

# Influence of late emerging weeds in glyphosate-resistant corn

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## ABSTRACT

Fifteen field trials were conducted from 2009 to 2011 in Ontario, Canada and Michigan, USA to determine how long glyphosate-resistant corn needs to be kept weed-free after emergence to prevent yield loss. Data were separated into two environments based on when yield loss first occurred after glyphosate application. In Environment 1 (4/15 sites) yield was not reduced when corn was kept weed-free until the 4-leaf stage. However, in Environment 2 (11/15 sites) there was no yield loss when corn was kept weed-free up to the 2-leaf stage. The most prominent weeds were velvetleaf, redroot pigweed, common ragweed, common lambsquarters and foxtail species. While later emerging weeds did not necessarily impact corn yield, weeds emerging after the 2- and 4-leaf corn stage likely produced seed that was added to the soil seed bank. Weeds emerging after 6-, 8-, and 10-leaf corn growth stages were small (low biomass/seedlings) and most likely did not reach reproductive maturity. Based on this research, corn must be maintained weed-free up to the 4-leaf stage. Any weeds emerging after that did not influence corn yield.

**Keywords:** Biomass; Density; Glyphosate-Resistant Corn; Leaf Stage; Maize; Plant Height; Yield

## 1. INTRODUCTION

Most of the corn produced in Canada is grown in Ontario (nearly 63%) where growers produce nearly 7.2 million tonnes of grain corn on approximately 822,000

hectares with a farm gate value of more than \$1.3 billion [1,2]. Effective weed control is an important component of profitable corn production. Current troublesome weeds include common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), common ragweed (*Ambrosia artemisiifolia* L.), velvetleaf (*Abutilon theophrasti* Medic.), ladythumb (*Polygonum persicaria* L.), wild mustard (*Sinapis arvensis* L.), annual nightshades (*Solanum* spp.), and annual grasses such as foxtails (*Setarias* pp.) [3].

Most of the corn grown in Ontario is glyphosate-resistant which has provided growers with additional weed management options with economic advantages [4,5]. Glyphosate-resistant corn was first introduced in Canada in 2001 and the market share has increased steadily over the years. In 2012, about 94% of the corn hectares in Eastern Canada were planted to glyphosate-resistant hybrids and the percentage is expected to increase in the future [4]. Glyphosate-resistant corn is popular in Eastern Canada as it provides many benefits to growers including excellent crop tolerance, a wide window of herbicide application, broad spectrum weed control, more consistent weed control under various environments, lower cost of weed control, greater yield, and higher net returns [5]. Growers often use one application of glyphosate applied early (EPOST) or late postemergence (LPOST) or a sequential application of glyphosate applied EPOST and LPOST as the primary weed management strategy to control troublesome weeds in glyphosate-resistant corn [6-9].

It is important to control weeds as early as 2 weeks after emergence (WAE) and as late as 6 WAE to avoid yield loss in corn and other crops [10-12]. This wide range of time to control weeds to avoid yield losses necessitate glyphosate applications timings that are specific to weed populations and environmental conditions where

glyphosate resistant cropping systems are being used [12]. Research has shown that a single-pass herbicide program with no residual activity can result in late emerging weeds and result in yield losses [13-18]. Other research has shown that it is possible to eliminate any yield loss due to weed interference with a single properly timed glyphosate application in glyphosate-resistant corn [19]. However, depending on weather conditions and weed species composition there is the potential for weeds to emerge after application. Control of late emerging weeds may increase corn yield, improve harvesting efficiency and reduce weed seed return to the soil.

Corn producers in Michigan and Ontario need more information to determine whether late emerging weeds have a negative impact on corn yield. The objective of this research was to determine the effect of late emerging weeds on the yield of glyphosate-resistant corn under Michigan and Ontario environmental conditions.

## 2. MATERIALS AND METHODS

### 2.1. Study Establishment

Fifteen field trials were established during 2009 to 2011 at various locations in Ontario, Canada and Michi-

gan, USA as listed in **Table 1**. Trials were established as a randomized complete block design with four replications. Treatments included a weedy and weed-free control and corn were maintained weed-free with glyphosate ( $900 \text{ gae}\cdot\text{ha}^{-1}$ ) up to the 2-, 4-, 6-, 8- or 10-leaf stage after which weeds were allowed to naturally infest the corn. Plots were 2 m wide and 8 or 10 m long. Glyphosate-resistant corn hybrids were seeded at approximately  $70,000 \text{ seeds}\cdot\text{ha}^{-1}$  in rows that were spaced 76 cm apart at a depth of 5 cm on dates listed in **Table 1**.

