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Glyphosate-Resistant Common Ragweed (*Ambrosia artemisiifolia*) Control with Postemergence Herbicides and Glyphosate Dose Response in Soybean in Ontario

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Field trials were conducted in Ontario in 2013 and 2014 in soybean to determine the efficacy of POST herbicides on common ragweed resistant to group 2 and group 9 herbicides. Glyphosate dose-response experiments were conducted in the field on two resistant common ragweed populations and one susceptible population. None of the POST herbicides evaluated provided 80% control of glyphosate-resistant (GR) common ragweed. The most effective POST herbicide mixture was glyphosate (Monsanto Canada Inc., 67 Scurfield Blvd., Winnipeg, Manitoba, Canada) plus fomesafen(Syngenta Canada Inc., 140 Research Lane, Research Park Guelph, Ontario, Canada), which provided 68 to 98% control of GR common ragweed. Chlorimuron, cloransulam, imazethapyr, and thifensulfuron provided control similar to glyphosate alone. An application of glyphosate/fomesafen reduced biomass by as much as 95%. Glyphosate plus acifluorfen reduced GR common ragweed biomass by as much as 92%. The remaining POST herbicide tank mixes evaluated reduced GR common ragweed biomass by less than 80%. Glyphosate plus bentazon, glyphosate plus chlorimuron, and glyphosate plus thifensulfuron resulted in soybean yields similar to the weedy control, with yield reductions of 70, 62, and 73%, respectively. An application of glyphosate plus fomesafen or glyphosate/fomesafen had the lowest soybean yield reductions of 29 and 34%, respectively. The resistant biotype required a 2- to 28-fold increase in glyphosate dose compared to the susceptible population to achieve 50% control.

Nomenclature: Acifluorfen; bentazon; chlorimuron; cloransulam; fomesafen; glyphosate; imazethapyr; thifensulfuron; common ragweed, *Ambrosia artemisiifolia* L.; soybean, *Glycine max*. L. Merr.

Key words: Glyphosate resistance, postemergence herbicides.

En 2013 y 2014 en Ontario, se realizaron estudios de campo en soja para determinar la eficacia de herbicidas POST sobre *Ambrosia artemisiifolia* resistente a herbicidas de los grupos 2 y 9. Experimentos de respuesta a dosis de glyphosate fueron realizados en el campo con dos poblaciones resistentes y una población susceptible de *A. artemisiifolia*. Ninguno de los herbicidas POST evaluados brindó >80% de control de *A. artemisiifolia* resistente a glyphosate (GR). Las mezclas de herbicidas POST más efectivas fueron glyphosate más fomesafen, las cuales brindaron 68 a 98% de control de *A. artemisiifolia* GR. Chlorimuron, cloransulam, imazethapyr, y thifensulfuron brindaron un control similar a glyphosate solo. Una aplicación de glyphosate/fomesafen redujo la biomasa hasta 95%. Glyphosate más acifluorfen redujo la biomasa de *A. artemisiifolia* GR hasta 92%. Glyphosate más bentazon, glyphosate más chlorimuron, y glyphosate más thifensulfuron resultaron en rendimientos de soja similares al testigo con malezas, con reducciones en el rendimiento de 70, 63, y 73%, respectivamente. Una aplicación de glyphosate más fomesafen o glyphosate/fomesafen tuvieron las menores reducciones en el rendimiento de la soja con 29 y 34%, respectivamente. El biotipo resistente requirió un incremento de 2 a 28 veces en la dosis de glyphosate al compararse con la población susceptible para alcanzar 50% de control.

Common ragweed is a common annual broadleaf weed in Ontario (Frick and Thomas 1992). Common ragweed is monoecious, with one plant able to produce up to 62,000 seeds (Jordan et al. 2013). It germinates between late April and early May (Jordan et al. 2013), which coincides with soybean emergence in Ontario. Common ragweed can have a negative effect on soybean yield by as

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much as 132 kg ha^{-1} when four weeds are present per 10-m row of soybean (Coble et al. 1981). In addition, common ragweed is a major problem for allergy sufferers because the pollen is one of the main causes of hay fever (Alex and Switzer 1975). This has caused common ragweed to be listed as a noxious weed in Ontario, requiring landowners to remove it from their property (Cowbrough 2006).

The first glyphosate resistant (GR) common ragweed population was found in Missouri in 2004 (Heap 2013; Pollard 2007). GR common ragweed has now been documented in 15 U.S. states and Ontario, Canada (Heap 2013). Previously, glyphosate provided excellent control of common ragweed (OMAFRA 2011). Its seeds can be viable in the soil for up to 39 yr (Lanini and Wertz 2013; Toole and Brown 1946); therefore, once resistance has developed in a field, seeds from those plants can germinate for many decades thereafter.

