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Integrated Management of Glyphosate-Resistant Giant Ragweed (*Ambrosia trifida*) with Tillage and Herbicides in Soybean

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Giant ragweed is one of the most competitive annual broadleaf weeds in soybean production fields in the midwestern United States and eastern Canada because of its early emergence, rapid growth rate, high plasticity, and resistance to glyphosate and acetolactate synthase inhibitors. Therefore, early-season management of giant ragweed is critical to avoid yield loss. The objectives of this study were to evaluate control of glyphosate-resistant giant ragweed through the integration of preplant tillage or 2,4-D; PRE or early POST (EPOST) followed by (fb) late POST (LPOST) herbicide programs with or without preplant tillage or 2,4-D; and their effect on soybean injury and yield. A field study was conducted in 2013 and 2014 in David City, NE in a field infested with glyphosate-resistant giant ragweed. Preplant tillage or 2,4-D application provided $> 90\%$ control of glyphosate-resistant giant ragweed 14 d after preplant treatment. Giant ragweed control and biomass reduction were consistently $> 90\%$ with preplant tillage or 2,4-D fb sulfentrazone plus cloransulam PRE or glyphosate plus cloransulam EPOST fb glyphosate plus fomesafen or lactofen LPOST compared with $\leq 86\%$ control with same treatments without preplant tillage or 2,4-D. PRE or EPOST fb LPOST herbicide programs preceded by preplant treatments resulted in giant ragweed density < 2 plants m^{-2} and soybean yield $> 2{,}400$ kg ha^{-1} compared with the density of ≥ 2 plants m^{-2} and soybean yield $< 1{,}800$ kg ha^{-1} under PRE or EPOST fb LPOST herbicide programs. The contrast analysis also indicated that preplant tillage or 2,4-D fb a PRE or POST program was more effective for giant ragweed management compared with PRE fb POST herbicide programs. Integration of preplant tillage would provide an alternative method for early-season control of giant ragweed; however, a follow up application of herbicides is needed for season-long control in soybean.

Nomenclature: 2,4-D amine; cloransulam; fomesafen; lactofen; sulfentrazone; giant ragweed, *Ambrosia trifida* L.; soybean, *Glycine max* (L.) Merr.

Key words: Preplant herbicides, preplanttillage, weed control, weed resistance management.

Ambrosia trifida es una de las malezas de hoja ancha más competitivas en campos de producción de soja en el centro-oeste de los Estados Unidos y en el este de Canada debido a su emergencia temprana, alta tasa crecimiento, alta plasticidad, y resistencia a glyphosate e inhibidores de acetolactate synthase. Por esta razón, el manejo de *A. trifida*, temprano durante la temporada de crecimiento, es crítico para evitar las pérdidas de rendimiento. Los objetivos de este estudio fueron evaluar el control de *A. trifida* resistente a glyphosate mediante la integración de labranza en pre-siembra o 2,4-D; aplicaciones PRE o POST temprana (EPOST) seguido por (fb) programas de herbicidas en POST tardía (LPOST) con o sin labranza en pre-siembra o 2,4-D; y su efecto sobre el daño y rendimiento de la soja. Se realizó un estudio de campo en 2013 y 2014 en David City, Nebraska en un campo infestado con *A. trifida* resistente a glyphosate. La labranza en pre-siembra o la aplicación de 2,4-D brindó $>90\%$ de control de *A. trifida* resistente a glyphosate 14 d después del tratamiento pre-siembra. El control y la reducción en la biomasa de *A. trifida* fueron $>90\%$ consistentemente con la labranza pre-siembra o 2,4-D fb sulfentrazone más cloransulam PRE o glyphosate más cloransulam EPOST fb glyphosate más fomesafen o lactofen POST al compararlo con $\leq 86\%$ de control con los mismos tratamientos sin labranza pre-siembra o 2,4-D. Programas de herbicidas PRE o de EPOST fb LPOST precedidos por tratamientos pre-siembra resultaron en una densidad de *A. trifida* <2 plantas m^{-2} y un rendimiento de soja $>2{,}400$ kg ha^{-1} al compararse con la densidad de ≥ 2 plantas m^{-2} y un rendimiento de soja $\leq 1{,}800$ kg ha^{-1} con programas de herbicidas PRE o EPOST fb LPOST. El análisis de contrastes también indicó que la labranza pre-siembra o 2,4-D fb de un programa PRE o POST fue más efectiva para el manejo de *A.*

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trifida al compararse con programas de herbicidas PRE fb POST. La integración de labranza pre-siembra brindaría una alternativa de manejo para el control de *A. trifida*, temprano en la temporada. Sin embargo, se requiere que a esto le siga una aplicación de herbicidas para obtener un control a lo largo de toda la temporada en soja.

