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Two-Pass Weed Management Programs for Identity-Preserved Soybean

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Abstract

Weed management is a challenge in Identity-Preserved (IP) soybean in Ontario, Canada. Six experiments were established in southwestern Ontario, Canada during 2021 and 2022 to evaluate weed control and soybean yield with preemergence (PRE), early postemergence (EPOST), and PRE followed by (fb) late POST (LPOST) herbicide programs. At 8 weeks after LPOST herbicide applications, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr applied PRE provided 7, 49, and 99% control of velvetleaf; 65, 98, and 100% control of green pigweed; 7, 8, and 82% control of common ragweed; 25, 68, and 98% control of common lambsquarters; 91, 77, and 89% control of barnyardgrass; and 62, 68, and 93% control of green foxtail, respectively. Imazethapyr + bentazon applied EPOST provided 91% control of velvetleaf; 91% control of green pigweed; 78% control of common ragweed; 95% control of common lambsquarters; 76% control of barnyardgrass; and 79% control of green foxtail. *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop applied LPOST provided 61, 86, and 100% control of velvetleaf; 97, 99, and 100% control of green pigweed; 94, 88, and 99% control of common ragweed; 96, 98, and 100% control of common lambsquarters; 97, 95, and 97% control of barnyardgrass; and 97, 96, and 99% control of green foxtail, respectively. There was minimal and transient soybean injury (6% or less) with all PRE or EPOST herbicide treatments, however, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST caused up to 22% injury in soybean. Weed interference reduced soybean yield 40%. Weed interference with *S*-metolachlor/metribuzin and pyroxasulfone/sulfentrazone applied PRE reduced soybean yield 25 and 31%, respectively. Reduced weed interference with flumioxazin/metribuzin/imazethapyr applied PRE, imazethapyr + bentazon applied EPOST, and the two-pass programs of a PRE fb LPOST herbicide resulted in soybean yield that was similar to the weed-free control. This study concludes that there are many effective weed management programs in IP soybean; however, the two-pass weed control programs are recommended since they provide good to excellent weed control, minimize soybean yield loss from weed interference, and ensure the use of multiple herbicide modes of action which reduces the selection intensity for the evolution of herbicide-resistant weeds.

Keywords: biomass, density, identity-preserved soybean, two-pass weed control, yield

1. Introduction

Soybean [*Glycine max* (L.) Merr.] (Fabaceae) has been grown in Canada for over 70 years and is currently the third-largest crop grown in Canada (SoyCanada, 2023). In 2020, Canadian growers seeded approximately 2.0 Mha of soybean and produced 6.4 Mt with farm cash receipts of $2.5 billion CAD (SoyCanada, 2023). Almost 4.4 Mt of this production, valued at $2.6 billion was exported to China, USA, Southeast Asia, Europe, and the Middle East while 1.8 Mt was processed in Canada (SoyCanada, 2023). Most of the soybean grown in Canada is produced in Ontario (OMAFRA, 2023). In 2020, soybean growers in Ontario seeded around 1.2 Mha and produced about 3.9 Mt with cash receipts value of approximately $2.0 billion (OMAFRA, 2024).

In the past 30 years, Identity Preserved (IP) soybean production in Canada has been grown by the producers to the customers' specifications (SoyCanada, 2023). Under IP soybean production, growers contract to produce soybean that must meet stringent customer specifications which can include specific cultivars (generally non-genetically modified), specific quality standards, and specialty traits (SoyCanada, 2023). IP soybean production is monitored carefully through every step of production including weed management programs. This begins with stringent production requirements in the field, to storage at the grain elevator, to transport via trucks, rail, and/or ships to ensure IP soybean quality and purity standards are maintained and are traceable back to the producer and seed lots used (SoyCanada, 2023). IP soybean is important to Ontario producers since purchasers pay a premium for this product.

Currently, most of the soybean grown in Ontario is glyphosate-resistant (GR) which has provided soybean producers with efficacious, low-cost weed management (Young et al., 2006; Sikkema & Soltani, 2007; Shurtleff & Aoyagi, 2010; Sikkema et al., 2013); however, glyphosate cannot be used in-crop in IP soybean production. As the number of herbicide-resistant weed biotypes increases across the province and the number of hectares infested expands, the number of viable herbicide options decreases for weed management in IP soybean (Heap, 2023).

Effective weed management is essential for sustainable, long-term IP soybean production in Ontario (Soltani et al., 2017). Herbicide options that can be used for weed control in IP soybean include preplant (PP), preplant incorporated (PPI), preemergence (PRE), early postemergence (EPOST), late postemergence (LPOST), and a sequential application of PP, PPI, or PRE soil-applied herbicides followed by (fb) LPOST herbicide programs. Studies have shown that a single-pass herbicide program can result in weed escapes and poor control of late-emerging weeds (Hartzler, 1996; Loux et al., 2008). The sequential application of a soil-applied herbicide(s) fb LPOST herbicides has the potential to improve weed control in soybean, minimize weed interference, increase soybean yield, and enhance net returns for soybean producers (Hartzler, 1996; Gonzini et al., 1999; Nurse et al., 2007; Loux et al., 2008; Stewart et al., 2011; Underwood et al., 2017). PRE herbicides with potential for weed control in IP soybean in Ontario include *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr. POST herbicides with potential for weed control in IP soybeans in Ontario include imazethapyr + bentazon applied EPOST and bentazon + fomesafen + quizalofop applied LPOST (OMAFRA, 2023).