Common ragweed resistant to the acetolactate synthase–inhibiting (Group 2) herbicides was first confirmed in Ontario in 2000 (Heap 2013). A survey conducted in southwestern Ontario from 2011 through 2013 found that all common ragweed populations tested were resistant to three families (sulfonylureas, imidazolinones, and triazolopyrimidines) of group 2 herbicides (Van Wely et al. 2015). In addition, some of these populations were also resistant to glyphosate, indicating multiple-resistant common ragweed is present in Ontario.

The environmental impact quotient (EIQ), developed by Kovach et al. (1992), is a value from an equation that estimates the environmental impact (EI) of a herbicide by taking into account the impact of the herbicide on the applicator, the consumer, and an ecological component. The impact of a specific herbicide is determined by taking the EIQ of the herbicide and multiplying it by the application rate; the lower the number, the lower the EI of the herbicide (Edwards-Jones and Howells 2001; Kovach et al. 1992, 1999). The EIQ has been used by various researchers to determine the environmental risks of various weed management strategies (Brimner et al. 2005; Edwards-Jones and Howells 2001; Fernandez-Cornejo 1998; Gallivan et al. 2001; Sikkema et al. 2007; Soltani et al. 2007). The EIQ allows researchers as well as applicators to make a more informed decision on the potential environmental impact of the herbicide being used.

Glyphosate is one of the most extensively used herbicides in GR soybean since it is effective on a range of weeds, including common ragweed. The development of GR common ragweed can cause substantial yield losses in soybean if not controlled early in the season; therefore, alternative herbicides need to be identified that will provide adequate control. The objectives of this study were (1) to determine the efficacy of POST herbicides for the control of GR common ragweed, (2) to determine the EI of the POST herbicides registered on soybean in Ontario, and (3) to determine the biologically effective rate of glyphosate on resistant and susceptible common ragweed populations.

Materials and Methods

Two studies were conducted over a 2-yr period (2013 and 2014) to determine the efficacy of POST herbicides for the control of confirmed GR common ragweed in soybean. The first study ("POST tank mixes I") evaluated mixtures of glyphosate (Monsanto Canada Inc., 67 Scurfield Blvd., Winnipeg, Manitoba, Canada) with one other herbicide, in which a total of four experiments were conducted: two in Windsor, ON, (R1 and R2) in 2013 where the experiments were separated in time and two sites near Windsor, ON, (R3) and Belle River, ON, (R4) in 2014. The second study ("POST tank mixes II") evaluated glyphosate mixed with more than one other herbicide and was conducted at a total of three sites: one in Windsor, ON, (R1) in 2013 and two sites near Windsor, ON, (R3) and Belle River, ON, (R4) in 2014. All POST herbicides registered for use in Ontario on soybean were evaluated. Herbicides were applied at the highest labeled rate in Ontario and are listed in Tables 3–6. Adjuvants were added as recommended on the herbicide labels.

Experiments were established as a randomized complete block design with three or four replications. Herbicides were applied when the common ragweed was 10 to 15 cm in height. The plots were 2.25 or 3 m wide by 7 or 8 m long (based on space available). A CO_2-pressurized backpack sprayer was used to apply the herbicides, which was calibrated to deliver 200 L ha^{-1} of liquid at 210 kPa using a 1- or 1.5-m-wide boom with ULD 120-20 flat fan nozzles (Hypro, New Brighton, MN) spaced 50 cm apart. Weedy and weed-free controls were

Table 1. Location, agronomic information, and height and density of multiple-resistant (groups 2 and 9) common ragweed experiments in Ontario, Canada, in 2013 and 2014.

Location	Year	Soil characteristics			pH	Planting date	Spray date	Common ragweed[a]	
		Closest city	Texture	OM[b]				Height	Density
				%				cm	No. m^{-2}
R1	2013	Windsor	Clay	3.1	7.2	May 27	June 3	up to 10	229
R2	2013	Windsor	Clay	3.1	7.2	May 27	June 11	up to 22	99
R3	2014	Windsor	Clay loam	3.4	7.2	May 26	June 10	up to 10	693
R4	2014	Belle River	Clay loam	2.8	7.5	May 26	June 10	up to 10	60
S1	2013	Ridgetown	Sandy clay loam	3.7	6.4	May 15	June 12	up to 9	60
S2	2013	Ridgetown	Sandy clay loam	3.7	6.4	May 15	June 19	up to 26	60
S3	2014	Ridgetown	Sandy clay loam	3.4	7.5	June 02	June 26	up to 8	15
S4	2014	Ridgetown	Sandy clay loam	3.4	7.5	June 2	July 3	up to 20	21

