Weed Technology 2014 28:569–577

Glyphosate-Resistant Giant Ragweed (*Ambrosia trifida*) Control in Glufosinate-Resistant Soybean

Simranpreet Kaur, Lowell D. Sandell, John L. Lindquist, and Amit J. Jhala*

Glyphosate-resistant giant ragweed is one of the most competitive weeds of agronomic crops in the United States. Early emergence and rapid growth rate makes giant ragweed a competitive weed early in the season and reduces crop yields. Therefore, early spring control of giant ragweed using a preplant herbicide is critical. Glufosinate is an alternative POST herbicide for weed control in glufosinate-resistant soybean. Field experiments were conducted at David City, NE, in 2012 and 2013 to evaluate the efficacy of preplant herbicides followed by glufosinate applied alone or in tank mixes for control of glyphosate-resistant giant ragweed in glufosinate-resistant soybean. Preplant treatments containing 2,4-D, flumioxazin, glufosinate, paraquat, saflufenacil, and sulfentrazone provided 79 to 99% control of giant ragweed 21 d after treatment (DAT), and subsequent application of glufosinate alone or in tank mixes resulted in 90 to 99% control at 21 DAT. Preplant application of *S*-metolachlor plus metribuzin or chlorimuron, flumioxazin plus thifensulfuron followed by glufosinate resulted in < 40% control of giant ragweed, and soybean yields were < 870 kg ha^{-1}. Although statistically comparable to several other treatments, preplant application of 2,4-D or saflufenacil tank mixes followed by glufosinate resulted in the highest level of control (> 97%) and soybean yield (2,624 to 3,378 kg ha^{-1}). This study confirms that preplant herbicide options are available for control of glyphosate-resistant giant ragweed, and a follow-up application of glufosinate will provide season-long control in glufosinate-resistant soybean.

Nomenclature: 2,4-D amine; acetochlor; chlorimuron; cloransulam; dimethenamid-P; flumioxazin, fomesafen; glufosinate; glyphosate; imazethapyr; lactofen; metribuzin; paraquat, *S*-metolachlor; saflufenacil; sulfentrazone; thifensulfuron-methyl; giant ragweed, *Ambrosia trifida* L.; soybean, *Glycine max* (L.) Merr.

Key words: POST herbicides, preplant herbicides, weed control, weed resistance management.

Ambrosia trifida resistente a glyphosate es una de las malezas más competitivas en cultivos agronómicos en Estados Unidos. Su emergencia temprana y tasa rápida de crecimiento hacen *A. trifida* una maleza competitiva temprano durante la temporada de crecimiento, y que reduce el rendimiento de los cultivos. De esta forma, el control de *A. trifida*, temprano en la primavera, usando herbicidas pre-siembra es crítico. Glufosinate es un herbicida POST alternativo para el control de malezas en soya resistente a glufosinate. Se realizaron experimentos de campo en David City, Nebraska, en 2012 y 2013 para evaluar la eficacia de herbicidas pre-siembra seguidos de glufosinate aplicado solo o en mezclas en tanque para el control de *A. trifida* resistente a glyphosate, en soya resistente a glufosinate. Los tratamientos pre-siembra con 2,4-D, flumioxazin, glufosinate, paraquat, saflufenacil, y sulfentrazone brindaron 79 a 99% de control de *A. trifida* 21 d después del tratamiento (DAT), y la subsecuente aplicación de glufosinate solo o en mezclas en tanque resultaron en 90 a 99% de control a 21 DAT. La aplicación pre-siembra de *S*-metolachlor más metribuzin o chlorimuron, flumioxazin más thifensulfuron seguidos de glufosinate resultaron en <40% de control de *A. trifida*, y los rendimientos de la soya fueron <870 kg ha^{-1}. Aunque fue estadísticamente comparable a otros tratamientos, la aplicación pre-siembra de mezclas en tanque de 2,4-D o saflufenacil seguidas de glufosinate resultaron en el mayor nivel de control (>97%) y el mayor rendimiento de la soya (2,624 a 3,378 kg ha^{-1}). Este estudio confirma que hay opciones de herbicidas pre-siembra disponibles para el control de *A. trifida* resistente a glyphosate, y que aplicaciones posteriores de glufosinate brindarán control a lo largo de toda la temporada de crecimiento en soya resistente a glufosinate.

Giant ragweed is an annual broadleaf species of the Asteraceae family (Bassett and Crompton 1982). Historically, giant ragweed was a weed primarily of ditch banks, waste areas, and fence rows (Bryson and DeFelice 2009). However, for the last three decades, it has become a competitive weed in

DOI: 10.1614/WT-D-14-00009.1

* Graduate Student, Extension Educator, Professor, and Assistant Professor, Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln, NE 68583-0915. Corresponding author's E-mail: amit.jhala@unl.edu.

agronomic crops, specifically in the eastern Corn Belt of the United States (Johnson et al. 2006). A survey conducted in 1985 reported giant ragweed among the 10 weeds that are most increasing in economic importance in Minnesota, Nebraska, and Ohio (Jordan 1985). By 1991, giant ragweed was ranked as one of the most problematic weeds in Ohio (Loux and Berry 1991).