Glyphosate was applied with a  $\text{CO}_2$ -pressurized backpack sprayer equipped with ULD 120-02 flat fan nozzles (Hypro, New Brighton, MN) calibrated to deliver  $200 \text{ L}\cdot\text{ha}^{-1}$  of water at 210/241 kPa in Ontario. In Michigan, glyphosate was applied with a tractor-mounted compressed-air sprayer equipped with flat-fan nozzles (Tee-Jet<sup>®</sup> XR 8003, Spraying Systems Co., Glendale Heights, IL) and calibrated to deliver  $187 \text{ L}\cdot\text{ha}^{-1}$  at a pressure of 207 kPa.

### 2.2. Data Collection

Weed control was evaluated on a scale of 0% to 100% (0 = no weed control, and 100 = complete weed control) 2 and 6 weeks after the last glyphosate application (WAT).

**Table 1.** Planting date, emergence date, and corn hybrids for fifteen field trials established during 2009 to 2011 at various locations in Ontario, Canada and Michigan, USA.

Location	Year	Planting Date	Emergence Date	Corn Hybrid
<u>Environment 1</u>				
Exeter	2009	May 12	May 25	Pioneer 38M58
East Lansing, MI	2010	April 30	-	DKC 46-61
Ridgetown	2009a	May 6	May 22	Pioneer 35F44
	2009c	May 4	May 22	Pioneer 35F44
<u>Environment 2</u>				
Exeter	2010	April 21	-	DKC 46-07
	2011	May 13	May 24	DKC 46-07
Harrow	2011	June 1	June 6	DKC 61-21
Entrican, MI	2010	April 28	-	DKC 46-61
East Lansing, MI	2011	May 10	-	DKC 46-61
Ridgetown	2009b	May 6	May 19	Pioneer 35F44
	2010a	May 5	May 21	DKC 50-45
	2010b	May 5	May 23	DKC 50-45
	2010c	May 17	May 24	DKC 50-45
	2011a	May 12	May 23	DKC 52-59
	2011b	May 12	May 23	DKC 52-59

Weed biomass was taken and the number and species of weeds were recorded from two half-meter quadrats in each plot 6 WAT. Corn height from the soil surface to the upper most extended leaf was measured from ten randomly selected corn plants per plot 2 and 6 WAT. Corn was harvested in October/November using a plot combine and yields were adjusted to 15.5% seed moisture content.

### 2.3. Statistical Analysis

All data were subjected to analysis of variance. Tests were combined over locations and years and analyzed using the MIXED procedure of SAS (Ver. 9.2, SAS Institute Inc., Cary, NC). Variances were separated into the random effects of location (year and location), replication (at each location) and location by treatment. Herbicide treatment was considered the fixed effect. The significance of the random effects (location, replication and location by treatment) and their interaction with fixed effects was tested using the Z-test of the variance estimate. To ensure the assumptions (errors are independent, homogenous and normally distributed) of the variance analysis were met; residual plots were examined. Data were tested for normality using the Shapiro-Wilk statistic as generated by the UNIVARIATE procedure in SAS. If necessary, a transformation of the data (natural log, square root or arcsine square root) was applied and chosen based on the highest Shapiro-Wilk statistic generated. Means were separated using Fisher's protected LSD at  $p < 0.05$ . Data were pooled into environments based on the significance level of the treatment\*year\*location interaction.

## 3. RESULTS AND DISCUSSION

Data were separated into two environments based on the impact of treatment on corn yield. Environment 1 included Exeter 2009, East Lansing, MI 2010, Ridgetown 2009a, and Ridgetown 2009c and Environment 2 included Exeter 2010, Exeter 2011, Harrow 2011, Entrican, MI 2010, East Lansing, MI 2011, Ridgetown 2009b, Ridgetown 2010a-c, and Ridgetown 2011a-b.

### 3.1. Weed Control

The most prominent weeds were velvetleaf (ABUTH), redroot pigweed (AMARE), common ragweed (AMBEL), common lambsquarters (CHEAL) and green foxtail (SETVI).

At 2 weeks after the last application of glyphosate, there was no improvement in weed control when corn was kept weed-free later than 2, 2, 4, 2, and 6-leaf stage in environment 1 and 2, 4, 4, 10, and 6-leaf stage in environment 2 for ABUTH, AMARE, AMBEL, CHEAL, and SETVI, respectively (**Tables 2 and 3**).