[a] Common ragweed size and density at time of herbicide application.
[b] Abbreviation: OM, organic matter.

included in each replicate of all experiments. The weed-free control was maintained weed free with an application of glyphosate (1,800 g ae ha^{-1}), *S*-metolachlor (1,600 g ai ha^{-1}), and metribuzin (653 g ai ha^{-1}) followed by hand hoeing when necessary. Soil characteristics, seeding and spray dates, and the size and density of common ragweed at time of application are listed in Table 1. Soybean were at the VE to VC stage at R1 to R4 and V1 to V4 stage at S1 to S4.

Common ragweed control was visually rated 4 and 8 wk after application (WAA) on a scale of 0 to 100%, where 0% was no control and 100% was complete control. Common ragweed density and dry weight were determined at 8 WAA by counting and cutting the common ragweed plants in two 0.25-m^2 quadrats in each plot. The common ragweed plants were then bagged, dried to constant moisture in a 60 C dryer, and then weighed. Soybean injury ratings were conducted on a 0 to 100% scale at 2 and 4 WAA, where 0% was no injury and 100% was plant death. At crop maturity, 2 m of soybean from the middle row of the plot were cut at the soil surface and threshed in a stationary thresher at the resistant locations. Soybean yield was not taken at the R4 site due to interference of other weed species at that location. A small-plot combine was used at the susceptible sites. Soybean weight and seed moisture content were recorded. Yield is presented as a percent reduction in yield compared to the weed-free control.

The PROC MIXED procedure in SAS (version 9.2, SAS Institute Inc., Cary, NC) was used to conduct an ANOVA on the tank-mix experiment data. Variances were divided into the random effects of location (year and location), replication within location, and the treatment by location interaction. The fixed effect was herbicide treatment. The significance of the environment, replication, and interaction of the environment by treatment was tested using the Z test. The significance of the fixed effects was tested using the F test. Sites were combined for analysis if there was no site by treatment interaction (P0.05). Residual plots were examined to ensure that the assumptions were met (homogenous, independent, and randomly distributed errors). Data were tested for normality using the Shapiro-Wilk statistic generated using the UNIVARIATE procedure in SAS. Transformations of the data (natural log, square root, and arcsine square root) were used when necessary. The transformation with the highest Shapiro-Wilk statistic was used.

The PROC MIXED procedure was used to obtain an ANOVA using the transformed data (where used). The transformed means were untransformed for presentation purposes. Transformed or least squared means were separated using Fisher's protected LSD at $P = 0.05$.

Glyphosate dose-response experiments were conducted in the field twice on one resistant (R1, R2) and one susceptible biotype (Ridgetown, ON, S1, S2) in 2013, and two resistant (R3 and R4) and one susceptible biotype (S3, S4) in 2014. These experiments were named the biologically effective rate (BER) of glyphosate. The doses of glyphosate used in the BER trial on the resistant biotype were 113, 225, 450, 900, 1,800, 2,700, 5,400, 10,800,

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21,600, and 43,200 g ha^{-1}. The glyphosate doses used on the susceptible biotype were 14, 28, 56, 113, 225, 450, 900, 1,800, 2,700 and 5,400 g ha^{-1}. The methods of the study were the same as those of the tank-mixes study except that density and biomass data was obtained at 4 WAA.

Nonlinear regressions of the biologically effective rate data were analyzed using the PROC NLIN procedure in SAS. The exponential to a maximum curve was used to analyze the control data and was obtained from the following equation:

$$Y = a + b(1 - e^{-cx}) \quad [1]$$

The inverse exponential curve was used for the common ragweed biomass and soybean yield reduction data and was obtained from the following equation

$$Y = a + be^{-cx} \quad [2]$$

where a is the lower asymptote, b is the change in y from the intercept and c is the slope.

The equation [1] was used to calculate the effective dose (ED) of glyphosate. The ED_{50}, ED_{80}, and ED_{95} represent the dose required to obtain 50, 80, and 95% control of common ragweed, respectively. The ED_{50}, ED_{80}, and ED_{95} for weed biomass represent the glyphosate dose required to reduce common ragweed dry weight by 50, 80, and 95%, respectively. The ED_{50}, ED_{80}, and ED_{95} for soybean yield represents the glyphosate dose required to reduce soybean yield 50, 80, and 95%, respectively, compared to the weed-free control.