Giant ragweed, a member of the Asteraceae family, is a highly competitive summer annual broadleaf weed. Giant ragweed is native to the United States and known for its allergenic pollen grains that are a major cause of hay fever (Kil et al. 2004; Rybnicek and Jager 2001). Historically, giant ragweed was commonly found in noncrop areas, including stream banks, flood plains, rights-of-way, fence lines, and disturbed locations (Abdul-Fatih and Bazzaz 1979; Bassett and Crompton 1982). However, over the last 2 decades, giant ragweed has adapted to agricultural cropping systems and become a challenging weed in several agronomic crops (Johnson et al. 2006; Norsworthy et al. 2010; Steckel 2007; Vink et al. 2012a). Due to its early emergence, rapid growth rate, large leaf size, high photosynthetic rate, and ability to germinate and survive in diverse environments (Abdul-Fatih and Bazzaz 1979; Bazzaz and Carlson 1979; Harrison et al. 2001), giant ragweed has a competitive advantage in agronomic crops early in the season compared with other weed species that emerge later (Werle et al. 2014). In addition, giant ragweed's adaptation toward a wider window of emergence in arable fields, high plasticity in plant vigor, and rapid biomass accumulation allows giant ragweed to dominate over all other vegetation in its vicinity (Davis et al. 2013; Glettner and Stoltenberg 2015; Kelly et al. 2012; Schutte et al. 2008, 2012).

Giant ragweed is a major weed in corn (*Zea mays* L.), soybean, and cotton (*Gossypium hirsutum* L.) and is enumerated as one of the most problematic and economically important weeds in Illinois, Indiana, Kentucky, Minnesota, Nebraska, Ohio, and Oklahoma (Johnson et al. 2004; Jordan 1985; Loux and Berry 1991). Previous studies have evaluated the competition of giant ragweed in corn, soybean, and cotton, and indicated that giant ragweed is most competitive in soybean even at low densities (Barnett and Steckel 2013; Baysinger and Sims 1991; Harrison et al. 2001). For instance, a yield reduction of 45 to 50% has been documented with 2 giant ragweed plants 9 m^{-1} of row length in soybean (Baysinger and Sims 1991). Webster et al. (1994) reported up to 77% reduction in soybean yield with interference of 1 giant ragweed plant m^{-2}. Additionally, Webster et al. (1994) documented two different growth habits used by giant ragweed to take competitive advantage over soybean at low densities. Early in the season, giant ragweed emerges rapidly and outgrows the crop in height to create a shading effect with little growth within the canopy. However, late in the season when its primary leaves begin to abscise, axillary leaves are produced within the canopy. These late-emerging axillary leaves are more shade tolerant, allowing giant ragweed to compete for light and resources not only above, but also within, the soybean canopy (Regnier and Stoller 1989; Webster et al. 1994).

The critical period of weed control in soybean is 4 to 6 wk after planting (Bloomberg et al. 1982; Coble et al. 1981; Williams and Hayes 1984); however, to avoid soybean yield losses due to giant ragweed interference, its critical period extends from 8 to 10 wk after soybean emergence (Baysinger and Sims 1991). Harrison et al. (2001) reported 76 to 87% reduction in yield losses with a 4-wk delay in emergence of giant ragweed in corn compared with losses with concurrent emergence. Therefore, early-season control of giant ragweed is essential to reduce yield losses and can provide the crops with an initial competitive advantage. Historically, acetolactate synthase (ALS) inhibitors such as cloransulam-methyl, chlorimuron-ethyl, and imazethapyr were used for giant ragweed control (Franey and Hart 1999). However, giant ragweed control options were reduced within a short time frame when ALS inhibitor-resistant biotypes were reported in several states including Indiana, Illinois, Iowa, and Ohio (Heap 2015; Patzoldt and Tranel 2002; Taylor et al. 2002; Zelaya and Owen 2004).

The commercialization and rapid adoption of glyphosate-tolerant soybean after 1997 enabled producers to effectively control giant ragweed, including ALS inhibitor-resistant biotypes, with glyphosate (Stachler 2008). However, the repeated and continuous use of glyphosate in glyphosate-tolerant corn and soybean resulted in the evolution of glyphosate-resistant giant ragweed. It was first

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confirmed in 2004 in Ohio and subsequently in 11 states including Arkansas, Indiana, Iowa, Kansas, Kentucky, Minnesota, Mississippi, Missouri, Nebraska, Tennessee, and Wisconsin (Heap 2015), and in Ontario, Canada (Sikkema et al. 2009; Vink et al. 2012a). The potential causes for the large-scale prevalence of glyphosate-resistant giant ragweed are the continuous use of glyphosate over several years, limited or no use of PRE herbicides, and shift toward no-till cropping systems (Ferrell and Witt 2002; Givens et al. 2009; Powles and Yu 2010; Young 2006). Moreover, since no herbicides with new modes of action have been introduced to the market for over 2 decades (Green 2014), the POST herbicide options for control of herbicide-resistant weeds, including giant ragweed, are limited (Duke 2012). Therefore, diversification of weed management programs is urgently needed. These include nonchemical options such as cover crops, tillage, crop rotation, and harvest and destruction of weed seeds to reduce weed seedbank addition (Norsworthy et al. 2012; Shaner and Beckie 2014; Walsh et al. 2013).

