Weed Science 2016 64:727–734

Glyphosate-Resistant Horseweed (*Conyza canadensis*) Dose Response to Saflufenacil, Saflufenacil plus Glyphosate, and Metribuzin plus Saflufenacil plus Glyphosate in Soybean

Christopher M. Budd, Nader Soltani, Darren E. Robinson, David C. Hooker, Robert T. Miller, and Peter H. Sikkema*

The control of glyphosate-resistant (GR) horseweed (*Conyza canadensis*) in soybean has been variable with glyphosate plus saflufenacil. The objective of this research was to determine the biologically effective rate (BER) of saflufenacil, saflufenacil mixed with glyphosate, and metribuzin mixed with saflufenacil and glyphosate applied preplant (PP) for the control of GR horseweed in no-till soybean; a study was conducted to determine each of the three treatments. For each study, seven field sites infested with GR horseweed were used over a 2-yr period (2014, 2015). Saflufenacil alone at 25 and 36 g ai ha^{-1} provided 90 and 95% control of GR Horseweed 8 wk after application, while the BER to achieve 98% control was outside of the treatment range tested. The saflufenacil plus glyphosate (900 g ai ha^{-1}) BER experiment found less saflufenacil was required as 25, 34, and 47 g ha^{-1} provided 90, 95, and 98% control of GR horseweed respectively. The metribuzin BER experiment found 61, 261, and 572 g ha^{-1} was required to provide 90, 95 and 98% control of GR horseweed, respectively, mixed with saflufenacil (25 g ha^{-1}) and glyphosate (900 g ha^{-1}). The addition of metribuzin with the recommended rate of saflufenacil (25 g ha^{-1}) plus glyphosate improved control and a second effective herbicide mode of action for the control of GR horseweed. The use of a three-way herbicide mixture can be an effective weed management strategy to control GR horseweed in soybean.

Nomenclature: Glyphosate; metribuzin; saflufenacil; horseweed, *Conyza canadensis* (L.) Cronq.; soybean, *Glycine max* (L.) Merr.

Key words: Biomass, glyphosate, herbicide resistance, horseweed, soybean, yield.

GR horseweed was first confirmed in Ontario in 2010, and by 2012 it was reported in eight counties within Ontario (Byker et al. 2013a). Five of those counties had multiple-resistant horseweed populations to glyphosate and cloransulam-methyl (Byker et al. 2013c). The rapid spread of GR horseweed can be attributed to the plant's ability to produce a large number (up to 230,000) of small seeds (Weaver 2001), with a specialized structure (pappus) that allows for wind dispersal (Royer and Dickenson 1999). Viable horseweed seed has been collected from the planetary boundary layer, about 550 km from the parent plant (Shields et al. 2006); however, 90% of the seed lands within 100 m of the parent plant (Dauer et al. 2007). Horseweed can act as a spring or winter annual; in Canada most emergence occurs between late August and October, when rosettes are formed that overwinter and continue growth early the following spring (Weaver 2001).

Mechanical and chemical control of horseweed has been shown to be variable. Newly emerged horseweed can be mechanically controlled (Brown and Whitwell 1988); however, larger plants such as established winter annual rosettes may escape tillage (Shrestha et al. 2008). Herbicides must be used to control horseweed in no-tillage crop production systems (Bruce and Kells 1990). Control of GR horseweed should focus on the use of PP or PRE herbicides because POST herbicides are limited in effectiveness (Loux et al. 2006), and there are multiple-resistant biotypes to POST herbicides in Ontario (Byker et al. 2013c). A PP herbicide application with residual activity is a desirable option due to the long emergence pattern of horseweed (Loux et al. 2006). Effective herbicide control options for GR horseweed in Ontario have included glyphosate mixtures with amitrole (2,000 g ai ha^{-1}), saflufenacil (25 g ai ha^{-1}), flumetsulam (70 g ai ha^{-1}), and metribuzin (1,120 g ai ha^{-1}) (Byker et al. 2013a).

