Weed Technology 2012 26:422–428

Glyphosate-Resistant Giant Ragweed (*Ambrosia trifida*) Control in Dicamba-Tolerant Soybean

Joseph P. Vink, Nader Soltani, Darren E. Robinson, François J. Tardif, Mark B. Lawton, and Peter H. Sikkema*

Glyphosate-resistant (GR) giant ragweed has been confirmed in Ontario, Canada. Giant ragweed is an extremely competitive weed and lack of control in soybean will lead to significant yield losses. Seed companies have developed new herbicide-resistant (HR) crop cultivars and hybrids that stack multiple HR traits. The objective of this research was to evaluate the efficacy of glyphosate and glyphosate plus dicamba tank mixes for the control of GR giant ragweed under Ontario environmental conditions in dicamba-tolerant (DT) soybean. Three field trials were established over a 2-yr period (2010 and 2011) on farms near Windsor and Belle River, ON. Treatments included glyphosate (900 g ae ha^{-1}), dicamba (300 g ae ha^{-1}), and dicamba (600 g ha^{-1}) applied preplant (PP), POST, or sequentially in various combinations. Glyphosate applied PP, POST, or sequentially provided 22 to 68%, 40 to 47%, and 59 to 95% control of GR giant ragweed and reduced shoot dry weight 26 to 80%, 16 to 50%, and 72 to 98%, respectively. Glyphosate plus dicamba applied PP followed by glyphosate plus dicamba applied POST consistently provided 100% control of GR giant ragweed. DT soybean yield correlated with GR giant ragweed control. This is the first report in Canada of weed control in DT soybean, specifically for the control of GR giant ragweed. Results indicate that the use of dicamba in DT soybean will provide an effective option for the control of GR giant ragweed in Ontario.
Nomenclature: dicamba; glyphosate; giant ragweed, *Ambrosia trifida* L.; soybean, *Glycine max* (L.) Merr.
Key words: Glyphosate resistance, multiple-herbicide–resistant crops, preplant herbicides, POST herbicides.

La presencia de *Ambrosia trifida* resistente a glyphosate (GR) se ha confirmado en Ontario, Canadá. *A. trifida e*s una maleza extremadamente competitiva y la falta de control en soya tendrá como resultado importantes pérdidas en el rendimiento. Las compañías de semillas han desarrollado nuevos cultivares e híbridos resistentes a herbicidas (HR), los cuales incluyen la combinación de múltiples mecanismos de resistencia a herbicidas. El objetivo de ésta investigación fue evaluar la eficacia de glyphosate y mezclas de glyphosate más dicamba para el control de *A. trifida* GR bajo las condiciones ambientales de Ontario en soya resistente a dicamba. Se establecieron tres ensayos de campo por un período de dos años (2010 y 2011) en fincas cercanas a Windsor y Belle River, Ontario. Los tratamientos incluyeron glyphosate (900 g ea ha^{-1}), dicamba (300 g ea ha^{-1}) y dicamba (600 g ha^{-1}), aplicados ya sea antes de la siembra (PP), POST, o secuencialmente en varias combinaciones. Glyphosate aplicado PP, POST o secuencialmente proporcionó de 22 a 68, de 40 a 47 y de 59 a 95% de control de *A. trifida* GR y redujo el peso seco de la parte aérea de 26 a 80, de 16 a 50 y de 72 a 98%, respectivamente. Glyphosate más dicamba aplicados PP seguido por glyphosate más dicamba aplicados POST, consistentemente proporcionaron 100% de control de *A. trifida* GR. El rendimiento de la soya resistente a dicamba estuvo correlacionado con el control de *A. trifida* GR. Este es el primer reporte en Canadá de control de malezas en soya-resistente a dicamba, específicamente para el control de *A. trifida* GR. Los resultados indican que el uso de dicamba en soya resistente a este herbicida proporcionará una opción efectiva para el control de *A. trifida* GR en Ontario.

The 1996 commercialization of GR soybean revolutionized crop production (Feng et al. 2010). Growers were able to use glyphosate in crops and replace more expensive, selective herbicides that controlled a narrower weed spectrum (Green and Castle 2010). Since then, the adoption of GR crops has been rapid and is increasingly common in world agriculture (Feng et al. 2010). In the United States, 91% of the total soybean and 68% of the total corn plantings were GR in 2009 (Reddy and Norsworthy 2010). Similar rates of adoption are evident in eastern Canada, where the area planted with GR soybean cultivars reached 72% and the area planted with GR corn hybrids reached 90% in 2011 (Stratus Agri-Marketing Inc., Guelph, ON personal communication). Several benefits have driven the success of GR crops, such as excellent weed control, excellent crop safety, simplicity of application, relatively low cost of weed control, reduced fuel costs, and improved soil conservation (Feng et al. 2010; Nandula 2010).

