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Volunteer Glyphosate and Glufosinate Resistant Corn Competitiveness and Control in Glyphosate and Glufosinate Resistant Corn

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Abstract

Glyphosate and glufosinate resistant (RR/LL) volunteer corn has become a problem when hybrid RR/LL corn follows hybrid RR/LL corn in the rotation. A total of six field trials were conducted over a three-year period (2008 to 2010) in southwestern Ontario to 1) evaluate the competitiveness of volunteer RR/LL corn in hybrid RR/LL corn, and 2) determine how to control volunteer RR/LL corn in hybrid RR/LL corn. The predicted volunteer RR/LL corn density to reduce hybrid RR/LL corn yield by 5% was 1.7 volunteer RR/LL corn plants m^{-2}. There was no crop injury in hybrid RR/LL corn with herbicides evaluated at 1 and 2 WAA except for rimsulfuron(15 g·ai·ha^{-1}) and foramsulfuron (35 g·ai·ha^{-1}) which caused as much as 5% and 11% injury in hybrid RR/LL corn, respectively. Glyphosate (1800 g·ae·ha^{-1}), glufosinate(500 g·ae·ha^{-1}) and glyphosate + glufosinate (1800 + 500 g·ae·ha^{-1}) provided up to 18%, 10% and 21% control of volunteer RR/LL corn, respectively. The POST application of rimsulfuron (15 g·ai·ha^{-1}), nicosulfuron (25 g·ai·ha^{-1}), nicosulfuron/rimsulfuron (25 g·ai·ha^{-1}), foramsulfuron (35 g·ai·ha^{-1}), and primisulfuron/dicamba (166 g·ai·ha^{-1}) did not provided any control of volunteer RR/LL corn. Glyphosate and glyphosate + glufosinate reduced volunteer corn density 26% and 30%, respectively. The other herbicides evaluated did not reduce volunteer RR/LL corn density compared to the weedy control. None of the herbicides evaluated reduced volunteer RR/LL corn cob numbers compared to the weedy control. Glyphosate + glufosinate applied POST reduced volunteer RR/LL corn yield 35% compared to the weedy control but other herbicides evaluated caused no reduction in volunteer RR/LL corn yield compared to the weedy control. Glyphosate applied POST resulted in hybrid RR/LL corn yield equivalent to the weed free control but all other herbicide treatments resulted hybrid RR/LL corn yield equivalent to the weedy control. This research concludes that volunteer RR/LL corn can be very competitive with RR/LL hybrid corn. None of the herbicides evaluated provided adequate control of volunteer RR/LL corn in hybrid RR/LL corn.

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Keywords

Crop Injury, Competitiveness, Control, Density, Yield, *Zea mays*

1. Introduction

Corn (*Zea mays* L.) production is important to agriculture and the economy of Ontario where annually 9.2 million tonnes of grain corn is produced on approximately 894,000 hectares compromising over 60% of Canada's total corn production with a farm-gate value of $2.4 billion [1]. Most of the corn grown in Ontario is resistant to both glyphosate and glufosinate (RR/LL) which has provided growers with additional weed management options that provide broad spectrum weed control, have a wide margin of crop safety thereby resulting higher net returns [2] [3].

Glyphosate-resistant corn was first introduced in Canada in 2001 and the market share has increased steadily over the years. In 2013, about 95% of the corn hectarage in Eastern Canada was planted to glyphosate-resistant corn and the percentage is expected to increase in the future [3]. With the increase of hybrid RR/LL corn production, volunteer RR/LL corn (*Zea mays*) has become a major problem whenever hybrid RR/LL corn follows hybrid RR/LL corn in the rotation since glyphosate or glufosinate do not control volunteer RR/LL corn from corn grown the previous year. Volunteer corn seeds are mainly as result of stalk lodging or breakage; dropped ears, kernel losses, and combine head shatter losses of very dry grain the previous year and can be significant in fields affected by storm damage, diseases, insects, and various environmental stresses [4]. Volunteer RR/LL corn in hybrid RR/LL corn competes for moisture, nutrients and light, reduces hybrid RR/LL corn yield, harvest efficiency and grain quality and can increase disease incidence [5]-[10].

