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Glyphosate-Resistant Giant Ragweed (*Ambrosia trifida* L.): 2,4-D Dose Response and Control with Postemergence Herbicides in Soybean

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ABSTRACT

Glyphosate resistant giant ragweed is an increasing problem in glyphosate resistant cropping systems in southwestern Ontario. The postemergence herbicides registered for use in soybean in Ontario do not provide consistent control of glyphosate resistant giant ragweed. There is limited research on the lowest effective rate of 2,4-D for the control of glyphosate resistant giant ragweed. Consequently, the objectives of this study were a) to determine the efficacy of herbicides applied postemergence for the control of glyphosate resistant giant ragweed in glyphosate resistant soybean, and b) to determine the lowest effective rate of 2,4-D for the control of glyphosate-resistant giant ragweed. Ten postemergence herbicide combinations and seven rates of 2,4-D were evaluated in field studies conducted in 2011 and 2012 at six locations confirmed with glyphosate-resistant giant ragweed. The post emergence herbicides evaluated did not provide acceptable/consistent control. Of the herbicides evaluated, glyphosate plus cloransulam-methyl provided 26% to 70% control 8 WAA of glyphosate resistant giant ragweed, which was the best of the herbicides combinations evaluated. The doses of 2,4-D required to reduce giant ragweed shoot dry weight by 50, 80 and 95% were 142, 310 and 1048 g a.e. ha^{-1}, respectively

Keywords: Glyphosate Resistance; Multiple Herbicide-Resistant Crops; Preplant Herbicides; Postemergence Herbicides

1. Introduction

Glyphosate is the most widely used postemergence, non-selective herbicide in the world [1] and is used in row crops, orchards, fallow lands and pastures [2]. Since the introduction of glyphosate resistant soybean in 1996, there has been a rapid increase in the use of glyphosate resistant crops [3]. In large soybean growing countries such as Argentina and the United States, more than 90% of soybeans grown are glyphosate resistant [3,4]. The use of glyphosate resistant crops has changed weed management practices causing intense selection pressure for glyphosate resistant weeds [5]. There is a widespread glyphosate resistance in weed species around the world. The first glyphosate resistant weed reported was a population of rigid ryegrass (*Lolium rigidum* L. Gaud) in Australia

in 1996 [6]. Since then, additional glyphosate resistant weeds were reported. Currently there are 24 weed species resistant to glyphosate worldwide [7].

Giant ragweed (*Ambrosia trifida* L.) is an erect broadleaf weed that can be found in southern areas of Manitoba, Ontario, Quebec, New Brunswick, Nova Scotia and Prince Edward Island in Canada [8]. In Ontario it is commonly found in crop production fields in the southwestern part of the province [9]. Giant ragweed is difficult to control due to its long emergence period. Giant ragweed seedlings begin to emerge in early March [10] and continue to emerge until late July [11]. Historically, growers in Ontario would control this problematic weed with glyphosate; however, in 2008 giant ragweed was confirmed to be resistant to glyphosate [12].

Glyphosate resistant giant ragweed is an increasing problem in glyphosate resistant cropping systems in On-

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tario. As of 2010 there were 48 locations confirmed with glyphosate resistant giant ragweed in Ontario (Vink *et. al.*, 2012). There are few herbicides applied postemergence that provide acceptable control of glyphosate resistant giant ragweed control in soybean. Vink *et al*. [13] reported that glyphosate (900 g a.e. ha^{-1}) plus cloransulam-methyl (17.5 g a.i h^{-1}) provided 80% to 81% control of glyphosate resistant giant ragweed 8 weeks after application (WAA). Research is required to identify additional postemergence herbicides for the control of glyphosate resistant giant ragweed in soybean. The first objective of this study was to determine the efficacy of all the currently registered postemergence broadleaf herbicides registered for use in Ontario in soybean.

2,4-D is a herbicide commonly used for the control of broadleaf weeds and has been reported to control giant ragweed with one application [8]. Similarly Vink *et al*. [14] reported that glyphosate (900 g a.e. ha^{-1}) plus 2,4-D (500 g a.e. ha^{-1}) applied as a preplant burndown provided 97 to 99% control of glyphosate resistant giant ragweed. Research is required to identify the lowest effective rate of 2,4-D for the control of glyphosate resistant giant ragweed. The second objective of this study was to determine the lowest effective rate of 2,4-D tank mixed with glyphosate and applied as a preplant burndown for the control of glyphosate-resistant giant ragweed in soybean.

2. Materials and Methods

Field studies were conducted in 2011 and 2012 at six locations for the postemergence broadleaf herbicide experiment and five locations for the 2,4-D dose response experiment with confirmed glyphosate resistant giant ragweed. The field sites were located near Windsor (L2 and L5), La Salle (L1, L4 and L6) and Amherstburg (L3), Ontario. The first series of experiments evaluated the effectiveness of postemergence broadleaf herbicides. The second series of experiments, evaluated the biologically

effective rate of 2,4-D, is referred to as "dose response". Soil texture, soil organic matter content, soil pH, soybean cultivar, seeding date, seeding rate, row spacing, herbicide application date and giant ragweed height are presented in **Table 1**.