Giant ragweed is an annual weed that is native to North America and commonly found in regions of southern Canada as well as the midwestern and eastern portions of the United States (Abul-Fatih and Bazzaz 1980; Bassett and Crompton 1982; Hunt and Bazzaz 1980). It is a member of the Asteraceae family, and is well known for its allergenic pollen, which is one of the main causes of hay fever (Bassett and Crompton 1982; Baysinger and Sims 1991). This species was previously known to occur in river valleys, meadows, roadsides, fence rows, and drainage ditches and occasionally in low, cultivated floodplain fields (Bassett and Crompton 1982; Johnson et al. 2007; OMAFRA 2001). More recently giant ragweed populations have appeared outside of

DOI: 10.1614/WT-D-11-00184.1
* First, second, third, and sixth authors: Graduate Student, Research Associate, Associate Professor, and Professor, respectively, Department of Plant Agriculture, University of Guelph Ridgetown Campus, 120 Main St. East, Ridgetown, ON, Canada N0P 2C0; fourth author: Associate Professor, Department of Plant Agriculture, Guelph, 50 Stone Road East, Guelph, ON, Canada N1G 2W1; fifth author: Technology Development Lead for Eastern Canada, Monsanto Canada Inc., Guelph, ON, Canada N1G 0B4. Corresponding author's E-mail: nsoltani@ridgetownc.uoguelph.ca

their primary habitats in many fertile fields in southwestern Ontario, across the Corn Belt (Hartzler et al. 2002; Johnson et al. 2007), and increasingly in agronomic crop fields in the U.S. mid-South (Norsworthy et al. 2010; Steckel 2007).

The germination pattern of giant ragweed contributes to its prevalence in row crops. It is one of the earliest annual weeds to germinate in the spring, which translates into an early competitive advantage over agronomic crops (Stoller and Wax 1973). Germination is unpredictable and populations emerge over an extended period beginning in March and continuing until late July. This has resulted in management challenges (Harrison et al. 2001; Johnson et al. 2007). For instance, early emerging plants are often too large at the time of the first glyphosate application whereas late-germinating plants often emerge after the last glyphosate application.

Prior to widespread use of GR soybean, some acetolactate synthase (ALS) inhibitors such as cloransulam-methyl, chlorimuron-ethyl, and imazethapyr provided excellent control of giant ragweed (Baysinger and Sims 1992; Franey and Hart 1999; Taylor et al. 2002). By the mid-1990s, resistance to ALS-inhibiting herbicides was already widespread and control became difficult (Johnson et al. 2007). After the introduction of GR soybean, growers were able to effectively manage ALS-resistant giant ragweed in-crop with POST applications of glyphosate (Johnson et al. 2007; Stachler 2008; Taylor et al. 2002). However, many previously effective herbicides have failed to provide adequate giant ragweed control (Johnson et al. 2007).

Giant ragweed can be very competitive in soybean, resulting in large yield losses. After emergence, giant ragweed grows more rapidly than soybean and can reach heights of up to 6 m. Giant ragweed interference resulted in greater than 90% soybean yield loss in field experiments conducted in Ontario (Joseph Vink, unpublished data). Webster et al. (1994) reported a soybean yield reduction of up to 77% at a giant ragweed density of 1 plant per m^{-2}. Baysinger and Sims (1991) reported soybean yield loss of up to 92% at a density of 16 plants per 9 m of row when giant ragweed and soybean emerged at the same time.

The widespread adoption and repeated use of glyphosate has led to selection of weed species that are naturally tolerant to glyphosate, late-emerging weed species that emerge after the last application of glyphosate, and weed biotypes that are resistant to glyphosate. GR giant ragweed was first reported in Ohio in 2004 (Heap 2011; Stachler 2008). Since the initial documented case of GR giant ragweed, it has been confirmed in nine additional states in the United States. Some populations of GR giant ragweed are also resistant to the ALS-inhibiting herbicides (Heap 2011; Stachler 2008).

In 2008, a giant ragweed biotype near Windsor, ON, Canada, was not controlled with glyphosate (Sikkema et al. 2009). Seed was collected, and greenhouse testing confirmed that the biotype from the Windsor population was resistant to glyphosate. This confirmed giant ragweed as the first weed species in Canada to evolve resistance to glyphosate. Since then, GR giant ragweed has been identified at 47 new locations in southwestern Ontario and some populations have shown reduced sensitivity to the ALS-inhibiting herbicide, cloransulam-methyl (Vink et al. 2011).

In response to the increased incidence of weed resistance to glyphosate and other herbicides, seed companies are now developing crop hybrids and cultivars with resistance to multiple herbicides such as glyphosate plus dicamba. Dicamba has been widely used for over 40 yr, and is an effective herbicide for the control of most broadleaf weed species (Behrens et al. 2007). Dicamba and other dicamba-based herbicides are recommended for the control of giant ragweed in corn (OMAFRA 2011). These multiple-HR crops will provide growers with new weed management tools, and if integrated with other weed management practices (effective residual herbicides, tillage) will help to preserve the utility of glyphosate and GR crops (Green and Castle 2010; Weller 2010). These multiple-HR crops are not expected to be commercialized until the middle of the decade. Limited information is available on herbicide efficacy in these new HR crops for the control of GR weed species. Therefore, the objective of this research was to evaluate the efficacy of dicamba for the control of GR giant ragweed in Ontario, in Roundup Ready® and DT soybean.

