Weed Control, Environmental Impact and Profitability of Two-Pass Weed Management Strategies in Glyphosate-Resistant Corn

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Abstract: Twelve field trials were conducted over a three-year period (2010, 2011, 2012) at different locations in southwestern Ontario, Canada to compare various two-pass weed management strategies in glyphosate-resistant corn for crop injury, weed control, environmental impact, corn yield and profit margin. No visible injury resulted from the herbicide treatments evaluated. One early postemergence (EPOST) application of glyphosate provided good full season control of pigweed species and lady's thumb and fair control of velvetleaf, common ragweed, lamb's-quarters, barnyard grass and green foxtail. One late postemergence (LPOST) application of glyphosate provided excellent control of all weed species evaluated but corn yield was reduced due to early weed interference. The sequential application of glyphosate (EPOST *fb* LPOST) provided excellent control of all weed species evaluated with no adverse effect on corn yield. The sequential application of a preemergence residual herbicide followed by an application of glyphosate LPOST provided excellent full season control of all weed species evaluated and corn yield was equal to the weed free control. Among the sequential herbicide programs the lowest environmental impact was glyphosate EPOST *fb* LPOST and saflufenacil/dimethenamid-p, isoxaflutole + atrazine or rimsulfuron + s-metolachlor + dicamba applied PRE fb glyphosate LPOST. Based on this study, the most efficacious and profitable weed management programs in glyphosate-resistant corn are a sequential application of glyphosate or a two-pass program of a preemergence residual herbicide followed by glyphosate LPOST. The two-pass programs have glyphosate stewardship benefits.

Keywords: Environmental impact quotient (EIQ), glyphosate, profit margin, corn.

INTRODUCTION

Corn (*Zea mays* L.) is important for agriculture and the economy of Ontario. In 2011, 7.2 million tonnes of grain corn was produced on approximately 822,000 hectares compromising nearly 63% of Canada's total corn production with a farm-gate value of $1.3 billion and ranks as the largest annually tilled field crop grown in Ontario [1,2]. Most of the corn grown in Ontario is glyphosate-resistant which has provided growers with additional weed management options with economic advantages [3,4]. 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].

There are different weed management strategies that can be utilized in glyphosate-resistant corn. These include one application of glyphosate applied early (EPOST) or late postemergence (LPOST), a sequential application of glyphosate applied EPOST and LPOST, an EPOST tankmix application with glyphosate, and a sequential application of a preemergence (PRE) residual herbicide followed by glyphosate applied LPOST [5-8]. Relying exclusively on glyphosate for weed management may result in the selection of

glyphosate resistant weed biotypes [8-10]. Selection pressure can be reduced with tankmixes or sequential applications that utilize more than one herbicide mode of action [8].

Nelson [11] found that yield was maximized when glyphosate was applied before weeds were 10 cm in height. Other studies have shown that a single-pass herbicide program with no residual activity can result in weed escapes and does not adequately control late emerging weeds [6,12-16]. Sequential in-crop applications of glyphosate or including a PRE residual herbicide followed by glyphosate applied LPOST herbicides have been shown to provide improved weed control in corn [5,6,15,17-19].

The demand on growers to economically produce environmentally sustainable food while maintaining herbicide stewardship is increasing [20]. To achieve this goal, data on weed control, crop yield, economics and environmental impact of herbicides are needed to help identify the most advantageous herbicide program. The environmental impact (EI) of different weed control strategies should be considered when making weed management decisions. The EI of weed management may be reduced by using lower herbicide application rates and/or safer products. The EIQ uses three risk components: farm worker, consumer, and environment to estimate the relative potential risk of pesticide active ingredients [21-23]. The EI of a particular pesticide treatment is obtained by multiplying the EIQ by the application rate. Thus, a higher EI indicates a greater risk of detrimental impact. The EIQ was designed to provide growers and weed

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management practitioners with a single number that indicates the magnitude of relative risk. The EIQ has been used effectively to compare environmental risk of different pesticides and/or production systems [24-28]. The EIQ can be used as a decision tool, along with herbicide efficacy, crop safety, and profit margins to identify the most advantageous weed management strategy in corn.

