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Alternative Herbicides for Control of Glyphosate-Resistant Giant Ragweed in Nebraska

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Abstract

Giant ragweed is an early emerging and one of the most competitive summer annual species found in many fields throughout North America. Extensive use of glyphosate in glyphosate-tolerant (GT) crops has evolved giant ragweed populations with glyphosate resistance. Field dose-response studies were conducted to determine the influence of growth stage on the level of glyphosate resistance in a suspected giant ragweed population. In addition, efficacy of alternative pre-plant, pre-emergence (PRE) and post-emergence (POST) herbicides were evaluated in corn and soybeans for glyphosate-resistant (GR) giant ragweed control. The field glyphosate dose-response studies confirmed that the suspected giant ragweed population were resistant ranging from 14- to 32-fold resistance depending on the growth stage of glyphosate application. The 10, 20 and 30 cm tall giant ragweed had 14, 17 and 32X resistance level, respectively. The dose-response studies indicated that the 10, 20, and 30 cm tall GR giant ragweed was controlled 90% with 214, 402 and 482 g ae ha^{-1} of dicamba, respectively, when tank-mixed with glyphosate (1060 g ae ha^{-1}) 21 days after treatment (DAT). All evaluated pre-plant herbicides for corn provided ≥ 90% control of the GR giant ragweed at 30 DAT; among which the best control (100%) was achieved with pre-plant application of atrazine (2240 g ai ha^{-1}), isoxaflutole (90 g ai ha^{-1}), and premix of flumioxazin/pyroxasulfone (315 g ai ha^{-1}). Herbicide combinations of different site of action provided greater than 90% control of the GR giant ragweed population in a PRE followed by POST herbicide program in corn and soybean, suggesting that alternative herbicide for giant ragweed control are available.

Keywords: corn, soybean, glyphosate resistance, giant ragweed, herbicides

1. Introduction

Giant ragweed (*Ambrosia trifida* L.) is a broadleaf weed species found in many fields in North America (Regnier et al., 2016). Giant ragweed is a summer annual weeds in field crops such as soybean and corn in Nebraska, with emergence beginning in March (Kaur et al., 2016). The early emergence, fast growth as well as the ability to survive in adverse environment have been attributed to the high competitive advantage of giant ragweed against field crops (Ganie et al., 2016; Goplen et al., 2017). Studies have shown that giant ragweed is very competitive in field crops even with low densities (Ganie et al., 2016; Harrison et al., 2001).

The control of giant ragweed in field crops over the last three decades has been more difficult due to development of herbicide resistant biotypes. For example, extensive use of acetolactate synthase (ALS) inhibitors led to the development of ALS-resistant giant ragweed in the 1990s (Heap, 2018; Schrage, 2018). In the more recent history, widespread adoption of glyphosate-tolerant (GT) crops and repeated use of glyphosate for both burndown and post-emergence weed control (Regnier et al., 2016) resulted in many glyphosate resistant species, including giant ragweed (Kaur et al., 2014; Heap & Duke, 2018).

Giant ragweed control using herbicides with multiple modes of action would reduce risk of weed resistance. Alternative herbicides such as auxin herbicides, photosystem II inhibitors, hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors, and protoporphyrinogen oxidase (PPO) inhibitors had shown to be effective for giant ragweed control (Riley & Bradley, 2014; Belfry & sikkema, 2015; Mahoney et al., 2015; Wuerffel et al., 2015; Ditschun et al., 2016; Goplen et al., 2018; Osipitan et al., 2018). Therefore, field studies were conducted in

Nebraska to determine the level of glyphosate resistance in a suspected glyphosate-resistant (GR) giant ragweed population and to evaluate alternative herbicides for pre-plant, pre-emergence (PRE) and post-emergence (POST) herbicides in corn and soybeans for GR giant ragweed control.

2. Materials and Methods

2.1 Field Dose-Response Studies

Field experiments were conducted in 2012 at two locations with a natural infestation of suspected GR giant ragweed located near David City, NE (41.258N, 97.138W). The study was laid out in a randomized complete block design with three replications for dose response studies on glyphosate alone, dicamba tank-mixed with glyphosate, or saflufenacil tank-mixed with glyphosate at three growth stages (10, 20, and 30 cm tall plants) of giant ragweed. The dose response studies consisted of four doses of glyphosate alone (1060, 4240, 8500, and 17000 g ae ha^{-1}); four doses of saflufenacil (12.5, 25, 50 and 100 g ai ha^{-1}) tank-mixed with a recommended dose of glyphosate (1060 g ae ha^{-1}); and four doses of dicamba (210, 420, 840 and 1680 g ai ha^{-1}) mixed with a recommended dose of glyphosate (1060 g ae ha^{-1}); as well as a non-treated control. Each experimental plot was 8 m long by 3 m wide and was planted with two rows of corn and two rows of soybean on May 21, 2012 in 76 cm rows with a four-row planter. The first application of herbicide was made when giant ragweed plants were 10 cm tall as early POST (EPOST), the second application to 20 cm tall plants, at mid-POST (MPOST), and the third application to 30 cm tall plants as late POST (LPOST).