Saflufenacil is a protoporphyrinogen oxidase–inhibiting herbicide (Grossmann et al. 2010), that

DOI: 10.1614/WS-D-15-00211.1

* Graduate Student, Adjunct Professor, Associate Professor, Assistant Professor, Field Development Representative, and Professor, Department of Plant Agriculture, University of Guelph, 120 Main St. East, Ridgetown, ON, N0P 2C0, Canada. Corresponding author's E-mail: soltanin@uoguelph.ca

when mixed with glyphosate, provides broad-spectrum grass and broadleaf weed control (Mellendorf et al. 2013). The application timing for saflufenacil on soybean is PP and it can be used as a desiccant prior to harvest (Anonymous 2014). Saflufenacil has activity on several weed species resistant to glyphosate, acetolactate synthase inhibitors, triazine, and dicamba, including horseweed (Liebl et al. 2008; Soltani et al. 2010; Trolove et al. 2011). Control of GR horseweed increased as the rate of saflufenacil increased from 25 to 50 g ha^{-1}, above which control did not increase (Mellendorf et al. 2013). In comparison, Owen et al. (2011) reported equivalent residual control of GR horseweed of greater than 90% at 30 d after planting, with saflufenacil applied at either 25 or 50 g ha^{-1}. Saflufenacil applied PP in soybean can cause injury due to cultivar sensitivity, depending on environmental conditions soon after application (Miller 2012). The most sensitive cultivar tested by Miller (2012) was 'OAC Hanover', which had up to a 10% reduction in yield from 22 g ha^{-1} vs. 46 g ha^{-1} under cool and wet vs. warm and dry conditions, respectively. Variable control of GR horseweed with saflufenacil has been reported by Ikley (2012) in a greenhouse study where 25 g ai ha^{-1} of saflufenacil provided 35, 32, and 20% control at 7, 14, and 28 d after application (DAA) respectively. The addition of glyphosate to saflufenacil (25 g ha^{-1}) increased GR horseweed control to 61 and 67% at 7 and 14 DAA with no significant increase at 28 DAA (Ikley 2012).

Metribuzin alone does not provide acceptable control of horseweed at current application rates in Ontario. Tardif and Smith (2003) reported 73% control of horseweed with 1,120 g ha^{-1} of metribuzin. The addition of glyphosate to a lower rate of metribuzin (420 g ha^{-1}) has provided 58% control 4 wk after application (WAA). A high rate of metribuzin with glyphosate can improve GR horseweed control as reported by Byker et al. (2013a), where 1,120 g ha^{-1} of metribuzin provided greater than 97% control 8 WAA; however, high rates of metribuzin can cause soybean injury, especially on coarse-textured, high-pH soils.

GR horseweed is widely distributed in Ontario; its distribution is expected to increase (Byker et al. 2013c) due to the large number of wind-dispersed seeds. The widespread use of no-tillage crop production practices creates a large area for GR horseweed to establish as it readily establishes in undisturbed soils (Nandula et al. 2005). The increasing prevalence of GR horseweed coupled with its ability to reduce soybean yield up to 93% where no control strategies were applied (Byker et al. 2013b), illustrated the need for a reliable control strategy. A common method of controlling GR weeds is to mix herbicides with different mechanisms of action; however, this will only reduce resistant weed populations if each herbicide has activity, and mixing can be expensive for farmers (Evans et al. 2015). To produce consistent control of GR horseweed with saflufenacil, Mellendorf et al. (2013) suggested growers apply glyphosate plus saflufenacil when the plants are relatively small and to include a third herbicide with another mode of action. Three-way herbicide mixtures with glyphosate plus saflufenacil (25 g ha^{-1}) were investigated by Budd et al. (2016) to determine options for controlling GR horseweed in soybean. Metribuzin (400 g ha^{-1}) and 2,4-D ester (500 g ai ha^{-1}) were determined to be the best additional herbicides with saflufenacil plus glyphosate in GR soybean (Budd et al. 2016). It has also been suggested by Loux (2014) that glyphosate plus saflufenacil plus metribuzin is very effective for the control of GR horseweed. The objective of this study was to determine the dose response of saflufenacil, saflufenacil mixed with glyphosate, and metribuzin plus saflufenacil plus glyphosate for the control of GR horseweed in soybean. It is hypothesized that GR horseweed can be controlled in soybean by optimizing the rate of a third herbicide tank-mix partner.