Research has shown that for any weed management program to succeed growers must consistently get acceptable weed control and an increase in profitability for them to implement these weed management techniques. The viability for various weed management programs needs to be assessed based on profit margins over weed control costs. Limited information exists on the weed control efficacy, corn yield, environmental impact, and profitability of two-pass weed control strategies in corn of a PRE residual herbicide followed by glyphosate applied LPOST in glyphosate-resistant corn under Ontario environmental conditions. Therefore, the objectives of this study were to determine the level of weed control, yield, net returns, and environmental impact of various PRE/POST programs in glyphosate-resistant corn.

MATERIALS AND METHODS

A total of twelve field trials were conducted in southwestern Ontario at the Greenhouse and Processing Crops Research Centre, Agriculture and Agri-Food Canada, Harrow, at the Huron Research Station, Exeter, Ontario and at the University of Guelph, Ridgetown Campus, Ridgetown, Ontario during 2010, 2011 and 2012. The soils ranged from Fox sandy loam to Brookston clay loam with 33-82% sand, 5-41% silt, 15-29% clay, 12-33% organic matter and pH of 6.0-7.9. Site preparation included moldboard plowing or disking in the autumn followed by two passes with a field cultivator in the spring.

Experiments were arranged in a randomized complete block design with four replicates. There were a total of sixteen treatments: 1. Weedy; 2. Weed-free; 3. Glyphosate (EPOST); 4. Glyphosate (LPOST); 5. Glyphosate fb glyphosate (EPOST fb LPOST); 6. Dicamba/atrazine fb glyphosate (PRE fb LPOST); 7. Pendimethalin + atrazine fb glyphosate (PRE fb LPOST); 8. Pendimethalin + dicamba/atrazine fb glyphosate (PRE fb LPOST); 9. Saflufenacil/dimethenamid-p fb glyphosate (PRE fb LPOST); 10. Isoxaflutole + atrazine fb glyphosate (PRE fb LPOST); 11. S-metolachlor/atrazine + flumetsulam fb glyphosate (PRE fb LPOST); 12. S-metolachlor + flumetsulam + clopyralid fb glyphosate (PRE fb LPOST); 13. Rimsulfuron + s-metolachlor + dicamba fb glyphosate (PRE fb LPOST); 14. Atrazine fb glyphosate; 15. S-metolachlor/atrazine fb glyphosate (PRE fb LPOST); and 16. S-metolachlor/atrazine + mesotrione fb glyphosate(PRE fb LPOST). Application doses selected were based on the manufacturers recommended dose for each herbicide in Ontario and are listed in Table **4**.

All plots were 3 m (4 corn rows spaced 75 cm apart) wide and 8 m long at Harrow and Ridgetown and 10 m long at Exeter. Glyphosate-resistant corn hybrids were seeded at a density of 80 000 seeds ha^{-1}. Herbicides were applied using a CO_2 -pressurized sprayer calibrated to deliver 222 L ha^{-1} aqueous solution at 210 kPa at Harrow, 200 L ha^{-1} aqueous solution at 240 kPa at Exeter and 200 L ha^{-1} aqueous solution

at 200 kPa at Ridgetown. The boom was 1.5 m wide with four ultra-low drift nozzles (ULD120-02, Hypro, New Brighton, MN) spaced 50 cm apart. PRE treatments were applied 0-7 days after seeding, EPOST treatments were applied at 3-4 corn leaf stage and the LPOST treatments were applied at 6-8 corn leaf stage.

Crop injury was evaluated visually 2 and 3 weeks after emergence (WAE), using a scale of 0 to 100% where a rating of 0 was defined as no visible plant injury and a rating of 100 was defined as plant death. Percent weed control was visually assessed 4 and 8 weeks after the LPOST herbicide application (WAA) using a scale of 0 to100% where a rating of 0 was defined as no weed control and a rating of 100 was defined as complete control. Weed density and biomass (dry weight) were evaluated at approximately 3 WAE (prior to LPOST glyphosate application) by counting and cutting plants at the soil surface in two 0.5 m^2 quadrats per plot and separating by species. Plants were dried at 60 ^{0}C to constant moisture and then weighed. Corn was mechanically harvested at physiological maturity using a plot combine at all sites. Corn yields were adjusted to a 15.5% moisture level.