Herbicide treatments were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} solution at 172 kPa with TeeJet XR 110015 flat-fan nozzles at a speed of 4.3 km h^{-1}. The GR giant ragweed control was visually rated at 7, 14 and 21 days after treatment (DAT) on a scale of 0% (no control) to 100% (complete control). At 21 DAT, the giant ragweed plants within 0.25 m^2 quadrat randomly placed in each plot were severed at the soil surface and oven-dried at 35 C for 7 days, then shoot biomass was measured. The shoot biomass reduction (%) was expressed as:

$$\text{Shoot biomass reduction (\%)} = [(G\text{-}H)/G] \times 100 \quad (1)$$

Where *G* was the biomass (above ground) of giant ragweed plants in non-treated plots and *H* was the biomass of giant ragweed plants in the respective herbicide treated plots.

A four-parameter log-logistic model was best to relate giant ragweed responses (visual control and biomass reduction) to herbicide treatments using “drc” package in R statistical software (R Development Core Team, 2018; Knezevic et al., 2007). The model was given as:

$$Y = C + \{D - C / 1 + \exp[B(\log X - \log E)]\} \quad (2)$$

where Y was the giant ragweed response, *C* was the lower limit, *D* was the upper limit, *X* was the herbicide dose, *E* was the dose resulting to 50% response between the upper and lower limit (also known as ED_{50}), *B* was the slope around *E*. The effective dose needed to suppress the giant ragweed population by 50% (ED_{50}) and 90% (ED_{90}) was estimated from the above model (equation 2). Differences between the ED values for each growth stage and herbicide treatment were determined by the standard errors (SE) (Knezevic et al., 2018).

2.2 Evaluation of Alternative Herbicide Programs on GR Giant Ragweed

Field experiments were conducted in 2013 and 2014, near David City, NE to evaluate control of GR giant ragweed with pre-plant, and PRE followed by (fb) POST herbicides in corn; as well as PRE fb POST and POST-only in soybean. The soil texture of the location was silty clay loam (20% sand, 54% silt, 38% clay) with a pH of 5.7, and 2.2% organic matter. Total rainfall from April to October was 67.3 cm in 2013 and 61.0 cm in 2014. Average daily temperature was 23 and 25 ℃ in 2013 and 2014, respectively. Glyphosate-tolerant corn (H-9138, Golden Harvest Seeds, Waterloo, NE 68069) was planted at 69,780 seeds ha^{-1} in rows spaced 76 cm apart on June 12, 2013 and June 5, 2014. Glyphosate-tolerant soybean (92Y70, Pioneer Seed, Allen, NE 68710) was planted at 360,760 seeds ha^{-1} also in rows spaced 76 cm apart on May 18, 2013 and May 28, 2014. Each of the herbicide programs has 12 treatments except POST-only (5 treatments) in soybean (Table 1, 2, 3 and 4). Experiments were conducted in a randomized complete block design with three replications for each of the program in corn and soybean. Individual plots were 8 m long and 3 m wide.

Herbicide applications were made using a CO_2-pressurized backpack boom sprayer calibrated to deliver 140 L ha^{-1} at 172 kPa (for PRE) and 276 kPa (for Pre-plant and POST), through four AIXR 11002 (for PRE) and 10015 (for Pre-plant and POST) nozzle tips (Turbo TeeJet, Spraying systems Co., P.O. Box 7900, Wheaton, IL 60187) with a boom length of 200 cm. The Pre-plant herbicides applications were conducted in April prior to planting of corn or soybean in May or June. The PRE herbicides were applied immediately after planting corn or soybean, while POST herbicides were applied when the GR giant ragweed plants were 8 to 11 cm tall.

Visually rated weed control on the scale of 0 (no control) to 100% (complete control) were collected at 30, 60 and 75 DAT for pre-plant; 30 days after PRE (DAPRE) and 30 days after POST (DAPOST) for PRE fb POST; 30 DAT for POST-only. GR giant ragweed biomass was collected from plants within 0.25 m^2 quadrats placed the middle two corn or soybean rows in each plot at 30 DAT for all herbicide programs. Biomass reduction (%) was calculated as shown in equation 1.

An initial test of normality of data using the PROC Univariate procedure in SAS v. 9.4 software (SAS Institute, Cary, NC 27513) suggested that the collected data did not follow a normal distribution. Hence, data were arcsine transformed to reduce the heterogeneity of treatment variances. Tests of significance of treatments on GR giant ragweed population was conducted with ANOVA using the PROC MIXED procedure in SAS, with replicates and years considered random variables. The untreated plot data were excluded from the analyses of the visually rated GR giant ragweed control. If ANOVA indicated significant treatment effects, means of the transformed data were separated with Fisher's protected LSD test at $P \leq 0.05$; however, back-transformed data were presented in tables for easy interpretation.