There is limited information on the efficacy of two-pass weed management strategies for IP soybean where PRE residual herbicides are followed by LPOST herbicides under Ontario environmental conditions. The objective of this research is to evaluate *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr applied PRE; imazethapyr + bentazon applied EPOST; and sequential applications of *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop applied LPOST for weed management in IP soybean production.

2. Materials and Methods

A total of six experiments were established at the Huron Research Station, Exeter, Ontario and at the University of Guelph, Ridgetown Campus, Ridgetown, Ontario during 2021 and 2022. 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 in the autumn followed by two passes with a field cultivator with rolling basket harrows in the spring.

Experiments were arranged in a randomized complete block design with four replicates. There were a total of nine treatments as listed in Tables 1-7. Herbicide application doses and adjuvants selected were based on the manufacturers' recommended dose and adjuvant for each herbicide in Ontario.

All plots were 3 m (4 soybean rows spaced 75 cm apart) wide and 8 m long at Ridgetown and 10 m long at Exeter. Soybean seeds were seeded at a density of approximately 400,000 seeds per ha^{-1}. Herbicides were applied using a CO_2-pressurized sprayer calibrated to deliver 200 L per ha^{-1} aqueous solution at 210 kPa. The boom was 1.5 m wide with four ultra-low drift nozzles (ULD120-02, Hypro, New Brighton, MN) spaced 50 cm apart producing a spray width of 2.0 m. PRE herbicides were applied 0-7 days after seeding, EPOST treatments were applied when weeds were up to 2.5 cm in height, and LPOST herbicides were applied when weed escapes were up to 5 cm in height and prior to V5 soybean.

Soybean injury was evaluated visually 2 weeks after emergence (WAE) and 1 and 4 weeks after LPOST herbicide treatment (WAT), using a scale of 0 to 100% where a rating of 0 was defined as no visible soybean injury and a rating of 100 was defined as total soybean necrosis. Percent weed control was visually assessed 2 WAE, and 4 and 8 weeks after the LPOST herbicide treatment (WAT) using a scale of 0 to 100% 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 (shoot dry weight) were evaluated at approximately 8 WAT by counting the weeds by species and cutting plants at the soil surface in two 0.25 m^2 quadrats per plot and separating by species. Plants were dried at

60 ^{o}C to a constant moisture and then weighed. Soybean was harvested with a small-plot combine at crop maturity and moisture content and weight were recorded. Soybean yield was adjusted to 13% moisture prior to analysis.

The GLIMMIX procedure in SAS (Ver. 9.4, SAS Institute Inc., Cary, NC) was utilized for data analysis and the chosen level of significance was 0.05. For the generalized linear mixed model, herbicide treatment was the fixed effect, and environment, environment by treatment interaction, and replicate within environment were the random effects. Soybean yield was analyzed using a Gaussian distribution and visible percent soybean injury and percent weed control were arcsine square root transformed prior to analysis using a Gaussian distribution. Weed density and dry biomass were analyzed using a lognormal distribution. Differences among least-square means were subjected to Tukey's adjustment. Contrasts comparing the overall differences among application timings were also generated.

3. Results and Discussion

The dominant weed species in this study were velvetleaf (*Abutilon theophrasti* Medic.; ABUTH); green pigweed (*Amaranthus palmeri* Wats.; AMAPO), common ragweed (*Ambrosia artemisiifolia* L.; AMBEL), common lambsquarters (*Chenopdium album* L.; CHEAL); barnyardgrass (*Echinochloa crusgalli*; ECHCG), and green foxtail (*Setaria viridis* L.; SETVI). There was no significant interaction between environments and treatments, therefore data were pooled and averaged over environments.

3.1 Soybean Injury and Yield

At 2 WAE, flumioxazin/metribuzin/imazethapyr applied PRE caused up to 6% soybean injury (Table 1). At 1 and 4 weeks after LPOST herbicide application, the PRE herbicides caused no soybean injury. Imazethapyr + bentazon applied EPOST caused 3 and 1% soybean injury at 1 and 4 WAT, respectively (Table 1). However, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST caused up to 20, 20, and 22% soybean injury, respectively (Table 1). Orthogonal contrasts indicated that there was 3% greater injury with EPOST treatments in comparison to PRE treatments at 1 WAT, but the difference was not significant at 4 WAT (Table 1). At 1 and 4 WAT, the PRE fb LPOST treatments caused 21 and 20% greater soybean injury in comparison to the PRE herbicide applications. Similarly, the PRE fb LPOST treatments caused 18 and 19% greater soybean injury in comparison to the EPOST herbicide application at 1 and 4 WAT, respectively (Table 1).