Historically, tillage has been one of the most important methods for weed control in agricultural crops (Shrestha et al. 2006). Tillage usually affects weeds by splitting shoots from roots, uprooting or covering unwanted vegetation, stirring weed seeds both vertically and horizontally, and modifying the soil environment to promote or inhibit seed germination and establishment (Clements et al. 1996; Shaw et al. 2012; Swanton et al. 2000). Wilson (1993) reported 86% reduction in weed density with preplant tillage compared with a nontreated control, and observed broad-spectrum weed control by integrating preplant tillage with herbicides compared with tillage or herbicides alone. In addition, tillage integrated with herbicides has been substantial for the management of important herbicide-resistant weeds, such as Palmer amaranth (*Amaranthus palmeri* S. Wats.) in the southern United States (Aulakh et al. 2012; Culpepper et al. 2009; Kelton et al. 2013).

Currently, protoporphyrinogen oxidase (PPO) inhibitors and some ALS-inhibiting herbicides, particularly cloransulam-methyl, are frequently used for the control of giant ragweed in soybean (Knezevic 2015; Vink et al. 2012b). Several studies have reported effective (> 89%) control of giant ragweed with PPO inhibitors such as bentazon, carfentrazone, flumioxazin, and fomesafen (Norsworthy et al. 2010, 2011). However, dependence on herbicide(s) with the same mode of action for control of troublesome weeds, such as giant ragweed, increases the potential risk for evolution of new herbicide resistance. In addition, for early- and late-season control of glyphosate-resistant giant ragweed, diverse strategies are needed that will allow the planting of soybean in a weed-free environment and prevent the enrichment of the weed seedbank in the soil (Bagavathiannan and Norsworthy 2012; Norsworthy et al. 2012). Scientific literature is not available on the effect of early spring tillage on the control of giant ragweed.

The objectives of this study were to evaluate an integrated approach for the management of glyphosate-resistant giant ragweed in glyphosate-tolerant soybean by determining: (1) the effectiveness of preplant tillage or 2,4-D, and (2) the relative effectiveness of PRE fb POST vs. EPOST fb LPOST herbicide programs with or without preplant tillage or 2,4-D and their impact on soybean injury and yield. We hypothesized that preplant tillage or 2,4-D fb PRE or EPOST fb LPOST herbicides would result in early- and late-season control of glyphosate-resistant giant ragweed compared with PRE or EPOST fb LPOST herbicide programs.

Materials and Methods

A field study was conducted at David City (41.25°N, 97.13°W), NE in 2013 and 2014 in a grower's field infested with glyphosate-resistant giant ragweed. A giant ragweed biotype from this site was confirmed to be resistant to glyphosate in 2011, with the level of resistance ranging from 14 to 36× (where × is the labeled rate of glyphosate [i.e, 1,260 g ae ha^{-1}] required for > 90% control of susceptible populations) compared with susceptible biotypes (Rana et al. 2013). The level of resistance was determined by calculating a ratio of glyphosate rate required for 90% control of glyphosate-resistant and -susceptible giant ragweed biotypes. The density of glyphosate-resistant giant ragweed at this site was 18 to 30 plants m^{-2}. The soil texture of the experimental site was silty loam with a pH of 5.4, and a composition of 18% sand, 50% silt, 32% clay, and 2.1% organic matter (AgSource Laboratories, Lincoln, NE 68502). Glyphosate-resistant soybean seeds (Cv. 'Pioneer 93Y12' [2013] and 'NK S28U7' [2014]) were planted 3 cm deep on May 24, 2013 and May 17, 2014. Individual plots were 3 m wide and 9 m long, containing four soybean rows spaced 76 cm apart. The treatments were arranged in a split-plot design with four replications, where the main plot was preplant control methods (preplant tillage, 2,4-D, or no preplant control), and the subplot was PRE/POST herbicide treatments. A total of 12 treatment combinations, including preplant tillage or 2,4-D application, or no preplant control fb PRE or POST herbicides, was compared for control of glyphosate-resistant giant ragweed in soybean (Table 1). A treatment with no preplant tillage or herbicide application served as a nontreated control for comparison. The application rates of herbicides were selected on the basis of the labeled rates in soybean.

Preplant tillage was accomplished using a tandem disk harrow on May 10, 2013 and May 3, 2014 and 2,4-D was applied on the same day during both years. Herbicide treatments were applied as PRE (May 24, 2013 and May 17, 2014), early POST (EPOST) (June 14, 2013 and June 10, 2014), and late POST (LPOST) (June 28, 2013 and June 30, 2014). Herbicides were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 276 kPa equipped with a four-nozzle boom fitted with AIXR 110015 flat-fan nozzles (TeeJet, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189). The experimental site was under rain-fed/dryland conditions during both years without any supplemental irrigation.