Materials and Methods

Three field experiments were conducted over a 2-yr period (2010 and 2011) on two Ontario farms with known GR giant ragweed infestations. In 2010, the trial was established at a site near Windsor, ON (42°16′72″N, 82°57′64″W). In 2011, the trial was established at two sites: one near Windsor, ON, and one near Belle River (42°17′08″N, 82°45′11″W), ON. The soil at Windsor was a sandy clay loam with 50% sand, 27% silt, 23% clay, 3.3 to 4.0% organic matter, and pH of 6.5 to 7.3. The soil at Belle River was clay with 25% sand, 34% silt, 41% clay, 3.3% organic matter, and pH of 6.8.

At Windsor, continuous reduced-tillage soybean was grown for at least 8 yr prior to the establishment of this experiment. For most growing seasons, glyphosate alone was applied PP and POST at the recommended rate. The exceptions were in 2007 when glyphosate and cloransulam-methyl were applied PP followed by glyphosate POST, and in 2004 when *S*-metolachlor and metribuzin were applied PRE in identity-preserved soybean. Prior to 2003, continuous identity-preserved soybean was grown and glyphosate alone was applied PP. In 2008, winter wheat and grass were planted in the autumn and the field was used as a buffer zone beside an airport runway for the 2009 growing season. Prior to giant ragweed emergence in the spring of 2010, glufosinate was applied as an overspray to control the existing stand of grass and wheat as well as mouse-eared chickweed (*Cerastium fontanum* L.). However, control of the wheat and grass was not adequate and quizalofop p-ethyl was applied prior to soybean planting in the spring. In the autumn of 2010, the site was rototilled several times after harvest and glyphosate was applied to control mouse-eared chickweed seedlings. Cropping history at Belle River consisted of a corn (*Zea mays* L.), soybean, and wheat (*Triticum aestivum* L.) rotation and glyphosate was applied each year since 2006. Site preparation at Belle River included disking in the autumn followed by no-tillage management in the spring. Giant ragweed was the predominant weed at Belle River, therefore an overspray to control other emerged weeds was not required.

The experiments were arranged in a randomized complete block design with three replications. Dicamba-DT soybean (MON 87708, Monsanto Canada Inc., Guelph, ON, Canada, N1G 0B4) was seeded at the rate of approximately 556,000 seeds ha^{-1} on May 27, 2010, and 444,789 seeds ha^{-1} on June 7, 2011. Plots consisted of six 6-m-long rows of soybean spaced 0.38 m apart. Herbicides used included glyphosate (900 g ae ha^{-1}; Roundup WeatherMax®, 540 g ae L^{-1}, Monsanto Canada Inc., 900 One Research Road, Winnipeg, MB, Canada, R3T 6E3), dicamba (300 g ae ha^{-1}, Banvel® II, 480 g ae L^{-1}, BASF Canada Inc., 100 Milverton Drive, Mississauga, ON, Canada, L5R 4H1) and dicamba (600 g ha^{-1}) applied PP only, POST only, or sequentially (PP followed by POST) in various combinations. The rates selected for dicamba are the lowest and highest label rate registered in corn in eastern Canada. The rate selected for glyphosate is the recommended label rate for a single application registered in soybean in eastern Canada. Each trial included a weedy and a weed-free control. Weed-free control plots were maintained with an application of glyphosate (1,800 g ha^{-1}) plus dicamba (600 g ha^{-1}) applied PP followed by hand-hoeing as required. Herbicide treatments were applied with a CO_2-pressurized backpack sprayer equipped with ULD 120-02 flat fan nozzles (Hypro, New Brighton, MN) calibrated to deliver 200 L ha^{-1} of water at 210 kPa. Herbicide applications were made with a 1.5-m boom with four nozzles spaced 50 cm apart over the center of the plot. PP treatments were applied 4 to 17 d before planting soybean when the giant ragweed was up to 13 cm in height. POST treatments were applied when the soybean reached the one- to two-trifoliate vegetative growth stage. Giant ragweed height in the weedy control ranged from 10 to 92 cm and the density ranged from 5 to 144 plants m^{-2} at the time of the POST application.

Visual estimate of soybean injury at 1, 2, and 4 wk after the POST treatment application (WAA) and giant ragweed control at 1, 2, 4, and 8 WAA were rated on a scale of 0 to 100%, where a rating of 0 was defined as no injury or control and 100 was defined as plant death or total control. At 4 WAA, giant ragweed density and biomass (shoot dry weight) in each plot was determined by counting giant ragweed plants and by cutting the plants at the soil surface from two 0.25-m^2 quadrats. Plants were bagged by plot and dried at 60 C to constant weight; the dry weights were recorded. At crop maturity, the soybean from the center four rows were harvested with a small-plot combine and the weight and moisture was recorded. Soybean yields were adjusted to 13% moisture.