Studies have shown that early weed interference in corn can result in decreased leaf emergence, reduced leaf area and lower corn grain yield [11]-[13]. Leaf tip emergence, crop growth rate and yield have been shown to be effected by weed competition in hybrid corn [14]. Control of volunteer corn in hybrid corn is difficult as most hybrids used by growers in Ontario are stacked with resistance traits to both glyphosate and glufosinate, therefore, glyphosate or glufosinate do not adequately control volunteer RR/LL corn in hybrid RR/LL corn in the following year [4]. Therefore, it is critical to develop new weed management strategies to control volunteer RR/LL corn in hybrid RR/LL corn.

Limited published information is available on the competitive effects of volunteer RR/LL corn in hybrid RR/LL corn and strategies for the control of volunteer RR/LL corn in hybrid RR/LL corn under Ontario growing conditions. Growers need herbicide options that are safe, efficacious and economically sustainable to control volunteer RR/LL corn in hybrid RR/LL corn to be competitive in the global market.

The objectives of this study were to determine the competitive effects of volunteer RR/LL corn in hybrid RR/LL corn and to evaluate glyphosate, glufosinate, glyphosate + glufosinate, rimsulfuron, nicosulfuron, nicosulfuron/rimsulfuron, foramsulfuron, and primisulfuron/dicamba applied postemergence (POST) for the control of volunteer RR/LL corn in hybrid RR/LL corn.

2. Materials and Methods

2.1. Study Establishment

Six field trials (3 for competiveness and 3 for volunteer control control) were conducted over a three year period (2008 to 2010) at the University of Guelph Ridgetown Campus in southwestern Ontario. The soil at Ridgetown is a Watford (Grey to Brown Brunisolic)-Brady (Gleyed Brunisolic Grey to Brown Luvisol, mixed) sandy clay loam with 53% sand, 27% silt, 20% clay, 5.3% organic matter and a pH of 7.0 in 2008, 56% sand, 27% silt, 17% clay, 5.4% organic matter and a pH of 6.7 in 2009, and 52% sand, 28% silt, 20% clay, 5.9% organic matter and a pH of 6.4 in 2010. Seedbed preparation consisted of fall moldboard plowing followed by three passes with a field cultivator with rolling basket harrows in the spring.

2.2. Competitiveness Studies

The experimental design was a randomized complete block design (RCBD) with four replications. Plots were 3 m wide (four rows spaced 0.75 m apart) and 8 m long. Each plot consisted of four rows of 4 rows of "DKC50-45 RR" corn. Hybrid RR/LL corn was planted in late April to early May of each year at a rate of 80,000 seeds·ha^{-1}. The glyphosate-resistant volunteer corn seed used to establish the experiments was from glyphosate-resistant "DKC50-45 RR" corn grown the previous year from a commercial field in Ontario. The corn seed was spread prior to seeding the hybrid corn at approximately 7500, 15,000, 30,000, 45,000, 60,000, and 75,000 volunteer seeds·ha^{-1} using a broadcast fertilizer spreader and tilled into the soil with two passes of a cultivator with rolling basket harrows.

At 4, 8 and 12 week after emergence (WAE), volunteer corn density, hybrid corn height, leaf collars and leaf tips were determined. All variables involving hybrid corn (height, leaf collars, leaf tips, and yield) were converted to a percent of the weed-free check. Volunteer RR/LL corn was hand harvested prior to hybrid RR/LL corn harvest. Number of cobs and yield for volunteer RR/LL corn were recorded. Hybrid RR/LL corn was harvested with small plot combine and moisture content and yield were recorded.

PROC MIXED procedures of SAS 9.2 (SAS Institute Inc. 2008) was used to determine which environments could be combined for regression analysis (data combined, if the environment by rate interaction was not significant). All three environments could be combined for each variable.

2.2.1. Regression Equations (Models) Used

Parameters were regressed against volunteer RR/LL corn density at the corresponding timing, designated as DENS in the equations.

Hybrid RR/LL corn height, leaf collars, leaf tips and yield; predicted values for volunteer RR/LL corn cob number and yield (linear):

$$[1]\ Y = a0 + b1 * DENS$$

where a0 is the intercept and b1 is the slope.