Experiments were set up in a randomized complete block design with four replications. Each plot was 8 m long and 2.5 m wide. Herbicides in the postemergence study included glyphosate (900 g a.e. ha^{-1}) applied alone, and acifluorfen (600 g a.i. ha^{-1}), fomesafen (240 g a.i. ha^{-1}) + Turbocharge (0.50% v/v), bentazon (1080 g a.i. ha^{-1}), thifensulfuron-methyl (6 g a.i. ha^{-1}) + Agral 90 (0.010% v/v) + UAN 28% (8.0 L·ha^{-1}), chlorimuron-ethyl (9 g a.i. ha^{-1}) + Agral 90 (0.20% v/v) + UAN 28% (2.0 L·ha^{-1}), cloransulam-methyl (17.5 g a.i. ha^{-1}) + Agral 90 (0.25% v/v) + UAN 28% (2.5% v/v), imazethapyr (100 g a.i. ha^{-1}) + Agral 90 (0.25% v/v) + UAN 28% (2.0 L· ha^{-1}), or imazethapyr (75 g a.i. ha^{-1}) plus bentazon (840 g a.i. ha^{-1})+ UAN 28% (2.0 L·ha^{-1}) applied with glyphosate (900 g a.e. ha^{-1}) and glyphosate/ fomesafen (1200 g a.i. ha^{-1}). The herbicide rates used were the maximum labeled rate registered for use in Ontario. The dose response experiment evaluated glyphosate (900 a.e. ha^{-1}) applied with 2,4-D at 31.25, 62.5, 125, 250, 500, 1000 or 2000 g a.e. ha^{-1}. A weedy and weed-free check was included in each experiment. All weed-free check plots were maintained with 2,4-D ester (500 g a.e. ha^{-1}) and glyphosate (900 g a.e. ha^{-1}) applied preplant (PP) and subsequent hand hoeing as required.

Herbicide treatments were applied with a CO_2-ressurized backpack sprayer equipped with ULD 120 - 02 nozzles (Hypro, New Brighton, MN) calibrated to deliver 200 L·ha^{-1} of water at 210 kPa. Herbicide treatments were applied with a 1.5 meter boom with four nozzles spaced 50 cm apart over the centre of the plot. Herbicide treatments were applied when giant ragweed reached 15 cm in height (**Table 1**).

Table 1. Location and soil characteristics, soybean cultivar, seeding date, soybean population, herbicide application date, and giant ragweed height at time of application for a post herbicide and 2,4-D dose experiments conducted in Ontario in 2011 and 2012.

Location	Year	Soil texture	Soil OM	Soil pH	Soybean cultivar	Seeding date	Soybean population	Herbicide application date	Giant ragweed height
			(%)				(seeds·ha^{-1})		(cm)
1-LaSalle	2011	Loam	2.6	7.5	Dekalb 31 - 10	June 13	467,029	May 21	0 - 7
2-Windsor	2011	Loam	2.8	6.9	Pioneer 92Y80	June 15	420,079	June 2	0 - 12
3-Amherstburg	2012	Clay loam	3.7	7.9	Pioneer 92Y53	May 22	568,100	May 1	0 - 7
4-LaSalle	2012	Loam	3.1	7.3	Dekalb 21 - 11	May 16	444,780	May 8	0 - 10
5-Windsor	2012	Clay loam	4.6	6.6	Pioneer 93Y05	June 8	432,250	May 8	0 - 10
6-LaSalle	2012	Loam	3.1	7.3	Dekalb 21 - 11	May 16	444,780	May 8	0 - 11

Weed control was rated visually 1, 2, 4 and 8 WAA on a scale of 0% to 100%, where 0% was no control of giant ragweed compared to the weedy check and 100% was complete control of giant ragweed. At each control rating giant ragweed height and density (plants per two 0.25 m² quadrats) were recorded. At 4 WAA, giant ragweed density and biomass was determined in each plot by counting giant ragweed plants in two 0.25 m² quadrats. Giant ragweed plants were cut off at the soil surface from the two quadrats, placed in bags, dried at 60°C to a constant moisture content and the dry weights were recorded. Soybean injury was rated 1, 2, 4 and 8 WAA. Soybean injury was rated visually on a scale of 0% to 100%, where 0% was no soybean injury and 100% was soybean death. At crop maturity, soybeans were hand harvested from 2 m of row from each plot at all locations. Soybeans were threshed in a stationary thresher and the weight and moisture were recorded. Yields were adjusted to 13.5% moisture.

