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Control of Glyphosate-Resistant Giant Ragweed in Winter Wheat

Kris J. Mahoney, Kristen E. McNaughton, and Peter H. Sikkema*

Four field experiments were conducted over a 2-yr period (2012 and 2013) in winter wheat to evaluate POST herbicides for the control of glyphosate-resistant (GR) giant ragweed. POST herbicides were evaluated for winter wheat injury and GR giant ragweed control, population density, and aboveground biomass. The herbicides used in this study provided 54 to 90% and 51 to 97% control of GR giant ragweed at 4 and 8 wk after treatment (WAT), respectively. At 8 WAT, auxinic herbicide treatments or herbicide tank mix/premix treatments that contained auxinics provided 78 to 97% control of GR giant ragweed. Reductions in GR giant ragweed population density and aboveground biomass were 62 to 100% and 83 to 100%, respectively, and generally reflected the level of control. The results of this research indicate that Ontario, Canada, corn and soybean growers should continue to incorporate winter wheat into their crop rotation as one component of an integrated weed management (IWM) strategy for the control of GR giant ragweed.

Nomenclature: Glyphosate; giant ragweed, *Ambrosia trifida* L.; winter wheat, *Triticum aestivum* L.
Key words: Glyphosate resistance, integrated weed management, POST herbicides, weed control.

Cuatro experimentos de campo fueron realizados durante un período de dos años (2012 y 2013) en trigo de invierno para evaluar herbicidas POST para el control de *Ambrosia trifida* resistente a glyphosate (GR). Se evaluó el efecto de los herbicidas POST sobre el daño en el trigo de invierno y el control, densidad de población y la biomasa aérea de *A. trifida* GR. Los herbicidas usados en este estudio brindaron 54 a 90% y 51 a 97% de control de *A. trifida* GR a 4 y 8 semanas después del tratamiento (WAT), respectivamente. A 8 WAT, los tratamientos con herbicidas tipo auxina o mezclas/pre-mezclas en tanque que contenían herbicidas tipo auxina brindaron 78 a 97% de control de *A. trifida* GR. Las reducciones en la densidad de la población y la biomasa aérea de *A. trifida* GR fueron 62 a 100% y 83 a 100%, respectivamente, y generalmente reflejaron el nivel de control. Los resultados de esta investigación indican que los productores de maíz y soja de Ontario, Canada, deberían continuar incorporando el trigo de invierno en sus rotaciones de cultivos como un componente de una estrategia de manejo integrado de malezas (IWM) para el control de *A. trifida* GR.

In 2014, nearly 80% of Ontario, Canada's total field crop acreage was seeded to corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] (Kulasekera 2015), and most of these growers relied on glyphosate for weed management. For example, approximately 96% of the corn acreage and 76% of the soybean acreage was seeded to hybrids/cultivars that contained the glyphosate-resistance trait (M. Reidy, personal communication). Unfortunately, the repeated use of glyphosate can exert selection pressure, which results in weed shifts to those species that are naturally tolerant to glyphosate or in the selection of GR biotypes (Beckie 2011; Johnson et al. 2009; Owen 2008). For example, giant ragweed, a species native to riparian and noncropland areas (Basset and Crompton 1982), has become adapted to southwestern Ontario corn and soybean production systems.

Glyphosate has been effective in controlling giant ragweed in GR corn and soybean (OMAFRA 2013), but in 2008, a biotype found near Windsor, ON, survived multiple glyphosate applications and was identified as the first weed species in Canada to evolve resistance to glyphosate (Vink et al. 2012d). Since then, field surveys have documented that GR giant ragweed is present in more than 80 locations across seven Ontario counties (Follings et al. 2013b; Vink et al. 2012d). GR giant ragweed can still be controlled in Ontario corn and soybean fields (Belfry and Sikkema 2015; Follings et al. 2013a,c; Vink et al. 2012a–c; Walsh et al. 2014). However, implementing better glyphosate stewardship practices could have mitigated resistance evolution and prolonged the utility of this technology.