2.2.2. Predicted Values

Regression equations were used to calculate predicted volunteer RR/LL corn densities (per·m^2) that resulted in a 5% reduction (R_{95}) of hybrid RR/LL corn height, leaf collars, leaf tips and yield.

If the predicted volunteer corn density was higher than the highest volunteer corn density (**Table 1**, **Table 2**) then it was expressed as ">" because it would not be proper to extrapolate outside the range of densities evaluated in these experiments.

The R_{95} value was also used to calculate the predicted volunteer cob number and yield at that volunteer RR/LL corn density.

2.3. Volunteer Corn Control Studies

The experimental design was a randomized complete block design (RCBD) with four replications. Treatments

Table 1. Target and actual volunteer corn densities at 4, 8 and 12 WAE for Ridgetown 2008-2010.[a]

Target volunteer corn density	Volunteer corn density								
	2008			2009			2010		
	4 WAE	8 WAE	12 WAE	4 WAE	8 WAE	12 WAE	4 WAE	8 WAE	12 WAE
	plants·m^{-2}								
0.75	0.3	0.4	0.3	0.5	0.4	0.3	0.3	0.3	0.3
1.5	0.5	0.6	0.6	0.8	0.9	0.8	0.8	1.1	0.8
3	1.2	1.2	1.2	1.6	1.5	1.4	1.6	1.7	1.4
4.5	1.5	1.6	1.4	2.5	2.3	2.2	1.7	1.3	1.4
6	2.3	2.5	2.2	3.3	3.0	2.9	2.7	1.9	2.0
7.5	2.7	2.8	2.6	4.2	4.0	3.7	3.0	2.6	2.5

[a]Abbreviations: WAE, weeks after hybrid corn emergence.

Table 2. Regression parameter estimates and predicted volunteer corn density, cob number and yield from regression models of hybrid corn height, leaf collars, leaf tips and yield.[a]

Variable	WAE	Parameter estimates[b] (±SE)				Volunteer corn		
		a0		b1		R_{95}[c]	Cobs[d]	Yield
						Plants·m^{-2}	# m^{-2}	MT·ha^{-1}
Height (cm)	4	100.6	1.35	0.56	0.68	-	-	-
	8	99.9	0.69	−0.47	0.37	>	>	>
	12	99.9	0.81	−0.27	0.44	>	>	>
Leaf collars (# plant^{-1})	4	99.2	0.56	−0.02	0.28	>	>	>
	8	99.3	0.53	−0.48	0.28	>	>	>
	12	100.1	0.44	−0.51	0.24	>	>	>
Leaf tips (# plant^{-1})	4	99.8	0.43	−0.20	0.22	>	>	>
	8	99.5	0.47	−0.51	0.25	>	>	>
	12	100.1	0.44	−0.51	0.24	>	>	>
Yield (MT·ha^{-1})		99.0	0.85	−2.86	0.49	1.7	0.6	0.4

> denotes a predicted volunteer corn density, cob number or yield outside the range evaluated in these experiments. [a]Abbreviations: WAE, weeks after hybrid corn emergence. [b]Linear parameters (Equation (1)): a0, intercept; b1, slope. [c]R_{95} is the volunteer corn density at which a given variable is reduced by 5%. [d]The number of cobs predicted for the corresponding R_{95} density.

consisted of glyphosate (1800 g·ae·ha^{-1}), glufosinate (500 g·ae·ha^{-1}), glyphosate + glufosinate (1800 + 500 g·ae·ha^{-1}), rimsulfuron (15 g·ai·ha^{-1}), nicosulfuron (25 g·ai·ha^{-1}), nicosulfuron/rimsulfuron (25 g·ai·ha^{-1}), foramsulfuron (35 g·ai·ha^{-1}), and primisulfuron/dicamba (166 g·ai·ha^{-1}) All treatments except primisulfuron/dicamba included dicamba (141 g·ai·ha^{-1}). Rimsulfuron, nicosulfuron, nicosulfuron/rimsulfuron, and primisulfuron/dicamba treatments included a non-ionic surfactant (Agaral 90®) at 0.2% v/v. Foramsulfuron treatment included 28% urea ammonium nitrate (UAN) at 2.5 L·ha^{-1}.