2.1. Statistical Analysis

2.1.1. Postemergence Herbicides

An analysis of variance was conducted on all data using the PROC MIXED procedure in SAS (Ver. 9.2, SAS Institute Inc., Cary, NC). Variances were separated into the random effects of location (year and location), replication (at each location) and location by treatment. Herbicide treatment was considered the fixed effect. The significance of the random effects (location, replication and location by treatment) and their interaction with fixed effects was tested using the Z-test of the variance estimate. The significance of the fixed effects was tested using the F-test. Significant location by treatment interactions were found for all variables; therefore, locations were analyzed according to their interaction and presented accordingly. To ensure the assumptions (errors are independent, homogenous and normally distributed) of the variance analysis were met; residual plots were examined. Data were tested for normality using the Shapiro-Wilk statistic as generated by the UNIVARIATE procedure in SAS. If necessary, a transformation of the data (natural log, square root or arcsine square root) was applied and chosen based on the highest Shapiro-Wilk statistic generated. Control data 1 WAA were arcsine square root transformed at L2, L4, L5 and L6 and data at L1 and L3 were log transformed. Control data 2 WAA were arcsine square root transformed at L1, L2, L5 and L6 and data at L3 and L4 were log transformed. Control data 4 WAA were arcsine transformed at L1 and L2 and data at L3, L4, L5 and L6 were log transformed. Control data 8 WAA were square root transformed at L1, L2 and L3 and data at L4, L5, and L6 were log transformed. All

giant ragweed shoot dry weight data was square root transformed. Soybean yield data were square root transformed at L1 and L2 and data at L3, L4, L5 and L6 were arcsine square root transformed. The means between treatments were separated using Fisher's protected LSD at P < 0.05.

2.1.2. Field Dose Response

An analysis of variance was conducted on all data using the PROC MIXED procedure in SAS (Ver. 9.2, SAS Institute Inc., Cary, NC). Variances were separated into the random effects of location (year and location), replication (at each location) and location by treatment. Herbicide treatment was considered the fixed effect. The significance of the random effects (location, replication and location by treatment) and their interaction with fixed effects was tested using the Z-test of the variance estimate. The significance of the fixed effects was tested using the F-test. Significant location by treatment interactions were found for all variables; therefore, locations were analyzed according to their interaction and presented accordingly. To ensure the assumptions (errors are independent, homogenous and normally distributed) of the variance analysis were met; residual plots were examined. Data were tested for normality using the Shapiro-Wilk statistic as generated by the UNIVARIATE procedure in SAS. If necessary, a transformation of the data (natural log, square root or arcsine square root) was applied and chosen based on the highest Shapiro-Wilk statistic generated. Control data 1 WAA were arcsine square root transformed at L1, L2, L3 and L5 and data at L4 was log transformed. Control data 2 WAA were arcsine square root transformed at L1, L2, L3, and L5 and data at L4 were not transformed. Control data 4 WAA were arcsine square root transformed at L1, L4, L3 and L5 and data at L2 was square root transformed. Control data 8 WAA were arcsine square root transformed at all locations. Giant ragweed shoot dry weight was presented as a percent of the weedy control and was log transformed. Soybean yield was presented as a percent of the weed-free control and was not transformed.

A non-linear regression analysis was conducted on all data using the PROC NLIN procedure in SAS (Ver. 9.2, SAS Institute Inc., Cary, NC). A sigmoidal log-logistic curve was used:

$$Y = C + (D - C) \big/ \left\{ 1 + \exp\left[B\left(\ln(\text{dose}) - \ln(I_{50}) \right) \right] \right\}$$

where Y is percent giant ragweed control or percent soybean yield, C is the lower limit, D is the upper limit, B is the slope, and I50 is the dose where there is a 50% response [15]. The effective dose (ED) of 2,4-D was also calculated using this equation. Where possible, the ED50,

ED80 and ED95 were calculated and represent the dose required to achieve 50%, 80%, and 95% control of glyphosate resistant giant ragweed compared to the weed-free control. The ED50, ED80 and ED95 also represent 50%, 80%, and 95% of the soybean yield compared to the weed-free control. For giant ragweed shoot dry weight, the ED50, ED80, and ED95 represent the dose needed to reduced giant ragweed shoot dry weight by 50%, 80% and 95%.

3. Results and Discussion

3.1. Postemergence Herbicides

Control of glyphosate resistant giant ragweed with post-emergence herbicides is extremely difficult as no herbicide consistently provided greater than 75% control at 1 WAA (**Table 2**). At 1 WAA, control data at L4, L5 and L6 could be combined and L1, L2 and L3 were analyzed separately (**Table 2**). Control with glyphosate ranged from 30% to 56% confirming the resistance status of the sites. Glyphosate plus fomesafen as a tank mix and glyphosate/fomesafen as a premix were the most effective treatments providing 75% to 88% and 69% to 83% control, respectively. The highest level of control 1 WAA with the addition of acifluorfen or bentazon to glyphosate was 81% and 82% control, respectively (**Table 2**). Glyphosate plus thifensulfuron, chlorimuron-ethyl, cloran-

sulam-methyl, imazethapyr, or imazethapyr plus bentazon provided less than 80% control.