Biomass data were log-transformed for the R1 and R4 sites for the POST tank mixes I experiment. Density data for sites R1, R2, and R4 were also log-transformed. The biomass data in the POST tank mixes II experiments were square root–transformed, while the density data was log-transformed.

The values for the EIQ were obtained from Kovach et al. (1992,), and were multiplied by the rate used. Adjuvants and surfactants were not included in the EIQ due to lack of toxicological and phytochemical information.

Results and Discussion

Herbicide phytotoxicity (leaf burn) in both tank-mix experiments was minimal (< 10 %) on the lower leaves of the soybean in 2013 and 2014 (data not shown).

POST Tank Mixes I. None of the POST herbicides evaluated consistently provided $> 90\%$ control of GR common ragweed. At 4 WAA at R1 to R3, the most efficacious herbicide tank mixes were glyphosate plus aciflurofen, glyphosate plus fomesafen, and glyphosate/fomesafen (premixed), with control ratings of 62, 67 and 67%, respectively (Table 2). All other POST herbicide tank mixes evaluated provided control levels similar to glyphosate alone (Table 2). The poor control with chlorimuron, cloransulam, imazethapyr, and thifensulfuron is because the common ragweed at this site is resistant to both glyphosate and the acetolactate synthase–inhibiting herbicides (Van Wely et al. 2015). At the R4 site 4 WAA, tank mixes of glyphosate plus fomesafen and glyphosate/fomesafen provided 98 and 87% control of GR common ragweed, respectively. At 8 WAA, glyphosate plus fomesafen and glyphosate/fomesafen provided 68 and 71% control of GR common ragweed, respectively, at sites R1 to R3, and 94 and 90%, respectively, at site R4 (Table 2).

Common ragweed biomass was measured at 8 WAA (Table 3). At the R1 and R4 sites, an application of glyphosate plus fomesafen or glyphosate/fomesafen reduced GR common ragweed biomass as much as 98%. Glyphosate plus acifluorfen reduced GR common ragweed biomass as much as 92%. The remaining POST herbicide tank mixes evaluated reduced GR common ragweed biomass by less than 90%. At the R2 and R3 sites, glyphosate plus fomesafen and glyphosate/fomesafen reduced GR common ragweed biomass by 93 and 83%, respectively. All other treatments resulted in reductions of less than 68%.

Common ragweed density data were combined from the R1, R2, and R4 sites, whereas data from the R3 site were analyzed separately (Table 3). Data for the R3 sites were not similar to the others as this site had much higher densities compared to the other three sites (Table 1). Across R1, R2, and R4 sites, the application of glyphosate plus acifuorfen, glyphosate plus fomesafen, and glyphosate/fomesafen resulted in similar densities of < 15 common ragweed plants m^{-2} (Table 3). All of the other POST herbicide tank mixes evaluated resulted in GR common ragweed densities similar to the weedy control. At the R3 site, glyphosate plus fomesafen and glyphosate/fomesafen reduced common ragweed density by 95 and 90%, respectively.

Table 2. Percentage of control of multiple-resistant (groups 2 and 9) common ragweed 4 and 8 WAA in the POST tank mixes I study conducted in Ontario, Canada, in 2013 and 2014.[a]

Treatment	Rate	Control 4 WAA		Control 8 WAA	
		R1, R2, R3	R4	R1, R2, R3	R4
	g ae or ai ha^{-1}	%			
Weedy control		0 e[b]	0 g	0 d	0 g
Weed-free control		100 a	100 a	100 a	100 a
Glyphosate	900	37 cd	61 f	41 c	55 f
Glyphosate + acifluorfen	900 + 600	62 b	68 ef	58 b	60 ef
Glyphosate + bentazon	900 + 1080	24 d	45 f	28 c	53 f
Glyphosate + chloransulam[c]	900 + 17.5	38 c	71 d	33 c	75 d
Glyphosate + chlorimuron[d]	900 + 9	36 cd	83 bcd	41 c	81 bcd
Glyphosate + fomesafen[e]	900 + 240	67 b	98 ab	68 b	94 ab
Glyphosate + imazethapyr[f]	900 + 100	38 c	77 de	38 c	73 de
Glyphosate + imazethapyr + bentazon[g]	900 + 75	36 cd	75 cd	40 c	76 cd
Glyphosate + thifensulfuron-methyl[h]	900 + 6	30 cd	65 de	36 c	73 de
Glyphosate/fomesafen[i]	1,200	67 b	87 abc	71 b	90 abc

[a] Abbreviations: R1, R2, R3, Windsor; R4, Belle River; WAA, weeks after application of herbicide.

[b] Means followed by the same letter are not statistically different with Fisher's protected LSD at P = 0.05.