Plots were 3 m wide and 8 m long. Each plot consisted of four rows of "DKC50-45 RR" corn spaced 0.75 m apart. Hybrid RR/LL corn was planted in late April to early May of each year at a rate of 80,000 seeds·ha^{-1}. The volunteer RR/LL corn seed used to establish the experiments was from "DKC50-45 RR" RR/LL corn grown the previous year from a commercial field in Ontario. The volunteer RR/LL corn seed was spread prior to seeding hybrid RR/LL corn using a broadcast fertilizer spreader and tilled into the soil with two passes of a cultivator with rolling basket harrows.

Herbicide applications were made with 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 55112) spaced 50 cm apart. Herbicide applications were made when the volunteer RR/LL corn was up to 15 cm in height.

Hybrid RR/LL corn injury was rated visually 1 and 2 weeks after application (WAA), and volunteer RR/LL corn control was rated visually 2, 4 and 8 WAA on a scale of 0% to 100%. A rating of 0 was defined as no visible hybrid RR/LL corn injury, and a rating of 100 was defined as total corn necrosis. At 8 WAA volunteer RR/LL corn density and at 16 WAT volunteer RR/LL corn cob number and yield in each plot was determined. Yield for the hybrid RR/LL corn was measured at crop maturity by harvesting the middle two rows of each plot with a plot combine. All corn yields were adjusted to 15.5% moisture.

All data were subjected to analysis of variance (ANOVA) and were combined over experiments and years and analysed using the PROC MIXED procedure of SAS. Weedy and weed free checks were not included in analysis of injury. The weedy check was not included in the analysis of volunteer RR/LL corn control and weed free check was not included in the analysis of volunteer RR/LL corn density, cobs or yield. However, all values were compared independently to zero to evaluate treatment differences with the weedy/weed free check. Environment by treatment interaction was significant for all injury ratings. All other variables could be combined across the three environments. Injury data at 1 WAA in 2008 and 2009 were all zero and could not be combined with 2010 (log transformed). Injury data at 2 WAA in 2008 and 2009 were all zero and could not be combined with 2010 (no transformation). To meet assumptions of normality, volunteer RR/LL corn control 4 and 8 WAA were arcsine square root transformed for analysis, and back-transformed for presentation of results. All other variables did not need transformation. Treatment means were separated using Fisher's protected LSD at $P < 0.05$.

3. Results and Discussions

3.1. Competitiveness Studies

Volunteer RR/LL corn densities varied between years (**Table 1**). Actual volunteer corn densities ranged from 0.3 to 4.0 plants·m^{-2} depending on the year and WAE (4, 8, and 12 WAE) for the targeted seeding rates (**Table 1**). The predicted volunteer corn density to reduce hybrid corn height, leaf collars (# plant^{-1}) and leaf tips (# plant^{-1}) by 5% was greater than the range of volunteer corn densities established in these experiments (**Table 2**). The predicted volunteer corn density to reduce hybrid corn yield 5% was 1.7 volunteer corn plants·m^{-2}, 0.6 volunteer corn cobs·m^{-2}, and 0.4 MT·ha^{-1} volunteer corn yield (**Table 2**). Alms *et al*. (2007) in South Dakota, USA studied the effects of volunteer corn densities of 0, 0.2, 0.8, 1.2, 1.9, 2.5, 2.7, or 3.5 plants·m^{-2} in Dekalb DKC 46 - 60 VT3 corn and reported 0% - 13% hybrid corn yield loss or 0% - 9% yield loss when accounting for corn grain produced by volunteer corn. However, volunteer corn at the same density reduced RR soybean yield 0% - 54% indicating that volunteer corn is more competitive in soybean than in corn [15]. Wilson *et al*. [16] in Nebraska, USA reported 2% corn yield loss from a volunteer corn density of 1.4 plants·m^{-2} and 10% corn yield loss from a volunteer corn density of 2.8 plants·m^{-2}. In contrast, soybean yield was reduced 10% and 27% at volunteer corn density of 1.4 and 2.8 plants·m^{-2}, respectively [16]. Stahl and Coulter [17] in Minnesota, USA studying volunteer corn densities at the rate of 1.6 to 14.5 plants·m^{-2} also found a reduction of 26% in the yield of hybrid corn. Stahl and Coulter [17] found that volunteer corn density had to reach 3.2 plants·m^{-2} before hybrid corn yield was reduced 18% on average. They also concluded that the volunteer corn growth lagged one to 6 leaf stages behind the hybrid corn and was unlikely to offset hybrid corn yield losses as ears were too small (at high density) at the harvest time [4] [17].