Giant ragweed usually emerges through early spring (end of March) until early summer (end of May) (Johnson et al. 2006); however, research in Ohio indicated late-emerging populations until the second week of July (Harrison et al. 2001). The extremely vigorous vegetative growth habit of giant ragweed is due to a high photosynthetic rate (Bazzaz and Carlson 1979) that makes it very competitive with crops, including corn and soybean. For example, yield loss in soybean was recorded up to 77% at a giant ragweed density of 1 plant m^{-2} (Webster et al. 1994). Research shows that season-long interference of giant ragweed at 1 plant m^{-2} in soybean and 1 plant $(10\ m)^{-2}$ in corn (*Zea mays* L.) reduced yields up to 70 and 14%, respectively (Harrison et al. 2001; Webster et al. 1994).

Before the commercialization of glyphosate-resistant soybean, control of giant ragweed was achieved using a combination of tillage and soil-applied herbicides such as imidazolinone herbicides, metribuzin, *S*-metolachlor, and their tank mixes (Riley 2013). However, after commercialization of glyphosate-resistant soybean, application of soil-applied (PRE) herbicides declined significantly (Young 2006). Additionally, the majority of soybean growers adopted reduced or conservation tillage practices (Givens et al. 2009). Therefore, weed control was primarily through the sequential application of glyphosate (Ferrell and Witt 2002). Although glyphosate has been effective for broad-spectrum weed control, repeated use for several years resulted in evolution of glyphosate-resistant weeds (Owen and Zelaya 2005; Powles and Yu 2010). By 2014, 28 weed species worldwide have evolved resistance to glyphosate, including 14 species in the United States (Heap 2014a).

Increased prevalence of giant ragweed in corn–soybean cropping systems is due to the rapid rate at which evolution of herbicide-resistance occurred in this species (Patzoldt and Tranel 2002). The acetolactate synthase (ALS)–inhibiting herbicides were used extensively for control of broadleaf weeds, including giant ragweed (Saari et al. 1994). Therefore, overreliance on ALS inhibitors resulted in the evolution of ALS inhibitor–resistant giant ragweed (Schultz et al. 2000; Taylor et al. 2002). In 2007, glyphosate-resistant giant ragweed was confirmed in Tennessee (Norsworthy et al. 2010), and now it has been confirmed in at least 11 states (Heap 2014b). Additionally, multiple herbicide-resistant giant ragweed biotypes have been reported in Ohio and Minnesota (Heap 2014b) that have reduced herbicide options for effective management of this economically important weed species.

Glufosinate is a nonselective, broad-spectrum, contact herbicide for vegetation control in crop and noncrop areas. Before commercialization of glufosinate-resistant crops, glufosinate was applied in fall after crop harvest or early spring as a preplant treatment for control of emerged broadleaf and grass weeds (Coetzer et al. 2002). Glufosinate-resistant soybean was commercialized in 2009 (Craigmyle et al. 2013a), providing flexibility of in-crop application of glufosinate applied once or in a sequential application depending on weed density and size (Beyers et al. 2002). Several studies reported excellent weed control in glufosinate-resistant soybean with POST-applied glufosinate (Beyers et al. 2002; Norsworthy et al. 2010; Wiesbrook et al. 2001). However, glufosinate-resistant soybean has not been widely adopted by soybean growers in Nebraska (I Schleufer, personal communication). This scenario may change in the future because of the evolution of glyphosate-resistant weeds and limited effective POST herbicide options in soybeans. For example, after evolution of glyphosate-resistant Palmer amaranth [*Amaranthus palmeri* (S.) Wat] in glyphosate-resistant cotton (*Gossypium hirsutum* L.) in the Southeast and Midsouth regions of the United States, growers have rapidly adopted WideStrike® cotton (cultivar resistant to glyphosate, glufosinate, and lepidopteran pests) (Barnett et al. 2013a) and glufosinate-resistant soybean.

Glufosinate has been reported as one of the most effective herbicides for controlling glyphosate-resistant giant ragweed in a greenhouse study (Norsworthy et al. 2010). Limited literature is available for control of glyphosate-resistant giant ragweed in glufosinate-resistant soybean under field conditions (Riley et al. 2014). Therefore, the objectives of this research were to evaluate the efficacy of preplant herbicides for early season control of giant ragweed and the subsequent application of glufosinate applied alone or in tank mixes on giant ragweed control, density, biomass, and soybean yield. We hypothesized that preplant herbicides applied in early spring, followed by in-crop application of glufosinate applied alone or in tank mixes would provide season-long control of glyphosate-resistant giant ragweed and would increase soybean yield.