Materials and Methods

Three distinct studies were conducted to evaluate the dose response of saflufenacil alone, saflufenacil plus glyphosate (900 g ha^{-1}), and metribuzin plus saflufenacil (25 g ha^{-1}) plus glyphosate (900 g ha^{-1}) as a mixture for the control of GR horseweed applied PP in soybean (herein termed saflufenacil BER, saflufenacil/glyphosate BER, and metribuzin BER; BASF Canada, Mississauga, ON). Each of the three studies had seven location-years over a 2-yr period (2014, 2015), totaling 21 field trials with previously confirmed GR horseweed across southwestern Ontario. A randomized complete block design with four replications was used for each trial. The plot dimensions were 2.25 m wide by 8 m in length with three soybean rows spaced 0.75 m apart. A backpack sprayer was used to apply all herbicide treatments PP and was calibrated to deliver 200 L ha^{-1} of spray mixture at 240 kPa using pressurized CO_2 as the propellant. The sprayer boom was 1.5 m wide with four ULD120-02 nozzles (Hypro, New

https://doi.org/10.1614/WS-D-15-00211.1 Published online by Cambridge University Press

Table 1. Location, agronomic information, and height and density of glyphosate-resistant horseweed in BER[a] studies in Ontario, Canada, in 2014 and 2015.

Location	Year	Closest town	Soil characteristics (0–15cm)			Seeding date	Spray date	Horseweed[b]	
			Texture	OM	pH			Size	Density
				%				cm	no. m^{-2}
Q1[c]	2014	Mull	Loam	3.1	6.6	June 10	June 6	Up to 5	5,648
Q2	2014	Blenheim	Sandy loam	2.9	6.5	June 20	June 4	Up to 10	1,232
Q3	2014	Harrow	Sandy loam	2.1	6.6	June 2	May 28	Up to 10	321
Q4	2014	Harrow	Sandy loam	2.1	6.6	June 2	May 28	Up to 7	674
Q5	2015	Mull	Loam	2.6	6.0	June 12	June 4	Up to 9	1,048
Q6	2015	Blenheim	Sandy loam	4.2	6.2	June 6	June 1	Up to 8	340
Q7	2015	Harrow	Sandy loam	2.5	6.1	May 29	May 21	Up to 7	349
R1	2014	Mull	Loam	3.1	6.6	June 10	June 6	Up to 6	2,781
R2	2014	Blenheim	Sandy loam	2.9	6.5	June 20	June 4	Up to 11	724
R3	2014	Harrow	Sandy loam	2.1	6.6	June 2	May 28	Up to 11	145
R4	2014	Harrow	Sandy loam	2.1	6.6	June 2	May 28	Up to 11	796
R5	2015	Mull	Loam	2.6	6.0	June 12	June 4	Up to 7	826
R6	2015	Blenheim	Sandy loam	4.2	6.2	June 6	June 1	Up to 8	505
R7	2015	Harrow	Sandy loam	2.5	6.1	May 29	May 21	Up to 11	501
S1	2014	Mull	Loam	3.1	6.6	June 10	June 6	Up to 5	1,379
S2	2014	Blenheim	Sandy loam	2.9	6.5	June 20	June 4	Up to 10	973
S3	2014	Harrow	Sandy loam	2.1	6.6	June 2	May 28	Up to 7	146
S4	2014	Harrow	Sandy loam	2.1	6.6	June 2	May 28	Up to 8	299
S5	2015	Mull	Loam	2.6	6.0	June 12	June 4	Up to 8	604
S6	2015	Blenheim	Sandy loam	4.2	6.2	June 6	June 1	Up to 11	783
S7	2015	Harrow	Sandy loam	2.5	6.1	May 29	May 21	Up to 6	121

[a] Abbreviations: BER, biologically effective rate; OM, organic material.

[b] Horseweed size and density at time of treatment from untreated control plots.

[c] Q1 to Q7, location years for saflufenacil BER study; R1 to R7, location years for saflufenacil/glyphosate BER study; S1–S7, location years for metribuzin BER study.