Table 1. List of pre-plant herbicides used for control of GR Giant Ragweed in Corn in 2013 and 2014

Herbicides	Trade name	Rate	Manufacturer	Adjuvant
		g ai ha^{-1}		
Atrazine	Aatrex®	2240	Syngenta Crop Protection, Inc., Greensboro, NC 27419	COC
Isoxaflutole	Balance Flexx®	90	Bayer CropScience, Research Triangle Park, NC 27709	MSO
Isoxaflutole + Atrazine	Balance Flexx® + Aatrex®	90 + 1120	Bayer CropScience + Syngenta Crop Protection	MSO + AMS
Mesotrione	Callisto®	300	Syngenta Crop Protection	AMS
Thiencarbazone-methyl/isoxaflutole	Corvus®	129	Bayer CropScience	AMS + COC
Flumioxazin/Pyroxasulfone	Fierce®	315	Valent USA Corporation, Walnut Creek, CA 94596	AMS
Dimethenamid-P/atrazine	Guardsman Max®	723	BASF Corporation	COC
S-metolachlor/mesotrione/atrazine	Lumax EZ®	2780	Syngenta Crop Protection	AMS
Saflufenacil	Sharpen®	75	BASF Corporation	AMS
Flumioxazin + Atrazine	Valor® + Aatrex®	210 + 1120	Valent USA Corporation	AMS + COC
Saflufenacil/dimethenamid-P	Verdict®	730	BASF Corporation	AMS
Mesotrione + S-metolachlor	Zemax®	600	Syngenta Crop Protection	AMS

[a]Abbreviations: Herbicide premix (/); herbicide tank-mix (+)

[b]AMS, ammonium sulfate (DSM Chemicals North America Inc., Augusta, GA); COC, crop oil concentrate (Agridex®, Helena Chemical Co., Collierville, TN); MSO, methylated seed oil (Noble®, Winfield Solutions, Shoreview, MN).

Table 2. List of PRE followed by (fb) POST herbicides used for control of GR giant ragweed in corn in 2013 and 2014

Herbicide	Trade name	Rate	Manufacturer	Adjuvant
		g ai (ae) ha^{-1}		
Atrazine fb 2,4-D	Aatrex® fb 2,4-D	2240 fb 535	Sygenta Crop Protection, Inc., Greensboro, NC 27419 fb Winfield Solutions, LLC, St. Paul, MN 55164	COC + NIS
Isoxaflutole fb 2,4-D	Balance Flexx® fb 2,4-D	90 fb 535	Bayer CropScience, Research Triangle Park, NC 27709 fb Winfield Solutions	MSO + NIS
Isoxaflutole + atrazine fb 2,4-D	Balance Flexx® + Atrazine® fb 2,4-D	90 + 1120 fb 535	Bayer CropScience + Sygenta Crop Protection fb Winfield Solutions	MSO + COC + NIS
Mesotrione fb flumetsulam/ clopyralid	Callisto® fb Hornet®	300 fb 54	Syngenta Crop Protection fb Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268	AMS
Thiencarbazone-methyl/isoxaflutole fb 2,4-D	Corvus® fb 2,4-D	129 fb 535	Bayer CropScience fb Winfield Solutions	MSO + NIS
2,4 D (POST-only)	2,4-D	535	Winfield Solutions	NIS
Dimethenamid-P/atrazine fb 2,4-D	Guardsman Max® fb 2,4-D	723 fb 535	BASF Corporation fb Winfield Solutions	COC + NIS
S-metolachlor/mesotrione/atrazine fb 2,4-D	Lumax EZ® fb 2,4-D	2780 fb 535	Sygenta Crop Protection	
Saflufenacil fb diflufenzopyr/ dicamba	Sharpen® fb Distinct®	75 fb 360	BASF Corporation	
Saflufenacil/dimethenamid-P fb diflufenzopyr/dicamba	Verdict® fb Status®	730 fb 360	BASF Corporation	MSO + AMS
Mesotrione + S-metolachlor fb diflufenzopyr/dicamba	Zemax® fb Status®	600 fb 360	Sygenta Crop Protection fb BASF Corporation	MSO + AMS

[a]Abbreviations: Herbicide premix (/); herbicide tank-mix (+); fb, followed by.

[b]AMS, ammonium sulfate (DSM Chemicals North America Inc., Augusta, GA); COC, crop oil concentrate (Agridex®, Helena Chemical Co., Collierville, TN); NIS, nonionic surfactant (Induce®, Helena Chemical Co., Collierville, TN), MSO, methylated seed oil (Noble®, Winfield Solutions, Shoreview, MN).

Table 3. List of PRE followed by (fb) POST herbicides used for control of GR giant ragweed in soybean in 2013 and 2014