At 2 WAA, L1 and L2, L5 and L6 could be combined while L3 and L4 were analyzed separately (**Table 3**). Two weeks after application, all treatments had a level of control that was declining compared to the 1 WAA assessment. Glyphosate provided less than 40% control of glyphosate resistant giant ragweed across all locations, while the addition of fomesafen provided 52% to 74% control which is similar to the findings of Vink *et al*. [13] who reported 50% to 86% control with glyphosate plus fomesafen applied at the same rate. Glyphosate/fomesafen or glyphosate plus acifluorfen, thifensulfuron, chlorimuron-ethyl, cloransulam-methyl, bentazon, imazethapyr, or imazethapyr plus bentazon provided less than 76% control across all locations (**Table 3**).

At 4 WAA data could be combined and analyzed in groups L1 and L2 and L3, L4, L5 and L6 (**Table 4**). Glyphosate provided 23% to 32% control, while glyphosate plus imazethapyr provided 46% to 82% control. This is similar to the findings of Vink *et al*. [13] who reported 69% to 82% control with glyphosate plus imazethapyr applied at 900 g a.e. ha^{-1} + 100 g a.i. ha^{-1}. Surprisingly, glyphosate plus cloransulam-methyl provided 56% to 74% control 4 WAA opposite to what was observed before with this herbicide combination providing 88% to 92% control [13]. Cloransulam-methyl POST is espe-

Table 2. Percent control of glyphosate resistant giant ragweed 1 WAA with herbicides applied post emergence.

Treatment	Rate	Control 1 WAA[a]			
		L1[a]	L2	L3	L4, L5, and L6
	(g a.i. ha^{-1})			%	
Weedy Check		0 i	0 f	0 h	0 e
Weed Free Check		100 a	100 a	100 a	100 a
Glyphosate	900	56 g	34 e	30 ef	36 d
Glyphosate + Acifluorfen	900 + 600	76 cd	81 b	60 c	72 b
Glyphosate + Fomesafen[b]	900 + 240	88 b	75 bc	76 b	76 b
Glyphosate + Bentazon	900 + 1080	64 ef	82 b	30 ef	55 c
Glyphosate + Thifensulfuron[c]	900 + 6	46 h	63 cd	29 fg	51 c
Glyphosate + Chlorimuron-ethyl[d]	900 + 9	70 de	74 bcd	26 g	52 c
Glyphosate + Cloransulam-methyl[e]	900 + 17.5	78 c	63 d	34 de	55 c
Glyphosate + Imazethapyr[e]	900 + 100	66 e	77 b	35 d	55 c
Glyphosate + Imazethapyr + Bentazon[f]	900 + 75 + 840	60 fg	79 b	30 ef	57 c
Glyphosate/Fomesafen	1200	82 bc	83 b	69 b	75 b

[a]L1, LaSalle; L2, Windsor; L3, Amherstburg; L4, LaSalle; L5, Windsor; L6, LaSalle, WAA, weeks after herbicide application. [b]Included Turbocharge at 0.50% vol/vol. [c]Included Agral 90 at 0.10% vol/vol plus UAN 28%. [d]Included Agral 90 at 0.20% vol/vol plus UAN 28%. [e]Included Agral 90 at 0.25% vol/vol plus UAN 28%. [f]Included UAN 28%. [a-i]Means followed by the same letter are not significantly different according to Fisher's Protected LSD at P < 0.05.

Table 3. Percent control of glyphosate resistant giant ragweed 2 WAA with herbicides applied post emergence.

Treatment	Rate	Control 2 WAA[a]			
		L1 and L2[a]	L3	L4	L5, and L6
	(g a.i. ha^{-1})	_____% _____			
Weedy Check		0 d	0 h	0 h	0 g
Weed Free Check		100 a	100 a	100 a	100 a
Glyphosate	900	38 c	37 ef	32 g	34 f
Glyphosate + Acifluorfen	900 + 600	72 b	70 b	52 f	68 b
Glyphosate + Fomesafen[b]	900 + 240	74 b	65 b	59 de	52 cde
Glyphosate + Bentazon	900 + 1080	67 b	31 g	57 def	44 def
Glyphosate + Thifensulfuron[c]	900 + 6	50 bc	34 fg	56 ef	40 ef
Glyphosate + Chlorimuron-ethyl[d]	900 + 9	70 b	40 e	61 cde	50 cde
Glyphosate + Cloransulam-methyl[e]	900 + 17.5	75 b	62 b	66 bc	56 bcd
Glyphosate + Imazethapyr[e]	900 + 100	76 b	47 c	66 bc	63 bc
Glyphosate + Imazethapyr + Bentazon[f]	900 + 75 + 840	75 b	41 de	69 b	53 bcde
Glyphosate/Fomesafen	1200	72 b	46 cd	62 bcd	65 bc

[a]L1, LaSalle; L2, Windsor; L3, Amherstburg; L4, LaSalle; L5, Windsor; L6, LaSalle, WAA, weeks after herbicide application. [b]Included Turbocharge at 0.50% vol/vol. [c]Included Agral 90 at 0.10% vol/vol plus UAN 28%. [d]Included Agral 90 at 0.20% vol/vol plus UAN 28%. [e]Included Agral 90 at 0.25% vol/vol plus UAN 28%. [f]Included UAN 28%. [a-h]Means followed by the same letter are not significantly different according to Fisher's Protected LSD at P < 0.05.