During both years, data were collected for visual control estimates of giant ragweed using a scale of 0 (no control) to 100% (complete control) at 7 and 14 d after preplant treatments (DAPT); 7, 14, and 21 d after PRE (DAPRE) herbicide treatments; 30 and 60 d after EPOST (DAEPOST) herbicide treatments, and at harvest. Herbicide injury symptoms on soybean (if any) were recorded using a scale of 0 (no injury) to 100% (plant death) at 7, 14, and 21 d after herbicide treatments. Glyphosate-resistant giant ragweed density was recorded from two randomly selected 0.25-m^2 quadrats per plot at 30 and 60 DAEPOST herbicide treatments and 2 wk before soybean harvest. Glyphosate-resistant giant ragweed biomass was assessed from the same two 0.25-m^2 quadrats per plot randomly selected for density data at 60 DAEPOST. Giant ragweed plants 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 dried biomass was weighed (g). Soybeans were harvested using a plot combine and yields were adjusted to 13% moisture content. Giant ragweed biomass data were converted into percent shoot biomass reduction compared with the nontreated control (Wortman 2014) as:

$$\text{Percent shoot biomass reduction} = [(\bar{C} - B)/\bar{C}]^{*}100 \qquad (1)$$

where, $\bar{C}$ is the mean biomass of the four $\bar{C}$ nontreated control replicates, and B is the biomass of an individually treated experimental unit.

Statistical Analysis. Data were subjected to ANOVA using the PROC GLIMMIX procedure in SAS version 9.3 (SAS Institute Inc, Cary, NC). Data of visual control estimates of giant ragweed at 7 and 14 DAPT (Figure 1) were analyzed as randomized complete block design with preplant control methods (preplant tillage, 2,4-D, no-preplant control) year and their interactions considered as fixed effects and replication as a random effect in the model. This is because the subplot treatments (PRE/POST herbicides) were not applied at this time. The analysis of all other data was performed in split-plot design with year, preplant control methods, herbicide treatments, and their interactions considered as the fixed effects, and the replication as a random effect in the model. The treatments with zero response variables were not included in the data analysis. Before analysis, data were tested for normality of residuals using the PROC UNIVARIATE procedure. Visual estimates 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 the transformed data. If the ANOVA indicated that treatment effects were significant, means were separated at $P \leq 0.05$ using Tukey–Kramer's pairwise comparison test. Single degree-of-freedom contrast statements were used to compare herbicide programs with and without preplant treatment, and to compare herbicide programs with different application timings including PRE fb LPOST vs. EPOST fb LPOST. Year-by-treatment interaction was not

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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	Timing	Rate	Trade name	Manufacturer	Adjuvant[b]
		g ae or ai ha^{-1}			
Sulfentrzone + cloransulam fb	PRE	392	Authority First	FMC Corporations, Philadelphia, PA 19103;	AMS + COC
glyphosate	Late POST	870	Roundup PowerMax	Monsanto Company, 800 North Lindberg Ave., St. Louis, MO	AMS
Sulfentrzone + cloransulam fb	PRE	392	Authority First	FMC Corporations; Monsanto Company; +	AMS + COC
glyphosate + fomesafen	Late POST	870 + 263	Roundup PowerMax + Flexstar	Syngenta Crop Protection, Inc., Greensboro, NC 27419; Bayer Crop Science	AMS + COC
Glyphosate + cloransulam	Early POST	870 + 17.7	Roundup PowerMax + FirstRate	Monsanto Company + Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268;	AMS + NIS
fb glyphosate + lactofen	Late POST	870 + 220	Roundup PowerMax + Cobra	Monsanto Company + Valent USA Corporation, Walnut Creek, CA 94596	AMS + COC
2,4-D Amine	Preplant	560	2,4-D Amine	Winfield Solutions, LLC, St. Paul, MN 55164	AMS + NIS
2,4-D Amine fb	Preplant	560	2,4-D Amine	Winfield Solutions	AMS + NIS
sulfentrzone + cloransulam	PRE	392	Authority First	FMC Corporations	AMS + COC
fb glyphosate	Late POST	870	Roundup PowerMax	Monsanto Company	AMS
2,4-D Amine fb	Preplant	560	2,4-D Amine	Winfield Solutions	AMS + NIS
sulfentrzone + cloransulam fb	PRE	392	Authority First	FMC Corporations	AMS + COC
glyphosate + fomesafen	Late POST	870 + 263	Roundup PowerMax + Flexstar	Monsanto Company + Syngenta Crop Protection	AMS + COC
2,4-D Amine fb	Preplant	560	2,4-D Amine	Winfield Solutions	AMS + NIS
glyphosate + cloransulam fb	Early POST	870 + 17.7	Roundup PowerMax + FirstRate	Monsanto Company + Dow AgroSciences LLC	AMS + NIS
glyphosate + lactofen	Late POST	870 + 220	Roundup PowerMax + Cobra	Monsanto Company + Valent USA Corporation	AMS + COC
Sulfentrzone + cloransulam fb	PRE	392	Authority First	FMC Corporations	AMS + COC
glyphosate	Late POST	870	Roundup PowerMax	Monsanto Company	AMS
Sulfentrzone + cloransulam fb	PRE	392	Authority First	Monsanto Company + Dow AgroSciences LLC	AMS + NIS
glyphosate + fomesafen	Late POST	870 + 263	Roundup PowerMax + Flexstar	Monsanto Company + Valent USA Corporation	AMS + COC
Glyphosate + cloransulam	Early POST	870 +17.7	Roundup PowerMax + FirstRate	Monsanto Company + Dow AgroSciences LLC	AMS + NIS
fb glyphosate + lactofen	Late POST	870 + 220	Roundup PowerMax + Cobra	Monsanto Company + Valent USA Corporation	AMS + COC