Materials and Methods

Field experiments were conducted at David City, NE, in 2012 and 2013 in a grower's field infested with glyphosate-resistant giant ragweed. The history of the site is heavy reliance on glyphosate for weed control at least two times each season for the last 8 yr in a continuous glyphosate-resistant soybean system. Giant ragweed from this field was confirmed glyphosate resistant in 2011. Therefore, the site was selected on the basis of a dense infestation of glyphosate-resistant giant ragweed. Soil texture of the experimental site was silty loam with pH 5.4, 18% sand, 50% silt, 32% clay, and 2.1% organic matter. The experiment was laid out in a randomized complete block design with four replications. Glufosinate-resistant soybean (cv. 'Stine S100211') was planted on May 7, 2012, and May 24, 2013. The seeds were planted 3 cm deep and spaced 76 cm between rows. The plot size was 3 by 9 m and comprised four soybean rows. A total of 12 herbicide programs, including preplant followed by POST herbicides, were compared for control of glyphosate-resistant giant ragweed (Table 1). A nontreated control was included for comparison. The application rates of herbicides were selected on the basis of recommended labeled rates.

Herbicides were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 276 kPa equipped with a five-nozzle boom fitted with AIXR 11015 flat-fan nozzles (TeeJet, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189). Herbicide treatments were applied as preplant (April 23, 2012, and May 16, 2013), early POST (June 12, 2013, and June 28, 2013), and late POST (July 3, 2013, and July 19, 2013). An application of glufosinate at 594 g ai ha^{-1} was applied to the entire test site (except nontreated control plots) on July 3, 2012, and July 19, 2013. The experimental site was under rain-fed conditions both years.

During both years, data were collected for visual estimates of giant ragweed control on a scale of 0 (no control) to 100% (complete control) at 7, 14, and 21 d after preplant burndown treatment (DABT); 7 and 21 d after early-POST herbicide treatments, and at crop harvest. Herbicide injury symptoms on soybean, if any, were recorded on a scale of 0 (no injury) to 100% (plant death) at 7, 14, and 21 d after herbicide treatments. Giant ragweed densities and biomass were assessed from two randomly selected 0.25-m^2 quadrats per plot 1 wk before soybean harvest. Giant ragweed that survived herbicide treatments were cut at the stem base close to the soil surface, placed in paper bags, dried in an oven for 72 h at 50 C, and the biomass was recorded. Soybean was harvested using a plot combine, and yields were adjusted to 13% moisture content. Weed control efficiency (WCE) was calculated using the equation

$$\text{WCE}\,(\%) = [(A - B)/A] \times 100,$$

where WCE represents weed control efficiency; A represents biomass dry weight of nontreated control plots, and B represents biomass dry weight of treatment plot.

Statistical Analysis. Data were subjected to ANOVA using the PROC MIXED procedure in SAS version 9.3 (SAS Institute Inc., Cary, NC). Herbicide treatments were the fixed effects, whereas year (nested within replication) was considered a random effect. Before analysis, data were tested for normality with the use of PROC UNIVARIATE. Visual estimations of giant ragweed control, density, and biomass data were arcsine square-root transformed before analysis; however, back-transformed data are presented with mean separation based on transformed data. Due to a significant year by treatment interaction for soybean yield, the yield data of both years were analyzed separately using the PROC MIXED procedure. Herbicide treatments and years were considered fixed effects in the model, whereas replication was a random effect. Where the ANOVA indicated treatment effects were significant, means were separated at $P \leq 0.05$ using Tukey–Kramer's pairwise comparison test.

Table 1. Herbicide treatments, application timing and rates, as well as products used in a field study in Nebraska in 2012 and 2013.[a]