Table 1. Percent soybean injury and yield for soybean treated with a PRE, EPOST or 2-pass herbicide programs at Exeter, Ontario in 2021 (n = 1) and Ridgetown, Ontario in 2021 and 2022 (n = 5) [a]

Herbicide treatment	Rate	Timing	Soybean injury [b]			Yield
			2 WAE	1 WAT	4 WAT	
	g ai ha^{-1}		----------------	%	----------------	T ha^{-1}
Weed-free control			0.0 a	0 a	0 a	3.7 a
Non-treated control			0.0 a	0 a	0 a	2.2 c
S-metolachlor/metribuzin	1943	PRE	0.6 ab	0 a	0 a	2.8 bc
Pyroxasulfone/sulfentrazone	300	PRE	0.1 ab	0 a	0 a	2.6 c
Flumi/metribuzin/imazethapyr	630	PRE	5.6 b	0 a	0 a	3.3 ab
Imazethapyr + bentazon + UAN	75 + 840 + 2 L ha^{-1}	EPOST	-	3 b	1 a	3.5 a
S-metolachlor/metribuzin + bent + fom + quiz + SM	1943 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	20 c	20 b	3.3 ab
Pyroxasulfone/sulfentrazone + bent + fom + quiz + SM	300 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	20 c	20 b	3.3 ab
Flumi/metribuzin/imazethapyr + bent + fom + quiz + SM	630 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	22 c	21 b	3.5 a
Contrasts						
PRE vs EPOST			-	0 vs 3**	0 vs 1	2.87 vs 3.47**
PRE vs 2-pass			-	0 vs 21**	0 vs 20**	2.87 vs 3.37**
EPOST vs 2-pass			-	3 vs 21**	1 vs 20**	3.37 vs 3.47

Note. Means within a column followed by the same lowercase letter do not differ significantly according to Tukey's HSD at $P < 0.05$.

* and ** denote significance at $P < 0.05$ and $P < 0.001$, respectively.

[a] Abbreviations: Bent, bentazon; Flumi, flumioxazin; Fom, fomesafen; EPOST, postemergence up to 2.5 cm weeds; LPOST, postemergence up to 5 cm weed escapes and prior to V5 soybean; PRE, preemergence; Quiz, quizalofop-p-ethyl; SM, Sure-Mix; UAN, urea ammonium nitrate; WAE, weeks after crop emergence; WAT, weeks after LPOST herbicide application.

[b] No injury observed at 2 WAE and 4 WAT for all sites in 2021, and at 1 WAT for one site in 2021; data not included in analysis due to zero variance.

In other studies, chlorimuron + flumioxazin fb glyphosate (PRE fb LPOST); *S*-metolachlor + metribuzin fb glyphosate (PRE fb LPOST); *S*-metolachlor/metribuzin fb glyphosate (PRE fb LPOST); flumioxazin fb glyphosate (PRE fb LPOST); and pyroxasulfone + flumioxazin fb glyphosate (PRE fb LPOST) caused 4, 2, 2, 4, and 7% soybean injury, respectively (Soltani et al., 2014). Other studies have also shown minimal and transient soybean injury with PP/PRE application of herbicides such as pyroxasulfone + flumioxazin or *S*-metolachlor/metribuzin (Mahoney et al., 2014; Refsell et al., 2009; Underwood et al., 2017; Young et al. 2010).

Weed interference reduced soybean yield 40% (Table 1). Weed interference with *S*-metolachlor/metribuzin and pyroxasulfone/sulfentrazone applied PRE treatments reduced soybean yield 25 and 31%, respectively. Reduced weed interference with flumioxazin/metribuzin/imazethapyr applied PRE, imazethapyr + bentazon applied EPOST, and the two-pass programs of a PRE fb LPOST herbicide resulted in soybean yield that was similar to the weed-free control. Orthogonal contrasts indicated that soybean yield was 17% lower with PRE treatments in comparison to the EPOST treatment. Similarly, soybean yield was 15% lower with the PRE herbicides in comparison to the two-pass (PRE fb LPOST) herbicide applications. There was no difference in soybean yield between the EPOST and two-pass (PRE fb POST) herbicide applications. In other studies, weed interference reduced GR soybean yield 25% (Soltani et al., 2014). The same study showed that soybean yield was lower than the sequential application of glyphosate with chlorimuron or pyroxasulfone/flumioxazin fb glyphosate (Soltani et al., 2014). Another study reported lower soybean yield with PRE application of pyroxasulfone/flumioxazin, flumioxazin, pyroxasulfone, *S*-metolachlor + metribuzin, flumioxazin + imazethapyr + metribuzin, dimethenamid-p + imazethapyr + metribuzin, and *S*-metholachlor + metribuzin + chlorimuron compared to the weed-free control (Mahoney et al., 2014). In another manuscript, there was no reduction in GR soybean yield compared to weed-free control with the sequential application of PRE herbicides such as imazethapyr, *S*-metolachlor + metribuzin and flumetsulam/*S*-metolachlor followed by an application of glyphosate LPOST (Stewart et al., 2011).

3.2 Velvetleaf Control

At 2 WAE, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE controlled velvetleaf 27, 78 and 98%, respectively (Table 2).

