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SHORT COMMUNICATION

Biologically effective rate of metribuzin for glyphosate-resistant Canada fleabane control in soybean

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Abstract: Eight field experiments were conducted during 2013–2015 to determine the dose response of glyphosate-resistant Canada fleabane to preplant metribuzin in a tank mixture with glyphosate in soybean. The predicted metribuzin rates required to achieve 80%, 90%, and 95% visual control of glyphosate-resistant Canada fleabane were 659, 1093, and 1720 g a.i. ha^{-1} at 4 weeks after application and 783, 1355, and 2237 g a.i. ha^{-1} at 8 weeks after application, respectively.

Key words: Canada fleabane, glyphosate resistance, preplant herbicides, soybean.

Résumé : Entre 2013 et 2015, les auteurs ont réalisé huit expériences sur le terrain en vue d'établir la dose-réponse de la vergerette du Canada résistante au glyphosate à la présemis métribuzine mélangée à du glyphosate dans les cultures de soja. La quantité de métribuzine qu'il faudrait appliquer pour obtenir la destruction visible de 80, 90 ou 95 % de la vergerette du Canada résistante au glyphosate s'établissait respectivement à 659, 1093 et 1720 g de matière active par hectare, quatre semaines après le traitement, et à 783, 1355 et 2237 g de matière active par hectare, huit semaines après le traitement. [Traduit par la Rédaction]

Mots-clés : vergerette du Canada, résistance au glyphosate, herbicide de présemis, soja.

Soybean [*Glycine max* (L.) Merr.] is the most important grain crop in Ontario. It is grown on approximately 1.2 million ha annually with the production of nearly 3.6 million t, contributing a farm gate value of CAN$2 billion. One of the greatest challenges facing Ontario soybean growers is the control of glyphosate-resistant (GR) Canada fleabane [*Conyza canadensis* (L.) Cronq.]. GR Canada fleabane was first reported in Ontario in 2010 and has now been confirmed in 30 counties (from Essex county in the southwest to Glengarry county adjacent to the Quebec border) (Byker et al. 2013*c*).

Canada fleabane is a prolific winter or summer annual weed that is capable of producing over 200 000 seeds per plant (Weaver 2001). The seeds of Canada fleabane are small (1–2 mm long) and have a pappus that aids dispersal of this weed through wind (Weaver 2001). Ninety percent of Canada fleabane seeds fall within 100 m of the mother plant (Dauer et al. 2007). However, Canada fleabane seed is found in the planetary (atmospheric) boundary layer, allowing for dispersal as far as 500 km (Shields et al. 2006). Canada fleabane is an extremely competitive weed and lack of control in soybean can lead to significant yield losses. Byker et al. (2013*b*) found that in the absence of any weed management tactics, GR Canada fleabane interference can cause as much as a 93% reduction in soybean seed yield.

Canada fleabane emerges in the fall as well as in the spring; therefore, it has to be controlled in the fall or early spring before planting crops (Loux et al. 2006). Byker et al. (2013*a*) reported that saflufenacil can provide effective control of GR Canada fleabane; however, control has been inconsistent (Ikley 2012). Recent studies have shown that metribuzin tank-mixed with glyphosate can provide consistent control of GR Canada fleabane in Ontario. Byker et al. (2013*a*) found that glyphosate (900 g a.e. ha^{-1}) + metribuzin (1120 g a.i. ha^{-1}) provided greater than 97% control of GR Canada fleabane at 8 weeks after application (WAA); however, high rates of metribuzin have been reported to cause soybean injury

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depending on environmental conditions (Byker et al. 2013*a*).

The biologically effective rate (BER) of metribuzin for the control of GR Canada fleabane has not been determined. The BER is critical in determining the minimum effective dose of herbicides needed to control weeds (Byker et al. 2013*a*). The objective of this study was to determine the dose response of GR Canada fleabane to metribuzin applied before planting in a tank mixture with glyphosate (900 g a.e. ha^{-1}) in soybean. It was hypothesized that a lower rate of metribuzin (<1120 g a.i. ha^{-1}) can be identified that can provide effective control of GR Canada fleabane and has an acceptable margin of crop safety in soybean.

Eight field trials were conducted over a 3-yr period (2013, 2014, and 2015) in commercial soybean production fields in southwestern Ontario and southeast Nebraska with confirmed GR Canada fleabane populations. Field trials were established as a randomized complete block design with four replications. Soybean was seeded to a depth of approximately 5 cm at a rate of approximately 400 000 seeds ha^{-1}. Each plot was 2.25 m wide (3 rows spaced 75 cm apart) and 8.0 m long.