Table 4. Percent control of glyphosate resistant giant ragweed 4 WAA with herbicides applied post emergence.

Treatment	Rate	Control 4 WAA[a]	
		L1 and L2[a]	L3, L4, L5 and L6
	(g a.i. ha^{-1})	_____% _____	
Weedy Check		0 e	0 g
Weed Free Check		100 a	100 a
Glyphosate	900	32 d	23 f
Glyphosate + Acifluorfen	900 + 600	65 bcd	35 de
Glyphosate + Fomesafen[b]	900 + 240	63 bcd	28 ef
Glyphosate + Bentazon	900 + 1080	60 bcd	24 f
Glyphosate + Thifensulfuron[c]	900 + 6	44 cd	25 f
Glyphosate + Chlorimuron-ethyl[d]	900 + 9	73 bc	29 def
Glyphosate + Cloransulam-methyl[e]	900 + 17.5	74 bc	56 b
Glyphosate + Imazethapyr[e]	900 + 100	82 b	46 bc
Glyphosate + Imazethapyr + Bentazon[f]	900 + 75 + 840	71 bc	34 de
Glyphosate/Fomesafen	1200	69 bc	37 cd

[a]L1, LaSalle; L2, Windsor; L3, Amherstburg; L4, LaSalle; L5, Windsor; L6, LaSalle, WAA, weeks after herbicide application. [b]Included Turbocharge at 0.50% vol/vol. [c]Included Agral 90 at 0.10% vol/vol plus UAN 28%. [d]Included Agral 90 at 0.20% vol/vol plus UAN 28%. [e]Included Agral 90 at 0.25% vol/vol plus UAN 28%. [f]Included UAN 28%. [a-g]Means followed by the same letter are not significantly different according to Fisher's Protected LSD at P < 0.05.

cially active on this species with 18 g a.i. ha^{-1} providing 98% to 99% control of 12 to 15 cm glyphosate-resistant giant ragweed [16]. Glyphosate plus acifluorfen provided 35% to 65% control and was equivalent to glyphosate applied alone at L1 and L2. This is in contrast to the findings of Norsworthy *et al*. [16] who reported 76% to 87% control of glyphosate resistant giant ragweed with acifluorfen applied at 420 g a.i ha^{-1}. Similarly applying fomesafen with glyphosate either as a tank mix or a premix gave only 69% control (**Table 4**). Similar results were found with bentazon mixed with glyphosate. Glyphosate/ fomesafen, glyphosate plus chlorimuron-ethyl or imazethapyr plus bentazon provided up to 69%, 73% and 69% control, respectively (**Table 4**). Glyphosate plus fomesafen, bentazon and thifensulfuron provided less than 65% control and were equivalent to glyphosate applied alone across all locations. This is in contrast to the findings of Norsworthy *et al*. [16] who reported 100% control of glyphosate resistant giant ragweed with fomesafen applied alone at 263 g a.i. ha^{-1} or bentazon applied alone at 840 g a.i. ha^{-1}.

At 8 WAA data could be combined into groups L1 and L2 and L4, L5 and L6 while L3 was analyzed separately (**Table 5**). Control was generally higher with all herbicides evaluated for group L1 and L2 compared to L3 and L4, L5 and L6 and may be due to higher levels of rainfall in 2011. The average rainfall for the months of May and June 2011 were 179.4 mm and 83.4 mm, respectively for Windsor Ontario [17]. The average rainfall for the months of May and June 2012 were 88.6 mm and 42.2 mm, respectively for Windsor, Ontario [17]. Control may have also been higher in 2011 due to a higher proportion of resistant biotypes at sites L3 and L4, L5 and L6. Glyphosate provided 3% to 19% control. Glyphosate plus cloransulam-methyl was the most effective post emergence treatment providing 26% to 70% control. This is in contrast to the findings of Vink *et al*. [13] who reported 80% to 81% control with glyphosate plus cloransulam-methyl applied at 900 g a.e. ha^{-1} + 17.5 g a.i. ha^{-1}. Glyphosate/fomesafen, glyphosate plus acifluorfen, chlorimuron-ethyl, or imazethapyr provided up to 45%, 38%, 53% and 60% control, respectively. Glyphosate plus fomesafen, bentazon, thifensulfuron or imazethapyr plus bentazon were equivalent to glyphosate applied alone.