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IWM practices, such as crop rotation, have been advocated as one of many potential solutions for addressing GR weed problems (Beckie 2006; Mortensen et al. 2012; Swanton and Murphy 1996). Corn–soybean–winter wheat is a common Ontario crop rotation; however, the use of winter wheat as a third crop has been declining since 2011, whereas soybean acreage has been steadily increasing (Kulasekera 2015). Indeed, in some areas of southwestern Ontario, growers plant up to 4 consecutive yr of GR soybean (Beckie et al. 2014). For Ontario growers looking to implement an IWM strategy for GR giant ragweed, maintaining winter wheat in their crop rotation could be a viable option. Weed communities in corn and soybean production systems tend to be similar to each other (Swanton et al. 2006). Studies in Ontario have demonstrated that, over time, a corn–soybean–winter wheat crop rotation promotes weed species diversity (Murphy et al. 2006) but not a buildup of weed densities (Swanton et al. 2002). Furthermore, the weed seedbank has been shown to decline rapidly after the adoption of a three-crop rotation (Murphy et al. 2006). Within a corn–soybean–winter wheat crop rotation, the use of herbicides with different modes of action was the primary driver for changes to the weed communities (Swanton et al. 2006). Consequently, for crop rotations to be effective in reducing GR weed populations, herbicides other than glyphosate must be used for weed management (Davis et al. 2009). Unfortunately, when GR giant ragweed is present in a winter wheat crop, the herbicide options are limited because only pyrasulfotole/bromoxynil is labeled for giant ragweed control or suppression (OMAFRA 2013). Therefore, the objective of this research was to evaluate the efficacy of currently registered POST herbicides for the control of GR giant ragweed in winter wheat.

Materials and Methods

Four field experiments were conducted from 2012 to 2013 on farms near Harrow and Windsor, ON, Canada, with a documented history of GR giant ragweed (Follings et al. 2013b; Vink et al. 2012d). Treatments were arranged in a randomized complete block with four replications, with plots 2 m wide by 10 m long. Winter wheat was seeded with a drill in 15- or 19-cm rows, 2.5 to 3.8 cm deep, at a rate of 350 to 400 seeds m^{-2} in October of the previous year (Table 1). Nitrogen was applied in split applications (mid-April and late-May) as 46–0–0 to achieve approximately 100 kg N ha^{-1} at all locations. The herbicides used in these experiments were 2,4-D (2,4-D Ester 600, 564 EC, Loveland Products Canada Inc., Dorchester, ON, Canada), MCPA (MCPA Ester 500, 500 SN, Nufarm Agriculture Inc., Calgary, AB, Canada), dicamba/MCPA/mecoprop (Target, 400 SN, Syngenta Canada Inc., Guelph, ON, Canada), dichlorprop/2,4-D (Estaprop XT, 610 EC, Nufarm Agriculture), clopyralid (Lontrel 360, 360 SN, Dow AgroSciences Canada Inc., Calgary, AB, Canada), bromoxynil/MCPA (Buctril M, 560 EC, Bayer CropScience, Guelph, ON, Canada), thifensulfuron/tribenuron + MCPA (Refine SG, 50 SG, DuPont Canada Inc., Mississauga, ON, Canada + MCPA Ester 500), fluroxypyr + MCPA (Trophy A, 180 EC, Nufarm Agriculture + MCPA Ester 500), pyrasulfotole/bromoxynil (Infinity, 247.5 EC, Bayer CropScience), and prosulfuron + bromoxynil (Peak 75WG, 75 WG, Syngenta Canada + Pardner, 280 EC, Bayer CropScience). Herbicide treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 200 L ha^{-1} of water at 207 kPa through four Hypro Ultra-Low drift (120-02 nozzles, Hypro, New Brighton, MN) spaced 50 cm apart. Untreated control plots were included in each replicate of each trial. In the herbicide-treated plots, no additional methods of weed control were used for the remainder of the growing season.

Crop injury and weed control were estimated visually on a scale of 0 (no injury/control) to 100% (complete plant death). Winter wheat injury was rated 1 and 4 wk after herbicide treatment (WAT), and control of GR giant ragweed was rated at 4 and 8 WAT. Season-long control of GR giant ragweed was estimated by collecting GR giant ragweed population density and aboveground biomass data at 8 WAT. Population density and aboveground biomass data were obtained by counting the GR giant ragweed present in two randomly placed half-meter quadrats, and then, the plants were cut at the soil surface, dried, and weighed.

Data for giant ragweed control, population density, and aboveground biomass were analyzed using PROC MIXED in SAS software (SAS Ver. 9.2, SAS Institute Inc., Cary, NC). Variances were divided into fixed (herbicide treatment) and random effects (environment [i.e., location–year combinations], the herbicide treatment by environment interaction, and replication within environment). Significance of the fixed effect was tested using an F test and random effects were tested using a Z test of the variance estimate. PROC UNIVARIATE in SAS software was used to test data for normality and homogeneity of variance. Weed control ratings for the untreated control were excluded from the analyses. However, all values were compared independently to zero to evaluate treatment differences with the untreated control. When required, data were transformed to meet normality assumptions; giant ragweed visual weed control data at 8 WAT was arcsine square-root transformed, whereas a natural log transformation was used for giant ragweed population density and aboveground biomass data. Weed control data at 4 WAT did not need to be transformed. Transformed data were back-transformed for the presentation of results, and all treatment comparisons were made using a Fisher's protected LSD at $P < 0.05$.