Herbicide	Trade name	Rate	Manufacturer	Adjuvant
		g ai (ae) ha^{-1}		
Sulfentrazone/cloransulam fb imazamox + acifluorfen	Authority First® fb Raptor® + Ultra Blazer®	392 fb 35 + 280	FMC Corporations, Philadelphia, PA 19103 fb BASF Corporation + United Phosphorus, Inc, King of Prussia, PA 19406	AMS + COC
Chlorimuron/flumioxazin/ thifensulfuron fb imazamox + acifluorfen	Envive® fb Raptor® + Ultra Blazer®	106 fb 35 + 280	DuPont, Wilmington, DE 19898 fb BASF Corporation + United Phosphorus, Inc, King of Prussia, PA 19406	COC
Clorasulam fb lactofen	FirstRate® fb Phoenix®	10 fb 219	Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268 fb Valent USA Corporation	AMS
Flumioxazin/clorasulam + flumioxazin + clorasulam fb imazamox + acifluorfen	Gangster® + Valor SX®+ FirstRate® fb Raptor® + Ultra Blazer®	129 + 75 + 10 fb 35 + 280	Valent USA Corporation, Walnut Creek, CA 94596 + Valent + Dow AgroSciences fb BASF Corporation + United Phosphorus, Inc, King of Prussia, PA 19406	COC + AMS
Saflufenacil/imazethapyr fb lactofen	Op Till® fb Phoenix®	100 fb 219	BASF Canada Inc. 100 Milverton Drive, 5th Floor Mississauga, ON fb Valent Corporation	AMS
Imazethapyr fb lactofen	Pursuit® fb Phoenix®	70 fb 219	BASF Corporation fb Valent Corporation	MSO + AMS
Imazethapyr + S-metolachlor fb lactofen	Pursuit® + Dual II Magnum® fb Phoenix®	70 + 1411 fb 219	BASF Corporation + Sygenta Crop Protection fb Valent Corporation	MSO + AMS
Imazaquin fb lactofen	Scepter® + Dual II Magnum® fb Phoenix®	143 + 1411 fb 219	AMVAC Chemical Corporation, Los Angeles, CA 90023 +Sygenta Crop Protection fb Valent Corporation	NIS + AMS
Metribuzin fb lactofen	Sencor® fb Phoenix®	438 fb 219	Bayer CropScience, Research Triangle Park, NC 27709 fb Valent Corporation	-
Flumioxazin fb clorasulam	Valor SX® fb FirstRate®	113 fb 5	Valent USA Corporation fb Dow AgroSciences	COC
Flumioxazin/Chlorimuron fb imazamox + acifluorfen	Valor XLT® fb Raptor® + Ultra Blazer®	158 fb 35 + 280	Valent USA Corporation fb BASF Corporation + United Phosphorus	COC + AMS

[a]Abbreviations: Herbicide premix (/); herbicide tank-mix (+); fb, followed by.

[b]AMS, ammonium sulfate (DSM Chemicals North America Inc., Augusta, GA); COC, crop oil concentrate (Agridex®, Helena Chemical Co., Collierville, TN); NIS, nonionic surfactant (Induce®, Helena Chemical Co., Collierville, TN), MSO, methylated seed oil (Noble®, Winfield Solutions, Shoreview, MN).

Table 4. List of POST-only herbicides used for control of GR giant ragweed in soybean in 2013 and 2014

Herbicide	Trade name	Rate	Manufacturer	Adjuvant
		g ai ha^{-1}		
Clorasulam	FirstRate®	5	Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268	COC
Thifensulfuron + chlorimuron	Harmony SG® + Classic®	5 + 5	DuPont 4417 Lancaster Pike Wilmington, DE 19805, USA	COC + AMS
Lactofen	Phoenix®	219	Valent USA Corporation, Walnut Creek, CA 94596	COC
Imazamox + acifluorfen	Raptor® + Ultra Blazer®	35 +280	BASF Corporation + United Phosphorus, Inc, King of Prussia, PA 19406	COC + AMS
Fomesafen/glyphosate	Flexstar GT®	1382	Sygenta Crop Protection	AMS

[a]Abbreviations: Herbicide premix (/); herbicide tank-mix (+)

[b]AMS, ammonium sulfate (DSM Chemicals North America Inc., Augusta, GA); COC, crop oil concentrate (Agridex®, Helena Chemical Co., Collierville, TN)

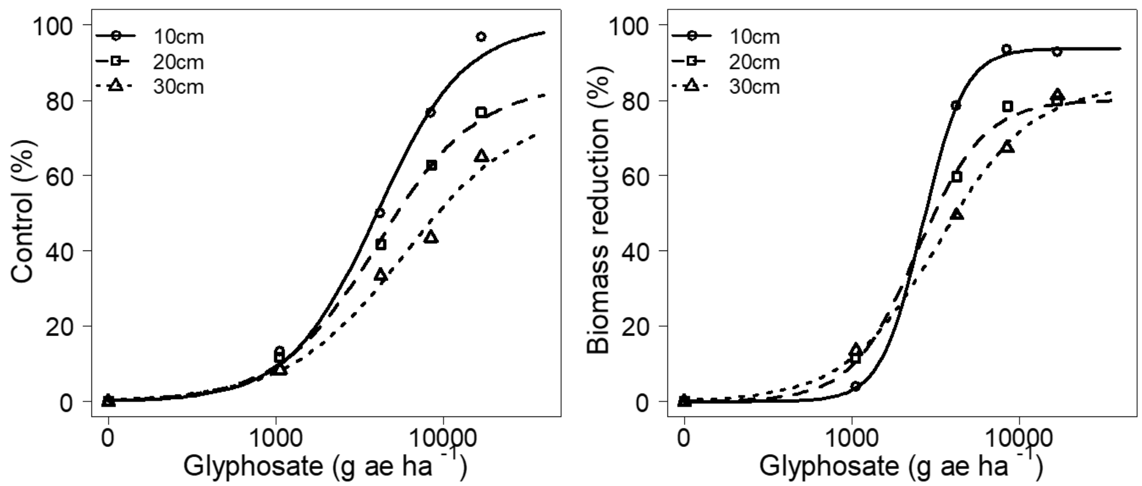

Figure 1. Control and biomass reduction of 10, 20 or 30 cm tall giant ragweed at 21 days after treatment (DAT) with POST-applied glyphosate in field dose-response studies