For giant ragweed shoot dry weight all data were combined and analyzed (**Table 6**). Glyphosate alone and glyphosate plus bentazon reduced giant ragweed shoot dry weight by 24% and 27% respectively and were equivalent to the weedy control. Glyphosate plus cloransulam-methyl reduced giant ragweed shoot dry weight by 64%. This is in contrast to Vink *et al*. [13] who reported a 98% reduction in giant ragweed shoot dry weight with glyphosate plus cloransulam-methyl applied at 900 g a.e. ha^{-1} + 17.5 g a.i. ha^{-1}. Glyphosate plus fomesafen or

Table 5. Percent control of glyphosate resistant giant ragweed 8WAA with herbicides applied post emergence.

Treatment	Rate	L1 and L2[a]	L3	L4, L5 and L6
	(g a.i. ha^{-1})		%	
Weedy Check		0 f	0 f	0 e
Weed Free Check		100 a	100 a	100 a
Glyphosate	900	19 e	3 e	11 d
Glyphosate + Acifluorfen	900 + 600	38 cde	11 cd	14 cd
Glyphosate + Fomesafen[b]	900 + 240	41 bcde	7 cde	12 cd
Glyphosate + Bentazon	900 + 1080	35 cde	5 de	12 cd
Glyphosate + Thifensulfuron[c]	900 + 6	29 de	5 de	10 d
Glyphosate + Chlorimuron-ethyl[d]	900 + 9	53 bcd	7 cde	12 cd
Glyphosate + Cloransulam-methyl[e]	900 + 17.5	70 ab	55 b	26 b
Glyphosate + Imazethapyr[e]	900 + 100	60 bc	13 c	18 bc
Glyphosate + Imazethapyr + Bentazon[f]	900 + 75 + 840	40 bcde	4 e	13 cd
Glyphosate/Fomesafen	1200	45 bcd	5 e	14 cd

Column header spanning L1 and L2[a], L3, L4, L5 and L6: **Control 8 WAA[a]**

[a]L1, LaSalle; L2, Windsor; L3, Amherstburg; L4, LaSalle; L5, Windsor; L6, LaSalle, WAA, weeks after herbicide application. [b]Included Turbocharge at 0.50% vol/vol. [c]Included Agral 90 at 0.10% vol/vol plus UAN 28%. [d]Included Agral 90 at 0.20% vol/vol plus UAN 28%. [e]Included Agral 90 at 0.25% vol/vol plus UAN 28%. [f]Included UAN 28%. [a-f]Means followed by the same letter are not significantly different according to Fisher's Protected LSD at P < 0.05.

Table 6. Glyphosate resistant giant ragweed shoot dry weight and soybean yield for herbicides applied post emergence.

Treatment	Rate	Giant ragweed shoot dry weight	Soybean yield[a]		
		All combined	L1 and L2[a]	L3	L4, L5, and L6
	(g a.i. ha^{-1})	(g·m^{-2})		(t·a^{-1})	
Weedy Check		43.1 e	0.65 c	0.20 c	0.26 cd
Weed Free Check		0.0 a	2.68 a	4.03 a	1.90 a
Glyphosate	900	32.9 de	1.10 bc	0.13 cd	0.28 cd
Glyphosate + Acifluorfen	900 + 600	22.6 bcd	1.57 b	0.08 cd	0.30 cd
Glyphosate + Fomesafen[b]	900 + 240	20.2 bc	1.31 bc	0.16 cd	0.33 c
Glyphosate + Bentazon	900 + 1080	31.4 de	1.37 b	0.09 cd	0.18 d
Glyphosate + Thifensulfuron[c]	900 + 6	28.9 cd	1.17 bc	0.07 cd	0.27 cd
Glyphosate + Chlorimuron-ethyl[d]	900 + 9	24.1 bcd	1.60 b	0.07 d	0.31 c
Glyphosate + Cloransulam-methyl[e]	900 + 17.5	15.7 b	1.70 b	0.45 b	0.50 b
Glyphosate + Imazethapyr[e]	900 + 100	16.6 b	1.63 b	0.18 cd	0.41 bc
Glyphosate + Imazethapyr + Bentazon[f]	900 + 75 + 840	23.0 bcd	1.02 bc	0.09 cd	0.34 bc
Glyphosate/Fomesafen	1200	25.9 cd	1.26 bc	0.09 cd	0.31 c

[a]L1, LaSalle; L2, Windsor; L3, Amherstburg; L4, LaSalle; L5, Windsor; L6, LaSalle. [b]Included Turbocharge at 0.50% vol/vol. [c]Included Agral 90 at 0.10% vol/vol plus UAN 28%. [d]Included Agral 90 at 0.20% vol/vol plus UAN 28%. [e]Included Agral 90 at 0.25% vol/vol plus UAN 28%. [f]Included UAN 28%, [a-e]Means followed by the same letter are not significantly different according to Fisher's Protected LSD at P < 0.05.

imazethapyr reduced giant ragweed shoot dry weight by 53% and 61%, respectively (**Table 6**). Glyphosate/fomesafen, glyphosate plus acifluorfen, thifensulfuron, chlorimuron-ethyl or imazethapyr plus bentazon reduced giant ragweed shoot dry weight by less than 50% (**Table 6**).