Herbicide common name[b]	Timing	Rate	Trade name	Manufacturer	Adjuvant[c]
		g ae or ai ha^{-1}			
Saflufenacil + imazethapyr + dimethenamid-P fb	Preplant	95 + 525	Optill + Outlook	BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709; www.basf.com; Bayer Crop Science, Research Triangle Park, NC 27709; www.cropscience.bayer.com	AMS + MSO
glufosinate	Early POST	594	Liberty 280		AMS
Sulfentrazone + cloransulam fb	Preplant	343	Authority First	FMC Corporations, Philadelphia, PA 19103; www.fmc.com;	AMS + COC
glufosinate	Early POST	594	Liberty 280	Bayer Crop Science;	AMS
Flumioxazin + chlorimuron fb	Preplant	85	Valor XLT	Valent USA Corporation, Walnut Creek, CA, 94596; www.valent.com; Bayer Crop Sciences	AMS + COC
glufosinate	Early POST	594	Liberty 280		AMS
S-metolachlor + metribuzin fb	Preplant	2,050	Boundary	Syngenta Crop Protection, Inc, Greensboro, NC 27419; www.syngenta.com; Bayer Crop Science	AMS + COC
glufosinate	Early POST	594	Liberty 280		AMS
Chlorimuron ethyl + flumioxazin + thifensulfuron fb	Preplant	98	Enlite	DuPont Sustainable Solutions, Wilmington, DE 19880-0013; www.dupont.com;Bayer Crop Science	AMS + COC
glufosinate	Early POST	594	Liberty 280		AMS
2,4-D amine fb	Preplant	560	2,4-D amine	Winfield Solutions, LLC, ST PAUL, MN 55164 www.winfield.com;	AMS + NIS
glufosinate + imazethapyr	Early POST	594 + 70	Liberty 280 + Pursuit	Bayer Crop Science + BASF Corporation	AMS + NIS
Glyphosate fb	Preplant	870	Roundup PowerMax	Monsanto Company, 800 North, Lindberg Ave., St. Louis, MO; www.monsanto.com; Bayer Crop Science + Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268; www.dowagro.com + Monsanto	AMS
glufosinate + cloransulam-methyl + acetochlor	Early POST	594 + 17.7 + 1,600	Liberty 280 + FirstRate + Warrant		AMS + NIS AMS + NIS
Paraquat fb	Preplant	560	Gramoxone SL	Syngenta Crop Protection	COC
glufosinate + chlorimuron-ethyl + acetochlor	Early POST	594 + 5.8 + 1,600	Liberty 280 + Classic + Warrant	Bayer Crop Science + DuPont Sustainable Solutions + Monsanto	AMS + COC
Glufosinate fb	Preplant	594	Liberty 280	Bayer Crop Science	AMS
glufosinate fb	Early POST	594	Liberty 280	Bayer Crop Science	AMS
lactofen	Late POST	220	Cobra	Valent USA Corporation	AMS + COC
Saflufenacil fb	Preplant	25	Sharpen	BASF Corporation	AMS + MSO
glufosinate + acetochlor	Early POST	594 + 1,600	Liberty 280 + Warrant	Bayer Crop Science + Monsanto Company	AMS
Saflufenacil + 2,4-D amine	Preplant	25 + 560	Sharpen + 2,4-D amine	BASF Corporation + Winfield Solutions	AMS + MSO
glufosinate + acetochlor	Early POST	594 + 1,600	Liberty 280 + Warrant	Bayer Crop Science + Monsanto Company	AMS

https://doi.org/10.1614/WT-D-14-00009.1 Published online by Cambridge University Press

Table 1. Continued.

Herbicide common name[b]	Timing	Rate	Trade name	Manufacturer	Adjuvant[c]
Saflufenacil + glyphosate fb glufosinate + acetochlor + imazethapyr	Preplant	25 + 870	Sharpen + Roundup PowerMax	BASF Corporation + Monsanto Company	AMS + MSO
	Early POST	594 + 1,600 + 70	Liberty 280 + Warrant + Pursuit	Bayer Crop Science + Monsanto Company + BASF Corporation	AMS + NIS

[a] Abbreviations: ae, acid equivalent; AMS, ammonium sulfate (DSM Chemicals North America Inc., Augusta, GA); COC, crop oil concentrate (Agridex, Helena Chemical Co., Collierville, TN); fb, followed by; MSO, methylated seed oil (Southern Ag Inc., Suwanee, GA); NIS, nonionic surfactant (Induce, Helena Chemical Co., Collierville, TN).

[b] All herbicide treatments were followed by late POST application of glufosinate at 594 g ai ha^{-1} + AMS 2% (wt/v).

[c] AMS at 2% (wt/v), COC or MSO at 1% (v/v), and NIS at 0.25% (v/v) were mixed with herbicides.

Results and Discussion

Control of glyphosate-resistant giant ragweed varied among preplant treatments (Table 2). Treatments including glufosinate, paraquat, or saflufenacil alone or in tank mixes resulted in 91 to 97% giant ragweed control at 7 DABT. Owen et al. (2011) reported > 90% control of glyphosate-resistant horseweed [*Conyza canadensis* (L.) Cronq.] with saflufenacil applied at 7 or 14 d before planting no-till cotton. At 14 DABT, 2,4-D, sulfentrazone plus cloransulam, and flumioxazin plus chlorimuron resulted in 75 to 90% control, which was comparable to glufosinate, paraquat, and saflufenacil alone or in tank mixes with 2,4-D or imazethapyr plus dimethenamid-P. Norsworthy et al. (2011) reported > 95% control of glyphosate-susceptible and -resistant giant ragweed biotypes with carfentrazone, cloransulam, and fomesafen. *S*-metolachlor plus metribuzin and chlorimuron plus flumioxazin plus thifensulfuron provided the lowest giant ragweed control (≤ 50%) at 21 DABT. Although comparable to several other treatments, 2,4-D and saflufenacil alone or in tank mixes resulted in 88 to 99% giant ragweed control at 21 DABT. Similarly, Barnett et al. (2013b) reported 90% control of glyphosate-resistant giant ragweed with 2,4-D at 30 d after application.