[c] Added agral 90 (0.250% v/v) and UAN 28% (2.5% v/v).

[d] Added agral 90 (0.200% v/v) and UAN 28% (2.00 L ha^{-1}).

[e] Added Turbocharge (0.500% v/v).

[f] Added agral 90 (0.250% v/v) and UAN 28% (2.00 L ha^{-1}).

[g] Added UAN 28% (2.00 L ha^{-1}).

[h] Added agral 90 (0.100% v/v) and UAN 28% (8.00 L ha^{-1}).

[i] Added Turbocharge (0.250 % v/v).

Soybean yield is presented as the yield reduction compared to the weed-free control (Table 3). None of the POST herbicide tank mixes evaluated resulted in soybean yield similar to the weed-free control. Glyphosate plus bentazon, glyphosate plus chlorimuron, and glyphosate plus thifensulfuron resulted in soybean yields similar to the weedy control, with yield reductions of 70, 62, and 73%, respectively. An application of glyphosate plus fomesafen or glyphosate/fomesafen had the lowest soybean yield reductions of 29 and 34%, respectively.

The results from this study are in contrast to the results of Pollard (2007) on a GR common ragweed biotype in Missouri, where glyphosate (840 g ha^{-1}) plus chlorimuron (13 g ha^{-1}), and glyphosate (840 g ha^{-1}) plus imazethapyr (71 g ha^{-1}) provided > 80 % control. However, because some of the Ontario common ragweed populations are also resistant to group 2 herbicides (Van Wely et al. 2015), they are not effectively controlled by applications of these herbicides. POST herbicide treatments that included fomesafen provided the highest control and had the lowest biomass and density, but they did not provide consistent control.

The EI of the most effective herbicides in the study, glyphosate plus fomesafen and glyphosate/fomesafen, are 19.7 and 20.2, respectively (Table 4). These correspond with some of the higher EI values in the experiment. The treatments that resulted in the lowest EIs were glyphosate and glyphosate tank-mixed with a group 2 herbicide. However, group 2 herbicides are not effective on multiple-resistant common ragweed, so therefore are not an effective option. The next lowest EI options are the treatments that include fomesafen. Applications that included bentazon had the highest EI values and resulted in the poorest control.

POST Tank Mixes II. The addition of a group 2 herbicide (chlorimuron, cloransulam, imazethapyr, and thifensulfuron) to glyphosate plus fomesafen in the POST tank mixes II study did not improve the control, density, or biomass of multiple-resistant common ragweed.

Soybean yield is represented as the reduction in yield compared to the weed-free control (Table 6).

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Table 3. Multiple-resistant (groups 2 and 9) common ragweed biomass and density 8 WAA in the POST tank mixes I study conducted in Ontario, Canada, in 2013 and 2014.[a]

Treatment	Rate	Biomass		Density		Yield reduction
		R1, R4	R2, R3	R1, R2, R4	R3	R1, R2, R3
	g ae or ai ha^{-1}	g m^{-2}		# m^{-2}		%
Weedy control		159.6 a[b]	367.0 a	30 abc	1,587 a	84 a
Weed-free control		0 d	0 d	0 d	0 c	0 f
Glyphosate	900	41.1 ab	142.3bc	33 abc	586 bc	46 cde
Glyphosate + acifluorfen	900 + 600	13.1 bc	116.8 bc	15 bcd	887 ab	39 de
Glyphosate + bentazon	900 + 1,080	38.4 ab	185.7 bc	48 abc	891 ab	70 abc
Glyphosate + chloransulam[c]	900 + 17.5	20.3 b	164.8 bc	33 abc	542 bc	41 de
Glyphosate + chlorimuron[d]	900 + 9	17.9 bc	170.7 bc	44 ab	867 ab	62 abcd
Glyphosate + fomesafen[e]	900 + 240	2.7 cd	27.5 cd	4 d	87 bc	29 e
Glyphosate + imazethapyr[f]	900 + 100	28.5 b	158.9 bc	43 abc	662 b	54 bcde
Glyphosate + imazethapyr + bentazon[g]	900 + 75	31.7 ab	147.5 bc	50 a	715 b	40 de
Glyphosate + thifensulfuron[h]	900 + 6	26.5 b	199.0 b	50 a	560 bc	73 ab
Glyphosate/fomesafen[i]	1,200	7.4 bc	64.2 bcd	14 cd	165 bc	34 e

[a] Abbreviations: R1, R2, R3, Windsor; R4, Belle River; WAA, weeks after application of herbicide.
[b] Means followed by the same letter are not statistically different with Fisher's protected LSD at P = 0.05.
[c] Added agral 90 (0.250% v/v) and UAN 28% (2.5% v/v).
[d] Added agral 90 (0.200% v/v) and UAN 28% (2.00 L ha^{-1}).
[e] Added Turbocharge (0.500% v/v).
[f] Added agral 90 (0.250% v/v) and UAN 28% (2.00 L ha^{-1}).
[g] Added UAN 28% (2.00 L ha^{-1}).
[h] Added agral 90 (0.100% v/v) and UAN 28% (8.00 L ha^{-1}).
[i] Added Turbocharge (0.250% v/v).