Statistical Analyses

All data were subjected to analysis of variance and analyzed using the PROC MIXED procedure in SAS statistical software (Version 9.2. SAS Institute, Inc., Box 8000, SAS Circle, Cary, NC 27512). Variances were partitioned into the fixed effect of herbicide treatment and into the random effects of environment (year and location). When there were no significant interactions between environment and treatment the data were pooled and averaged. The assumptions of the variance analysis were tested by ensuring that the residuals were random, homogeneous, with a normal distribution about a mean of zero using residual plots and a Shapiro-Wilk normality test. All percentage data required an arcsine square root transformation. Yield data did not require transformation. All percentage data presented in tables are on the back-transformed scale. Treatment means were separated at the 5% level of significance using Fisher's Protected LSD test.

Environmental Impact

The environmental risk for each herbicide treatment was determined using published EIQ values for all active ingredients (a.i.) [22]. The environmental impact of each treatment was calculated by multiplying herbicide EIQ by the amount applied in kg ai (ae) ha^{-1}. For herbicide products and/or tank mixes that contain more than one active ingredient, the EI was calculated by summing EIQs at the appropriate proportion.

Profitability Analysis

The profitability analysis is based on the level of profit margins over weed control costs, measured as gross income less herbicide and application costs. Gross income for each treatment was calculated as the yield multiplied the cash price of corn in Chatham, ON as of October 1 of each year and the herbicide costs for each treatment are based on the herbicide prices reported by AGRIS (AGRIS Co-operative Ltd., 835 Park Avenue West, Chatham, ON N7M 5J6, Canada). Application costs are determined based on cost of pro-

duction data reported by the Ontario Ministry of Agriculture, Food and Rural Affairs (Field Crop Budgets, Publication 60, updated annually; Ontario Ministry of Agriculture, Food and Rural Affairs, 1 Stone Road West, Guelph, ON N1G 4Y2, Canada). All other costs of production are assumed to be constant across treatments, thus they are not considered in the analysis. Pairwise comparisons were made between treatments to test for significant differences in average profit margins between treatments. These pairwise comparisons are made across all locations and years as well as for each location in each year.

RESULTS AND DISCUSSION

Weed Control

The dominant weed species in this study were velvetleaf (*Abutilon theophrasti* Medic.; ABUTH), green pigweed (*Amaranthus powellii* L.; AMAPO), common ragweed (*Ambrosia artemisiifolia* L.; AMBEL), common lamb's-quarters (*Chenopdium album* L.; CHEAL), lady's thumb (*Polygonum persicaria* L.; POLPE), barnyard grass (*Echinochloa crusgalli*; ECHCG), and green foxtail (*Setaria viridis* L.; SETVI). There was no significant interaction between environments and treatments, therefore these data were pooled and averaged over environments.

Weed Control Prior to In-Crop Glyphosate Application

At approximately 3 to 4 WAE, one EPOST application of glyphosate prior to the LPOST application of glyphosate controlled ABUTH 74%, AMAPO 93%, AMBEL 82%, CHEAL 81%, POLPE 73%, ECHCG 72%, and SETVI 88%

(Table **1**). All of PRE herbicides evaluated provided equivalent control of AMAPO and CHEAL 3 to 4 WAE prior to the LPOST application of glyphosate. The PRE application of atrazine provided the poorest control of ABUTH (44 to 52%) while mesotrione provided the best control of ABUTH (76%). The PRE application of atrazine provided the poorest control of AMBEL (62 to 68%) and ECHCG (39%) while all the remaining herbicides provided equivalent control of these weeds species. The PRE application of pendimethalin plus atrazine provided the poorest control of POLPE (74%) while all the remaining herbicides provided equivalent control of POLPE. Control of SETVI was the poorest with atrazine (42%) and dicamba/atrazine (45%) (Table **1**).