Glufosinate applied alone or in tank mixes was effective for control of giant ragweed and prevented regrowth from any partially controlled plants that were not completely eliminated with the preplant treatment (Table 2). Preplant herbicides followed by early POST application of glufosinate usually resulted in 88 to 100% giant ragweed control at 7 d after treatment. Similarly, Eubank et al. (2008) reported ≥ 88% control of horseweed with glufosinate applied alone at 4 wk after treatment. At 21 d after early POST glufosinate application, treatments with preplant application of *S*-metolachlor plus metribuzin and chlorimuron plus flumioxazin plus thifensulfuron provided ≤ 60% control compared with other treatments, perhaps because giant ragweed control was poor (≤ 50% at 21 DABT) in these preplant treatments, so by the time glufosinate was applied, giant ragweed plants were more than 55 cm tall. Weed size is one factor influencing degree of control achieved with glufosinate. For example, Craigmyle et al. (2013a) found that giant ragweed, common waterhemp (*Amaranthus rudis* Saur.), and cocklebur (*Xanthium strumarium* L.) control was reduced with glufosinate applied to 30-cm-tall compared to 15-cm-tall plants. Preplant application of glyphosate was not effective because giant ragweed was resistant to glyphosate. Early POST application of glufosinate plus cloransulam plus acetochlor resulted in 94% control at 7 and 21 d after treatment. Although comparable to several other treatments, 2,4-D applied alone or with saflufenacil resulted in 99% giant ragweed control. This indicated that the preplant program was critical for early season control of giant ragweed. Chahal and Johnson (2012) found that glufosinate tank mixed with 2,4-D provided > 80% control of glyphosate-resistant horseweed and common lambsquarters (*Chenopodium album* L.). Soybean injury was < 10% and transient, so it did not affect soybean yields in any treatment in this study (data not shown).

https://doi.org/10.1614/WT-D-14-00009.1 Published online by Cambridge University Press

Table 2. Control of glyphosate-resistant giant ragweed at 7, 14, and 21 d after preplant burndown treatment (DABT), 7 and 21 d after early POST (DAEP) treatment, and at harvest in glufosinate-resistant soybean in 2012 and 2013 at David City, NE.[a]

			Giant ragweed control after preplant treatments[c,d]			Giant ragweed control after POST herbicide treatments[c,d]		
Herbicide[b]	Application timing	Rate	7 DABT	14 DABT	21 DABT	7 DAEP	21 DAEP	At harvest
		g ae or ai ha^{-1}	%					
Nontreated control[e]	—	—	0	0	0	0	0	0
Saflufenacil + imazethapyr + dimethenamid-P fb glufosinate	Preplant Early POST	95 + 525	91 ab	93 a	97 a	97 ab	99 a	99 a
Sulfentrazone + cloransulam fb glufosinate	Preplant Early POST	343 594	68 c	75 ab	88 ab	95 abc	95 a	92 ab
Flumioxazin + chlorimuron fb glufosinate	Preplant Early POST	85 594	70 bc	79 ab	79 ab	91 c	94 a	70 abc
S-metolachlor + metribuzin fb glufosinate	Preplant Early POST	2,050 594	21 d	31 c	35 d	79 c	53 b	25 c
Chlorimuron ethyl + flumioxazin + thifensulfuron fb glufosinate	Preplant Early POST	98 594	69 bc	58 b	50 cd	80 bc	60 b	32 bc
2,4-D amine fb glufosinate + imazethapyr	Preplant Early POST	560 594 + 70	66 c	90 a	98 a	99 a	99 a	99 a
Glyphosate fb glufosinate + cloransulam- methyl + acetochlor	Preplant Early POST	594 594 + 17.7 + 1,600	41 d	32 c	33 d	94 abc	94 a	89 abc
Paraquat fb glufosinate + chlorimuron-ethyl + acetochlor	Preplant Early POST	560 594 + 5.8 + 1,600	91 ab	77 ab	80 ab	88 abc	90 a	76 abc
Glufosinate fb glufosinate fb lactofen	Preplant Early POST Late POST	594 594 220	91 ab	94 a	91 ab	93 abc	96 a	90 abc
Saflufenacil fb glufosinate + acetochlor	Preplant Early POST	25 594 + 1,600	97 a	96 a	93 ab	91 abc	90 a	80 abc
Saflufenacil + 2,4-D amine glufosinate + acetochlor	Preplant Early POST	25 + 560 594 + 1,600	95 a	99 a	99 a	100 a	99 a	99 a
Saflufenacil + glyphosate fb glufosinate + acetochlor + imazethapyr	Preplant Early POST	25 + 870 594 +1,600 + 70	91 ab	96 a	94 a	97 abc	98 a	97 ab
P			< 0.0001	< 0.0001	< 0.0001	0.0071	0.0056	0.0054

[a] Abbreviations: ae, acid equivalent; fb, followed by.

[b] All herbicide treatments were followed by late POST application of glufosinate at 594 g ai ha^{-1} + ammonium sulfate 2% (wt/v).