3. Results and Discussion

3.1 Field Dose-Response Studies

The field dose-response studies indicates that the giant ragweed population was resistant to glyphosate and that the level of resistance was influenced by the growth stage of glyphosate application (Figure 1 and Table 5). The resistance level was calculated by dividing the effective doses (ED values) of glyphosate for 50 or 90% control (or biomass reduction) by the label rate (1060 g ae ha^{-1}). Based on control rating, the ED_{90} values at 21 DAT for 10, 20, and 30 cm tall giant ragweed were 15212, 18071, and 34042 g ae ha^{-1}, respectively. The corresponding levels of glyphosate resistance (based on the ED_{90}) for 10, 20, and 30 cm tall giant ragweed at 21 DAT was 14X, 17X, and 32X, respectively. Similar glyphosate resistance levels were obtained in dose-response curves based on biomass reduction (Figure 1; Table 5). Based on biomass reduction, the GR giant ragweed was most resistant to glyphosate when plant was 30 cm tall (32X), followed by 20 cm tall (16X) and 10 cm tall (13X). These results suggest that resistance level of the GR giant ragweed population increased with increase in plant size. Varying levels of a weed species resistance to glyphosate at different growth stages have been previously reported (Koger et al., 2004; Shrestha et al., 2007; VanGessel, 2001; Norsworthy et al., 2010).

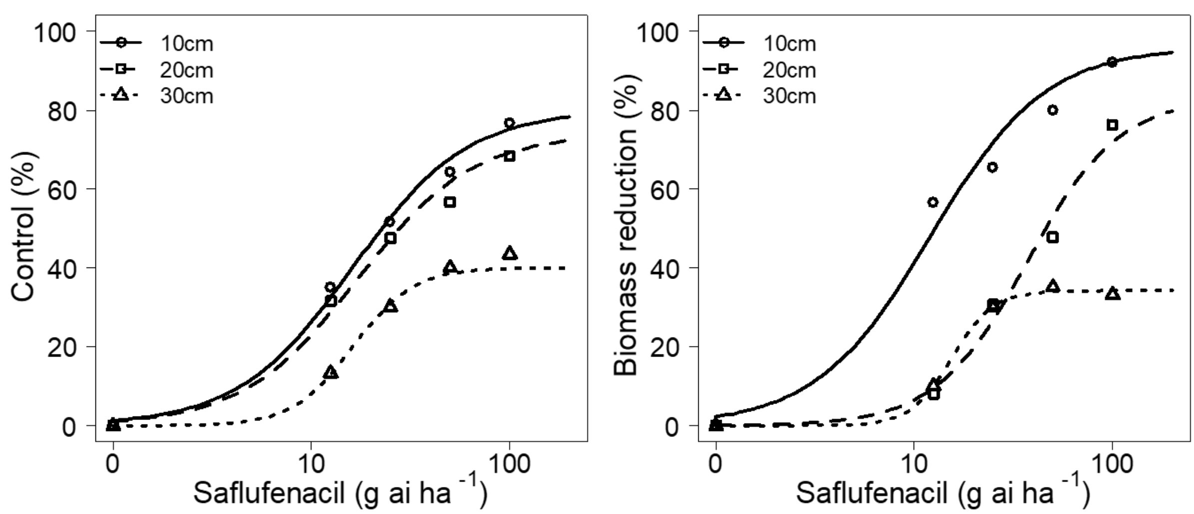

Figure 2. Control and biomass reduction of 10, 20 or 30 cm tall giant ragweed at 21 days after treatment (DAT) with POST-applied saflufenacil tank-mixed with glyphosate (1060 g ae ha^{-1}) in field dose-response studies

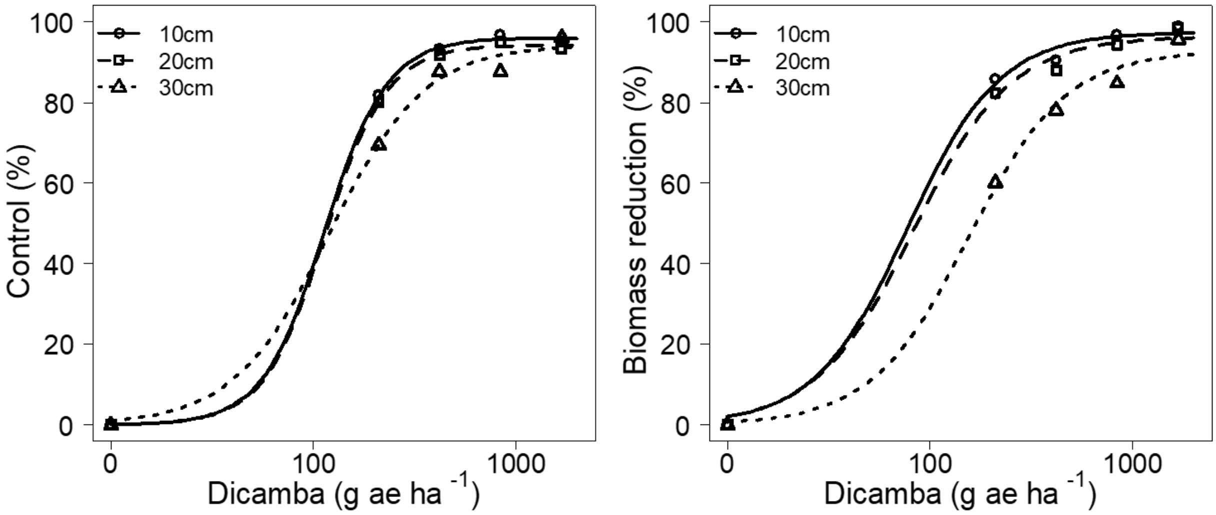

Figure 3. Control and biomass reduction of 10, 20 or 30 cm tall giant ragweed at 21 days after treatment (DAT) with POST-applied dicamba tank-mixed with glyphosate (1060 g ae ha^{-1}) in field dose-response studies