All data were subjected to ANOVA. Data were analyzed using the MIXED procedure of SAS (Ver. 9.1, SAS Institute Inc., Cary, NC). Variances were separated into the random effects of environment (year and location), replication (within environment), environment by treatment interaction, and the fixed effect of herbicide treatment. Significance of random effects and their interaction with fixed effects was tested using the Z test of the variance estimate, while the significance of fixed effects was tested using the F test. For all variables there was a significant environment by treatment interaction and the pooling of data was restricted to combinations of certain environments and is presented accordingly. Error assumptions of the variance analysis (random, independent, and homogenous) were confirmed by examining residual plots. Data were tested for normality using the Shapiro-Wilk statistic that was generated by the UNIVARIATE procedure in SAS. When necessary, a transformation (arcsine–square root, square root) of the data was applied to meet the assumption of normality, and the transformation that generated the highest Shapiro-Wilk statistic was chosen. After interpretation, treatment means were transformed back to the original scale for presentation. Means were separated using Fisher's Protected LSD at alpha < 0.05.

Results and Discussion

For control ratings, shoot dry weight and soybean yield, data from Windsor in 2010 and 2011 could be combined, and data from Belle River were analyzed separately. There was no soybean injury from the herbicides evaluated (data not shown). Results for the weed density and shoot dry weight were similar among treatments evaluated; therefore only shoot dry weight results are discussed.

Glyphosate plus dicamba applied PP provided 87 to 96% control of GR giant ragweed at Windsor compared to 98 to 100% control at Belle River 1, 2, 4, and 8 WAA (Table 1). Control with glyphosate applied PP was variable, and provided only 18, 15, 22, and 15% control at Windsor compared to 75, 80, 68, and 68% control at Belle River 1, 2, 4, and 8 WAA, respectively. Control with glyphosate plus dicamba applied POST was more variable than the PP treatments, and generally increased with the higher dose of dicamba (600 g ha^{-1}). At Windsor, giant ragweed in the weedy control was up to 92 cm tall with a density of 144 plants m^{-2} at the time of application. Control ranged from 46 to 63%, 70 to 82%, 76 to 88%, and 78 to 95% at 1, 2, 4, and 8 WAA, respectively. This suggests that large giant ragweed at a high density may be difficult to control with dicamba at the lower rate (300 g ha^{-1}). At Belle River, control ranged from 65 to 75%, 86 to 89%, 93 to 98%, and 98 to 100% at 1, 2, 4, and 8 WAA, respectively. Glyphosate applied POST provided only 24, 37, 40, and 46% control at Windsor and 43, 45, 47, and 40% control at Belle River 1, 2, 4, and 8 WAA, respectively.

The sequential glyphosate treatment (glyphosate applied PP followed by glyphosate applied POST) is commonly used for weed control in Ontario soybean production and provided variable control of GR giant ragweed. At Windsor, control ranged from 54 to 67% compared to Belle River where control ranged from 88 to 98%. The difference in control may be due to differences in the proportion of giant ragweed that are resistant to glyphosate at the two sites. In previous research conducted in Ontario, the proportion of GR biotypes in a surviving population was as high as 75% at Windsor compared to only 14% at Belle River (Joseph Vink, unpublished data). The addition of dicamba to the sequential glyphosate application improved control of GR giant ragweed, particularly at Windsor. Glyphosate applied PP followed by glyphosate plus dicamba applied POST at the low or high rate, provided 74 to 80%, 86 to 88%, 89 to 96%, and

Table 1. Control of glyphosate-resistant giant ragweed at Windsor (2010 and 2011) and Belle River (2011) for various treatment combinations in dicamba-resistant soybean.[a]