Weed Density Prior to In-Crop Glyphosate Application

One early postemergence application of glyphosate reduced density of ABUTH 86%, AMAPO 76 %, AMBEL 73%, CHEAL 63%, POLPE 71%, ECHCG 85%, and SETVI 81% compared to the weedy check (Table **2**). The PRE herbicides reduced the density of AMAPO (94-97%), CHEAL (83-98%) and POLPE (76-100%) equivalently. The PRE application mesotrione, saflufenacil, isoxaflutole and flumetsulam reduced ABUTH density the most. The PRE application of pendimethalin plus atrazine, atrazine and s-metolachlor/atrazine reduced AMBEL density the least. The PRE application atrazine and dicamba and Pendimethalin + atrazine and atrazine reduced ECHCG density least and there was no difference in density among the other herbicides evaluated. The PRE application atrazine and dicamba reduced SETVI density least (Table **2**).

**Table 1.	Mean Control (%) of Various Weeds in Response to Weed Management Strategies 4 Weeks After Emergence (Prior to the in-Crop Application of Glyphosate) in Twelve Field Trials Conducted at Exeter, Harrow and Ridgetown, ON, Canada During 2010 to 2012[z,y]**

Treatment	ABUTH[z]	AMAPO[z]	AMBEL[z]	CHEAL[z]	POLPE[z]	ECHCG[z]	SETVI[z]
3	74ab	93a	82a	81a	73b	72a	88a
6	60b	83a	78a	77a	97a	43b	45c
7	52c	75a	62b	75a	74b	42b	67b
8	61b	84a	74ab	82a	94a	48b	65b
9	64b	79a	74ab	74a	93a	53b	70b
10	65b	79a	77a	78a	90a	52b	68b
11	66b	79a	74ab	73a	90a	59b	74b
12	64b	79a	76a	75a	92a	46b	75b
13	59bc	82a	80a	75a	96a	58b	72b
14	48c	74a	68b	76a	88a	39c	42c
15	44c	79a	64b	72a	89a	53b	66b
16	76a	87a	83a	76a	93a	53b	68b

[z] Abbreviations: ABUTH, velvetleaf; AMAPO, green pigweed; AMBEL, common ragweed; CHEAL, common lambsquarters; POLPE, lady's thumb; ECHCG, barnyardgrass; and SETVI, green foxtail.
[y] 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). Treatment 4 was removed as there was no herbicide applied at this point. Treatment 5 was also removed since at this point in the season it was just a repeat of Treatment 3.

Table 2. **Mean Density (no. m⁻²) and Biomass (g m⁻²) of Various Weeds in Response to Weed Management Strategies 4 Weeks After Emergence (Prior to the in-Crop Application of Glyphosate) in Twelve Field Trials Conducted at Exeter, Harrow and Ridgetown, ON, Canada During 2010 to 2012^{z,y}**

Treatment	ABUTH^z		AMAPO^z		AMBEL^z		CHEAL^z		POLPE^z		ECHCG^z		SETVI^z	
	Density	Bio-mass	Den-sity	Bio-mass	Den-sity	Bio-mass	Density	Bio-mass	Den-sity	Bio-mass	Den-sity	Bio-mass	Den-sity	Bio-mass
	no. m⁻²	g m⁻²	no. m⁻²	g/m²	no. m⁻²	g m⁻²	no. m⁻²	g m⁻²	no. m⁻²	g m⁻²	no. m⁻²	g m⁻²	no. m⁻²	g m⁻²
1 weedy	21a	3.8a	34a	19.6a	26a	29.9a	54a	14.5a	17a	14.9a	20a	7.3b	122a	7.3a
3	3c	1.3a	8b	1.4b	7bc	18.1a	20a	3.9b	5b	5.8b	3b	2.0b	23c	0.16b
6	13b	2.6a	2c	1b	4cd	0.14b	2b	1.1b	1b	0.1b	28a	17.9a	54b	1.2b
7	16a	2.7a	1c	0.18b	11b	12.4a	3b	0.69b	4b	5.5b	21a	5.9b	12c	0.67b
8	11b	1.8a	2c	1.6b	3cd	0.35b	1b	0.84b	1b	0.1b	8b	5.6b	14c	0.16b
9	4c	1.3a	1c	0.7b	1d	1.7b	3b	1.9b	0b	0b	6b	2.0b	3d	0.16b
10	4c	1.4a	1c	0.3b	1d	1.7b	2b	0.49b	2b	3.2b	7b	3.9b	8cd	0.20b
11	7c	1.8a	1c	0.7b	3cd	2.6b	4b	1.9b	1b	1.3b	3b	2.8b	0d	0b
12	8bc	1.9a	2c	1b	4cd	1.3b	6b	2.4b	0b	0b	6b	5.2b	0d	0b
13	21a	3.5a	1c	0.7b	4cd	0.45b	4b	2.1b	1b	1.3b	6b	1.1b	2d	0.07b
14	13b	3.4a	1c	0.4b	7c	10.4ab	3b	0.9b	2b	2.0b	14a	4.7b	44b	1.1b
15	30a	4.7a	1c	0.3b	9bc	7.4b	9b	3.2b	2b	4.7b	4b	3.6b	5d	0.25b
16	2c	0.9a	1c	0.4b	1d	1.3b	6b	2.3b	0b	0b	3b	1.7b	3d	0.07b