[c] Data were arc-sine square-root transformed before analysis; however, data presented are the means of actual values for comparison based on interpretation from the transformed data.

[d] Means within columns with no common letter(s) are significantly different according to the Tukey–Kramer pairwise comparison test at $P \leq 0.05$.

[e] Control (0%) data from nontreated plots were not included in the analysis.

https://doi.org/10.1614/WT-D-14-00009.1 Published online by Cambridge University Press

Table 3. Effect of herbicide treatments on glyphosate-resistant giant ragweed density, biomass, weed control efficiency (WCE), and soybean yield in 2012 and 2013 at David City, NE.[a]

Herbicide[b]	Application timing	Rate	Giant ragweed[c,d]			Soybean yield[d,e]	
			Density	Biomass	WCE	2012	2013
		g ae or ai ha^{-1}	no. m^{-2}	g m^{-2}	%	kg ha^{-1}	
Nontreated control		—	51 a	674 a	—	0	0
Saflufenacil + imazethapyr + dimethenamid-P fb glufosinate	Preplant Early POST	95 + 525 594	0 e	0 c	100 a	0	2,741 abc
Sulfentrazone + cloransulam fb glufosinate	Preplant Early POST	343 594	7 d	53 bc	92 ab	0	2,464 abc
Flumioxazin + chlorimuron fb glufosinate	Preplant Early POST	85 594	12 c	68 bc	90 ab	0	1,770 abc
S-metolachlor + metribuzin fb glufosinate	Preplant Early POST	2,050 594	29 b	126 b	81 b	0	586 c
Chlorimuron ethyl + flumioxazin + thifensulfuron fb glufosinate	Preplant Early POST	98 594	30 b	80 bc	88 ab	0	863 bc
2,4-D amine fb glufosinate + imazethapyr	Preplant Early POST	560 594 + 70	0 e	0 c	100 a	1,143 a	3,378 a
Glyphosate fb glufosinate + cloransulam- methyl + acetochlor	Preplant Early POST	594 594 +17.7+ 1,600	6 d	46 bc	93 ab	0	2,363 abc
Paraquat fb glufosinate + chlorimuron-ethyl + acetochlor	Preplant Early POST	560 594 + 5.8 + 1,600	14 c	76 bc	88 ab	0	1,322 abc
Glufosinate fb glufosinate fb lactofen	Preplant Early POST Late POST	594 594 143 + 220	5 d	42 bc	93 ab	0	1,824 abc
Saflufenacil fb glufosinate + acetochlor	Preplant Early POST	25 594 + 1,600	7 d	40 bc	93 ab	0	1,245 abc
Saflufenacil + 2,4-D amine glufosinate + acetochlor	Preplant Early POST	25 + 560 594 + 1,600	0 e	0 c	100 a	1,614 b	3,079 ab
Saflufenacil + glyphosate fb glufosinate + acetochlor + imazethapyr	Preplant Early POST	25 + 870 594 +1,600 + 70	2 e	5 c	99 ab	0	2,624 abc
P			< 0.0001	< 0.0001	0.0345	0.005	0.0034

[a] Abbreviations: ae, acid equivalent; fb, followed by.

[b] All herbicide treatments were followed by late POST application of glufosinate at 594 g ai ha^{-1} + ammonium sulfate 2% (wt/v).

[c] Giant ragweed density and biomass data were arc-sine square-root transformed before analysis; however, data presented are the means of actual values for comparison based on interpretation from the transformed data.

[d] Means within columns with no common letter(s) are significantly different according to the Tukey–Kramer pairwise comparison test at $P \leq 0.05$.

[e] Treatments with zero yield values were not included in the analysis. Giant ragweed competition and drought condition in 2012 negatively affected yield.

Giant ragweed densities differed between herbicide treatments (Table 3). The nontreated control had the highest number of giant ragweed plants (51 m^{-2}). The treatments with preplant application of 2,4-D or saflufenacil tank mixes followed by glufosinate resulted in no giant ragweed plants and reflected 99% control. Barnett et al. (2013b) reported giant ragweed density of 2.8 plants m^{-2} after 30 d of 2,4-D applied alone compared with 0.3 plant m^{-2} when 2,4-D was tank mixed with glufosinate. The results of giant ragweed control and density were reflected in biomass. The nontreated control plots had the highest biomass (674 g m^{-2}). Although comparable to several other treatments, herbicide programs including a 2,4-D preplant application resulted in no biomass that resulted in 100% WCE. Similarly, Robinson et al. (2012) reported giant ragweed biomass as low as 0.1 g $plant^{-1}$ with 2,4-D applied at 280 to 1,120 g ae ha^{-1}.