The dose-response of the GR giant ragweed to saflufenacil tank-mixed with glyphosate (1060 g ae ha^{-}) showed a poor control (Figure 2; Table 6). For example, a label rate of saflufenacil (25 g ai ha^{-1}) tank-mixed with glyphosate (1060 g ae ha^{-1}) provided 48, 45 and 27% control of GR giant ragweed when plant was 10, 20 and 30 cm tall respectively, at 21 DAT. The ED_{90} indicated that 495 - 532 g ai ha^{-1} of the saflufenacil tank-mixed with 1060 g ae ha^{-1} of glyphosate was needed to provide 90% control of the 10 - 20 cm tall GR giant ragweed (Table 6), which are much higher than the label rate (25 g ai ha^{-1}). The 30 cm tall giant ragweed needed as much as 810 g ai ha^{-1} of saflufenacil to provide the same level of control. The estimated doses of saflufenacil for 90% biomass reduction were 238, 437, and 804 g ai ha^{-1} for 10, 20, and 30 cm tall giant ragweed, respectively. These results indicate that saflufenacil applied post-emergence is not a viable option for GR giant ragweed control.

Table 5. Effective doses of glyphosate at 21 DAT for 50% control or biomass reduction (ED_{50}) and 90% control or biomass reduction (ED_{90}) of 10, 20, or 30 cm tall giant ragweed

Measure	Weed height (cm)	ED_{50} (±SE)	ED_{90} (±SE)	Resistance level	
Control		-----Glyphosate (g ae ha^{-1})----		ED_{50}	ED_{90}
	10	4024 (103)	15212 (4246)	4	14
	20	4099 (735)	18071 (4012)	4	17
	30	5867 (1017)	34042 (12231)	6	32
Biomass reduction					
	10	2757 (357)	14956 (359)	3	13
	20	3119 (602)	17691 (1858)	3	16
	30	4215 (1210)	34562 (4159)	4	32

However, the dose-response curve showed that tank-mix of dicamba and glyphosate provided a good control of the GR giant ragweed across all growth stages (Figure 3; Table 6). The required doses of dicamba for 90% control were 214, 402 and 482 g ae ha^{-1} of dicamba for 10, 20, and 30 cm tall giant ragweed respectively, when tank-mixed with glyphosate (1060 g ae ha^{-1}). The estimated doses for 90% control were within the recommended label rate (560 g ae ha^{-1}) of dicamba, suggesting that GR giant ragweed can be effectively controlled by dicamba. Others also reported giant ragweed are known to be very susceptible to auxin herbicides including dicamba (Vink et al., 2012a; Robinson et al., 2012; Spaunhorst et al., 2014; Chahal et al., 2015). For example, Chahal et al. (2015) reported 93% control of 10 to 20 cm tall GR giant ragweed with 2,4-D, an auxnic herbicide; and giant ragweed was generally more susceptible to 2,4-D than other broadleaf weed species such as kochia (*Kochia scoparia*) and common waterhemp (*Amaranthus rudis*).

3.2 Pre-Plant Control in Corn

The GR giant ragweed was controlled 90 to 100% with all the evaluated pre-plant (soil applied) herbicides at 30

DAT (Table 7). For example, the use of a photosystem II inhibitor (atrazine, 2240 g ai ha^{-1}), HPPD inhibitor (isoxaflutole, 90 ai ha^{-1}) or their tank-mixture provided 97 to 100% control of the GR giant ragweed 30 DAT. In addition, tank-mixture of atrazine (1120 g ai ha^{-1}) plus a PPO inhibitor (flumioxazin, 210 g ai ha^{-1}) or a premix of atrazine with a shoot growth inhibitor (dimethenamid-p, 723 g ai ha^{-1}) provided 93 to 100% control of the GR giant ragweed 30 DAT. All tested pre-plant herbicides provided 87 to 97% biomass reduction of the giant ragweed 30 DAT. Re-evaluation of the herbicide treatments at 60 or 75 DAT showed that high rate of saflufenacil (75 g ai ha^{-1}) provided the lowest control (57 or 73%), followed by premix of flumioxazin/pyroxasulfone (85%), while other herbicide treatments maintained 90 to 100% control of the giant ragweed. Similarly, in a study conducted at two locations near Windsor, Vink et al. (2012b) reported a tank-mix of saflufenacil and glyphosate provided 82% control of GR giant ragweed 30 DAT. In general, our study suggests that several herbicides with different modes of action are available for pre-plant control of GR giant ragweed.