			1 WAA		2 WAA		4 WAA		8 WAA	
Treatment	Rate	Timing	2010/2011	2011	2010/2011	2011	2010/2011	2011	2010/2011	2011
	(g ae ha^{-1})		(%) control[b]							
Weedy control			0 e	0 e	0 h	0 e	0 g	0 e	0 g	0 e
Weed-free control			100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
Preplant application										
Glyphosate	900	PP	18 d	75 bc	15 g	80 c	22 f	68 c	15 f	68 c
Glyphosate + dicamba	900 + 300	PP	96 a	98 a	96 bc	100 a	90 bc	100 a	87 b	100 a
Glyphosate + dicamba	900 + 600	PP	95 a	100 a	96 abc	100 a	93 abc	100 a	93 abc	100 a
POST application										
Glyphosate	900	POST	24 d	43 d	37 f	45 d	40 ef	47 d	46 e	40 d
Glyphosate + dicamba	900 + 300	POST	46 c	75 bc	70 e	86 bc	76 cd	93 b	78 cd	98 b
Glyphosate + dicamba	900 + 600	POST	63 bc	65 c	82 de	89 abc	88 bc	98 ab	95 abc	100 a
Sequential application										
Glyphosate fb glyphosate	900, 900	PP POST	60 bc	88 ab	67 e	93 ab	59 de	95 b	54 de	98 b
Glyphosate fb glyphosate + dicamba	900, 900 + 300	PP POST	4 b	94 a	86 cd	99 a	89 ab	100 a	91 abc	100 a
Glyphosate fb glyphosate + dicamba	900, 900 + 600	PP POST	80 b	95 a	88 cd	98 ab	96 ab	100 a	99 ab	100 a
Glyphosate + dicamba fb glyphosate	900 + 300, 900	PP POST	98 a	99 a	99 ab	100 a	99 ab	100 a	98 ab	100 a
Glyphosate + dicamba fb glyphosate	900 + 600, 900	PP POST	99 a	100 a	100 a	100 a	100 a	100 a	100 ab	100 a
Glyphosate + dicamba fb glyphosate + dicamba	900 + 300, 900 + 600	PP POST	99 a	100 a	99 ab	100 a	100 a	100 a	100 a	100 a
Glyphosate + dicamba fb glyphosate + dicamba	900 + 600, 900 + 300	PP POST	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a
Glyphosate + dicamba fb glyphosate + dicamba	900 + 300, 900 + 300	PP POST	99 a	100 a	100 ab	100 a	100 a	100 a	100 a	100 a
Glyphosate + dicamba fb glyphosate + dicamba	900 + 600, 900 + 600	PP POST	100 a	100 a	100 a	100 a	100 a	100 a	100 a	100 a

[a] Abbreviations: WAA, weeks after application; PP, preplant; fb, followed by.

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

https://doi.org/10.1614/WT-D-11-00184.1 Published online by Cambridge University Press

Table 2. Glyphosate-resistant giant ragweed shoot dry weight and soybean yield at Windsor (2010 and 2011) and Belle River (2011) for various treatment combinations in dicamba-resistant soybean.[a]

Treatment	Dose	Timing	Shoot dry weight[b]		Soybean yield[b]	
			2010/2011	2011	2010/2011	2011
	(g ae ha^{-1})		(g m^{-2})		(kg ha^{-1})	
Weedy control			646.8 e	145.4 d	230 e	1750 f
Weed-free control			0.0 a	0.0 a	2,820 abc	3,520 abcd
Preplant application						
Glyphosate	900	PP	477.4 ab	29.7 b	420 e	3,210 d
Glyphosate + dicamba	900 + 300	PP	31.7 e	0.0 cd	2,500 bc	3,650 ab
Glyphosate + dicamba	900 + 600	PP	21.0 e	0.0 cd	2,980 abc	3,530 abcd
POST application						
Glyphosate	900	POST	325.6 bc	122.4 a	700 e	2,700 e
Glyphosate + dicamba	900 + 300	POST	247.2 bc	14.0 bc	1,990 cd	3,340 bcd
Glyphosate + dicamba	900 + 600	POST	43.4 de	13.1 bc	2,900 abc	3,280 cd
Sequential application						
Glyphosate fb glyphosate	900, 900	PP POST	180.9 cd	3.1 bc	1,200 de	3,470 abcd
Glyphosate fb glyphosate + dicamba	900, 900 + 300	PP POST	55.3 de	0.0 c	2,720 abc	3,520 abcd
Glyphosate fb glyphosate + dicamba	900, 900 + 600	PP POST	27.2 e	0.0 c	3,370 ab	3,630 ab
Glyphosate + dicamba fb glyphosate	900 + 300, 900	PP POST	9.1 e	0.0 c	3,270 abc	3,410 abcd
Glyphosate + dicamba fb glyphosate	900 + 600, 900	PP POST	0.0 e	0.0 c	3,860 a	3,750 a
Glyphosate + dicamba fb glyphosate + dicamba	900 + 300, 900 + 600	PP POST	0.0 e	0.0 c	3,420 ab	3,680 ab
Glyphosate + dicamba fb glyphosate + dicamba	900 + 600, 900 + 300	PP POST	0.0 e	0.0 c	3,410 ab	3,590 abc
Glyphosate + dicamba fb glyphosate + dicamba	900 + 300, 900 + 300	PP POST	0.0 e	0.0 c	3,490 ab	3,440 abcd
Glyphosate + dicamba fb glyphosate + dicamba	900 + 600, 900 + 600	PP POST	0.0 e	0.0 c	3,540 ab	3,560 abcd

[a] Abbreviations: PP, preplant; fb, followed by.

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

91 to 99% control at Windsor compared to 94 to 95%, 99 to 98%, 100%, and 100% control at Belle River 1, 2, 4, and 8 WAA, respectively (Table 1). Glyphosate plus dicamba applied PP provided better GR giant ragweed control than when applied POST, especially at the earliest assessments (Table 1). Control ranged from 98 to 100% across all environments and rating dates, and can be attributed to smaller giant ragweed at the time of application (2 to 13 cm) compared to giant ragweed that was up to 92 cm tall at the POST application timing. Glyphosate plus dicamba applied PP followed by glyphosate plus dicamba applied POST provided control equivalent to the weed-free check regardless of the dicamba rate, across all environments and rating dates (Table 1).