Brighton, MN) spaced 50 cm apart. All treatments included Merge© surfactant (50 : 50 surfactant blend to petroleum hydrocarbons) at 1 L ha^{-1} and the saflufenacil formulation was 342 g L^{-1} suspension concentrate. Untreated (weedy) and weed-free controls were included in each trial replication. Weed-free controls were established with a PP mixture of glyphosate (1,800 g ha^{-1}), saflufenacil (25 g ha^{-1}), and metribuzin (400 g ha^{-1}), followed by hand hoeing as required. Herbicide treatments in the saflufenacil BER and saflufenacil/glyphosate BER trials consisted of saflufenacil applied PP at 3.125, 6.25, 12.5, 25, 50, 100, and 200 g ha^{-1}. The metribuzin BER trials consisted of saflufenacil and glyphosate in all treatments and metribuzin at 12.5, 25, 50, 100, 200, 400, 800, and 1600 g ha^{-1}. Quizalofop-p-ethyl (36 g ai ha^{-1}) and glyphosate (900 g ha^{-1}) were applied as cover sprays in 2014 and 2015, respectively, to remove potentially confounding effects of other weed species. Soil characteristics, seeding dates, herbicide application dates, and horseweed height and density at application for all trials are listed in Table 1.

Horseweed control was visually assessed 1, 2, 4, and 8 WAA using a scale of 0 to 100% where 0 was no control and 100 was plant death. At 8 WAA GR horseweed density and aboveground biomass were measured by counting the plants in two 0.25-m^2 quadrants per plot; these plants were cut at the soil surface, placed in paper bags, and dried to a constant weight at 60 C and then weighed. At soybean maturity, seed yield was determined by harvesting a 2-m length of the center row and threshing it in a stationary machine. Seed moisture content and weight of the harvested grain was recorded for each plot. Soybean grain yield is presented in tonnes per hectare at 13% dry grain moisture. At 2 and 4 wk after soybean emergence, soybean injury was assessed visually on a scale of 0 (no injury) to 100% (plant death).

The PROC NLIN procedure in SAS (version 9.4, SAS Institute Inc., Cary, NC) was used to determine the BER in all studies. All environments were combined for statistical analysis. The weedy and weed-free controls were not included in regression analysis. Aboveground weed biomass and density were converted to a percentage of the

https://doi.org/10.1614/WS-D-15-00211.1 Published online by Cambridge University Press

glyphosate-alone treatment prior to analysis for the saflufenacil BER, and saflufenacil/glyphosate BER studies. Aboveground weed biomass and density were kept in their original scale for the metribuzin BER study because when examined as a percentage of the untreated check, the level of control from saflufenacil (25 g ha^{-1}) plus glyphosate (900 g ha^{-1}) without metribuzin generated misleading values.

Regression Equations (Models) Used. All parameters in the saflufenacil BER and the saflufenacil/glyphosate BER studies were regressed against saflufenacil dose, represented by DOSE in the equations. The parameters in the metribuzin BER study were regressed against metribuzin dose, also represented by DOSE in the equations. The exponential to a maximum curve was used to analyze the GR horseweed control data and was obtained from one of the three equations below (Equations 1 to 3), depending on the experiment:

$$\text{Exponential to a maximum } Y = a + b(1 - e^{-c\ \text{DOSE}}), \quad [1]$$

where a is the intercept, b is the magnitude, and c is the slope.

$$\text{Exponential to a maximum } Y = a - b(e^{-c\ \text{DOSE}}), \quad [2]$$

where a is the upper asymptote, b is the magnitude, and c is the slope.

$$\text{Exponential to a maximum } Y = a - c(b^{\text{DOSE}}), \quad [3]$$

where a is the upper asymptote, b is the slope, and c is the magnitude.

The inverse exponential curve was used for the aboveground biomass and density data for all studies and was obtained from the Equation 4:

$$\text{Inverse exponential } Y = a + be^{-c\ \text{DOSE}}, \quad [4]$$

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

The saflufenacil BER study used the exponential to a maximum Equation 2 for all control data; however, Equation 3 provided similar fit and predicted values. The saflufenacil/glyphosate BER study used the exponential to a maximum in Equation 3 for all control data because it had the best fit to the data. The metribuzin BER study used the exponential to a maximum in Equation 1 for 1 and 2 WAA control data and Equation 2 for 4 and 8 WAA control data (C Shropshire, personal communication; Vink et al. 2012). Saflufenacil provided short residual control that meant little metribuzin was required for control at 1 and 2 WAA. At 4 and 8 WAA, the residual control from saflufenacil decreased and more metribuzin was required to provide control. The use of both equations is appropriate to describe the control in these results based on the short residual time that saflufenacil provides for controlling GR horseweed.