All herbicide treatments were applied before planting when the Canada fleabane was up to 10 cm in height. Herbicide treatments in the metribuzin BER trials consisted of glyphosate (900 g a.e. ha^{-1}) in all treatments and metribuzin at 0, 35, 70, 140, 280, 560, 1120, and 2240 g a.i. ha^{-1}. A weedy and weed-free control was included in each replicate. The weed-free control was established with glyphosate (900 g a.e. ha^{-1}) + imazethapyr and (or) saflufenacil (100 g a.i. ha^{-1}) applied before planting, followed by hand-hoeing and hand-weeding as required throughout the growing season. Herbicide treatments were applied with a CO_2-pressurized backpack sprayer equipped with Hypro ULD120-02 nozzle tips (Hypro, New Brighton, MN) calibrated to deliver 200 L ha^{-1} of water at 200 kPa. Herbicide applications were made with a 1.5 m boom with four nozzles spaced 50 cm apart.

Soybean injury was visually estimated on a scale of 0% (no injury) to 100% (complete plant death) at 2 and 4 wk after soybean emergence (WAE). Control of GR Canada fleabane was visually estimated on a scale of 0% (no control) to 100% (complete control) at 4 and 8 WAA. GR Canada fleabane density and biomass was determined at 4 WAA by counting the number of plants in two 0.5 m^2 quadrats placed randomly between the center two soybean rows in each plot. Canada fleabane biomass was determined by cutting plants at the soil surface and oven-drying at 60 °C until they reached a constant weight.

Data were analyzed using nonlinear regression (PROC NLIN) in SAS 9.4 (Statistical Analysis Systems, Cary, NC). Herbicide treatment was considered a fixed effect while environment (year–location combinations), the interaction between environment and herbicide treatment, and replicate nested within environment were considered random effects. Significance of the fixed effect was tested using an *F*-test and random effects were tested using a *Z*-test of the variance estimate. The UNIVARIATE procedure was used to test data for normality and homogeneity of variance. The untreated control (for control ratings) and the weed-free control (for density and biomass) were excluded from the analysis; however, all values were compared independently to zero to evaluate treatment differences with the untreated control. Because glyphosate was applied with all metribuzin treatments, the glyphosate-alone treatment was equivalent to a metribuzin rate of zero.

All parameters were regressed against metribuzin rate, designated as RATE in the equations. Visible percent soybean injury at 2 and 4 WAE was related to metribuzin rate using the nonlinear, exponential equation (eq. 1):

$$(1) \qquad Y = f \times [\exp(g \times \text{RATE})]$$

where *Y* is the percent soybean injury, *f* is a magnitude constant, and *g* is a rate constant.

A four-parameter log–logistic model equation (eq. 2) was used to determine the dose response for percent GR Canada fleabane control.

$$(2) \qquad Y = C + (D - C)/\{1 + \exp[-b(\ln \text{RATE} - \ln I_{50})]\}$$

where *Y* is the percent GR Canada fleabane control, *C* is the lower asymptote, *D* is the upper asymptote, *b* is the slope, and I_{50} is the rate that gives a response halfway between *C* and *D*.

An inverse exponential equation (eq. 3) was used to determine the dose response for reduction in GR Canada fleabane density or biomass (dry weight).

$$(3) \qquad Y = h + j \times [\exp(-k \times \text{RATE})]$$

where *Y* is the GR Canada fleabane density or biomass, *h* is the lower asymptote, *j* is the magnitude of the response, and *k* is the slope of the response.

There were no significant interactions ($P < 0.05$) between year × location, herbicide × location, and herbicide × location × year; therefore, data for all environments were combined and averaged. Regression equations were used to calculate predicted metribuzin rates (g a.i. ha^{-1}) required to cause 5%, 10%, and 20% crop injury (R_5, R_{10}, and R_{20}), 80%, 90%, and 95% control of GR Canada fleabane, or 80%, 90%, and 95% reduction in GR Canada fleabane density or dry weight (R_{80}, R_{90}, and R_{95}). If any rate was predicted to be higher than 2240 g a.i. ha^{-1}, it was simply expressed as ">2240" as it would be improper to extrapolate outside the range of rates evaluated in this study.

Based on regression analysis, the predicted metribuzin rates required to cause 5%, 10%, and 20% soybean injury were 2062, >2240, and >2240 g a.i. ha^{-1} at 2 WAE and

Table 1. Regression parameter estimates and predicted metribuzin rates for various herbicide application models.