Results and Discussion

There was no winter wheat injury from any of the herbicides evaluated (data not shown), consistent with other work in our research group (McNaughton et al. 2014; Robinson et al. 2015); therefore, because no yield losses were expected, no winter wheat yield data were collected. However, some auxinic herbicides can cause injury to winter wheat. For example, when applied at approximately the same growth stage, Robinson et al. (2015) reported 3 to 4% injury when dicamba/MCPA/mecoprop was applied at a similar rate and 2 to 3% injury with 2,4-D or dichlorprop/2,4-D applied at an increased rate compared with this study. However, in that study, winter wheat yield reductions resulting from dicamba/MCPA/mecoprop injury were observed at only 2 out of 8 site–yr, whereas yields were similar to the untreated control for winter wheat treated with 2,4-D ester, dichlorprop/2,4-D, bromoxynil/MCPA, thifensulfuron/tribenuron + MCPA, fluroxypyr + MCPA, pyrasulfotole/bromoxynil, or prosulfuron + bromoxynil at all 8 site–yr (Robinson et al. 2015). Similarly, McNaughton et al. (2014) found no visible winter wheat injury in the spring and no yield losses at harvest after fall-applied

Table 1. Experiment location; winter wheat variety, seeding date, seeding rate, and emergence date; and spray dates, growth stages, and weed densities for studies evaluating POST herbicides for the control of glyphosate-resistant giant ragweed in Ontario.

Location	Winter wheat				Spray date	Winter wheat stage	Giant ragweed stage	Giant ragweed density
	Variety	Seeding date	Seeding rate	Emergence date				
			seeds m^{-2}			Zadoks	leaves	plants m^{-2}
Harrow (A)	Pioneer 25R47	October 27, 2011	350	November 5, 2011	April 12, 2012	23	2	14
Harrow (B)	Pioneer 25R47	October 27, 2011	350	November 5, 2011	April 25, 2012	25	4	33
Harrow (C)	Pioneer 25R51	October 13, 2012	400	October 21, 2012	May 6, 2013	24	4	74
Windsor	Pioneer 25R39	October 19, 2012	390	October 29, 2012	May 6, 2013	23	6	36

Table 2. Z-test estimates and the associated P-values for the PROC MIXED analyses of glyphosate-resistant giant ragweed control 4 and 8 weeks after treatment with POST herbicides and glyphosate-resistant giant ragweed population density and aboveground biomass 8 weeks after treatment in winter wheat in four studies near Harrow and Windsor, ON from 2012 to 2013.[a]

	Z test estimates				P values			
	Env	Rep (Env)	Env × Trt	Residual	Env	Rep (Env)	Env × Trt	Residual
Control 4 WAT	6.44	5.08	139.90	27.81	0.3655	0.0584	0.0002	< 0.0001
Control 8 WAT[b]	0.005	0.002	0.017	0.010	0.2068	0.0558	0.0007	< 0.0001
Density[c]	0.533	0.182	0.511	0.370	0.1478	0.0194	0.0036	< 0.0001
Biomass[c]	0.568	0.185	0.460	0.355	0.1517	0.0200	0.0005	< 0.0001

[a] Abbreviations: WAT, weeks after treatment; Env, location–year combinations; Trt, treatment.

[b] Data were arcsine square-root transformed before analysis.

[c] Data were natural-log transformed before analysis.

MCPA, dicamba/MCPA/mecoprop, clopyralid, bromoxynil/MCPA, thifensulfuron/tribenuron + MCPA, fluroxypyr + MCPA, or pyrasulfotole/bromoxynil.

For GR giant ragweed control at 4 and 8 WAT, population density, and aboveground biomass, significant herbicide treatment by environment interactions were detected (Table 2). However, to draw a broad, rather than narrow, inference as to the effect of the various POST herbicides on GR giant ragweed, the data for control, population density, and aboveground biomass were pooled across all four environments.