Predicted Values. Regression equations were used to calculate predicted saflufenacil or metribuzin doses (g ai ha^{-1}) that resulted in 90, 95, or 98% weed control, or reduction in GR horseweed aboveground biomass or density (ED_{90}, ED_{95}, and ED_{98}). Where any dose was predicted to be greater than the range of doses evaluated in these studies, it was expressed in the tables using a dash (—) because it would be improper to extrapolate outside of the range. Also in the metribuzin BER study, if the equation predicted no metribuzin was required, it was also expressed as a dash.

Results and Discussion

Soybean injury was minimal (<10%) in both saflufenacil and saflufenacil/glyphosate BER studies (Data not shown). The injury consisted of leaf puckering and distortion, but it was observed only at high doses and where there was high soil moisture during crop emergence. Soybean injury in the metribuzin BER study was up to 40 and 20% at 2 and 4 wk after emergence, respectively. This consisted of burning of the lower leaves for treatments with high metribuzin rates (800 and 1,600 g ha^{-1}), and when soil moisture was high after crop emergence.

The weed control data for 1 and 2 WAA is not discussed for each study. The results for 1 and 2 WAA weed control can be found in Tables 2 to 4.

Saflufenacil BER Study. To obtain 90, 95, and 98% control of GR horseweed at 4 WAA, 13, 18, and 30 g ha^{-1} of saflufenacil were required. In contrast, Knezevic et al. (2009) reported that 78 g ha^{-1} of saflufenacil were required for 90% control of horseweed 4 WAA with methylated seed oil instead of Merge. At 4 WAA, less than the label rate of saflufenacil (25 g ha^{-1}) was required for 90 and 95% control, while a 1.2× rate was required to achieve 98% control. At 8 WAA, higher rates ($\geq$ 25 g ha^{-1}) of saflufenacil were required to provide 90 and 95% control, than at 1, 2, and 4 WAA (ED_{98}

https://doi.org/10.1614/WS-D-15-00211.1 Published online by Cambridge University Press

Table 2. Regression parameters of exponential to a maximum and inverse exponential equations for glyphosate-resistant horseweed control 1, 2, 4, and 8 WAA, aboveground biomass, and density for saflufenacil BER field study conducted in 2014 and 2015 in Ontario, Canada.[a]

	Regression parameters[b] (SE)			Saflufenacil dose g ai ha^{-1}		
Exponential to maximum	a	b	c	ED_{90}	ED_{95}	ED_{98}
Weed control						
1 WAA	95.7 (1.5)	94.5 (3.4)	0.3 (0.02)	11	18	—[c]
2 WAA	97.0 (1.3)	95.9 (2.6)	0.1 (0.009)	18	27	—
4 WAA	98.4 (1.4)	100.1 (2.9)	0.2 (0.01)	13	18	30
8 WAA	97.5 (1.9)	95.4 (3.4)	0.1 (0.009)	25	36	—
Inverse exponential						
Aboveground biomass[d]	1.7 (6.3)	102.5 (11.1)	0.1 (0.03)	26	36	61
Density	2.4 (3.0)	98.8 (6.0)	0.2 (0.02)	16	22	—

[a] Abbreviations: WAA, weeks after application, BER, biologically effective rate (results combined across seven location years); ED, the effective dose for 90, 95, and 98% control or reduction in aboveground biomass or reduction in density compared to the control.

[b] Parameters: a, upper asymptote (exponential to maximum) or lower asymptote (inverse exponential); b, magnitude; c, slope.

[c] Saflufenacil dose required for ED_{98} was outside of the treatment range.