Table 6. Effective doses of saflufenacil and dicamba at 21 DAT for 50% control or biomass reduction (ED_{50}) and 90% control or biomass reduction (ED_{90}) of 10, 20, or 30 cm tall giant ragweed

	Control		Biomass reduction	
Weed height (cm)	ED_{50} (±SE)	ED_{90} (±SE)	ED_{50} (±SE)	ED_{90} (±SE)
	-------------------Saflufenacil (g ai ha^{-1})------------------			
10	197 (132)	532 (38)	103 (11)	238 (40)
20	227 (108)	495 (101)	210 (79)	437 (233)
30	652 (373)	810 (221)	265 (87)	804 (280)
	------------------Dicamba (g ae ha^{-1})----------------------			
10	52 (29)	214 (132)	37 (18)	120 (30)
20	210 (40)	402 (102)	146 (18)	252 (15)
30	284 (31)	482 (101)	439 (58)	603 (302)

Table 7. Pre-plant herbicide program on GR giant ragweed in Corn in 2013 and 2014

Herbicide	Rate	Control			Biomass reduction
		30 DAT	60 DAT	75 DAT	30 DAT
	g ai ha^{-1}	----------------------%-----------------------			
Atrazine	2240	100	90 a	90 a	96
Isoxaflutole	90	100	100 a	100 a	97
Isoxaflutole + Atrazine	90 + 1120	97	100 a	100 a	89
Mesotrione	300	97	100 a	100 a	89
Thiencarbazone-methyl/isoxaflutole	129	90	100 a	100 a	90
Flumioxazin/Pyroxasulfone	315	100	85 b	85 b	91
Dimethenamid-P/atrazine	723	100	100 a	100 a	96
S-metolachlor/mesotrione/atrazine	2780	97	100 a	100 a	91
Saflufenacil	75	90	73 c	57 c	87
Flumioxazin + Atrazine	210 + 1120	93	98 a	97 a	90
Saflufenacil/dimethenamid-P	730	100	90 a	80 b	94
Mesotrione + S-metolachlor	600	100	100 a	100 a	97
LSD ($\alpha \leq 0.05$)			*	*	

[a]Abbreviations: DAT, days after treatment; data of non-treated plots were excluded in the analyses. Reduction in biomass was relative to biomass of non-treated plot.

[b]Data within column with uncommon alphabet(s) are different based on Fisher's LSD test ($\alpha \leq 0.05$).

[c]Herbicide premix (/); herbicide tank-mix (+); * Significant difference among treatments ($\alpha \leq 0.05$).

3.3 PRE followed by POST Control in Corn

Most of the evaluated PRE herbicides provided 88 to 95% control of the GR giant ragweed, with an improved control up 100% when PRE was followed by POST application of auxin herbicides (Table 8). For example, PRE application of atrazine (2240 g ai ha^{-1}) or isoxaflutole (90 ai ha^{-1}) provided 93 or 95% control 30 DAT, while a complete (100%) control was recorded when followed by POST application of 2,4-D (535 g ae ha^{-1}). The lowest

(69%) control provided PRE application of saflufenacil (75 g ai ha^{-1}); however, POST application of dicamba (66 g ae ha^{-1}) improved control to 100%. Biomass was reduced at least 90% when PRE was followed by POST application of the any of the auxinic herbicides. Similarly, Vink et al. (2012b) reported at least 90% reduction in GR giant ragweed biomass with PRE followed by POST application of dicamba.

Table 8. PRE followed by (fb) POST herbicide program on GR giant ragweed in Corn in 2013 and 2014

		Control		Biomass reduction
Herbicide	Rate	30 DAPRE	30 DAPOST	30 DAPOST
	g ai (ae) ha^{-1}	------------------%--------------------		
Atrazine fb 2,4-D	2240 fb 535	93 a	100	90
Isoxaflutole fb 2,4-D	90 fb 535	94 a	100	90
Isoxaflutole + atrazine fb 2,4-D	90 + 1120 fb 535	95 a	100	95
Mesotrione fb flumetsulam/clopyralid	300 fb 54	88 ab	100	94
Thiencarbazone-methyl/isoxaflutole fb 2,4-D	129 fb 535	95 a	100	95
2,4 D (POST-only)	535	10 d	91	90
Dimethenamid-P/atrazine fb 2,4-D	723 fb 535	93 a	100	94
S-metolachlor/mesotrione/atrazine fb 2,4-D	2780 fb 535	94 a	100	93
Saflufenacil fb diflufenzopyr/dicamba	75 fb 360	69 c	100	96
Saflufenacil/dimethenamid-P fb diflufenzopyr/dicamba	730 fb 360	87 b	100	96
Mesotrione + S-metolachlor fb diflufenzopyr/dicamba	600 fb 360	89 ab	100	95
LSD (α ≤ 0.05)		*		

[a]Abbreviations: DAPRE, days after PRE; DAPOST, days after POST; data of non-treated plots were excluded in the analyses. Reduction in biomass was relative to biomass of non-treated plot.

[b]Data within column with uncommon alphabet(s) are different based on Fisher's LSD test (α ≤ 0.05).

[c]Herbicide premix (/); herbicide tank-mix (+)

*Significant difference among treatments (α ≤ 0.05).