Reduction in GR giant ragweed shoot dry weight correlated with the level of control. Glyphosate, glyphosate plus dicamba (300 g ha^{-1}), and glyphosate plus dicamba (600 g ha^{-1}) applied PP reduced giant ragweed shoot dry weight 26 to 80%, 95 to 100%, and 97 to 100%, respectively, compared to the weedy control at Windsor and Belle River. Shoot dry weight reduction was poorer with POST application where glyphosate, glyphosate plus dicamba (300 g ha^{-1}), and glyphosate plus dicamba (600 g ha^{-1}) reduced giant ragweed shoot dry weight 16 to 50%, 62 to 90%, and 91 to 93% at Windsor and Belle River, respectively (Table 2). PP applications of glyphosate plus dicamba reduced giant ragweed shoot dry weight equivalent to the weed-free check, whereas POST applications were more variable. This once again suggests that an early application of glyphosate plus dicamba reduces giant ragweed shoot dry weight more effectively than POST applications. Sequential applications of glyphosate reduced giant ragweed shoot dry weight 72 to 98%, whereas glyphosate applied PP followed by glyphosate plus dicamba applied POST reduced giant ragweed shoot dry weight equivalent to the weed-free check by 91 to 100% (Table 2). Glyphosate plus dicamba applied PP followed by glyphosate applied POST reduced giant ragweed shoot dry weight by 99 to 100% (Table 2). Glyphosate plus dicamba applied PP followed by glyphosate plus dicamba applied POST reduced giant ragweed shoot dry weight 100% across all environments (Table 2).

Untreated GR giant ragweed interference in soybean reduced soybean yield 92 and 50% at the Windsor and Bell River sites, respectively. All of the herbicide treatments evaluated increased soybean yield compared with the weedy control (Table 2). However, yield losses up to 85, 75, and 57% were observed compared to the weed-free check when glyphosate was applied PP, POST, and sequentially, respectively. Weed control improvement with the addition of dicamba increased soybean yield. Glyphosate plus dicamba applied PP only and glyphosate plus dicamba applied POST only resulted in yields equivalent to the weed-free check (Table 2). Glyphosate applied PP followed by glyphosate plus dicamba applied POST or glyphosate plus dicamba applied PP followed by glyphosate applied POST increased soybean yield relative to the weedy control. Glyphosate plus dicamba applied PP followed by glyphosate plus dicamba applied POST resulted in yields equivalent to the weed-free check.

The results of this research are consistent with other studies in the literature. Stachler (2008) reported only 32% control of

GR giant ragweed when glyphosate was applied at 840 g ha^{-1}. Johnson et al. (2007) reported 39% control with glyphosate applied POST at 1680 g ha^{-1}. In another study, Norsworthy et al. (2010) reported < 50% control of GR giant ragweed 4 WAA in a greenhouse experiment when glyphosate was applied at 870 g ha^{-1} to four- to six-node plants. In other experiments, dicamba-based herbicides provided adequate control of giant ragweed. Soltani et al. (2011) reported up to 90% control with dicamba (600 g ha^{-1}) applied POST, 8 WAA. In the same experiment, dicamba plus atrazine applied POST provided 82 to 94% control. This is consistent with Ferrell and Witt (2002) who reported up to 98% giant ragweed control with dimethenamid plus atrazine applied PRE followed by dicamba (100 g ha^{-1}) applied POST. In other experiments, atrazine applied PRE provided limited control of giant ragweed (Soltani 2011; Woodyard et al. 2009); dimethenamid is primarily used for annual grass control with limited activity on broadleaf weed species such as giant ragweed. Therefore, dicamba has traditionally been found to provide excellent control of giant ragweed (Johnston and Webb 1985). Other herbicides with a mode of action similar to that of dicamba such as 2,4-D, 2,4,5-T, 2,4-DB, MCPA, and mecoprop have been shown to adequately control giant ragweed (Bassett and Crompton 1982; Robinson and Johnson 2010).

When a single herbicide is used as the basis for weed management, selection intensity will lead to the evolution of herbicide-resistant weeds (Shaner et al. 2011). Therefore, growers that adopt DT soybean should not apply dicamba as a single weed management solution (Seifert-Higgins 2010). Synthetic auxin herbicides have been used for over six decades and resistance has been documented in 29 species, but none in *Ambrosia* (Heap 2011). This suggests that the evolution of dicamba resistance in giant ragweed is low; however, repeated use in consecutive years may lead to the selection of new resistant biotypes (Egan et al. 2011; Wright et al. 2011). The use of glyphosate and dicamba in DT soybean must be complemented with an integrated weed management system that includes tillage or other mechanical/cultural weed control, herbicide rotations and sequences, and residual herbicide treatments that promote sustainable use of this technology (Duke and Powles 2009; Wright et al. 2011).