[d] Aboveground biomass and density were sampled at 8 WAA.

could not be calculated). Saflufenacil at 25 and 36 g ha^{-1} provided 90 and 95% control 8 WAA respectively, or 1.4× the label rate for 95% control. This is in contrast to Soltani et al. (2012) who reported that greater than 58 g ha^{-1} of saflufenacil was required for 95% control of five different annual broadleaf weeds (common ragweed, *Ambrosia artemisifolia* L.; common lambsquarters, *Chenopodium album* L.; wild buckwheat, *Polygonum convolvulus* L.; green smartweed, *Polygonum scabrum* Moench.; and wild mustard, *Sinapis arvensis* L.) 8 wk after oat (*Avena sativa* L.) emergence.

The dose of saflufenacil required to reduce GR horseweed aboveground biomass by 90 and 95% were similar to the dose for weed control at 8 WAA. Saflufenacil at 26, 36, and 61 g ha^{-1} reduced GR horseweed aboveground biomass by 90, 95, and 98% respectively, or 1.0, 1.4, and 2.4× the label rate of saflufenacil was required (Table 2). A lower dose of saflufenacil of 16 and 22 g ha^{-1} reduced GR horseweed density by 90 and 95%, respectively which is less than the label rate for saflufenacil. This is in contrast to Mellendorf et al. (2013) where 25 and 50 g ha^{-1} of saflufenacil reduced GR horseweed density 76 and 97% respectively, 4 WAA. The ED_{98} could not be calculated for GR horseweed density reduction.

Table 3. Regression parameters of exponential to a maximum and inverse exponential equations for glyphosate-resistant horseweed control 1, 2, 4, and 8 WAA, aboveground biomass, and density for saflufenacil/glyphosate BER field study conducted in 2014 and 2015 in Ontario, Canada.[a]

	Regression parameters[b] (SE)			Saflufenacil dose g ai ha^{-1}		
Exponential to maximum	a	b	c	ED_{90}	ED_{95}	ED_{98}
				g ai ha^{-1}		
Weed control						
1 WAA	98.1 (1.0)	0.7 (0.02)	85.3 (2.3)	8	11	20
2 WAA	96.8 (1.0)	0.8 (0.01)	71.7 (2.2)	10	16	—[c]
4 WAA	98.6 (1.3)	0.8 (0.02)	64.8 (2.8)	11	15	25
8 WAA	99.4 (2.3)	0.9 (0.01)	86.1 (3.9)	25	34	47
Inverse exponential						
Aboveground biomass[d]	0.9 (4.0)	105.8 (6.6)	0.08 (0.01)	31	42	59
Density	0.01 (3.3)	102.4 (6.6)	0.1 (0.02)	16	21	28

[a] Abbreviations: WAA, weeks after application, BER, biologically effective rate (results combined across seven location years); ED, the effective dose for 90, 95, and 98% control or reduction in aboveground biomass or reduction in density compared to the control.

[b] Parameters: a, upper asymptote (exponential to maximum) or lower asymptote (inverse exponential); b, magnitude; c, slope.

[c] Saflufenacil dose required for ED_{98} was outside of the treatment range.

[d] Aboveground biomass and density were sampled at 8 WAA.

Table 4. Regression parameters of exponential to a maximum and inverse exponential equations for glyphosate-resistant horseweed control 1, 2, 4, and 8 WAA, aboveground biomass, and density for metribuzin BER field study conducted in 2014 and 2015 in Ontario, Canada.[a]

	Regression parameters[b] (SE)			Metribuzin dose g ai ha^{-1}		
Exponential to maximum	a	b	c	ED_{90}	ED_{95}	ED_{98}
				g ai ha^{-1}		
Weed control						
1 WAA	2.85×10^{-11} (0)[c]	99.3 (2.5)	0.2 (0.1)	5	6	9
2 WAA	2.72×10^{-11} (0)	95.6 (2.4)	0.5 (1.9)	6	11	—[d]
4 WAA	99.8 (0.6)	3.1 (0.6)	0.003 (0.001)	—	—	217
8 WAA	99.3 (2.6)	11.8 (3.0)	0.004 (0.003)	61	261	572
Inverse exponential						
Aboveground biomass[e]	0.5 (8.7)	35.3 (8.8)	0.003 (0.002)	523	820	1,251
Density	4.4 (10.9)	53.3 (15.1)	0.008 (0.007)	283	557	—

[a] Abbreviations: WAA, weeks after application, BER, biologically effective rate (results combined across seven location years); ED, the effective dose for 90, 95, and 98% control or reduction in aboveground biomass or reduction in density compared to the control.