3.2. Volunteer Corn Control Studies

There was no crop injury in hybrid RR/LL corn with the herbicides evaluated at 1 and 2 WAA except for rimsulfuron and foramsulfuron which caused as much as 5 and 11% crop injury in hybrid corn, respectively (**Table 3**). Glyphosate (1800 g·ae·ha^{-1}), glufosinate (500 g·ae·ha^{-1}) and glyphosate + glufosinate (1800 + 500 g·ae·ha^{-1}) provided 15% - 18%, 6% - 10% and 16% - 21% control of volunteer RR/LL corn at 1, 2, 4, and 8 WAA, respectively (**Table 3**). Rimsulfuron (15 g·ai·ha^{-1}), nicosulfuron (25 g·ai·ha^{-1}), nicosulfuron/rimsulfuron (25 g·ai·ha^{-1}), foramsulfuron (70 g·ai·ha^{-1}), and primisulfuron/dicamba (166 g·ai·ha^{-1}) did not provide any control of volunteer RR/LL corn at the rates evaluated.

Glyphosate (1800 g·ae·ha^{-1}) and glyphosate + glufosinate (1800 + 500 g·ae·ha^{-1}) reduced volunteer corn density 26% and 30%, respectively. However, glufosinate (500 g·ae·ha^{-1}), rimsulfuron (15 g·ai·ha^{-1}), nicosulfuron (25 g·ai·ha^{-1}), nicosulfuron/rimsulfuron (25 g·ai·ha^{-1}), foramsulfuron (70 g·ai·ha^{-1}), and primisulfuron/dicamba (166 g·ai·ha^{-1}) caused no reduction in volunteer corn density compared to the weedy control (**Table 4**).

None of the herbicides evaluated reduced volunteer corn cob numbers compared to the weedy control (**Table 4**). Glyphosate + glufosinate reduced volunteer RR/LL corn yield 35% compared to the weedy control but glyphosate, glufosinate, rimsulfuron, nicosulfuron, nicosulfuron/rimsulfuron, foramsulfuron, and primisulfuron/dicamba caused no reduction in volunteer corn yield compared to the weedy control (**Table 4**).

Yield of hybrid RR/LL corn was similar to weedy control with glyphosate (1800 g·ae·ha^{-1}), glufosinate (500 g·ae·ha^{-1}), glyphosate + glufosinate (1800 + 500 g·ae·ha^{-1}), rimsulfuron (15 g·ai·ha^{-1}), nicosulfuron (25 g·ai·ha^{-1}), nicosulfuron/rimsulfuron (25 g·ai·ha^{-1}), foramsulfuron (70 g·ai·ha^{-1}), and primisulfuron/dicamba (166 g·ai·ha^{-1}). All herbicides evaluated except glyphosate had lower yield than weed free control (**Table 4**). In other studies, Alms *et al*. [15] found effective control of volunteer RR volunteer corn at a density of 3.5 plant·m^{-2} with glufosinate applied POST at 470 g·ae·ha^{-1} in RR hybrid corn.