Multiple resistant common ragweed interference with all of the herbicide tank mixes evaluated reduced soybean yield between 35 and 69%, which was similar to the weedy control.

In general, the addition of a group 2 herbicide to fomesafen did not improve the control of multiple-resistant common ragweed. However, if there are other weed species present in a field that are controlled by group 2 herbicides, there may be a benefit to the tank mixes evaluated. The treatments that included fomesafen in the tank mix had the highest EI of the herbicides in the experiment (Table 7). The addition of a group 2 herbicide to glyphosate plus fomesafen tank mixes did not increase the EI substantially with increases of 0.1 to 1.9. However, the EI does not take into account

Table 4. Environmental impact of herbicides used in the POST tank mixes I study conducted in Ontario, Canada, in 2013 and 2014.

Active ingredients	Individual EIQ values[a]	Product rate	EI[a]
		g ae or ai ha^{-1}	
Glyphosate	15.3	900	13.8
Glyphosate + acifluorfen	15.3 + 23.57	900 + 600	27.9
Glyphosate + fomesafen	15.3 + 24.46	900 + 240	19.7
Glyphosate + bentazon	15.3 + 18.67	900 + 1080	34.0
Glyphosate + thifensulfuron	15.3 + 28.9	900 + 6	14.0
Glyphosate + chlorimuron	15.3 + 19.20	900 + 9	14.0
Glyphosate + cloransulam	15.3 + 15.33	900 + 17.5	14.1
Glyphosate + imazethapyr	15.3 + 19.57	900 + 100	15.8
Glyphosate + imazethapyr + bentazon	15.3 + 19.57 + 18.67	900 + 75 + 840	31.0
Glyphosate/fomesafen	15.3/24.46	1,200	20.6

[a] Abbreviations: EIQ, environmental impact quotient; EI, environmental impact.

Table 5. Percentage of control of multiple-resistant (groups 2 and 9) common ragweed 4 and 8 WAA in the POST tank mixes II study conducted in Ontario, Canada, in 2013 and 2014.[a]

Treatment	Rate	Control 4 WAA[a]		Control 8 WAA	
		R1, R3	R4	R1	R3, R4
	g ae or ai ha^{-1}				
Weedy control		0 e[b]	0 f	0 f	0 f
Weed-free control		100 a	100 a	100 a	100 a
Glyphosate	900	27 d	60 e	23 e	43 e
Glyphosate + chlorimuron	900 + 9	43 bcd	60 e	50 bcd	47 de
Glyphosate + cloransulam	900 + 17.5	30 d	65 de	32 cde	54 bcde
Glyphosate + fomesafen	900 + 240	56 b	65 de	52 bc	62 bcd
Glyphosate + imazethapyr	900 + 100	33 cd	67 cde	37 bcde	48 cde
Glyphosate + thifensulfuron	900 + 6	30 d	60 e	30 de	51 cde
Glyphosate + fomesafen + chlorimuron	900 + 240 + 9	56 b	68 cde	55 b	61 bcde
Glyphosate + fomesafen + cloransulam	900 + 240 + 17.5	58 b	82 b	50 bcd	71 b
Glyphosate + fomesafen + imazethapyr	900 + 240 + 100	50 bc	76 bc	35 bcde	63 bcd
Glyphosate + fomesafen + thifensulfuron	900 + 240 + 6	52 b	72 bcd	30 de	66 bc

[a] Abbreviations: R1, R3, Windsor; R4, Belle River; WAA, weeks after application of herbicide.
[b] Means followed by the same letter are not significantly different with Fisher's protected LSD at $P < 0.05$.

the chance of a weed developing resistance to a herbicide if it is continually being used due to its low EI, and therefore the propensity for selecting resistance should not be overlooked when determining the appropriate herbicide based on the EI.