[b] Parameters: a, upper asymptote (exponential to maximum) or lower asymptote (inverse exponential); b, magnitude; c, slope.

[c] SAS 9.4 does not have the computing power to determine the standard error for very small parameter estimates.

[d] Metribuzin was not required for ED_{90} and ED_{95}, or the dose required for ED_{98} was outside of the treatment range.

[e] Aboveground biomass and density were sampled at 8 WAA.

Saflufenacil/Glyphosate BER Study. The addition of glyphosate (900 g ha^{-1}) reduced the dose of saflufenacil required for the control of GR horseweed compared to the saflufenacil alone. At 4WAA, a saflufenacil dose of 11, 15, and 25 g ha^{-1} was required for 90, 95 and 98% GR horseweed control, respectively. In contrast, 25 g ha^{-1} of saflufenacil provided only 91% control, which was less than the 75 g ha^{-1} of saflufenacil that provided 98% control 4 WAA with glyphosate (900 g ha^{-1}) (Mellendorf et al. 2013). Similar to the results from this study, Byker et al. (2013a) reported that glyphosate (900 g ha^{-1}) plus saflufenacil (25 g ha^{-1}) provided greater than 95% control 4 WAA but regrowth was reported on escaped plants. Ford et al. (2014) found that glyphosate (900 g ha^{-1}) plus saflufenacil (50 g ha^{-1}) provided greater than 93% control at four sites, but less than 44% control at a fifth site at 4 WAA. The dose of saflufenacil for ED_{90}, ED_{95}, and ED_{98} for GR horseweed control 1, 2, and 4 WAA was less than or equal to the label rate of saflufenacil when mixed with glyphosate. At 8 WAA, saflufenacil at 25, 34, and 47 g ha^{-1} provided 90, 95, and 98% control, respectively. To provide 95 and 98% control 8 WAA, 1.4 and 1.9× the label rate of saflufenacil was required. Similarly, four of five sites in a study by Ford et al. (2014) showed greater than 98% control with 50 g ha^{-1} of saflufenacil 8 WAA; however, in contrast, one site had only 49% control.

The dose of saflufenacil required to reduce GR horseweed aboveground biomass by 90, 95, and 98% was greater than required for control at 8 WAA. Saflufenacil at 31, 42, and 59 g ha^{-1} reduced GR horseweed aboveground biomass by 90, 95, and 98% or 1.2, 1.7, and 2.4× the label rate, respectively (Table 3). Ford et al. (2014) reported similar results at four of five sites where 50 g ha^{-1} of saflufenacil plus glyphosate reduced GR horseweed aboveground biomass greater than 95% while in contrast one site showed a 58% reduction. The dose of saflufenacil required to provide 90, 95 and 98% reduction in GR horseweed density was less than that was required for aboveground biomass. Saflufenacil at 16, 21, and 28 g ha^{-1} reduced GR horseweed density 90, 95, and 98%, respectively. ED_{90} and ED_{95} for density required less than the label rate of saflufenacil, while ED_{98} required 1.1× the label rate. In contrast, Mellendorf et al. (2013) reported 25 g ai ha^{-1} and 50 g ha^{-1} of saflufenacil provided 91 and 97% reduction in density respectively. In contrast to our result, Ford et al. (2014) reported 50 g ha^{-1} of saflufenacil provided an 85% reduction in density at one site; however, greater than 97% density reduction was reported at four other sites.

Metribuzin BER Study. The label rate of saflufenacil plus glyphosate (900 g ha^{-1}) provided short residual control of GR horseweed, requiring low doses of metribuzin to achieve 90, 95, and 98% control. In a study by Budd et al. (2016), 25 g ha^{-1} of saflufenacil provided 99% control 4 WAA, which explains the low requirement for metribuzin at 4

https://doi.org/10.1614/WS-D-15-00211.1 Published online by Cambridge University Press