In summary, glyphosate plus dicamba provided excellent control of GR giant ragweed in DT soybean. Glyphosate applied alone provided unacceptable control. GR giant ragweed control was most consistent when glyphosate plus dicamba was applied PP followed by glyphosate plus dicamba applied POST. In some situations, growers may want to apply glyphosate plus dicamba either PP only or POST only. At a site with heavy GR giant ragweed pressure, glyphosate plus dicamba applied PP will minimize early season competition with soybean and based on these results, only one application of dicamba can provide excellent control of GR giant ragweed. Prior to the introduction of GR crops, the evolution of GR weeds was limited because glyphosate was used for nonselective burn-down of weeds before crop planting (Duke and Powles 2009). Therefore, to minimize selection pressure for the potential evolution of dicamba-resistant giant ragweed, dicamba could be applied PP only as a nonselective burn-down. If dicamba is not applied at the PP timing, glyphosate plus dicamba applied POST at the highest label rate (600 g ha^{-1}) will provide better control of large giant ragweed. However, delaying control of GR giant ragweed until the POST application timing resulted in soybean yield loss of up to 29%. The results of this research suggest that the use of dicamba in DT soybean will provide growers with an additional weed management tool for the control of GR giant ragweed in Ontario.

Acknowledgments

The authors acknowledge Adam Pfeffer, Christy Shropshire, and Chris Kramer for their expertise and technical assistance in these experiments. Funding for this project was provided in part by Monsanto Canada Inc., the Grain Farmers of Ontario, and the Agricultural Adaptation Council through the Canadian Agricultural Adaptation Program.

Literature Cited

Abul-Fatih, H. A. and F. A. Bazzaz. 1980. The biology of *Ambrosia trifida* L. IV. Demography of plants and leaves. New Phytol. 84:107–111.

Bassett, I. J. and C. W. Crompton. 1982. The biology of Canadian weeds. 55. *Ambrosia trifida* L. Can. J. Plant Sci. 62:1003–1010.

Baysinger, J. A. and B. D. Sims. 1991. Giant ragweed (*Ambrosia trifida*) interference in soybeans (*Glycine max*). Weed Sci. 39:358–362.

Baysinger, J. A. and B. D. Sims. 1992. Giant ragweed (*Ambrosia trifida*) control in soybean (*Glycine max*). Weed Technol. 6:13–18.

Behrens, M. R., N. Mutlu, S. Chakraborty, R. Dumitru, W. Z. Jiang, B. J. LaVallee, P. L. Herman, T. E. Clemente, and D. P. Weeks. 2007. Dicamba resistance: enlarging and preserving biotechnology-based weed management strategies. Science 316:1185–1187.

Duke, S. O. and S. B. Powles. 2009. Glyphosate-resistant crops and weeds: now and in the future. Agric. Biol. Forum 12:346–357.

Egan, J. F., B. D. Maxwell, D. A. Mortensen, M. R. Ryan, and R. G. Smith. 2011. 2,4-Dichlorophenoxyacetic acid (2,4-D)-resistant crops and the potential for evolution of 2,4-D-resistant weeds. Proc. Natl. Acad. Sci. U. S. A. 108:E37.

Feng, P.C.C., C. A. Jacob, S. J. Martino-Catt, R. E. Cerny, G. A. Elmore, G. R. Heck, J. Huang, W. M. Kruger, M. Malven, J. A. Miklos, and S. R. Padgette. 2010. Glyphosate-resistant crops: Developing the next generation products. Pages 45–65. *in* V. K. Nandula, ed. Glyphosate Resistance in Crops and Weeds: History, Development, and Management. Hoboken, NJ: J. Wiley.

Ferrell, J. A. and W. W. Witt. 2002. Comparison of glyphosate with other herbicides for weed control in corn (*Zea mays*): efficacy and economics. Weed Technol. 16:701–706.

Franey, R. J. and S. E. Hart. 1999. Time of application of cloransulam for giant ragweed (*Ambrosia trifida*) control in soybean (*Glycine max*). Weed Technol. 13:825–828.

Green, J. M. and L. A. Castle. 2010. Transitioning from single to multiple herbicide-resistant crops. Pages 67–91. *in* V. K. Nandula, ed. Glyphosate Resistance in Crops and Weeds: History, Development, and Management. Hoboken, NJ: J. Wiley.

Harrison, S. K., E. E. Regnier, J. T. Schmoll, and J. E. Webb. 2001. Competition and fecundity of giant ragweed in corn. Weed Sci. 49:224–229.

Hartzler, R. G., K. Harrison, and C. Sprague. 2002. Emergence characteristics of giant ragweed biotypes from Ohio, Illinois and Iowa. Proc. North Cent. Weed Sci. Soc. 57:51.

Heap, I. 2011. The International Survey of Herbicide Resistant Weeds. http://www.weedscience.org. Accessed: December 2, 2011.

Hunt, R. and F. A. Bazzaz. 1980. The Biology of *Ambrosia trifida* L. V. Response to fertilizer, with growth analysis at the organismal and sub-organismal levels. New Phytol. 84:113–121.