At 4 WAT, most of the herbicides provided a similar level of GR giant ragweed control, which ranged from 76 to 90% (Table 3). The exception was prosulfuron + bromoxynil, thifensulfuron/tribenuron + MCPA, and MCPA, which provided 54, 58, and 69% control of GR giant ragweed, respectively. Visual estimates of GR giant ragweed control tended to increase over time for most herbicides. At 8 WAT, excellent control (ranging from 92 to 97%) was provided by 2,4-D, dicamba/MCPA/mecoprop, dichlorprop/2,4-D, clopyralid, and fluroxypyr + MCPA (Table 3), similar to other research with auxinic herbicides (Basset and Crompton 1982; Follings et al. 2013c; Vink et al. 2012a,b). MCPA, bromoxynil/MCPA, thifensulfuron/tribenuron + MCPA, and pyrasulfotole/bromoxynil suppressed GR giant ragweed (control

Table 3. Visual estimates of GR giant ragweed control 4 and 8 WAT with POST herbicides and GR giant ragweed population density and aboveground biomass at 8 WAT in winter wheat in four studies near Harrow and Windsor, ON, Canada, from 2012 to 2013.[a,b]

Treatment	Rate	Weed control[b] 4 WAT	Weed control[b] 8 WAT	Density 8 WAT	Biomass 8 WAT
	g ai ha^{-1}	%	%	plants m^{-2}	g m^{-2}
Untreated control		0 d	0 e	47 a	37.4 a
2,4-D	528	88 a	95 ab	0 d	0.0 d
MCPA	630	69 bc	83 bc	4 bc	1.3 cd
Dicamba/MCPA/mecoprop	93.75/412.5/93.75	85 ab	92 abc	1 cd	0.6 cd
Dichlorprop/2,4-D	252/480	90 a	96 a	1 cd	0.2 cd
Clopyralid	200	76 ab	92 abc	0 d	0.1 cd
Bromoxynil/MCPA	280/280	83 ab	80 c	3 bc	1.6 bcd
Thifensulfuron/tribenuron + MCPA[c]	10/5 + 540	58 c	78 c	5 b	1.6 bcd
Fluroxypyr + MCPA	108 + 560	89 a	97 a	1 cd	0.3 cd
Pyrasulfotole/bromoxynil[d]	31.1/174.3	79 ab	82 c	4 bc	2.3 bc
Prosulfuron + bromoxynil[c]	10 + 140	54 c	51 d	18 a	6.5 b

[a] Abbreviations: GR, glyphosate-resistant; WAT, weeks after treatment.

[b] Means followed by the same letter within a column are not significantly different according to Fisher's protected LSD at $P < 0.05$.

[c] Nonionic surfactant added at 0.2% v/v.

[d] Ammonium sulfate added at 1 L ha^{-1}.

ratings at 8 WAT ranged from 78 to 83%), whereas poor control was provided by prosulfuron + bromoxynil (51% control 8 WAT), consistent with OMAFRA (2013) recommendations.

Reductions in GR giant ragweed population density generally reflected the level of control, whereas aboveground biomass was reduced by at least 83% regardless of the herbicide used. For example, herbicides that provided a high level of control (i.e., 2,4-D, dicamba/MCPA/mecoprop, dichlorprop/2,4-D, clopyralid, and fluroxypyr + MCPA) reduced GR giant ragweed population density by 98 to 100% at 8 WAT compared with the untreated control (Table 3). In addition, herbicides that provided a moderately high level of GR giant ragweed control 8 WAT (i.e., MCPA, bromoxynil/MCPA, thifensulfuron/tribenuron + MCPA, and pyrasulfotole/bromoxynil) reduced plant-population density by 89 to 94%. However, GR giant ragweed population density at 8 WAT with prosulfuron + bromoxynil was similar to the untreated control. Yet, prosulfuron + bromoxynil still reduced GR giant ragweed aboveground biomass by 83% at 8 WAT compared with the untreated control (Table 3). As for the remaining herbicides, reductions in aboveground biomass ranged from 94 to 100%.

For Ontario corn and soybean growers who incorporate winter wheat into their crop rotation as an IWM strategy for the control of GR giant ragweed, this research demonstrated most of the herbicides tested were highly effective. For example, at 8 WAT, auxinic herbicide treatments or herbicide tank mix/premix treatments that contained auxinics provided control of GR giant ragweed ranging from 78 to 97%. Furthermore, these auxinic treatments reduced GR giant ragweed population density and aboveground biomass by 89 to 100% and 96 to 100%, respectively. Although the use of auxinic herbicides to manage GR giant ragweed is not exclusive to winter wheat, the use of auxinics in corn (Belfry and Sikkema 2015) could be injurious (Rodgers 1952), and the use of auxinics in soybean (Follings et al. 2013c) is reliant on resistance-trait technology not widely available (Vink et al. 2012a) or is generally limited to burndown applications (Follings et al. 2013a; Vink et al. 2012b). Therefore, this research not only provides valuable information to winter wheat growers but also provides data needed to amend herbicide labels and weed control guidelines (OMAFRA 2013).

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