Table 2. Percent control, density and dry biomass of ABUTH treated with a PRE, EPOST or 2-pass herbicide programs at Ridgetown, Ontario in 2021 and 2022 (n = 4) [a]

Herbicide treatment	Rate	Timing	ABUTH control			ABUTH density	ABUTH dry biomass
			2 WAE	4 WAT	8 WAT		
	g ai ha^{-1}		----------------	%	----------------	plants m^{-2}	g m^{-2}
Weed-free control			100	100	100	0.0 a	0.0 a
Non-treated control			0 c	0 e	0 e	10.5 d	21.2 d
S-metolachlor/metribuzin	1943	PRE	27 b	10 d	7 d	6.0 cd	20.6 cd
Pyroxasulfone/sulfentrazone	300	PRE	78 ab	52 c	49 c	4.6 bcd	5.9 bc
Flumi/metribuzin/imazethapyr	630	PRE	98 a	99 ab	99 a	0.9 ab	0.3 ab
Imazethapyr + bentazon + UAN	75 + 840 + 2 L ha^{-1}	EPOST	-	93 ab	91 ab	1.7 bc	0.1 ab
S-metolachlor/metribuzin + bent + fom + quiz + SM	1943 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	72 bc	61 bc	3.2 bc	3.6 b
Pyroxasulfone/sulfentrazone + bent + fom + quiz + SM	300 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	90 abc	86 abc	2.7 bc	3.0 b
Flumi/metribuzin/imazethapyr + bent + fom + quiz + SM	630 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	100 a	100 a	0.5 ab	0.0 ab
Contrasts							
PRE vs EPOST			-	59 vs 93*	55 vs 91**	3.9 vs 1.7	8.9 vs 0.1**
PRE vs 2-pass			-	59 vs 91**	55 vs 87**	3.9 vs 2.1	8.9 vs 2.2*
EPOST vs 2-pass			-	93 vs 91	91 vs 87	1.7 vs 2.1	0.1 vs 2.2

Note. Means within a column followed by the same lowercase letter do not differ significantly according to Tukey's HSD at P < 0.05.

* and ** denote significance at P < 0.05 and P < 0.001, respectively.

[a] Abbreviations: ABUTH, velvetleaf; Bent, bentazon; Flumi, flumioxazin; Fom, fomesafen; EPOST, postemergence up to 2.5 cm weeds; LPOST, postemergence up to 5 cm weed escapes and prior to V5 soybean; PRE, preemergence; Quiz, quizalofop-p-ethyl; SM, Sure-Mix; UAN, urea ammonium nitrate; WAE, weeks after crop emergence; WAT, weeks after LPOST herbicide application.

At 4 and 8 weeks after LPOST herbicide applications, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr applied PRE controlled velvetleaf 7-10%, 49-52%, and 99%, respectively (Table 2). Imazethapyr + bentazon applied EPOST provided 91-93% control of velvetleaf. *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST controlled velvetleaf 61-72%, 86-90%, and 100%, respectively (Table 2). Orthogonal contrasts indicated that there was 34 and 36% greater control of velvetleaf with the EPOST treatment in comparison to PRE treatments at 4 and 8 weeks after LPOST herbicide application, respectively (Table 2). The PRE fb LPOST treatments provided 32% greater control of velvetleaf in comparison to the PRE herbicide applications alone (Table 2). There was no difference in velvetleaf control between EPOST and PRE fb LPOST treatments (Table 2).

S-metolachlor/metribuzin, or pyroxasulfone/sulfentrazone applied PRE did not reduce velvetleaf density but flumioxazin/metribuzin/imazethapyr applied PRE reduced velvetleaf density 91% (Table 2). Imazethapyr + bentazon applied EPOST reduced velvetleaf density 84% (Table 2). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced velvetleaf density 70, 74, and 95%, respectively (Table 2). Orthogonal contrasts indicated that there was no significant difference in velvetleaf density between PRE vs EPOST, PRE vs two-pass, and EPOST vs two-pass treatments (Table 2).

S-metolachlor/metribuzin applied PRE did not reduce velvetleaf biomass but pyroxasulfone/sulfentrazone and flumioxazin/metribuzin/imazethapyr applied PRE reduced velvetleaf biomass 72 and 99%, respectively (Table 2). Imazethapyr + bentazon applied EPOST reduced velvetleaf biomass 100% (Table 2). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced velvetleaf biomass 83, 86, and 100%, respectively (Table 2). Orthogonal contrasts indicated that velvetleaf biomass was reduced 99% greater with EPOST and 75% greater with 2-pass treatments compared to the PRE treatments alone, respectively. However, there was no significant difference in velvetleaf biomass between EPOST vs two-pass treatments (Table 2).

Results are similar to other studies that have shown that two-pass programs of PRE herbicides such as imazethapyr, *S*-metolachlor + metribuzin, or flumetsulam/*S*-metolachlor followed by an application of glyphosate LPOST provided 78-100% control of velvetleaf in GR soybean (Stewart et al., 2011). In another study, the sequential application of a PRE herbicide followed by an application of glyphosate LPOST controlled velvetleaf 99-100% (Soltani et al., 2014). Gonzini et al. (1999) reported 13-22% and 17-27% increase in velvetleaf control compared to a single application of glyphosate when PRE herbicides such as chlorimuron + metribuzin, cloransulam-methyl, or sulfentrazone were followed by glyphosate or sequential applications of glyphosate were applied, respectively.

3.3 Green Pigweed

At 2 WAE, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE controlled green pigweed 99-100% (Table 3).