At 6 weeks after the last application of glyphosate, there was no improvement in weed control when corn was kept weed-free later than 4, 4, 6, 6, and 8-leaf stage in environment 1 and 6, 8, 6, 4, and 8-leaf stage in environment 2 for ABUTH, AMARE, AMBEL, CHEAL, and SETVI, respectively (**Tables 2 and 3**).

### 3.2. Weed Biomass and Density

There was improved weed control the longer corn was kept weed-free compared to weedy control. At 6 WAT, there were as much as 47%, 89%, 99%, 81%, and 3%

**Table 2.** Control of various weed species (2 and 6 WAT) after corn was maintained weeds free for different lengths of time in environment 1 (Exeter 2009, East Lansing 2010, Ridgetown 2009a, Ridgetown 2009c.).

Treatment <sup>z</sup>	Environment 1									
	Weed Control (%)									
	ABUTH		AMARE		AMBEL		CHEAL		SETVI	
	2 WAT	6 WAT	2 WAT	6 WAT	2 WAT	6 WAT	2 WAT	6 WAT	2 WAT	6 WAT
Weedy Control	0b	0c	0b	0c	0c	0d	0b	0d	0c	0d
Last glyphosate at 2lf	100a	65b	98a	39b	81b	38c	94a	38c	99a	32c
Last glyphosate at 4lf	100a	100a	99a	93a	99a	70b	92a	76b	88b	38c
Last glyphosate at 6lf	100a	100a	99a	99a	98a	90a	97a	88ab	92ab	70b
Last glyphosate at 8lf	100a	98a	100a	100a	98a	92a	97a	93a	94a	79ab
Last glyphosate at 10lf	100a	100a	100a	100a	100a	100a	100a	100a	98a	97a
Weed-Free Control	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a

<sup>z</sup>Glyphosate was applied postemergence at 900 gae·ha<sup>-1</sup>. <sup>y</sup>Data were averaged for environments. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ( $p < 0.05$ ).

**Table 3.** Control of various weed species (2 and 6 WAT) after corn was maintained weeds free for different lengths of time in environment 2 (Exeter 2010, Exeter 2011, Harrow 2011, Entrican 2010, East Lansing 2011, Ridgetown 2009b, Ridgetown 2010a-c, Ridgetown 2011a-b).

Treatment <sup>z</sup>	Environment 2									
	Weed control (%)									
	ABUTH		AMARE		AMBEL		CHEAL		SETVI	
	2 WAT	6 WAT	2 WAT	6 WAT	2 WAT	6 WAT	2 WAT	6 WAT	2 WAT	6 WAT
Weedy control	0b	0d	0c	0e	0c	0d	0d	0c	0d	0e
Last glyphosate at 2lf	95a	65c	92b	80d	94b	79c	94c	70b	91c	72d
Last glyphosate at 4lf	94a	79b	97a	87cd	97a	88b	94c	81ab	94bc	81c
Last glyphosate at 6lf	95a	92a	97a	92bc	99a	96a	96bc	100a	97ab	90b
Last glyphosate at 8lf	95a	96a	98a	96ab	100a	98a	96bc	93ab	99a	96ab
Last glyphosate at 10lf	100a	99a	99a	99a	100a	100a	98ab	98a	99a	98ab
Weed-free control	100a	100a	100a	100a	100a	100a	100a	100a	100a	100a

<sup>z</sup>Glyphosate was applied postemergence at 900 gae-ha<sup>-1</sup>. <sup>y</sup>Data were averaged for environments. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ( $p < 0.05$ ).

reduction in biomass of ABUTH, AMARE, AMBEL, CHEAL, and SETVI respectively compared to weedy control when corn was kept weed-free until the 2-leaf corn stage (Tables 4 and 5). At 6 weeks after the last application of glyphosate, there was no decrease in weed biomass when corn was kept weed-free later than 4, 4, 4, 4, and 6-leaf corn stage under both environments for ABUTH, AMARE, AMBEL, CHEAL, and SETVI, respectively (Tables 4 and 5).

At 6 WAT, there were as much as 60%, 70%, 90%, 49%, and 22% reduction in density of ABUTH, AMARE, AMBEL, CHEAL, and SETVI respectively compared to weedy control when corn was kept weed-free until the 2-leaf corn stage (Tables 4 and 5). There was no decrease in weed density when corn was kept weed-free later than 2, 2, 4, 6, and 8-leaf stage under both environments for ABUTH, AMARE, AMBEL, CHEAL, and SETVI, respectively (Tables 4 and 5).