BER of Glyphosate. The recommended field dose of glyphosate of 900 g ha^{-1} did not provide acceptable control of the GR common ragweed. The two resistant populations, Windsor (R1, R2, R3) and Belle River (R4), were analyzed separately due to the lower level of resistance at the Belle River site. At 4 WAA, the glyphosate doses required to provide 50 and 80% control of susceptible common ragweed were 143 and 842 g ha^{-1}, respectively (Table 8). At the Windsor site, the glyphosate doses required to provide 50, 80, and 95% control of GR common ragweed were 1,606, 6,703, and 7,675 g ha^{-1} of glyphosate, respectively. This corresponds to 1.75, 7.5, and 8.5× the field rate of glyphosate to obtain 50, 80, and 95% control, respectively. Compared to the susceptible population, the

Table 6. Multiple-resistant common ragweed biomass, density, and soybean yield in the POST tank mixes II study conducted in Ontario, Canada, in 2013 and 2014.[a]

Treatment	Rate	Weed biomass R1, R3, R4	Density R1, R3, R4	Yield reduction R1, R3
	g ae or ai ha^{-1}	g m^{-2}	# m^{-2}	%
Weedy control		228.7 a[b]	350 a	61 ab
Weed-free control		0 f	0 f	0 c
Glyphosate	900	135.8 b	290 ab	48 ab
Glyphosate + chlorimuron	900 + 9	115.1 b	206 abc	58 ab
Glyphosate + cloransulam	900 + 17.5	85.7 bcd	124 cd	50 ab
Glyphosate + fomesafen	900 + 240	38.5 e	50 e	62 ab
Glyphosate + imazethapyr	900 + 100	115.1 b	129 cd	61 ab
Glyphosate + thifensulfuron	900 + 6	106.9 bc	189 bc	69 a
Glyphosate + fomesafen + chlorimuron	900 + 240 + 9	62.3 cde	91 d	35 b
Glyphosate + fomesafen + cloransulam	900 + 240 + 17.5	54.0 de	82 de	64 ab
Glyphosate + fomesafen + imazethapyr	900 + 240 + 100	54.6 de	78 de	46 ab
Glyphosate + fomesafen + thifensulfuron	900 + 240 + 6	46.0 de	47 e	69 a

[a] Abbreviations: R1, R3, Windsor; R4, Belle River; WAA, weeks after application of herbicide.
[b] Means followed by the same letter are not significantly different with Fisher's protected LSD at $P < 0.05$.

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Table 7. Environmental impact of herbicides used in the POST tank mixes II study conducted in Ontario, Canada, in 2013 and 2014.

Active ingredients	Individual EIQ[a] values	Product rate	EI
		g ai or ae ha^{-1}	
Glyphosate	15.3	900	13.8
Glyphosate + chlorimuron	15.3 + 19.20	900 + 9	14.0
Glyphosate + cloransulam	15.3 + 15.33	900 + 17.5	14.1
Glyphosate + fomesafen	15.3 + 24.46	900 + 240	19.7
Glyphosate + imazethapyr	15.3 + 19.57	900 + 100	15.8
Glyphosate + thifensulfuron	15.3 + 28.9	900 + 6	14.0
Glyphosate + fomesafen + chlorimuron	15.3 + 19.2 + 24.46	900 + 9 + 240	19.8
Glyphosate + fomesafen + cloransulam	15.3 + 15.33 + 24.46	900 + 17.5 + 240	19.9
Glyphosate + fomesafen + imazethapyr	15.3 + 19.57 + 24.46	900 + 100 + 240	21.6
Glyphosate + fomesafen + thifensulfuron	15.3 + 28.9 +24.46	900 + 6 + 240	19.8

[a] Abbreviations: EIQ, environmental impact quotient; EI, environmental impact.

Windsor population had a resistance factor of 11× based on the ED_{50}. At the Belle River site, the glyphosate doses required to provide 50, 80, and 95% control of GR common ragweed were 761, 2,576, and 5,262 g ha^{-1} of glyphosate, respectively. The doses are 2.8 and 6× the field rate of glyphosate at ED_{80} and ED_{95}, respectively, and 5× the rate compared to the susceptible population.

Control ratings at 8 WAA at the susceptible site resulted in ED_{50}, ED_{80}, and ED_{95} values of 132, 643, and 1,735 g ha^{-1}, respectively. At the Windsor site, the ED_{50} and ED_{80} were 1,394 and 8,455g ha^{-1}, which are 1.5 and 9× the field rate, respectively and 10× the rate of the susceptible population. The Belle River site required doses of 628 and 2,474 g ha^{-1} to obtain ED_{50} and ED_{80}, respectively, equaling 5× the rate required compared to the susceptible population.