A significant year-by-treatment interaction for soybean yield occurred because of a severe drought condition in 2012; hence, soybean yield results are presented separately by year (Table 3). The effect of herbicide treatments did not correlate with the yield data in 2012. For example, despite giant ragweed control $> 90\%$, most of the treatments resulted in zero yield because of severe drought in 2012. The nontreated control resulted in no soybean yield in both years. Although comparable to several other treatments, 2,4-D in a preplant program followed by glufosinate tank mixes resulted in soybean yield $> 3{,}000$ kg ha^{-1}. Tank mixing cloransulam, imazethapyr, or acetochlor with glufosinate did not improve giant ragweed control or soybean yield compared with glufosinate applied alone, suggesting that preplant treatments were more effective than in-crop glufosinate tank mixtures.

Results of this study confirmed that glyphosate-resistant giant ragweed is extremely competitive; therefore, growers should not allow this weed to remain uncontrolled. Several preplant herbicides tested in this study provided effective control initially, and sequential application of glufosinate alone or in tank mixes provided season-long giant ragweed control. Riley and Bradley (2014) reported that POST-only glyphosate tank mix combinations would not provide season-long giant ragweed control in glyphosate-resistant soybean and other management practices, as demonstrated in this study, such as preplant followed by POST herbicide program will be needed. Soybean cultivars with traits conferring resistance to preplant or POST applications of 2,4-D are being developed and may be commercialized in the near future (Craigmyle et al. 2013a). This will provide flexibility of in-crop 2,4-D application for control of glyphosate-resistant weeds, including giant ragweed (Craigmyle et al. 2013b).

In summary, results of this study indicate that glyphosate-resistant giant ragweed can be effectively controlled in glufosinate-resistant soybean. Preplant application of several herbicides, including 2,4-D, flumioxazin, glufosinate, paraquat, saflufenacil, and sulfentrazone alone or in tank mixes followed by glufosinate alone or in tank mixes resulted in season-long giant ragweed control and greater soybean yields. Italian ryegrass (*Lolium perenne* L. *ssp. multiflorum*) is the only species in the United States that has evolved resistance to glufosinate (Avila-Garcia et al. 2012). Therefore, glufosinate might be an additional POST herbicide option for control of glyphosate-resistant weeds in glufosinate-resistant soybean. However, use of the same herbicide or herbicides with the same site of action results in evolution of herbicide-resistant weeds (Powles and Yu 2010). Therefore, an integrated management approach should be adopted that may include tillage, use of herbicides with different sites of action, rotation of herbicide-resistant trait, and crop rotation for control of glyphosate-resistant weeds.

Literature Cited

Avila-Garcia WV, Sanchez-Olguin E, Hulting AG, Mallory-Smith C (2012) Target-site mutation associated with glufosinate resistance in Italian rygrass (*Lolium perenne* L. ssp. *multiflorum*). Pest Manag Sci 68:1248–1254

Barnett KA, Culpepper AS, York AC, Steckel LE (2013a) Palmer amaranth (*Amaranthus palmeri*) control by glufosinate plus fluometuron applied postemergence to WideStrike® cotton. Weed Technol 27:291–297

Barnett KA, Mueller TC, Steckel LE (2013b) Glyphosate-resistant giant ragweed (*Ambrosia trifida*) control with glufosinate or fomesafen combined with growth regulator herbicides. Weed Technol 27:454–458

Bassett IJ, Crompton CW (1982) The biology of Canadian weeds. 55. *Ambrosia trifida* L. Can J Plant Sci 62:1003–1010

Bazzaz FA, Carlson RW (1979) Photosynthesis contribution of flowers and seeds to reproductive effort of an annual colonizer. New Phytol 82:223–232

Beyers JT, Smeda RJ, Johnson WG (2002) Weed management programs in glufosinate-resistant soybean (*Glycine max*). Weed Technol 16:267–273

Bryson CT, DeFelice MS (2009) Weeds of the South. Athens, GA: University of Georgia Press. 480 p

Chahal GS, Johnson WG (2012) Influence of glyphosate or glufosinate combinations with growth regulator herbicides and other agrochemicals in controlling glyphosate-resistant weeds. Weed Technol 26:638–643

Coetzer E, Al-Khatib A, Peterson DE (2002) Glufosinate efficacy on *Amaranthus* species in glufosinate-resistant soybean. Weed Technol 16:326–331

Craigmyle BD, Ellis JM, Bradley KW (2013a) Influence of weed height and glufosinate plus 2, 4-D combinations on weed control in soybean with resistance to 2, 4–D. Weed Technol 27:271–280

Craigmyle BD, Ellis JM, Bradley KW (2013b) Influence of herbicide program on weed management in soybean with resistance to glufosinate and 2, 4-D. Weed Technol 27:78–84

Eubank TW, Poston DH, Nandula VJ, Koger CH, Shaw DR, Reynolds DB (2008) Glyphosate-resistant horseweed control using glyphosate-, paraquat, and glufosinate-based herbicide programs. Weed Technol 22:16–21

Ferrell JA, Witt WW (2002) Comparison of glyphosate with other herbicides for weed control in corn (*Zea mays*): efficacy and economics. Weed Technol 16:701–706