^{z} Abbreviations: ABUTH, velvetleaf; AMAPO, green pigweed; AMBEL, common ragweed; CHEAL, common lambsquarters; POLPE, lady's thumb; ECHCG, barnyardgrass; and SETVI, green foxtail.
^{y} 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). Treatment 4 was removed as there was no herbicide applied at this point. Treatment 5 was also removed since at this point in the season it was just a repeat of Treatment 3.

Weed Biomass Prior to In-Crop Glyphosate Application

One early postemergence application of glyphosate reduced biomass of ABUTH 66%, AMAPO 93 %, AMBEL 39%, CHEAL 73%, POLPE 61%, ECHCG 73%, and SETVI 98% compared to the weedy check however, results were not always statistically significant (Table **2**). The PRE herbicides reduced the density of ABUTH, AMAPO, CHEAL, POLPE and SETVI equivalently. Generally, the biomass of AMBEL was not reduced as much with atrazine and the biomass of ECHCG was decreased the least with dicamba/atrazine (Table **2**).

Weed Control after In-Crop Glyphosate Application

Data for 4 and 8 WAA were similar; therefore only data for 8 WAA are presented (Table **3**). One EPOST application of glyphosate controlled ABUTH 53%, AMAPO 80%, AMBEL 72%, CHEAL 67%, POLPE 83%, ECHCG 49%, and SETVI 56%. One LPOST application of glyphosate provided control of ABUTH 82%, AMAPO 97%, AMBEL 85%, CHEAL 93%, POLPE 73%, ECHCG 96%, and SETVI 91% which was greater than the EPOST application with the exception of POLPE which was reduced. The sequential application of glyphosate (EPOST fb LPOST) improved efficacy and controlled ABUTH 92%, AMAPO 98%, AMBEL 93%, CHEAL 95%, POLPE 93%, ECHCG 97%, and SETVI 92%. The sequential application of a preemergence herbicide followed by an application of glyphosate LPOST controlled ABUTH 91-98%, AMAPO 99-100%, AMBEL 95-98%, CHEAL 97-99%, POLPE 95-99%, ECHCG 97-99%, and SETVI 93-99% which was equivalent to the sequential application of glyphosate. Results are similar to other studies that have shown sequential in-crop applications of glyphosate or including a residual PRE herbicide with POST herbicides control weed escapes and late-emerging weeds in corn [5,6,15,17-19].

In other studies Stewart *et al.* [7] found 7-11% lower redroot pigweed control with an EPOST application of glyphosate compared to a sequential application of glyphosate in corn. However, a sequential application of glyphosate did not improve redroot pigweed control in comparison to a single EPOST application in soybean [16]. Other studies have found that the sequential application of glyphosate or by following a PRE herbicide with a POST application of glyphosate effectively controls late-emerging weeds in glyphosate-resistant corn [6,15,18]. The sequential glyphosate applications also increased common lamb's-quarters control 5-9% in corn and 4-9% in soybean compared to a single application of glyphosate [7,18]. However, other studies have shown adequate season long control of common lamb's-quarters with a single application of glyphosate under certain environmental conditions [16]. Gonzini *et al.* [18] found 13-22% and 17-27% increase in velvetleaf control compared to a single application of glyphosate when PRE herbicides were followed by glyphosate or sequential applications of