Soybean yield data L1 and L2 and L4, L5 and L6 could be combined while L3 was analyzed separately (**Table 6**). Giant ragweed interference caused a reduction in soybean yield of 76% to 95% across all sites. Baysinger and Sims [18] reported a 92% yield loss in soybean due to giant ragweed interference. Giant ragweed interference with glyphosate alone caused a 59 to 97% reduction in soybean yield and was equivalent to the weedy control across all sites. Giant ragweed interference where glyphosate plus cloransulam-methyl was applied reduced soybean yield by 37% to 89%. In a previous study, there was no reduction in soybean yield with cloransulam-methyl applied at 17.5 g a.i. ha^{-1} and there was a 32% to 40% reduction in soybean yield with glyphosate plus cloransulam-methyl applied at 900 g a.e. h^{-1} + 17.5g a.i. ha^{-1} [13]. Glyphosate plus acifluorfen, bentazon, chlorimuron-ethyl or imazethapyr reduced soybean yield by 41% to 98%, 49% to 98%, 40% to 98%, 39% to 96%, respectively. This is similar to the findings of a previous study that reported a reduction in soybean yield equivalent to the weedy control when glyphosate plus clorimuron-ethyl, fomesafen and imazethapyr plus ben-

tazon was applied [13]. Giant ragweed interference with glyphosate/fomesafen, glyphosate plus fomesafen, thifensulfuron, or imazethapyr plus bentazon reduced soybean yield by up to 98%, 96%, 98% and 98%, respectively and were equivalent to the weedy control. The reduction in yields with these herbicides is consistent with the control ratings and giant ragweed shoot dry weight.

3.2. 2,4-D Dose Response

Soybean injury was observed at L4 1 WAE (weeks after emergence) with 2,4-D at rates of 1000 g a.e. ha^{-1} or greater. Soybean injury (delayed emergence) of 10% and 50% was observed at 1000 and 2000 g a.e. ha^{-1}, respectively (data not shown). Soybean injury was not observed at rates of 500 g a.e. ha^{-1} or less. Accentuated soybean injury at this site may be due to higher rainfall before and after application in 2011. The average rainfall for the month of May 2011 at this location was 179.4 mm [17]. In contrast the average rainfall for the month of May 2012 at this location was 88.6 mm [17].

Generally there was a high dose required for 80% and 95% control compared to the dose required for 50% control (**Table 7**). This may be due to the greater chance of error as the experiment was not designed specifically for evaluating the ED$_{80}$ and ED$_{95}$ [15]. The 2,4-D dose needed to achieve 50% control 1 WAA was 19 to 57 g

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Table 7. 2,4-D dose response for glyphosate-resistant giant ragweed control 1, 2, 4, and 8 WAA, shoot dry weight and soybean yield[a].

Dose Response	Location[d]	Regression parameters[b] (±SE)				2,4-D Dose (g a.e. ha^{-1})[c]		
		D	C	B	I_{50}	ED_{50}	ED_{80}	ED_{95}
Giant ragweed control								
1 WAA	L1, L2	88.8 (0.0)	30.6 (0.4)	3.0 (0.8)	72.3 (7.5)	57.4	128.5	-
	L3, L5	84.8 (0.0)	0.0 (0.0)	2.4 (0.2)	16.6 (1.1)	19.3	53.6	-
	L4	89.6 (0.1)	0.0 (0.0)	1.1 (0.2)	24.5 (2.4)	30.3	168.4	-
2 WAA	L1, L2	91.7 (0.0)	24.5 (0.2)	3.7 (0.8)	97.3 (7.7)	85.2	148.2	-
	L3, L5	92.8 (0.0)	0.0 (0.0)	0.9 (0.1)	31.1 (2.0)	37.0	238.3	-
	L4	91.0 (1.4)	0.0 (0.0)	1.4 (0.1)	40.2 (2.1)	46.3	165.9	-
4 WAA	L1	100.0 (1.3)	25.0 (9.4)	1.0 (0.5)	118.6 (65.8)	59.3	326.2	1660.4
	L2	95.7 (1.3)	14.4 (-0.4)	6.5 (2.7)	98.3 (11.2)	94.6	122.5	204
	L4	100 (0.1)	9.5 (1.4)	1.6 (0.2)	84.9 (12.5)	74.4	186.6	500.6
	L3, L5	100 (0.1)	0.0 (0.0)	1.0 (0.1)	68.2 (12.5)	68.2	272.8	1295.8
8 WAA	L1, L2	99.2 (0.2)	4.5 (1.1)	2.4 (0.6)	115.2 (13.7)	111.5	203.8	414.0
	L3, L5	100.0 (0.1)	1.5 (2.0)	1.5 (0.3)	95.9 (14.7)	94.0	238.6	675.6
	L4	100.0 (0.1)	0.0 (0.0)	1.1 (0.1)	84.4 (5.8)	84.4	297.6	1227.0
Giant ragweed shoot dry weight	All combined	97.0 (0.2)	0.0 (0.0)	1.9 (0.2)	137.3 (11.7)	141.8	310.2	1047.5
Soybean yield	All combined	100.0 (0.0)	20.0 (4.6)	1.5 (0.3)	190.9 (28.9)	135.8	397.1	1161.1