WAA in this study. At 4 WAA, ED_{90} and ED_{95} could not be calculated using the exponential to a maximum in Equation 2 because the saflufenacil provided residual control; however, at 4 WAA 217 g ha^{-1} of metribuzin was required for 98% control of GR horseweed. Tardif and Smith (2003) reported 73% control of glyphosate-susceptible horseweed with metribuzin (1,120 g ha^{-1}) 4 WAA; over five times the amount needed to provide 98% control with saflufenacil (25 g ha^{-1}) in this study. Eubank et al. (2008) reported glyphosate plus metribuzin (420 g ha^{-1}) provided 58% control of GR horseweed 4 WAA. At 8 WAA, 61, 261, and 572 g ha^{-1} of metribuzin was required for 90, 95, and 98% control, respectively. Similarly, Budd et al. (2016) reported that saflufenacil (25 g ha^{-1}) plus glyphosate (900 g ha^{-1}) plus metribuzin (400 g ha^{-1}) provided 96% control of GR horseweed 8 WAA.

A higher dose of metribuzin was required to reduce GR horseweed aboveground biomass compared to the untreated control at 8 WAA. Metribuzin at 523, 820, and 1,251 g ha^{-1} was required for 90, 95, and 98% reduction in GR horseweed aboveground biomass, respectively (Table 4). Budd et al. (2016) reported a 92% reduction in GR horseweed aboveground biomass with glyphosate plus saflufenacil plus metribuzin (400 g ha^{-1}), which is slightly less than the rate required in this study. Also in contrast, Byker et al. (2013a) found that glyphosate (900 g ha^{-1}) plus metribuzin (1,120 g ha^{-1}) reduced GR horseweed aboveground biomass by 100% at 8 WAA. Metribuzin applied at 283 and 557 g ha^{-1} reduced GR horseweed density 90 and 95%, respectively, while the ED_{98} for GR horseweed density could not be calculated. Glyphosate (900 g ha^{-1}) plus metribuzin (420 g ha^{-1}) reduced GR horseweed density by 66% (Eubank et al. 2008). In contrast to these results, Budd et al. (2016) reported glyphosate (900 g ha^{-1}) plus saflufenacil (25 g ha^{-1}) plus metribuzin (400 g ha^{-1}) reduced GR horseweed density by 98%.

In this study, the label rate of saflufenacil provided 90% control of GR horseweed up to 8 WAA. The control of GR horseweed with saflufenacil was improved with the addition of glyphosate (900 g ha^{-1}). Mellendorf et al. (2013) reported that the addition of glyphosate to saflufenacil reduced the frequency of GR horseweed regrowth compared to saflufenacil applied alone. Where regrowth was observed, it began more than 4 WAA, an observation also reported by Byker et al. (2013a).

The addition of metribuzin to glyphosate plus saflufenacil reduces GR horseweed escapes and provides residual control of late-emerging horseweed (Ikley 2012). The addition of metribuzin (572 g ha^{-1}) provided 98% control of GR horseweed with no crop injury. In this study, soybean injury was observed when metribuzin was applied at 800 g ha^{-1} and greater; however, metribuzin has been reported to cause soybean injury at 400 g ha^{-1} on light-textured soils that have high soil pH (P. Sikkema, personal communication).

Saflufenacil compliments glyphosate for the control of weeds that are resistant to several herbicide mode-of-action groups (Groups 2, 4, 5, and 9) (Liebl et al. 2008; Soltani et al. 2010; Trolove et al. 2011). For the control of GR horseweed, an application of glyphosate plus saflufenacil allows for 98% control 8 WAA while saflufenacil alone does not; however, saflufenacil rates with glyphosate to achieve 95 and 98% control 8 WAA are greater than the Ontario soybean use rate (25 g ha^{-1}). The inclusion of metribuzin with saflufenacil and glyphosate allows for 90, 95, and 98% control of GR horseweed with the maximum saflufenacil use rate in soybean in Ontario. Also the inclusion of metribuzin provides two effective herbicide modes of action on GR horseweed, which is very desirable. The use of a three-way mixture for GR horseweed control is a robust weed management strategy that provides excellent control of GR horseweed and reduces the potential for the selection of herbicide resistant biotypes (Mellendorf et al. 2013).

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Received December 27, 2015, and approved June 27, 2016.

Associate Editor for this paper: Muthukumar V. Bagavathiannan.