Table 3. Percent control, density and dry biomass for AMAPO treated with a PRE, EPOST or 2-pass herbicide programs at Ridgetown, Ontario in 2021 and 2022 (n = 3) [a]

Herbicide treatment	Rate	Timing	AMAPO control			AMAPO density	AMAPO dry biomass
			2 WAE	4 WAT	8 WAT		
	g ai ha^{-1}		---------------- % ----------------			plants m^{-2}	g m^{-2}
Weed-free control			100	100	100	0.0 a	0.0 a
Non-treated control			0 b	0 c	0 c	12.1 c	8.9 c
S-metolachlor/metribuzin	1943	PRE	99 a	70 b	65 b	2.1 b	2.6 bc
Pyroxasulfone/sulfentrazone	300	PRE	99 a	98 a	98 a	0.5 ab	0.7 ab
Flumi/metribuzin/imazethapyr	630	PRE	100 a	100 a	100 a	0.0 a	0.0 a
Imazethapyr + bentazon + UAN	75 + 840 + 2 L ha^{-1}	EPOST	-	91 ab	91 ab	1.3 b	1.2 b
S-metolachlor/metribuzin + bent + fom + quiz + SM	1943 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	99 a	97 a	0.2 ab	0.2 ab
Pyroxasulfone/sulfentrazone + bent + fom + quiz + SM	300 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	99 a	99 a	0.1 ab	0.1 ab
Flumi/metribuzin/imazethapyr + bent + fom + quiz + SM	630 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	100 a	100 a	0.0 a	0.0 a
Contrasts							
PRE vs EPOST			-	94 vs 91	93 vs 91	0.9 vs 1.3	1.1 vs 1.2
PRE vs 2-pass			-	94 vs 100*	93 vs 99*	0.9 vs 0.1*	1.1 vs 0.1*
EPOST vs 2-pass			-	91 vs 100*	91 vs 99*	1.3 vs 0.1*	1.2 vs 0.1*

Note. Means within a column followed by the same lowercase letter do not differ significantly according to Tukey's HSD at P < 0.05.

* and ** denote significance at P < 0.05 and P < 0.001, respectively.

[a] Abbreviations: AMAPO, green pigweed; Bent, bentazon; Flumi, flumioxazin; Fom, fomesafen; EPOST, postemergence up to 2.5 cm weeds; LPOST, postemergence up to 5 cm weed escapes and prior to V5 soybean; PRE, preemergence; Quiz, quizalofop-p-ethyl; SM, Sure-Mix; UAN, urea ammonium nitrate; WAE, weeks after crop emergence; WAT, weeks after LPOST herbicide application.

At 4 and WAT, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE controlled green pigweed 65-70, 98, and 100%, respectively (Table 3). Imazethapyr + bentazon applied EPOST provided 91% control of green pigweed at 4 and 8 WAT. *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen +

quizalofop LPOST controlled green pigweed 97-99, 99, and 100%, respectively (Table 3). Orthogonal contrasts indicated that there was no difference with EPOST treatments in comparison to PRE treatments at 4 and 8 weeks WAT (Table 3). The PRE fb LPOST treatments provided 6% greater control of green pigweed in comparison to the PRE herbicide applications alone (Table 3). Two-pass treatments (PRE fb LPOST) provided up to 9% greater control of green pigweed than the EPOST treatment alone (Table 3).

S-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE reduced green pigweed density 83, 96, and 100%, respectively (Table 3). Imazethapyr + bentazon applied EPOST reduced green pigweed density 89% (Table 3). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced green pigweed density 98, 99, and 100%, respectively (Table 3). Orthogonal contrasts indicated that there was no significant difference in green pigweed density between PRE vs EPOST treatments, but two-pass weed management programs reduced green pigweed density 89% and 92% compared to PRE and EPOST treatments, respectively (Table 3).

S-metolachlor/metribuzin applied PRE did not reduce green pigweed biomass, but pyroxasulfone/sulfentrazone and flumioxazin/metribuzin/imazethapyr applied PRE reduced green pigweed biomass 92 and 100%, respectively (Table 3). Imazethapyr + bentazon applied EPOST reduced green pigweed biomass 87% (Table 3). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced green pigweed biomass 98, 99, and 100%, respectively (Table 3). Orthogonal contrasts indicated that there was no significant difference in green pigweed biomass between PRE vs EPOST treatments but two-pass treatments reduced biomass 91 and 92% compared to PRE and EPOST treatments, respectively (Table 3).

In other research, the sequential application of PRE herbicides such as imazethapyr, *S*-metolachlor + metribuzin, and flumetsulam/*S*-metolachlor followed by an application of glyphosate LPOST provided 99-100% control of pigweed in GR soybean (Stewart et al., 2011). In another study, the sequential application of glyphosate + chlorimuron or glyphosate + pyroxasulfone/flumioxazin applied PRE fb an application of glyphosate LPOST controlled pigweed 99-100% which was similar to the sequential application of glyphosate (Soltani et al., 2014).

3.4 Common Ragweed

At 2 WAE, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE controlled common ragweed 21, 18, and 93%, respectively (Table 4).