Weeds emerging after the 6th leaf stage of corn were small (low biomass/seedlings) and most likely did not reach reproductive maturity. In other studies, Stewart *et al.* [8] found 91% - 100% control of AMARE, 85% - 100% of CHEAL and 78% - 97% control of SETVI with a single POST application of glyphosate at 3 - 4 leaf corn. Another study [20] found that ABUTH, AMARE, AMBEL, CHEAL, and annual grasses were controlled 38% - 93%, 93%, 99% - 100%, 71% - 100%, 30% - 98% at 3 - 4 leaf stage and 98% - 99%, 100%, 78% - 100%, 71% - 98%, and 91% - 100% at 7 - 8 leaf stage in glyphosate resistant corn, respectively. Thomas *et al.* [21] reported 96% - 100% control of CHEAL, 100% control of AMBEL, 66% - 91% control of IPOSP (morningglory), 72% - 98% control of ELEIN (goosegrass) and 79% - 96%

control of DIGSA (large crabgrass) with glyphosate POST applications at 4 - 6 leaf stage in glyphosate resistant corn.

### 3.3. Corn Height and Yield

Corn height was as much as 14% and 16% taller at 2 WAT and 16% and 31% higher at 6 WAT compared to the weedy control with glyphosate treatments in environment 1 and 2, respectively (Table 6). There was no decrease in corn height if weeds were allowed to emerge after the 2 leaf stage of corn at 2 or 6 WAT (Table 6). There were no differences in corn height due to the length of time the corn was kept weed-free or between environments (Table 6).

In Environment 1 (4/15 sites) corn had to be kept weed-free up to the 4-leaf stage to prevent any yield loss due to late-emerging weeds. There was no yield loss in corn if weeds were allowed to emerge after the 4-leaf stage of corn (Table 6). Yield was 40% higher than weedy control when corn was kept weed free until the 2-leaf corn stage. Similarly, yield was as much as 52% higher than the weedy control when the last glyphosate treatment was applied at 4 - 10 leaf corn stage (Table 6).

In Environment 2 (11/15 sites) corn had to be kept weed-free up to the 2-leaf stage to prevent any yield loss due to late-emerging weeds. There was no yield loss in corn if weeds were allowed to emerge after the 2-leaf stage of the corn (Table 6). Yield was as much as 53% higher than weedy control when the last glyphosate treatment was applied at 2 - 10 leaf corn stage (Table 6). While weeds which emerged after various corn leaf stages did not necessarily impact yield, it is probable that

**Table 4.** Aboveground biomass and density of various weed species (6 WAT) after corn was maintained weeds free for different lengths of time in environment 1 (Exeter 2009, East Lansing 2010, Ridgetown 2009a, Ridgetown 2009c).

Treatment <sup>z</sup>	Environment 1									
	ABUTH		AMARE		AMBEL		CHEAL		SETVI	
	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density
	g/m <sup>2</sup>	no./m <sup>2</sup>	g/m <sup>2</sup>	no./m <sup>2</sup>	g/m <sup>2</sup>	no./m <sup>2</sup>	g/m <sup>2</sup>	no./m <sup>2</sup>	g/m <sup>2</sup>	no./m <sup>2</sup>
Weedy control	2.9a	4a	9.8a	3a	82.3a	20a	193.1a	34a	17.3ab	25a
Last glyphosate at 2lf	2.0a	2a	14.6a	5a	18.3b	8b	49.6b	25abc	24.4a	41a
Last glyphosate at 4lf	1.6a	3a	0.3b	2a	0.3c	2bc	9.6c	29ab	13.9ab	22a
Last glyphosate at 6lf	0.1a	1a	0.2b	1a	5.2c	1bc	0.5c	12bcd	2.5b	43a
Last glyphosate at 8lf	0.2a	3a	0b	0a	0.2c	1bc	0.6c	8cd	1.7b	35a
Last glyphosate at 10lf	0a	0a	0b	0a	0c	0c	0c	0	0.1b	13a
Weed-free control	0a	0a	0b	0a	0c	0c	0c	0d	0b	0a

<sup>z</sup>Glyphosate was applied postemergence at 900 gae·ha<sup>-1</sup>. <sup>y</sup>Data were averaged for environments. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ( $p < 0.05$ ).

**Table 5.** Aboveground biomass and density of various weed species (6 WAT) after corn was maintained weeds free for different lengths of time in environment 2 (Exeter 2010, Exeter 2011, Harrow 2011, East Lansing 2010, East Lansing 2011, Ridgetown 2009b, Ridgetown 2010a-c, Ridgetown 2011a-b).