[a] Abbreviations: fb, followed by; AMS, ammonium sulfate (DSM Chemical North America Inc., Augusta, GA); COC, crop oil concentrate (Agridex, Helena Chemical Co., Collierville, TN); DAPT, days after preplant treatment; DAPRE, days after PRE treatment; DAPOST, days after POST treatment; NIS, nonionic surfactant (Induce, Helena Chemical Co.).

[b] AMS at 2% (w/v), COC at 1% (v/v), and NIS at 0.25% (v/v) were mixed with herbicides.

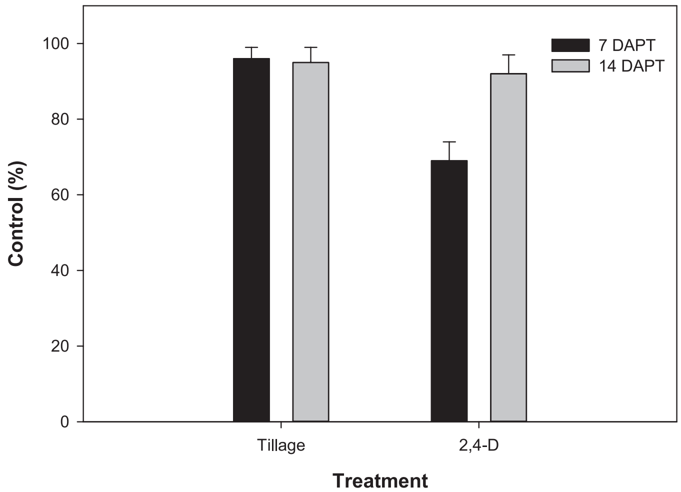

Figure 1. Control of glyphosate-resistant giant ragweed at 7 and 14 d after preplant treatment (DAPT) of tillage or 2,4-D in a field experiment conducted at David City, NE in 2013 and 2014. Year-by-treatment interaction was not significant; therefore, data from both years were combined. The bars with no common letter(s) are significantly different according to Tukey–Kramer's pairwise comparison test at $P \leq 0.05$.

significant; therefore, data of both years were combined for variables including giant ragweed control estimates, density, and biomass.

Results and Discussion

The interaction between main plot treatments (preplant tillage, 2,4-D, no-preplant control) and subplot treatments (PRE/POST herbicides) was significant ($P < 0.05$) for all variables including giant ragweed control estimates, density, and biomass. Preplant tillage or 2,4-D application provided 96 and 69% control of glyphosate-resistant giant ragweed, respectively, at 7 DAPT. Giant ragweed control improved to 94% at 14 d after 2,4-D preplant application and was comparable with tillage (Figure 1). The improvement is because of systemic activity of 2,4-D and it takes about 10 to 20 d to fully express growth inhibition symptoms on broadleaf weeds (Kelley et al. 2005; Robinson et al. 2013). Jhala et al. (2014) reported ≤ 66% control of glyphosate-resistant giant ragweed 7 d after 2,4-D applied preplant, which improved to > 85% at 14 d after treatment. The application of sulfentrazone plus cloransulam PRE without preplant tillage or 2,4-D resulted in < 75 and 84% control, respectively, at 7 and 21 DAPRE compared with > 96% control when preceded with preplant treatments.

The contrast analysis suggested > 95% control with preplant fb PRE programs compared with PRE-only treatments (< 85%) at 7 and 21 DAPRE (Table 2). Similarly, Kaur et al. (2014) reported 68% control of giant ragweed with sulfentrazone plus cloransulam at 7 DAPT. Ganie et al. (2015) reported ≥ 80% control of glyphosate-resistant giant ragweed with preplant tillage at 10 DAPT in corn. Thus, results of this study emphasize the importance of preplant tillage or 2,4-D application for effective management of glyphosate-resistant giant ragweed in soybean because it resulted in ≥ 89% control regardless of PRE herbicide treatments at 7 and 21 DAPRE. Additionally, these results provided further evidence to the recommendations including preplant tillage or herbicide application made by Johnson et al. (2006) for control of emerged giant ragweed plants.