Table 4. Percent control, density and dry biomass for AMBEL treated with a PRE, EPOST or 2-pass herbicide programs at Exeter, Ontario in 2021 (n = 1) and Ridgetown, Ontario in 2021 and 2022 (n = 5) [a]

Herbicide treatment	Rate	Timing	AMBEL control			AMBEL density	AMBEL dry biomass
			2 WAE	4 WAT	8 WAT		
	g ai ha^{-1}		----------------- % ----------------			plants m^{-2}	g m^{-2}
Weed-free control			100	100	100	0 a	0.0 a
Non-treated control			0 c	0 d	0 d	47 g	69.9 d
S-metolachlor/metribuzin	1943	PRE	21 b	13 c	7 c	17 ef	47.9 d
Pyroxasulfone/sulfentrazone	300	PRE	18 b	14 c	8 c	34 fg	97.9 d
Flumi/metribuzin/imazethapyr	630	PRE	93 a	88 ab	82 b	3 abc	10.7 bc
Imazethapyr + bentazon + UAN	75 + 840 + 2 L ha^{-1}	EPOST	-	83 b	78 b	14 de	6.4 c
S-metolachlor/metribuzin + bent + fom + quiz + SM	1943 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	95 ab	94 ab	4 abc	1.4 abc
Pyroxasulfone/sulfentrazone + bent + fom + quiz + SM	300 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	93 ab	88 ab	10 cd	4.6 bc
Flumi/metribuzin/imazethapyr + bent + fom + quiz + SM	630 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	100 a	99 a	1 ab	1.1 ab
Contrasts							
PRE vs EPOST			-	37 vs 83**	29 vs 78**	18 vs 14	52.1 vs 6.4**
PRE vs 2-pass			-	37 vs 97**	29 vs 95**	18 vs 5**	52.1 vs 2.4**
EPOST vs 2-pass			-	83 vs 97*	78 vs 95*	14 vs 5**	6.4 vs 2.4*

Note. Means within a column followed by the same lowercase letter do not differ significantly according to Tukey's HSD at $P < 0.05$.

* and ** denote significance at $P < 0.05$ and $P < 0.001$, respectively.

[a] Abbreviations: AMBEL, common ragweed; Bent, bentazon; Flumi, flumioxazin; Fom, fomesafen; EPOST, postemergence up to 2.5 cm weeds; LPOST, postemergence up to 5 cm weed escapes and prior to V5 soybean; PRE, preemergence; Quiz, quizalofop-p-ethyl; SM, Sure-Mix; UAN, urea ammonium nitrate; WAE, weeks after crop emergence; WAT, weeks after LPOST herbicide application.

At 4 and 8 WAT, *S*-metolachlor/metribuzin and pyroxasulfone/sulfentrazone applied PRE provided only 7-14% control of common ragweed but flumioxazin/metribuzin/imazethapyr applied PRE provided 82-88% control of common ragweed (Table 4). Imazethapyr + bentazon applied EPOST provided 78-83% control of common ragweed. *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST provided up to 95, 93, and 100% control of common ragweed, respectively (Table 4). Orthogonal contrasts indicated the EPOST treatments provided 46 and 49% greater control of common ragweed at 4 and 8 WAT, respectively (Table 4). The PRE fb LPOST controlled common ragweed 60 and 66% greater than the PRE treatments at 4 and 8 WAT, respectively. The PRE fb LPOST controlled common ragweed 14 and 17% greater than EPOST at 4 and 8 WAT, respectively (Table 4).

Pyroxasulfone/sulfentrazone applied PRE did not reduce common ragweed density (Table 4). .*S*-metolachlor/metribuzin and flumioxazin/metribuzin/imazethapyr applied PRE reduced common ragweed density 64 and 94%, respectively (Table 4). Imazethapyr + bentazon applied EPOST reduced common ragweed density 70% (Table 4). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop applied LPOST reduced common ragweed density 91, 79, and 98%, respectively (Table 4). Orthogonal contrasts indicated that there was no significant difference in common ragweed density between PRE vs EPOST treatments, but two-pass weed management programs reduced common ragweed density 72% greater than PRE treatments and 64% greater than the EPOST treatment (Table 4).

S-metolachlor/metribuzin and pyroxasulfone/sulfentrazone applied PRE did not affect common ragweed biomass, but flumioxazin/metribuzin/imazethapyr applied PRE reduced common ragweed biomass 85% (Table 4). Imazethapyr + bentazon applied EPOST reduced common ragweed biomass 91% (Table 4). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced common ragweed biomass 98, 93, and 98%, respectively (Table 4). Orthogonal contrasts indicated that common ragweed biomass was reduced 88% more with EPOST compared to PRE treatments and the two-pass programs reduced common ragweed biomass 95% more than the

PRE treatments. Two-pass treatments also reduced common ragweed biomass 63% compared to the EPOST treatment alone, respectively (Table 4).

Results are similar to other studies that have reported that the sequential application of PRE herbicides such as imazethapyr, *S*-metolachlor + metribuzin, and flumetsulam/*S*-metolachlor followed by an application of glyphosate LPOST provided 91-94% control of common ragweed in GR soybean (Stewart et al., 2011). In another study, the sequential application of a PRE herbicide followed by an application of glyphosate LPOST controlled common ragweed 96-98% which was comparable to the sequential application of glyphosate (Soltani et al., 2014).

3.5 Common Lambsquarters

At 2 WAE, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE controlled common lambsquarters 24, 67, and 99%, respectively (Table 5).