Treatment <sup>z</sup>	Environment 2									
	ABUTH		AMARE		AMBEL		CHEAL		SETVI	
	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Density
	g/m <sup>2</sup>	no./m <sup>2</sup>	g/m <sup>2</sup>	no./m <sup>2</sup>	g/m <sup>2</sup>	no./m <sup>2</sup>	g/m <sup>2</sup>	no./m <sup>2</sup>	g/m <sup>2</sup>	no./m <sup>2</sup>
Weedy control	9.3a	5a	70.6a	27a	89.0a	10a	77.1a	49a	23.3a	18a
Last glyphosate at 2lf	4.9ab	2b	7.6b	8b	1.3b	1b	14.9b	25ab	22.7a	14ab
Last glyphosate at 4lf	1.7b	2b	1.5b	6b	0.1b	1b	8.3b	24ab	9.5ab	10ab
Last glyphosate at 6lf	1.4b	1b	0b	2b	0b	0b	2.2b	20b	2.9b	6ab
Last glyphosate at 8lf	0b	0b	0b	0b	0.1b	1b	1.1b	14b	0.4b	3b
Last glyphosate at 10lf	0b	0b	0b	0b	0b	0b	0.3b	1b	0.4b	2b
Weed-free control	0b	0b	0b	0b	0b	0b	0b	0b	0b	0b

<sup>z</sup>Glyphosate was applied postemergence at 900 gae·ha<sup>-1</sup>. <sup>y</sup>Data were averaged for environments. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ( $p < 0.05$ ).

weed seeds were added to the soil seed bank for weeds emerging after the 2- and 4-leaf stage of corn (supported by visual ratings; data not shown).

In other studies, Ritchie *et al.* [22] found that a single application of glyphosate at 3-leaf corn stage prevented yield losses in corn. In north central USA, Gower *et al.* [23] found a glyphosate application at 4-leaf stage was generally needed to avoid yield losses in corn. In north-eastern USA Cox *et al.* [24] found that a glyphosate application at 3 - 4 leaf corn stage is sufficient to avoid yield losses in glyphosate-resistant corn. Another study, in southwestern Ontario, Canada [20] found that there

was no yield loss with a single application of glyphosate at 3 - 4 leaf stage but there was as much as 19% yield loss when glyphosate was applied at 7 - 8 leaf stage in glyphosate-resistant corn. Other researchers have reported that depending on environmental conditions corn needs to be kept weed-free from the 3 - 14 leaf stage to avoid yield losses due to weed interference [23,25-27].

#### 4. CONCLUSION

Based on these results, there is improved weed control with each additional application of glyphosate. For most

**Table 6.** Effect of late emerging weeds on height and yield of corn in fifteen field trials established during 2009 to 2011 at various environments in Ontario, Canada and Michigan, USA. Means with the same letters within a column are not significantly different at  $P < 0.05$ .<sup>z,y</sup>

Treatment <sup>x</sup>	Corn height (cm)				Yield (t·ha <sup>-1</sup> )	
	Environment 1		Environment 2		Environment 1	Environment 2
	2 WAT	6 WAT	2 WAT	6 WAT		
Weedy control	159b	219b	150b	206b	6.1c	7.1b
Last glyphosate at 2lf	175a	244a	175a	238a	10.1b	12.8a
Last glyphosate at 4lf	179a	256a	178a	300a	12.1a	12.8a
Last glyphosate at 6lf	182a	261a	179a	243a	12.6a	13.2a
Last glyphosate at 8lf	184a	257a	178a	243a	12.7a	13.3a
Last glyphosate at 10lf	182a	255a	177a	238a	12.6a	13.3a
Weed-free control	180a	260a	177a	237a	12.6a	13.4a

<sup>z</sup>Environment 1 = Exeter 2009, East Lansing 2010, Ridgeway 2009a, Ridgeway 2009c. <sup>y</sup>Environment 2 = Exeter 2010, Exeter 2011, Harrow 2011, Entrican 2010, East Lansing 2011, Ridgeway 2009b, Ridgeway 2010a-c, Ridgeway 2011a-b. <sup>x</sup>Glyphosate was applied postemergence at 900 gae·ha<sup>-1</sup>.

weeds evaluated, there is no improvement in weed control when corn is kept weed-free until the 6-leaf stage of corn. Corn must be maintained weed free up to the 4-leaf stage. Weeds emerging after the 4-leaf stage do not influence corn yield. There were no differences among corn height for any treatments or between environments. Weeds emerging after the 6-leaf corn stage are less likely to reach reproductive maturity and contribute to the seed bank.

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