Preplant tillage or 2,4-D resulted in < 71 and < 45% control of giant ragweed at 30 and 60 DAEPOST, respectively (Table 2). This was primarily due to the regrowth of partially controlled plants or the new emergence of giant ragweed seedlings after tillage or 2,4-D applied preplant. Similarly, Jhala et al. (2014) reported ≤ 68% control of glyphosate-resistant giant ragweed at 30 DAPT in soybean when preplant herbicide treatments were not followed by PRE or POST herbicide treatments. Preplant tillage or 2,4-D fb sulfentrazone plus cloransulam PRE fb glyphosate or glyphosate plus fomesafen LPOST or glyphosate plus cloransulam EPOST fb glyphosate plus lactofen LPOST resulted in ≥ 98% control of glyphosate-resistant giant ragweed at 30 and 60 DAEPOST. However, without preplant treatments, sulfentrazone plus cloransulam PRE fb glyphosate or glyphosate plus fomesafen LPOST resulted in 84 to 86% control at 30 DAEPOST, and decreased to ≤ 78% control at harvest (Table 2). A similar trend was observed at the harvest. Control of giant ragweed with preplant treatments alone reduced to < 20% (Table 2). Results indicated that > 95% control of glyphosate-resistant giant ragweed throughout the season is possible with preplant tillage or 2,4-D fb PRE or EPOST fb LPOST herbicide programs (Table 2). Similarly, previous research has reported that without effective preplant management, in-crop application of glyphosate tank mixture with fomesafen/bentazon/chlorimuron-ethyl or other POST-only herbicide programs provided unacceptable control of glyphosate-resistant giant ragweed (Follings et al.

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Table 2. Effect of tillage and herbicides on control of giant ragweed at 7 and 21 d after PRE treatment, 30 and 60 d after early POST treatment, and at harvest in 2013 and 2014 at David City, NE.

Treatment[a]	Application timing	Rate	Giant ragweed control[b,c,d,e]				
			7 DAPRE	21 DAPRE	30 DAEPOST	60 DAEPOST	At harvest
		g ae or ai ha^{-1}	%				
Tillage	Preplant	-	98 a	94 ab	70 c	33 d	10 d
Tillage fb	Preplant		98 a	99 a	99 a	99 a	98 a
sulfentrzone + cloransulam fb	PRE	392					
glyphosate	Late POST	870					
Tillage fb	Preplant		99 a	99 a	99 a	99 a	98 a
sulfentrzone + cloransulam fb	PRE	392					
glyphosate + fomesafen	Late POST	870 + 263					
Tillage fb	Preplant		89 a	92 ab	98 a	98 a	98 a
glyphosate + cloransulam	Early POST	870 + 17.7					
fb glyphosate + lactofen	Late POST	870 + 220					
2,4-D Amine	Preplant	560	95 a	94 ab	67 c	42 d	16 d
2,4-D Amine fb	Preplant	560	98 a	99 a	99 a	99 a	97 a
sulfentrzone + cloransulam fb	PRE	392					
glyphosate	Late POST	870					
2,4-D Amine fb	Preplant	560	97 a	99 a	99 a	98 a	98 a
sulfentrzone + cloransulam fb	PRE	392					
glyphosate + fomesafen	Late POST	870 + 263					
2,4-D Amine fb	Preplant	560	94 a	94 ab	99 a	99 a	98 a
glyphosate + cloransulam fb	Early POST	870 + 17.7					
glyphosate + lactofen	Late POST	870 + 220					
Sulfentrzone + cloransulam fb	PRE	392	74 b	82 b	86 b	81 b	78 b
glyphosate	Late POST	870					
Sulfentrzone + cloransulam fb	PRE	392	73 b	83 b	84 b	80 b	78 b
glyphosate + fomesafen	Late POST	870 + 263					
Glyphosate + cloransulam	Early POST	870 +17.7	0	0	77 bc	75 b	74 b
fb glyphosate + lactofen	Late POST	870 + 220					
P-value			0.023	0.034	0.041	0.031	0.022
Contrasts							
Preplant fb PRE vs. PRE alone			$P < 0.0001$	$P < 0.0001$	—	—	—
Preplant fb PRE fb LPOST vs. PRE fb LPOST			—	—	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$
Preplant fb PRE fb LPOST vs. preplant fb EPOST fb LPOST			—	—	$P < 0.9000$	$P < 0.9872$	$P < 0.9575$
PRE fb LPOST vs. EPOST fb LPOST			—	—	$P < 0.0001$	$P < 0.0001$	$P < 0.0001$

[a] The experiment was arranged in a split-plot design, but to reduce the size of table main (preplant tillage, 2,4-D, no control) and subplot (PRE/POST herbicides), treatments were presented in the same column.

[b] Abbreviations: DAPT, days after preplant treatment; DAPRE, days after PRE; DAEPOST, days after early POST; fb, followed by.

[c] Year-by-treatment interaction was not significant; therefore, data were combined over 2 yr.

[d] 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 values.