Table 3.   Mean control (%) of various weeds in response to weed management strategies 8 WAA in twelve field trials conducted at Exeter, Harrow and Ridgetown, ON, Canada during 2010 to 2012 (data averaged over environments)[y]

Treatment	ABUTH[z]	AMAPO[z]	AMBEL[z]	CHEAL[z]	POLPE[z]	ECHCG[z]	SETVI[z]
3	53c	80b	72b	67b	83b	49b	56b
4	82b	97a	85ab	93a	73c	96a	91a
5	92a	98a	93a	95a	93a	97a	92a
6	94a	99a	97a	98a	95a	98a	94a
7	95a	100a	96a	97a	96a	97a	97a
8	91a	99a	97a	99a	99a	98a	97a
9	95a	100a	98a	97a	97a	99a	96a
10	98a	100a	98a	99a	98a	99a	97a
11	98a	100a	98a	99a	97a	99a	98a
12	97a	100a	97a	99a	98a	99a	99a
13	98a	99a	98a	98a	98a	99a	97a
14	92a	99a	95a	97a	98a	98a	93a
15	91a	100a	97a	98a	97a	99a	98a
16	96a	100a	97a	98a	98a	98a	98a

[z] Abbreviations: ABUTH, velvetleaf; AMAPO, green pigweed; AMBEL, common ragweed; CHEAL, common lambsquarters; POLPE, lady's thumb; ECHCG, barnyardgrass; and SETVI, green foxtail.
[y] 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).

glyphosate were applied, respectively. Similarly, giant foxtail control improved 2-15% with sequential applications of glyphosate POST or PRE herbicides followed by a POST application of glyphosate compared to a single-pass application of glyphosate POST [18].

Crop Injury and Yield

No visible injury resulted from the herbicide treatments evaluated at 2 and 3 WAE (data not shown). Herbicide treatments increased corn yield 5.4 to 6.8 t ha^{-1} compared to the non-treated weedy control (Table **4**). There was no difference in corn yield between glyphosate applied EPOST, LPOST and sequential glyphosate applications (EPOST fb LPOST). Yields generally tended to be higher with PRE herbicides *fb* glyphosate LPOST compared to glyphosate applied alone EPOST or LPOST although results were not always statistically significant (Table **4**). Higher yields can be attributed to increased weed control (Table **3**). In other studies PRE herbicide (flufenacet + metribuzin) *fb* glyphosate increased corn yield compared to the glyphosate alone which was attributed to early season weed control [6].

Profitability Analysis

Profitability analysis indicated that weeds decreased profit margin 1412 CAN $ ha^{-1} compared to the weed-free control (Table **4**). Herbicide treatments increased profit margin 1149 to 1343 CAN $ ha^{-1} compared to non-treated weedy control (Table **4**). There was no significant difference in profit margin between glyphosate applied EPOST (2545 CAN $ ha^{-1}), LPOST (2605 CAN $ ha^{-1}) or sequential gly-

phosate applications EPOST fb LPOST (2680 CAN$ ha^{-1}). The sequential application of dicamba/atrazine PRE fb glyphosate LPOST had a higher profit margin than glyphosate EPOST (2815 vs 2545 CAN$ ha^{-1}) and LPOST (2815 vs 2605 CAN$ ha^{-1}) but had no significant difference with the sequential application of glyphosate EPOST fb LPOST (Table **4**). S-metolachlor + flumetsulam + clopyralid PRE fb glyphosate LPOST had the lowest profit margin (1149 CAN$ ha^{-1}) but the difference was only significant with dicamba/atrazine PRE fb glyphosate LPOST (2815 CAN$ ha^{-1}) and weed-free control (2785 CAN$ ha^{-1}). There was generally no other differences between weed management strategies in respect to profit margins. Overall, profit margin was equivalent regardless of the PRE herbicides used except for s-metolachlor + flumetsulam + clopyralid.