[a]Abbreviations: WAA, weeks after application. [b]Regression parameters: D, upper limit; C, lower limit; B, slope at I_{50}; I_{50}, rate needed for 50% response. [c]ED_{50}, ED_{80} and ED_{95}: Rates needed to achieve 50%, 80% and 95% control of giant ragweed compared to weed-free control. Rates needed to achieve 50%, 80% and 95% soybean yield compared to the weed-free control. Rates needed to achieve 50%, 80% and 95% reduction in giant ragweed shoot dry weight compared to the weedy control. [d]Location: L1, LaSalle; L2, Windsor; L3, Amherstburg; L4, LaSalle; L5, Windsor.

a.e. ha^{-1}. To achieve 80% control 1 WAA, the 2,4-D dose required was 53 to 168 g a.e. ha^{-1}. At 2 WAA, the dose needed to obtain 50% control was 37 to 85 g a.e. ha^{-1} while the dose needed to achieve 80% control was 148 to 238 g a.e. ha^{-1}.

At 4 WAA, L3 and L5 could be combined and L1, L2 and L4 were analyzed separately (**Table 7**). At L1 and L3 and L5, 59 and 68 g a.e. ha^{-1} of 2,4-D was needed to achieve 50% control and 1660 and 1296 g a.e. ha^{-1} was needed to achieve 95% control, respectively. In contrast at L2 and L4, 95 and 74 g a.e. ha^{-1} was needed to achieve 50% control and 204 and 501 g a.e. ha^{-1} was needed to achieve 95% control, respectively. This is similar to the findings of Vink *et al*. [14] who reported 97% to 98% control of glyphosate-resistant giant ragweed with glyphosate plus 2,4-D ester applied at 900 g a.e. ha^{-1} + 500 g a.e. ha^{-1} 4 WAA.

At 8 WAA L1 and L2 and L3 and L5 could be combined and L4 was analyzed separately (**Table 7**). At L1 and L2, 414 g a.e. ha^{-1} of 2,4-D was needed to achieve 95% control. At L3 and L5 94 g a.e. ha^{-1} of 2,4-D was needed to achieve 50% control and 676 g a.e. ha^{-1} was

needed to achieve 95% control. In contrast, at L4 1227 g a.e. ha^{-1} of 2,4-D was needed to achieve 95% control.

For giant ragweed shoot dry weight all data could be combined (**Table 7**). The 2,4-D dose required to reduce giant ragweed shoot dry weight by 50, 80 and 95% was 142, 310 and 1048 g a.e. ha^{-1}, respectively, which was generally higher than the dose required for control 4 WAA.

For soybean yield all data could be combined (**Table 7**). The dose of 2,4-D required for 50, 80 and 95% of the soybean yield in the weed free control was 136, 397 and 1161 g a.e. ha^{-1}, respectively which closely follows the rate of 2,4-D required to reduce giant ragweed shoot dry weight by 50, 80 and 95%. These data confirm that weed shoot dry weight is a good indicator of weed interference.

4. Conclusion

In summary, the postemergence broadleaf herbicides registered for use in Ontario provided variable control of glyphosate resistant giant ragweed across all sites. In general, the postemergence broadleaf herbicides did not

provide commercially acceptable control of glyphosate resistant giant ragweed. Glyphosate plus cloransulammethyl was the best of the herbicides evaluated; however, it did not provide acceptable control. The reduced control observed in this study may be due to multiple resistant giant ragweed. For the 2,4-D dose response experiment, 414 to 1227 g a.e. ha^{-1} of 2,4-D plus glyphosate applied at 900 g a.e. ha^{-1} was needed to achieve 95% control. This research concludes that growers must control glyphosate resistant giant ragweed before soybean emergence since none of the postemergence broadleaf herbicides registered in Ontario provides commercially acceptable control of glyphosate resistant giant ragweed. In addition, the lowest effective rate of 2,4-D applied preplant for the control of glyphosate resistant giant ragweed is 500 g a.e. ha^{-1}. Future research should study other herbicide tank mixes coupled with alternative management strategies such as tillage and crop rotation.

5. Acknowledgements

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