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

2013; Riley and Bradley 2012, 2014). However, Vink et al. (2012b) reported that sequential applications of glyphosate plus dicamba applied preplant fb POST resulted in 100% control of glyphosate-resistant giant ragweed in dicamba-tolerant soybean. Moreover, the contrast statements confirmed that preplant fb PRE fb LPOST program provided > 95% giant ragweed control compared with < 87% control with PRE fb LPOST program alone, and indicated similar control with PRE fb

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Table 3. Effect of tillage or herbicide treatments on glyphosate-resistant giant ragweed density, biomass, and soybean yield in a field experiment conducted in 2013 and 2014 at David City, NE.

			Giant ragweed[b,c,d,e]			Soybean[e,f]		
			Density		Biomass reduction	Injury[g]	Yield	
Treatment[a]	Application timing	Rate	60 DAEPOST	At harvest	60 DAEPOST	14 DALPOST	2013	2014
		g ae or ai ha^{-1}	No. m^{-2}		%		kg ha^{-1}	
Nontreated control	—	—	22 a	19 a	0	0	0	0
Tillage	Preplant	—	8 b	8 bc	53 cd	0	904 c	656 c
Tillage fb sulfentrzone + cloransulam fb glyphosate	Preplant PRE Late POST	 392 870	0 d	0 d	100 a	0	2,954 ab	3,071 ab
Tillage fb sulfentrzone + cloransulam fb glyphosate + fomesafen	Preplant PRE Late POST	 392 870 + 263	1 d	1 d	95 a	12 b	2,881 ab	3,319 a
Tillage fb glyphosate + cloransulam fb glyphosate + lactofen	Preplant Early POST Late POST	 870 + 17.7 870 + 220	0 d	0 d	99 a	15 ab	2,582 ab	2,445 b
2,4-D Amine	Preplant	560	10 b	9 b	45 d	0	1,178 c	716 c
2,4-D Amine fb sulfentrzone + cloransulam fb glyphosate	Preplant PRE Late POST	560 392 870	1 d	1 d	95 a	0	3,219 a	3,581 a
2,4-D Amine fb sulfentrzone + cloransulam fb glyphosate + fomesafen	Preplant PRE Late POST	560 392 870 + 263	0 d	0 d	98 a	13 ab	3,492 a	3,301 a
2,4-D Amine fb glyphosate + cloransulam fb glyphosate + lactofen	Preplant Early POST Late POST	560 870 + 17.7 870 + 220	0 d	1 d	96 a	15 ab	2,862 ab	2,859 ab
Sulfentrzone + cloransulam fb glyphosate	 PRE Late POST	 392 870	5 c	3 cd	89 a	0	1,790 bc	1,480 c
Sulfentrzone + cloransulam fb glyphosate + fomesafen	 PRE Late POST	 392 870 + 263	4 c	2 d	86 ab	12 b	1,355 c	1,196 c
Glyphosate + cloransulam fb glyphosate + lactofen	 Early POST Late POST	 870 + 17.7 870 + 220	8 b	9 b	66 bc	16 a	0	1,184 c
P-value			< 0.0002	< 0.0001	0.04	0.008	0.03	0.041
Contrasts								
Preplant fb PRE fb LPOST vs. PRE fb LPOST			P < 0.0001	P = 0.2998	P < 0.0001	—	P < 0.0001	P < 0.0001

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Table 3. Continued.

Treatment[a]	Application timing	Rate	Giant ragweed[b,c,d,e] Density 60 DAEPOST	Density At harvest	Biomass reduction 60 DAEPOST	Soybean[e,f] Injury[g] 14 DALPOST	Yield 2013	Yield 2014
		g ae or ai ha^{-1}	———No. m^{-2}———		————%————		———kg ha^{-1}———	
Preplant fb PRE fb LPOST vs. Preplant fb EPOST fb LPOST			P = 0.0010	P = 0.3539	P < 0.0001	—	P = 0.4688	P < 0.0001
PRE fb LPOST vs. EPOST fb LPOST			P = 0.0297	P = 0.0173	P < 0.0398	—	P < 0.0001	P < 0.0001

[a] The treatments were arranged in split-plot design, but to reduce the size of table main (preplant tillage, 2,4-D) and subplot (PRE/POST herbicides), treatments were presented in the same column and when PRE/POST herbicides were applied alone, no-preplant control was mentioned in the table.

[b] Abbreviations: DAPT, days after preplant treatment; DAPRE, days after PRE; DAEPOST, days after early POST; DALPOST, days after late POST; fb, followed by.

[c] ata were combined over the years for analysis because there was no treatment-by-year interaction.

[d] 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.

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

[f] Treatments with zero yield values (nontreated control) were not included in the analysis.

[g] Soybean injury data were collected at 14 DALPOST; zero values were not included in the analysis.

LPOST and EPOST fb LPOST programs when preceded by preplant treatments (Table 2).