Johnston, G. B. and F. J. Webb. 1985. Control of giant ragweed in corn and soybean. Proc. Northeast. Weed Sci. Soc. 39:54.

Johnson, W., M. Loux, D. Nordby, C. Sprague, G. Nice, A. Westhoven, and J. Stachler. 2007. Biology and Management of Giant Ragweed. http://www.ces.purdue.edu/extmedia/BP/GWC-12.pdf. Accessed: December 2, 2011

Nandula, V. K. 2010. Herbicide resistance: Definitions and concepts. Pages 35–43. in V. K. Nandula, ed. Glyphosate Resistance in Crops and Weeds: History, Development, and Management. Hoboken, NJ: J. Wiley.

Norsworthy, J. K., P. Jha, L. E. Steckel, and R. C. Scott. 2010. Confirmation and control of glyphosate-resistant giant ragweed (*Ambrosia trifida*) in Tennessee. Weed Technol. 24:64–70.

[OMAFRA] Ontario Ministry of Agriculture, Food, and Rural Affairs. 2001. Ontario weeds. Publication 505. Guelph, ON: Queen's Printer for Ontario. 215 p.

[OMAFRA] Ontario Ministry of Agriculture, Food, and Rural Affairs. 2011. Guide to weed control. Publication 75. Toronto, ON: Queen's Printer for Ontario. 400 p.

Reddy, K. N. and J. K. Norsworthy. 2010. Glyphosate-resistant crop production systems: Impact on weed species shifts. Pages 165–184. in V. K. Nandula, ed. Glyphosate Resistance in Crops and Weeds: History, Development, and Management. Hoboken, NJ: J. Wiley.

Robinson, A. P. and W. G. Johnson. 2010. Control of summer annual weeds with 2,4-D plus glyphosate tank mixes. Proc. North Cent. Weed Sci. Soc. 65:22.

Seifert-Higgins, S. 2010. Weed management systems in dicamba-tolerant soybeans (DTS). Proc. North Cent. Weed Sci. Soc. 65:91.

Shaner, D. L., R. B. Lindenmeyer, and M. H. Ostlie. 2012. What have the mechanisms of resistance to glyphosate taught us? Pest Manag. Sci. 68:3–9.

Sikkema, P. H., N. Soltani, C. Shropshire, P. J. Smith, M. B. Lawton, and F. J. Tardif. 2009. Suspected glyphosate-resistant giant ragweed in Ontario. Proc. North Cent. Weed Sci. Soc. 64:167.

Soltani, N., C. Shropshire, and P. H. Sikkema. 2011. Giant ragweed (*Ambrosia trifida* L.) control in corn. Can. J. Plant. Sci. 91:577–581.

Stachler, J. M. 2008. Characterization and management of glyphosate-resistant giant ragweed (*Ambrosia trifida* L.) and horseweed [*Conyza canadensis* (L.) Cronq.]. Ph.D. dissertation. Columbus, Ohio: The Ohio State University. Pp. 60–107.

Steckel, L. 2007. Giant ragweed. https://utextension.tennessee.edu/publications/Documents/ W119.pdf. Accessed: December 8, 2011.

Stoller, E. W. and L. M. Wax. 1973. Periodicity of germination and emergence of some annual weeds. Weed Sci. 21:574–580.

Taylor, J. B., M. M. Loux, S. K. Harrison, and E. Regnier. 2002. Response of ALS-resistant common ragweed (*Ambrosia artemisiifolia*) and giant ragweed (*Ambrosia trifida*) to ALS-inhibiting and alternative herbicides. Weed Technol. 16:815–825.

Vink, J. P., P. H. Sikkema, F. Tardif, D. E. Robinson, and M. B. Lawton. 2011. Glyphosate-resistant giant ragweed in Ontario: survey and control. Proc. North Cent. Weed Sci. Soc. 66:87.

Webster, T. M., M. M. Loux, E. E. Regnier, and S. K. Harrison. 1994. Giant ragweed (*Ambrosia trifida*) canopy architecture and interference studies in soybean (*Glycine max*). Weed Technol. 8:559–564.

Weller, S. C., M.D.K. Owen, and W. G. Johnson. 2010. Managing glyphosate-resistant weeds and population shifts in midwestern U.S. cropping systems. Pages 213–232. in V. K. Nandula, ed. Glyphosate Resistance in Crops and Weeds: History, Development, and Management. Hoboken, NJ: J. Wiley.

Woodyard, A. J., G. A. Bollero, and D. E. Riechers. 2009. Broadleaf weed management in corn utilizing synergistic postemergence herbicide combinations. Weed Technol. 23:513–518.

Wright, T., G. Shan, T. Walsh, and M. Peterson. 2011. Reply to Egan et al.: Stewardship for herbicide-resistance crop technology. Proceedings of the National Academy of Sciences 108:E38.

Received December 10, 2011, and approved February 16, 2012.