Table 5. Percent control, density and dry biomass for CHEAL treated with a PRE, EPOST or 2-pass herbicide programs at Exeter, Ontario in 2021 (n = 1) and Ridgetown, Ontario in 2021 and 2022 (n = 4) [a]

Herbicide treatment	Rate	Timing	CHEAL control			CHEAL density	CHEAL dry biomass
			2 WAE	4 WAT	8 WAT		
	g ai ha^{-1}		---------------- % ----------------			plants m^{-2}	g m^{-2}
Weed-free control			100	100	100	0.0 a	0.0 a
Non-treated control			0 c	0 d	0 c	75.2 e	18.7 c
S-metolachlor/metribuzin	1943	PRE	24 b	35 c	25 b	9.7 d	16.3 c
Pyroxasulfone/sulfentrazone	300	PRE	67 ab	66 bc	68 ab	1.3 bc	1.6 b
Flumi/metribuzin/imazethapyr	630	PRE	99 a	99 ab	98 a	0.7 abc	0.2 ab
Imazethapyr + bentazon + UAN	75 + 840 + 2 L ha^{-1}	EPOST	-	95 ab	95 a	7.5 cd	0.9 b
S-metolachlor/metribuzin + bent + fom + quiz + SM	1943 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	97 ab	96 a	1.3 bc	0.7 ab
Pyroxasulfone/sulfentrazone + bent + fom + quiz + SM	300 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	98 ab	98 a	1.1 abc	0.5 ab
Flumi/metribuzin/imazethapyr + bent + fom + quiz + SM	630 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	100 a	100 a	0.3 ab	0.1 ab
Contrasts							
PRE vs EPOST			-	72 vs 95*	69 vs 95*	3.9 vs 7.5	6.0 vs 0.9
PRE vs 2-pass			-	72 vs 98**	69 vs 98**	3.9 vs 0.9*	6.0 vs 0.4**
EPOST vs 2-pass			-	95 vs 98	95 vs 98	7.5 vs 0.9*	0.9 vs 0.4

Note. Means within a column followed by the same lowercase letter do not differ significantly according to Tukey's HSD at $P < 0.05$.

* and ** denote significance at $P < 0.05$ and $P < 0.001$, respectively.

[a] Abbreviations: Bent, bentazon; CHEAL, common lambsquarters; Flumi, flumioxazin; Fom, fomesafen; EPOST, postemergence up to 2.5 cm weeds; LPOST, postemergence up to 5 cm weed escapes and prior to V5 soybean; PRE, preemergence; Quiz, quizalofop-p-ethyl; SM, Sure-Mix; UAN, urea ammonium nitrate; WAE, weeks after crop emergence; WAT, weeks after LPOST herbicide application.

At 4 and 8 WAT, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE controlled common lambsquarters 25-35, 66-68, and 98-99%, respectively (Table 5). Imazethapyr + bentazon applied EPOST provided 95% control of common lambsquarters. *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST provided 96-97, 98, and 100% control of common lambsquarters, respectively (Table 5). Orthogonal contrasts indicated that there was 23 and 26% greater control of common lambsquarters with EPOST treatment in comparison to PRE treatments at 4 and 8 WAT (Table 5). The PRE fb LPOST treatments provided 26 and 29% greater control of common lambsquarters in comparison to the PRE herbicide applications alone at 4 and 8 WAT, respectively (Table 5). Two-pass treatments (PRE fb LPOST) did not provide any significant increase in control of common lambsquarters compared to the EPOST treatment alone (Table 5).

S-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE reduced common lambsquarters density 87, 98, and 99%, respectively (Table 5). Imazethapyr + bentazon applied

EPOST reduced common lambsquarters density 90% (Table 5). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced common lambsquarters density 98, 99, and 100%, respectively (Table 5). Orthogonal contrasts indicated that there was no significant difference in common lambsquarters density between PRE vs EPOST treatment, but two-pass weed management programs reduced common lambsquarters density 77% greater than PRE treatments and 88% greater than the EPOST treatment (Table 5).

S-metolachlor/metribuzin applied PRE did not reduce common lambsquarters biomass but pyroxasulfone/sulfentrazone and flumioxazin/metribuzin/imazethapyr applied PRE reduced common lambsquarters biomass 91 and 99%, respectively (Table 5). Imazethapyr + bentazon applied EPOST reduced common lambsquarters biomass 95% (Table 5). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced common lambsquarters biomass 96, 97, and 99%, respectively (Table 5). Orthogonal contrasts indicated that there was no significant difference in common lambsquarters biomass between PRE vs EPOST or EPOST vs two-pass treatments, but the two-pass treatments reduced biomass 93% greater than the PRE treatments (Table 5).

Results are similar to Stewart et al. (2014) that showed 97-98% control of common lambsquarters with the sequential application of PRE herbicides such as imazethapyr, S-metolachlor + metribuzin and flumetsulam/*S*-metolachlor followed by an application of glyphosate in GR soybean. Similarly, Soltani et al. (2014) observed that the sequential application of a PRE herbicide followed by an application of glyphosate LPOST provided 99-100% control of common lambsquarters in GR soybean. Gonzini et al. (1999) also reported a 13-27% increase in control of common lambsquarters when PRE herbicides such as chlorimuron + metribuzin, cloransulam-methyl, or sulfentrazone were followed by glyphosate (LPOST).