(*a*) Exponential model of visual crop injury 2 and 4 WAE[a]

	Parameter estimates (± standard error)		Predicted metribuzin rate (g a.i. ha^{-1})		
Variable	*f*	*g*	R_5	R_{10}	R_{20}
Injury 2 WAE	0.38 (0.31)	0.0013 (0.0004)	2062	>2240	>2240
Injury 4 WAE	0.48 (0.26)	0.0015 (0.0003)	1599	2074	>2240

(*b*) Dose-response model of visual Canada fleabane control 4 and 8 WAA[b]

	Parameter estimates (± standard error)				Predicted metribuzin rate (g a.i. ha^{-1})		
Variable	*C*	*D*	*b*	I_{50}	R_{80}	R_{90}	R_{95}
Control 4 WAA	14 (3)	100 (0)	1.6 (0.2)	319 (26)	659	1093	1730
Control 8 WAA	8 (3)	100 (0)	1.5 (0.2)	334 (33)	783	1355	2237

(*c*) Inverse exponential model of Canada fleabane density and dry weight 4 WAA[c]

	Parameter estimates (± standard error)			Predicted metribuzin rate (g a.i. ha^{-1})		
Variable	*h*	*j*	*k*	R_{80}	R_{90}	R_{95}
Density	1.3 (68)	767 (93)	0.0039 (0.0014)	410	588	768
Dry weight	0 (0)	179 (26)	0.0032 (0.0013)	497	711	925

Note: WAE, weeks after soybean emergence; WAA, weeks after herbicide application.

[a]Exponential parameters (eq. 1): *f*, magnitude constant; *g*, rate constant. R_5, R_{10}, and R_{20} are the rates required to give 5%, 10%, and 20% soybean injury.

[b]Dose-response parameters (eq. 2): *b*, slope; *C*, lower asymptote; *D*, upper asymptote; I_{50}, rate required for 50% response. R_{80}, R_{90}, and R_{95} are the rates required to give 80%, 90%, and 95% control of Canada fleabane or an 80%, 90%, and 95% reduction in Canada fleabane density or dry weight.

[c]Inverse exponential parameters (eq. 3): *h*, lower asymptote; *j*, magnitude of response; *k*, slope of response. R_{80}, R_{90}, and R_{95} are the rates required to give 80%, 90%, and 95% control of Canada fleabane or an 80%, 90%, and 95% reduction in Canada fleabane density or dry weight.

1599, 2074, and >2240 g a.i. ha^{-1} at 4 WAE, respectively (Table 1). Crop injury consisted of leaf burn of the lower leaves for treatments with high metribuzin rates (1120 and 2240 g a.i. ha^{-1}). Our results are similar to studies by Ikley (2012) that found no soybean injury with the addition of metribuzin (572 g a.i. ha^{-1}) to glyphosate. Eubank et al. (2008) also found no soybean injury with the addition of metribuzin (420 g a.i. ha^{-1}) to glyphosate (860 g a.e. ha^{-1}) in soybean.

The predicted metribuzin rates required to achieve 80%, 90%, and 95% control of GR Canada fleabane were 659, 1093, and 1730 g a.i. ha^{-1} at 4 WAA and 783, 1355, and 2237 g a.i. ha^{-1} at 8 WAA, respectively (Table 1). In other studies, Tardiff and Smith (2003) reported metribuzin (1120 g a.i. ha^{-1}) provided 73% control of non-glyphosate-resistant Canada fleabane at 4 WAA in Ontario. Similarly, Eubank et al. (2008) also reported that metribuzin (420 g a.i. ha^{-1}) + glyphosate (860 g a.i. ha^{-1}) provided 66%–73% and 53%–60% control of GR Canada fleabane at 2 and 4 WAA under Mississippi environmental conditions, respectively. Ikley (2012) found as much as 98% control of GR Canada fleabane with the addition of metribuzin (572 g a.i. ha^{-1}) to glyphosate under Maryland environmental conditions.

The predicted metribuzin rates required to achieve a 80%, 90%, and 95% reduction in GR Canada fleabane density were 410, 588, and 768 g a.i. ha^{-1}, respectively, similar to the 497, 711, and 925 g a.i. ha^{-1} required to reduce the aboveground biomass of GR Canada fleabane by 80%, 90%, and 95%, respectively (Table 1). The highest current registered rate for metribuzin, 1120 g a.i. ha^{-1}, is sufficient in providing a >80% reduction in Canada fleabane density and biomass. Our results are in agreement with Byker et al. (2013*a*), who found a 100% reduction in GR Canada fleabane aboveground biomass with glyphosate (900 g a.i. ha^{-1}) + metribuzin (1120 g a.i. ha^{-1}) at 8 WAA under Ontario environmental conditions. Eubank et al. (2008) also found as much as an 86% reduction in GR Canada fleabane density with metribuzin (420 g a.i. ha^{-1}) + glyphosate (860 g a.i. ha^{-1}) under Mississippi environmental conditions.

This study concludes that the current highest label rate of metribuzin (1120 g a.i. ha^{-1}) tank-mixed with glyphosate (900 g a.i. ha^{-1}) does not always provide acceptable control of GR Canada fleabane. As higher rates of metribuzin can also result in unacceptable soybean injury under some conditions, further studies are needed to explore three-way tank-mixes of metribuzin for the control of GR Canada fleabane. For example, saflufenacil has shown relatively good efficacy for control of GR Canada fleabane; therefore, a BER should be determined for a tank mixture of metribuzin, glyphosate, and saflufenacil.

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