: PPI, preplant incorporated; COT, cotyledon stage weeds; EP, 0.5 to 2.5 cm weeds; MP, 2.5 to 10 cm weeds or 7 to 10 days after EP; LP 7 to 10 days after LP; LLP, 7 to 10 days after LP.

[§]Sugarbeet were harvested October 15, 1998.

(continued)

Table 8 (continued). Sugarbeet injury and yield with glufosinate applied alone, in combination with, or following ethofumesate, 1998.

Treatment [†]	Rate	Timing [‡]	Sugarbeet	Sugarbeet [§]				
			Injury 14 DAT ---- % ----	Root yield kg/ha	Sucrose content %	Extraction %	Estimated recoverable sucrose	
	kg ai/ha						kg/ha	g/kg
Glufosinate fb	0.3	EP	5	75,488	16.17	90.53	11,118	146
Glufosinate + etho	0.3 + 1.12	MP						
Glufosinate fb	0.4	EP	0	87,360	16.09	90.40	12,723	145
Glufosinate + etho	0.4 + 1.12	MP						
Glufosinate fb	0.3	MP	7	79,968	16.57	90.72	11,887	150
Glufosinate + etho	0.3 + 1.12	LP						
Glufosinate fb	0.4	MP	18	86,688	16.04	90.13	12,499	144
Glufosinate + etho	0.4 + 1.12	LP						

Ethofumesate fb	1.12	PPI	17	97,888	16.09	89.80	14,082	144
EDP fb	0.3	COT						
EDP + trif fb	0.37 + 0.0175	EP						
EDP + trif + seth	0.37 + 0.0175 + 0.34	MP						

Untreated			0	17,920	15.96	91.15	2,576	145
LSD (0.05)			12	7,392	NS	0.74	1,135	NS

[†]Abbreviations: etho, ethofumesate; EDP, commercial premix of ethofumesate + desmedipham + phenmedipham; trif, triflurosulfuron; seth, sethoxydim.

[‡]Herbicide application timings: PPI, preplant incorporated; COT, cotyledon stage weeds; EP, 0.5 to 2.5 cm weeds; MP, 2.5 to 10 cm weeds or 7 to 10 days after EP; LP 7 to 10 days after LP; LLP, 7 to 10 days after LP.

[§]Sugarbeet were harvested October 15, 1998.

Table 9. Sugarbeet injury and yield with glufosinate applied alone, in combination with, or following ethofumesate, 1999.

Treatment [†]	Rate kg ai/ha	Timing [‡]	Sugarbeet	Sugarbeet [§]				
			Injury 14 DAT ---- % ----	Root yield kg/ha	Sucrose content %	Extraction %	Estimated recoverable sucrose	
							kg/ha	g/kg
Ethofumesate fb	1.12	PPI	2	82,880	18.3	93.25	14,100	170
Glufosinate	0.3	MP + LP						
Ethofumesate fb	1.12	PPI	0	90,048	17.9	93.00	14,956	166
Glufosinate	0.4	MP + LP						

Glufosinate	0.3	EP + MP + LP	0	86,016	18.3	93.22	14,676	171
Glufosinate	0.4	EP + MP + LP	3	93,184	18.2	93.23	15,818	170
Glufosinate	0.3	MP + LP + LLP	2	83,104	17.9	92.82	13,822	166
Glufosinate	0.4	MP + LP + LLP	0	84,672	18.0	92.78	14,147	167

[†]Abbreviations: etho, ethofumesate; EDP, commercial premix of ethofumesate + desmedipham + phenmedipham; trif, triflurosulfuron.

[‡]Herbicide application timings: PPI, preplant incorporated; COT, cotyledon stage weeds; EP, 0.5 to 2.5 cm weeds; MP, 2.5 to 10 cm weeds or 7 to 10 days after EP; LP 7 to 10 days after LP; LLP, 7 to 10 days after LP.

[§]Sugarbeet were harvested October 6 and 7, 1999.

(continued)

Table 9 (continued). Sugarbeet injury and yield with glufosinate applied alone, in combination with, or following ethofumesate, 1999.

Treatment [†]	Rate kg ai/ha	Timing [‡]	Sugarbeet	Sugarbeet [§]				
			Injury 14 DAT ---- % ----	Root yield kg/ha	Sucrose content %	Extraction %	Estimated recoverable sucrose kg/ha g/kg	
Glufosinate fb	0.3	EP	0	72,352	18.2	93.20	12,305	170
Glufosinate + etho	0.3 + 1.12	MP						
Glufosinate fb	0.4	EP	5	83,776	18.2	93.33	14,270	170
Glufosinate + etho	0.4 + 1.12	MP						
Glufosinate fb	0.3	MP	10	77,504	18.1	93.14	13,098	169
Glufosinate + etho	0.3 + 1.12	LP						
Glufosinate fb	0.4	MP	10	78,624	18.0	93.27	13,208	168
Glufosinate + etho	0.4 + 1.12	LP						

Ethofumesate fb	1.12	PPI	0	81,312	18.1	93.19	13,721	168
EDP fb	0.3	COT						
EDP + trif fb	0.37 + 0.0175	EP						
EDP + trif + seth	0.37 + 0.0175 + 0.34	MP						

Untreated			0	28,448	18.4	93.42	4,925	172
LSD (0.05)			5	10,080	NS	NS	1,736	NS

[†]Abbreviations: etho, ethofumesate; EDP, commercial premix of ethofumesate + desmedipham + phenmedipham; trif, triflurosulfuron.

[‡]Herbicide application timings: PPI, preplant incorporated; COT, cotyledon stage weeds; EP, 0.5 to 2.5 cm weeds; MP, 2.5 to 10 cm weeds or 7 to 10 days after EP; LP 7 to 10 days after LP; LLP, 7 to 10 days after LP.

[§]Sugarbeet were harvested October 6 and 7, 1999.

addition of AMS to lower rates may provide more consistent weed control than lower rates applied alone. The use of PPI ethofumesate followed by glufosinate applied twice can control weeds similar to glufosinate applied alone three times, but may or may not provide an advantage in increased weed control or reduced herbicide cost. Combining ethofumesate with the second of two glufosinate applications did not appear to offer any advantage over glufosinate alone applied three times, and increased injury from postemergence ethofumesate would likely be undesirable.

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