Givens WA, Shaw DR, Kruger GR, Young BG, Wilson RG, Wilcut JW, Jordan DL, Weller SC (2009) Survey of tillage trends following the adoption of glyphosate-resistant crops. Weed Technol 23:162–166

Harrison SK, Regnier EE, Schmoll JT, Webb JE (2001) Competition and fecundity of giant ragweed in corn. Weed Sci 49:224–229

Heap IM (2014a) International survey of herbicide resistant weeds: Weeds resistant to EPSP synthase inhibitors (G/9) http://www.weedscience.org/summary/MOA.aspx?MOAID=12 Accessed: April 10, 2014

Heap IM (2014b) International Survey of Herbicide Resistant Weeds: Herbicide Resistant Giant Ragweed Globally. http://www.weedscience.org/summary/Species.aspx Accessed April 10, 2014

Johnson B, Loux MM, Nordby D, Sprague C, Nice G, Westhoven A, Stachler J (2006) Biology and Management of Giant Ragweed. West Lafayette, IN: Purdue Extension Publication GWC-12

Jordan TN (1985) Weed survey of the north central weed control conference. Pages 344–455 *in* Proceedings of the 42nd North Central Weed Control Conference. Las Cruces, NM: North Central Weed Science Society

Loux MM, Berry MA (1991) Use of a grower survey for estimating weed problems. Weed Technol 5:460–466

Norsworthy JK, Jha P, Steckel LE, Scott RC (2010) Confirmation and control of glyphosate-resistant giant ragweed (*Ambrosia trifida*) in Tennessee. Weed Technol 24:64–70

Norsworthy JK, Riar D, Jha P, Scott RC (2011) Confirmation, control, and physiology of glyphosate-resistant giant ragweed (*Ambrosia trifida*) in Arkansas. Weed Technol 25:430–435

Owen LN, Mueller TC, Main CL, Bond J, Steckel LE (2011) Evaluating rates and application timings of saflufenacil for control of glyphosate-resistant horseweed (*Conyza canadensis*) prior to planting no-till cotton. Weed Technol 25:1–5

Owen MDK, Zelaya IA (2005) Herbicide-resistance crops and weed resistance to herbicides. Pest Manag Sci 61:301–311

Patzoldt WL, Tranel PJ (2002) Molecular analysis of cloransulam resistance in a population of giant ragweed. Weed Sci 50:299–305

Powles SB, Yu Q (2010) Evolution in action: plants resistant to herbicides. Anu Rev Plant Biol 61:317–347

Riley EB (2013) Evaluation of Herbicide Programs for the Management of Glyphosate- Resistant Giant Ragweed in Soybean. M.S. dissertation. Columbia, MO: University of Missouri. 71 p

Riley EB, Bradley KW (2014) Influence of application timing and glyphosate tank mix combinations on the survival of glyphosate-resistant giant ragweed (*Ambrosia trifida*) in soybean. Weed Technol 28:1–9

Riley EB, Raymond EM, Bradley KW (2014) Influence of herbicide programs on glyphosate-resistant giant ragweed (*Ambrosia trifida* L.) density, soybean yield, and net economic return in glyphosate- and glufosinate-resistant soybean. Crop Manag 13: doi:10.2134/CM-2013-0015b-RS

Robinson AP, Simpson DM, Johnson WG (2012) Summer annual weed control with 2,4-D and glyphosate. Weed Technol 26:657–660

Saari LL, Cotterman JC, Thill DC (1994) Resistance to acetolactate synthase inhibiting herbicides. Pages 83–140 *in* Powles SB, Holtum JAM, eds. Herbicide Resistance in Plants: Biology and Biochemistry. Boca Raton, FL: Lewis Publishers

Schultz ME, Schmitzer PR, Alexander AL, Dorich RA (2000) Identification and management of resistance to ALS inhibiting herbicides in giant ragweed (*Ambrosia trifida*) and common ragweed (*Ambrosia artemissifolia*). Weed Sci Soc Am Abstr 40:42 [Abstract]

Taylor JB, Loux MM, Harrison SK, Regnier E (2002) Response of ALS-resistant common ragweed (*Ambrosia artemisiifolia*) and giant ragweed (*Ambrosia trifida*) to ALS-inhibiting and alternative herbicides. Weed Technol 16:815–825

Webster TM, Loux MM, Regnier EE, Harrison SK (1994) Giant ragweed (*Ambrosia trifida*) canopy architecture and interference studies in soybean (*Glycine max*). Weed Technol 8:559–564

Wiesbrook ML, Johnson WG, Hart SE, Bradley PR, Wax LM (2001) Comparison of weed management systems in narrow-row, glyphosate- and glufosinate-resistant soybean (*Glycine max*). Weed Technol 15:122–128

Young BG (2006) Changes in herbicide use patterns and production practices resulting from glyphosate-resistant crops. Weed Technol 20:301–307

Received January 29, 2014, and approved April 23, 2014.