Common ragweed dry weight was analyzed using the inverse exponential equation. The susceptible population had ED_{50}, ED_{80} and ED_{95} doses of 63, 223, and 497 g ha^{-1}, respectively. The Windsor population had ED_{50}, ED_{80} and ED_{95} values of 1,733, 3,535, and 9,616 g ha^{-1}, respectively. The Belle River population required doses of 117, 563, and 1,385 g ha^{-1} to obtain the ED_{50}, ED_{80}, and

Table 8. Exponential to a maximum and inverse exponential parameter values for common ragweed control 4 and 8 WAA, dry weight, and soybean yield reduction for field dose-response experiments conducted in 2013 and 2014 in Ontario, Canada.[a]

		Regression parameters[b] (SE)			Glyphosate dose (g ae ha^{-1})		
	Location	a	b	c	ED_{50}	ED_{80}	ED_{95}
Exponential to a maximum							
Control							
4 WAA	S1, S2, S3, S4	28.7 (3.4)	61.2 (4.8)	0.003 (0.0007)	143	842	—
	R1, R2, R3	26.3 (4.1)	62.0 (6.6)	0.0003 (0.00008)	1,606	6,703	7,675
	R4	26.7 (7.1)	73.6 (9.7)	0.0005 (0.0002)	761	2,576	5,262
8 WAA	S1, S2, S3, S4	35.8 (3.7)	61.1 (5.0)	0.002 (0.0006)	132	643	1,735
	R1, R2, R3	32.3 (3.8)	51.8 (5.9)	0.0003 (0.0001)	1,394	8,455	—
	R4	29.5 (7.5)	65.3 (10.4)	0.0006 (0.0003)	628	2,474	—
Inverse exponential							
Common ragweed dry weight	S1, S2, S3, S4	1.4 (4.6)	71.1 (7.1)	0.006 (0.002)	63	223	497
	R1, R2, R3	4.6 (5.3)	128.4 (7.4)	0.0006 (0.0001)	1,733	3,535	9,619
	R4	1.4 (3.3)	57.4 (6.7)	0.002 (0.0006)	117	563	1,385
Soybean yield reduction	S1, S2, S3, S4	3.0 (2.1)	15.1 (3.0)	0.005 (0.003)	227	—	—
	R1, R2, R3	20.7 (4.7)	48.9 (8.1)	0.001 (0.0005)	512	—	—

[a] Abbreviations: WAA, weeks after application; S1 to S4, susceptible populations; R1 to R3, Windsor; R4, Belle River.

[b] Parameters: a, lower limit; b, reduction in y from the intercept; c, slope; ED_{50}, ED_{80}, $ED9_5$, the effective doses for 50, 80 and 95% control or reduction in biomass or yield compared to the controls.

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ED_{95}, respectively, corresponding to 2× the rate required on the susceptible population.

Soybean yield is presented as the percent reduction in yield compared to the weed-free control. The susceptible population had an ED_{50} at a glyphosate dose of 227 g ha^{-1}. ED_{80} and ED_{95} could not be calculated because none of the doses resulted in > 80% reduction in yield. Doses below 227 g ha^{-1} resulted in a > 50% reduction in soybean yield. These yield reductions are likely due to weed competition. At the Windsor site, the ED_{50} for soybean yield was at a glyphosate dose of 512 g ha^{-1}. ED_{80} and ED_{95} could not be calculated. The soybean yield results at the resistant site did not show any pattern indicating that the glyphosate dose doesn't correspond with soybean yield reduction.

The results found in this study indicate that the Windsor population had a resistance factor of 10- to 28-fold, while the Belle River population had a resistant factor of 2- to 5-fold compared to the susceptible population. This is similar to the results found in Arkansas where two different GR common ragweed populations had two different levels of resistance (Brewer and Oliver 2009). One population had a 3.7- to 10-fold level of resistance compared to the susceptible population, while the other population had a 19- to 22-fold resistance level (Brewer and Oliver 2009). Similarly, a GR population of common ragweed from Missouri had a 9.6-fold resistance level compared to a susceptible population (Pollard et al. 2004), which corresponds with the Windsor population in Ontario.

The results indicate that high rates of glyphosate are required in GR populations in Ontario to achieve acceptable control (> 95%), which is not economical. Therefore, alternate herbicides need to be investigated to control GR common ragweed. Studies determining the efficacy of PRE herbicides on the control of multiple-resistant (groups 2 and 9) common ragweed in Ontario found that linuron and metribuzin provided 80 to 99% and 80 to 98% control, respectively, at 4 and 8 WAA; however, they did not provide season-long control of GR common ragweed (Van Wely et al. 2014). Because the most efficacious POST herbicide, fomesafen, provides < 70% control, these results show that a PRE herbicide in a two-pass program is the best option for control of GR common ragweed in Ontario.

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