Environmental Impact

Among the herbicide treatments evaluated, glyphosate EPOST or LPOST applied alone had the lowest EI value of 13.8 (Table **5**). As expected adding another active ingredient to the weed management strategy increased the EI. Among the sequential programs the environmental impact of applying glyphosate EPOST fb LPOST with the EI value of 27.6 was higher than EI of applying saflufenacil/dimethenamid-p, isoxaflutole + atrazine, and rimsulfuron + s-metolachlor + dicamba PRE fb glyphosate LPOST with EI values of 20.2, 26.5, 26.3, respectively (Table **5**). However, the EI of applying glyphosate EPOST fb LPOST with EI value of 27.6 was less than EI of applying dicamba/atrazine, pendimethalin + atrazine, pendimethalin + dicamba/atrazine, s-metolachlor/atrazine + flumetsulam, s-metolachlor +

Table 4. **Mean Corn Yield and Profit Margin of Weed Management Strategies Used at Twelve Field Trials Conducted in Exeter, Harrow, and Ridgetown, ON, Canada During 2010 to 2012[z,y]**

S.No.	Treatment	Timing	Herbicide Rate	Yield	Profit
			(g ai/ae ha^{-1})	(t ha^{-1})	(CAN $ ha[-1])
1.	Weedy			6.7 d	1372.74 d
2.	Weed-free			13.0 abc	2784.80 ab
3.	Glyphosate (early)	EPOST[y]	900	12.1 c	2544.73 bc
4.	Glyphosate (late)	LPOST[y]	900	12.3 bc	2604.81 abc
5.	Glyphosate fb glyphosate	EPOST fb LPOST[y]	900 fb 900	12.9 abc	2680.01 abc
6.	Dicamba/atrazine fb glyphosate	PRE fb LPOST[y]	1000 fb 900	13.5 a	2815.46 a
7.	Pendimethalin + atrazine fb glyphosate	PRE fb LPOST[y]	1000+1000 fb 900	13.1 ab	2715.56 abc
8.	Pendimethalin + dicamba/atrazine fb glyphosate	PRE fb LPOST[y]	1000+1000 fb 900	13.1 ab	2677.62 abc
9.	Saflufenacil/DMTA-p fb glyphosate	PRE fb LPOST[y]	490 fb 900	12.9 abc	2645.33 abc
10.	Isoxaflutole + AE0001789 + atrazine fb glyphosate	PRE fb LPOST[y]	52.5+500 fb 900	12.8 abc	2662.22 abc
11.	S-metolachlor/atrazine + flumetsulam fb glyphosate	PRE fb LPOST[y]	1800+50 fb 900	12.7 abc	2613.78 abc
12.	S-metolachlor + flumetsulam + clopyralid fb glyphosate	PRE fb LPOST[y]	1600+50+135 fb 900	12.8 abc	2521.92 c
13.	Rimsulfuron + s-metolachlor + dicamba fb glyphosate	PRE fb LPOST[y]	15+342+180 fb 900	13.2 ab	2683.84 abc
14.	Atrazine fb glyphosate	PRE fb LPOST[y]	1500 fb 900	12.9 abc	2690.49 abc
15.	S-metolachlor/atrazine fb glyphosate	PRE fb LPOST[y]	1800 fb 900	12.7 abc	2623.70 abc
16.	S-metolachlor/atrazine + mesotrione fb glyphosate	PRE fb LPOST[y]	1800+70 fb 900	13.2 ab	2687.54 abc

[z] 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).
[y] Abbreviations: EPOST, early postemergence; LPOST, late postemergence; fb, followed by.

Table 5. **Environmental Impact Quotient (EIQ) and Environmental Impact (EI) of Weed Management Strategies Used at Twelve Field Trials Conducted at Exeter, Harrow, and Ridgetown, ON During 2010 to 2012[z]**