The density and percent shoot biomass reduction of glyphosate-resistant giant ragweed reflected the results of visual control estimates. The highest density of giant ragweed (19 to 22 plants m^{-2}) was recorded in the nontreated control plots compared with other treatments (Table 3). Preplant tillage or 2,4-D fb PRE or EPOST fb LPOST treatments resulted in a density of < 2 plants m^{-2} and provided season-long control of giant ragweed (Table 3). Similarly, Kelton et al. (2013) reported a reduction of Palmer amaranth density to ≤ 4 plants m^{-2} with spring tillage compared with ≥ 4 plants m^{-2} without tillage in cotton. Sulfentrazone plus cloransulam PRE fb glyphosate or glyphosate plus fomesafen LPOST resulted in ≤ 5 plants m^{-2} at 60 DAEPOST but was comparable with preplant tillage or 2,4-D fb PRE or EPOST fb LPOST programs at harvest (Table 3). Jhala et al. (2014) reported ≤ 1 giant ragweed plant m^{-2} with 2,4-D preplant fb PRE treatments.

Giant ragweed shoot biomass reduction with preplant-only treatments was < 55%. However, preplant treatments fb PRE or EPOST fb LPOST herbicides resulted in ≥ 95% shoot biomass reduction compared with ≤ 89% reduction with PRE fb LPOST treatments. In comparable studies, 75 to 100% giant ragweed shoot biomass reduction was observed with 2,4-D or saflufenacil preplant fb POST application of glufosinate or ALS plus PPO-inhibiting herbicides (Jhala et al. 2014; Kaur et al. 2014). Similarly, Vink et al. (2012b) reported ≥ 99% reduction in giant ragweed shoot biomass with application of glyphosate plus dicamba preplant fb glyphosate plus dicamba POST in dicamba-tolerant soybean. The contrast analysis indicated low giant ragweed density and high shoot biomass reduction with preplant fb PRE fb LPOST programs compared with PRE fb LPOST programs at 60 DAEPOST. Similarly, PRE fb LPOST programs resulted in lower giant ragweed density (< 5 plants m^{-1}) and > 85% biomass reduction compared with EPOST fb LPOST programs, irrespective of preplant treatments (Table 3).

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Soybean injury was 12 to 16% at 14 d after LPOST application of fomesafen or lactofen; however, injuries were transient and had no impact on soybean yield (Table 3). Year-by-treatment interaction for soybean yield was significant probably because of differences in rainfall received during 2013 and 2014 (data not shown); hence, soybean yields are presented separately by year (Table 3). The nontreated control resulted in no soybean yield due to high giant ragweed density (19 to 22 plants m^{-2}). Similarly, recent studies in Nebraska have reported 100% soybean yield loss when giant ragweed plants (> 15 plants m^{-2}) were allowed to compete throughout the growing season (Jhala et al. 2014; Kaur et al. 2014). In 2013 no yield was harvested in the glyphosate plus cloransulam EPOST fb glyphosate plus lactofen LPOST herbicide program because of an inability to run the combine due to extreme giant ragweed competition, but a yield of 1,184 kg ha^{-1} was recorded in 2014 in the same treatment. Preplant tillage or 2,4-D fb PRE or EPOST fb LPOST treatments resulted in the highest soybean yield (> 2,440 kg ha^{-1}) compared with < 1,800 kg ha^{-1} with the PRE fb LPOST herbicide program. Preplant tillage or 2,4-D-only treatments resulted in soybean yield < 720 kg ha^{-1}, which clearly demonstrates that preplant tillage or 2,4-D were effective for management of giant ragweed early in the season; however, follow-up application of PRE and/or POST herbicides are needed for effective season-long control of giant ragweed and to avoid yield loss. The contrast statement suggested higher soybean yield with a PRE fb LPOST program compared with an EPOST fb LPOST program irrespective of preplant treatments, except in 2013, where no differences were observed in soybean yield between PRE fb LPOST vs. EPOST fb LPOST when preceded by preplant treatments (Table 3).

This is the first report describing integrated management of glyphosate-resistant giant ragweed in glyphosate-tolerant soybean. Results from this study showed the importance of preplant control of giant ragweed with tillage or 2,4-D fb PRE/POST herbicide treatments. Jhala et al. (2014) and Kaur et al. (2014) reported an effective control of glyphosate-resistant giant ragweed with 2,4-D preplant fb PRE or POST herbicides. Although no literature is available on integrated management of giant ragweed with preplant tillage and herbicides, previous studies have reported an effective management of glyphosate-resistant Palmer amaranth with the integrated use of tillage and herbicides (Aulakh et al. 2013; Kelton et al. 2013).

In summary, because giant ragweed is an early-emerging weed in Nebraska and exhibits a monophasic emergence pattern (Kaur 2015), preplant tillage is an effective tool for early-season management. The alternative approach is application of 2,4-D, particularly in no-till cropping systems. However, continuous use of 2,4-D should be avoided to prevent selection pressure, as 2,4-D-resistant common waterhemp has been confirmed in Nebraska in a continuous grass seed production system (Bernards et al. 2012). Therefore, preplant tillage would be a good alternative to include in integrated giant ragweed management programs. The potential limitations of tillage are lack of motivation for the preplant tillage, particularly among no-till growers; additional expenses; and weather, which is often not much suitable for early spring tillage.

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