Table 9. PRE followed by (fb) POST herbicide program on GR giant ragweed in Soybean in 2013 and 2014

		Control		Biomass reduction
Herbicide	Rate	30 DAPRE	30 DAPOST	30DAPOST
	g ai ha^{-1}	-------------------%-----------------		
Sulfentrazone/cloransulam fb imazamox + acifluorfen	392 fb 35 + 280	100 a	100	98
Chlorimuron/flumioxazin/thifensulfuron fb imazamox + acifluorfen	106 fb 35 + 280	100 a	100	99
Clorasulam fb lactofen	10 fb 219	100 a	100	97
Flumioxazin/clorasulam + flumioxazin + clorasulam fb imazamox + acifluorfen	129 + 75 + 10 fb 35 + 280	100 a	100	96
Saflufenacil/imazethapyr fb lactofen	100 fb 219	90 ab	100	98
Imazethapyr fb lactofen	70 fb 219	90 ab	98	96
Imazethapyr + S-metolachlor fb lactofen	70 + 1411 fb 219	85 b	100	96
Imazaquin fb lactofen	143 + 1411 fb 219	100 a	100	96
Metribuzin fb lactofen	438 fb 219	84 b	98	94
Flumioxazin fb clorasulam	113 fb 5	98 a	100	96
Flumioxazin/Chlorimuron fb imazamox + acifluorfen	158 fb 35 + 280	100 a	100	98
LSD (α ≤ 0.05)		*		

[a]Abbreviations: DAPRE, days after PRE; DAPOST, days after POST; data of non-treated plots were excluded in the analyses. Reduction in biomass was relative to biomass of non-treated plot.

[b]Data within column with uncommon alphabet(s) are different based on Fisher's LSD test (α ≤ 0.05).

[c]Herbicide premix (/); herbicide tank-mix (+)

*Significant difference among treatments (α ≤ 0.05).

Table 10. POST-only herbicide program on GR giant ragweed in Soybean in 2013 and 2014

Herbicide	Rate	Control 30 DAT	Biomass reduction 30 DAT
	g ai ha^{-1}	------------%-----------	
Clorasulam	5	80 b	75 b
Thifensulfuron + chlorimuron	5 + 5	40 c	41 c
Lactofen	219	85 b	82 b
Imazamox + acifluorfen	35 +280	62 c	61 c
Fomesafen/glyphosate	1382	96 a	92 a
LSD (α ≤ 0.05)		*	*

[a]Abbreviations: DAT, days after treatment; data of non-treated plots were excluded in the analyses. Reduction in biomass was relative to biomass of non-treated plot.

[b]Data within column with uncommon alphabet(s) are different based on Fisher's LSD test (α ≤ 0.05)

[c]Herbicide premix (/); herbicide tank-mix (+)

*Significant difference among treatments (α ≤ 0.05).

3.4 PRE followed by POST Control in Soybean

The GR giant ragweed population was controlled 90 to 100% with most of the evaluated PRE herbicides, with a sustained or improved control with POST application of herbicides (Table 9). For example, PRE applied premix of sulfentrazone/cloransulam (392 g ai ha^{-1}) provided 100% control of giant ragweed 30 days after PRE (DAPRE); this level of control was sustained with POST applied tank-mix of imazamox (35 g ai ha^{-1}) plus acifluorfen (280 g ai ha^{-1}) 30 days after POST (DAPOST). In addition, PRE application of imazethapyr (70 g ai ha^{-1}) provided 90% control, while 100% control was achieved when followed by POST application of lactofen (219 g ai ha^{-1}) 30 DAPOST.

The least control (84%) was provided by PRE application of metribuzin (438 g ai ha^{-1}) 30 DAPOST; however, 98% control was achieved when followed by POST application of lactofen (219 g ai ha^{-1}). Giant ragweed biomass reduction with the herbicide programs was similar to the visual control ratings 30 DAPOST (Table 8). These results indicates that there are available herbicide options for GR giant ragweed control in soybean.

3.5 POST-only Control in Soybean

POST-only herbicide program provided ≤ 90% GR giant ragweed control, except POST-application of fomesafen/glyphosate (1380 g ai ha^{-1}) which provided 96% control 30 DAT (Table 10). The poor control of giant ragweed by the POST-only herbicides may be attributed to high ragweed density and taller plants at the time of application. Giant ragweed usually emerges early in the growing season; thus, a delayed POST weed control program would result in poor giant ragweed control. Previous research has shown that without pre-plant or PRE weed control, POST-only herbicide program could provide undesirable control of GR giant ragweed (Ganie et al., 2016; Follings et al., 2013).

Weed control programs based on rotation of herbicides or mixtures of multiple site of actions has been widely recommended to minimize selection pressure often associated with evolution of resistant weeds (Knezevic et al., 2009; Robinson et al., 2012; Regnier et al., 2016; Osipitan and Dille, 2017; Evans et al., 2018). In addition, risk of herbicide resistance may be reduced when PRE followed by POST application programs are used as part of diverse approach to weed control (Livingston et al. 2015). Research also showed that that sequential application of PRE followed by POST herbicides would control cohorts that emerge over longer period of time in the growing season, especially early- and mid-season emerging weeds (Vink et al., 2012a; Kaur et al., 2016). In general, it is recommended that PRE followed by POST herbicide program would be a good tool for GR giant ragweed control in corn and soybean. Results from this study confirmed that giant ragweed population near David city, Nebraska was truly glyphosate resistant and that dicamba can effectively control the GR giant ragweed, particularly when applied at early growth stage (10 to 20 cm tall) of the weed. Most importantly and from the practical standpoint, we determined that there are herbicide programs available to effectively control GR ragweed in corn and soybean, at least under Nebraska's growing conditions.

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