S.No.	Active ingredient(s)	Timing	Individual EIQ values[y]	Herbicide Rate g ai/ae ha^{-1}	EI[x]
1.	Weedy check				
2.	Weed free check				
3.	Glyphosate	EPOST[z]	15.3	900	13.8
4.	Glyphosate	LPOST[z]	15.3	900	13.8
5.	Glyphosate fb glyphosate	EPOST fb LPOST[z]	15.3 fb 15.3	900 fb 900	27.6
6.	Dicamba/atrazine fb glyphosate	PRE fb LPOST[z]	26.3/22.9 fb 15.3	1000 fb 900	37.8
7.	Pendimethalin+atrazine fb glyphosate	PRE fb LPOST[z]	30.2+22.9 fb 15.3	1000+1000 fb 900	66.9
8.	Pendimethalin+dicamba/atrazine fb glyphosate	PRE fb LPOST[z]	30.2+26.3/22.9 fb 15.3	1000+1000 fb 900	68.0
9.	Saflufenacil/dimethenamid-p fb glyphosate	PRE fb LPOST[z]	22.3/12.0 fb 15.3	490 fb 900	20.2
10.	Isoxaflutole+atrazine fb glyphosate	PRE fb LPOST[z]	24.0+22.9 fb 15.3	52.5+500 fb 900	26.5
11.	S-metolachlor/atrazine+flumetsulam fb glyphosate	PRE fb LPOST[z]	22.0/22.9+15.6 fb 15.3	1800+50 fb 900	54.9
12.	S-metolachlor+flumetsulam+clopyralid fb glyphosate	PRE fb LPOST[z]	22.0+15.6+18.1 fb 15.3	1600+50+135 fb 900	52.2
13.	Rimsulfuron+s-metolachlor+dicamba fb glyphosate	PRE fb LPOST[z]	15.8+22.0+26.3 fb 15.3	15+342+180 fb 900	26.3

(Table 5) contd….

S.No.	Active ingredient(s)	Timing	Individual EIQ values[y]	Herbicide Rate g ai/ae ha^{-1}	EI[x]
14.	Atrazine fb glyphosate	PRE fb LPOST[z]	22.9 fb 15.3	1500 fb 900	48.2
15.	S-metolachlor/atrazine fb glyphosate	PRE fb LPOST[z]	22.0/22.9 fb 15.3	1800 fb 900	54.1
16.	S-metolachlor/atrazine+mesotrione fb glyphosate	PRE fb LPOST[z]	22.0/22.9+18.7 fb 15.3	1800+70 fb 900	55.4

[z]Abbreviations: EPOST, early postemergence; LPOST, late postemergence; fb, followed by; EIQ, environmental impact quotient; EI, environmental impact.
[y] EIQ values for each a.i. obtained from Kovach *et al.* (1999 updated 2010)
[x] EI values for products with more than one a.i. were obtained by summing the relative proportion of each a.i.

flumetsulam + clopyralid, atrazine, s-metolachlor/atrazine, and s-metolachlor/atrazine + mesotrione PRE fb glyphosate LPOST with EI values of 37.8, 66.9, 68.8, 54.9, 52.2, 48.2, 54.1, and 55.4, respectively (Table **5**). Thus, the addition of the saflufenacil/dimethenamid-p, isoxaflutole + atrazine and rimsulfuron + s-metolachlor + dicamba applied PRE fb glyphosate applied LPOST to glyphosate-resistant corn production is strongly recommended based on equivalent environmental risk as well as resistance management.

CONCLUSIONS

Based on results of this study, herbicide efficacy is weed species specific and the PRE herbicide of choice is dependent on historical field records. All PRE herbicides evaluated provided excellent control of green pigweed, lamb's-quarters and lady'sthumb. Atrazine is weak on velvetleaf and common ragweed. Dicamba and atrazine were weak on barnyard grass and green foxtail. Glyphosate was the great equalizer as the control of all weeds 8 WAA was equivalent regardless of the PRE herbicide applied. Corn yield was equivalent regardless of the PRE herbicide applied. Net returns were equivalent regardless of the PRE herbicide applied with the exception of s-metolachlor + flumetsulam + clopyralid. The Environmental Impact is influenced by herbicide choice. The single application of glyphosate had the lowest EI. The EI of some PRE/POST programs were equivalent (or less) than two applications of glyphosate. However, the EI of some PRE/POST programs had a greater EI such as pendimethalin, s-metolachlor and atrazine. This study concludes that a sequential application of glyphosate or a two-pass program of a preemergence herbicide followed by glyphosate LPOST provides the most efficacious and profitable weed management programs in glyphosate-resistant corn. These two-pass programs have the potential to reduce selection pressure and have glyphosate stewardship benefits.

CONFLICT OF INTEREST

The author(s) confirm that this article content has no conflicts of interest.

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