Table 3. Visual estimates of hybrid corn injury 1 and 2 WAA and volunteer corn control 1, 2, 4 and 8 WAA with various herbicide treatments. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P < 0.05.[a]

Treatment[b]	Rate	Crop injury		Volunteer corn control			
		1 WAA	2 WAA	1 WAA	2 WAA	4 WAA	8 WAA
	g·ai·ha^{-1}	%					
Weedy control		0 a	0 a	0 d	0 d	0 d	0 d
Weed free control		0 a	0 a	100 a	100 a	100 a	100 a
Glyphosate	1800	0 a	0 a	16 b	18 b	17 b	15 b
Glufosinate	500	0 a	0 a	7 c	10 c	7 c	6 c
Glyphosate + glufosinate	1800 + 500	0 a	0 a	21 b	21 b	17 b	16 b
Rimsulfuron[c]	15	5 b	0 a	0 d	0 d	0 d	0 d
Nicosulfuron[c]	25	0 a	0 a	0 d	0 d	0 d	0 d
Nicosulfuron/rimsulfuron[c]	25	0 a	0 a	0 d	0 d	0 d	0 d
Foramsulfuron[d]	35	11 c	4 b	0 d	0 d	0 d	0 d
Primisulfuron/dicamba[c]	166	0 a	0 a	0 d	0 d	0 d	0 d
SE		1	0	3	3	3	3

[a]Abbreviations: WAA, weeks after application. [b]All treatments except primisulfuron/dicamba included dicamba (141 g·ai·ha^{-1}). [c]Included non-ionic surfactant (0.2% v/v). [d]Included 28% UAN (2.5 L·ha^{-1}).

Table 4. Density, number of cobs and yield for volunteer corn, and yield for hybrid corn with various herbicide treatments. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P < 0.05.

Treatment[a]	Rate	Volunteer corn			Hybrid corn yield
		Density	Cobs	Yield	
	g·ai·ha^{-1}	# m^{-2}	# m^{-2}	MT·ha^{-1}	MT·ha^{-1}
Weedy control		2.3 cd	1.1 a	0.74 bc	14.2 b
Weed free control		0 a	0 a	0 a	15.8 a
Glyphosate	1800	1.7 b	0.8 a	0.58 ab	15.1 ab
Glufosinate	500	2.2 c	1.0 a	0.66 abc	14.7 b
Glyphosate + glufosinate	1800 + 500	1.6 b	0.7 a	0.48 a	14.7 b
Rimsulfuron[b]	15	2.6 d	1.0 a	0.67 bc	14.6 b
Nicosulfuron[c]	25	2.4 cd	1.0 a	0.73 bc	14.6 b
Nicosulfuron/rimsulfuron[c]	25	2.4 cd	1.1 a	0.75 bc	14.4 b
Foramsulfuron[c]	70	2.3 cd	0.9 a	0.62 abc	14.4 b
Primisulfuron/dicamba[c]	166	2.4 cd	1.1 a	0.81 c	14.3 b
SE		0.1	0.1	0.04	0.1

[a]All treatments except primisulfuron/dicamba included dicamba (141 g·ai·ha^{-1}). [b]Included non-ionic surfactant (0.2% v/v). [c]Included 28% UAN (2.5 L·ha^{-1}).

4. Conclusion

This research concludes that competition from volunteer RR/LL corn can alter the growth and reduce the yield of hybrid RR/LL corn. Postemergence application of glyphosate (1800 g·ae·ha^{-1}), glufosinate (500 g·ae·ha^{-1}), glyphosate + glufosinate (1800 + 500 g·ae·ha^{-1}), rimsulfuron (15 g·ai·ha^{-1}), nicosulfuron (25 g·ai·ha^{-1}), nicosulfuron/rimsulfuron (25 g·ai·ha^{-1}), foramsulfuron (70 g·ai·ha^{-1}), and primisulfuron/dicamba (166 g·ai·ha^{-1}) provide poor control of RR/LL volunteer corn. In summary, volunteer RR/LL corn can be a very aggressive competitor with hybrid RR/LL corn. Volunteer RR/LL corn should be controlled through diverse crop rotations rather than seeding continuous corn. Cultivation continues to be the only viable option to control volunteer RR/LL corn in hybrid RR/LL corn. Further studies are needed to evaluate new postemergence herbicide options to control volunteer RR/LL corn in hybrid RR/LL corn.

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Abbreviations

LL: glufosinate resistant;
POST: postemergence;
RR: glyphosate resistant;
WAE: week after emergence.