3.6 Barnyardgrass

At 2 WAE, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE controlled barnyardgrass 93, 78, and 91%, respectively (Table 6).

Table 6. Percent control, density and dry biomass for ECHCG treated with a PRE, EPOST or 2-pass herbicide programs at Ridgetown, Ontario in 2022 (n = 3) [a]

Herbicide treatment	Rate	Timing	ECHCG control			ECHCG density	ECHCG dry biomass
			2 WAE	4 WAT	8 WAT		
	g ai ha^{-1}		----------------	%	----------------	plants m^{-2}	g m^{-2}
Weed-free control			100	100	100	0 a	0.0 a
Non-treated control			0 b	0 d	0 c	29 c	25.8 c
S-metolachlor/metribuzin	1943	PRE	93 a	93 ab	91 ab	10 b	3.3 b
Pyroxasulfone/sulfentrazone	300	PRE	78 a	77 c	77 b	12 bc	4.4 b
Flumi/metribuzin/imazethapyr	630	PRE	91 a	90 b	89 ab	8 b	3.5 b
Imazethapyr + bentazon + UAN	75 + 840 + 2 L ha^{-1}	EPOST	-	76 c	76 b	6 b	1.3 ab
S-metolachlor/metribuzin + bent + fom + quiz + SM	1943 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	97 ab	97 a	4 b	0.5 ab
Pyroxasulfone/sulfentrazone + bent + fom + quiz + SM	300 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	95 ab	95 a	4 b	1.0 ab
Flumi/metribuzin/imazethapyr + bent + fom + quiz + SM	630 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	98 a	97 a	3 b	0.6 ab
Contrasts							
PRE vs EPOST			-	87 vs 76*	87 vs 76*	10 vs 6	3.7 vs 1.3*
PRE vs 2-pass			-	87 vs 97**	87 vs 96**	10 vs 4*	3.7 vs 0.7*
EPOST vs 2-pass			-	76 vs 97**	76 vs 96**	6 vs 4	1.3 vs 0.7

Note. Means within a column followed by the same lowercase letter do not differ significantly according to Tukey's HSD at $P < 0.05$.

* and ** denote significance at $P < 0.05$ and $P < 0.001$, respectively.

[a] Abbreviations: Bent, bentazon; ECHCG, barnyardgrass; Flumi, flumioxazin; Fom, fomesafen; EPOST, postemergence up to 2.5 cm weeds; LPOST, postemergence up to 5 cm weed escapes and prior to V5 soybean; PRE, preemergence; Quiz, quizalofop-p-ethyl; SM, Sure-Mix; UAN, urea ammonium nitrate; WAE, weeks after crop emergence; WAT, weeks after LPOST herbicide application.

At 4 and 8 WAT, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr applied PRE provided 91-93, 77, and 89-90% control of barnyardgrass, respectively (Table 6). Imazethapyr + bentazon applied EPOST provided 76% control of barnyardgrass. *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST provided 97, 95, and 97-98% control of barnyardgrass, respectively (Table 6). Orthogonal contrasts indicate that the PRE treatments provided 11% greater barnyardgrass control than the EPOST treatment at 4 and 8 WAT (Table 6). The PRE fb LPOST treatments provided 10 and 9% greater control of barnyardgrass in comparison to the PRE treatments alone at 4 and 8 WAT, respectively. The PRE fb LPOST treatments provided 21 and 20% greater control of barnyardgrass in comparison to the EPOST treatment at 4 and 8 WAT, respectively (Table 6).

Pyroxasulfone/sulfentrazone applied PRE did not reduce barnyardgrass density, but *S*-metolachlor/metribuzin and flumioxazin/metribuzin/imazethapyr applied PRE reduced barnyardgrass density 66 and 72%, respectively (Table 6). Imazethapyr + bentazon applied EPOST reduced barnyardgrass density 79% (Table 4). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced barnyardgrass density 86, 86, and 90%, respectively (Table 6). Orthogonal contrasts indicated that there was no significant difference in barnyardgrass density between PRE vs EPOST or EPOST vs two-pass treatments, but the two-pass weed management programs reduced barnyardgrass density 60% greater than PRE alone treatments (Table 6).

S-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr applied PRE reduced barnyardgrass biomass 87, 83, and 86%, respectively (Table 6). Imazethapyr + bentazon applied EPOST reduced barnyardgrass biomass 95% (Table 6). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced barnyardgrass biomass 98, 96, and 98%, respectively (Table 6). Orthogonal contrasts indicated that barnyardgrass biomass was reduced 65% greater with EPOST compared to PRE treatments and 81% with two-pass treatments compared to the PRE treatments. The two-pass treatments reduced barnyardgrass biomass similar to the EPOST treatment (Table 6).

Results are similar to other studies in which the sequential application of a PRE herbicide followed by an application of glyphosate LPOST controlled barnyardgrass 97-100% in GR soybean, which was the same as the sequential application of glyphosate (EPOST fb LPOST) (Soltani et al., 2014).

3.7 Green Foxtail

At 2 WAE, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE controlled green foxtail 55, 72, and 95%, respectively (Table 7).

Table 7. Percent control, density and dry biomass for SETVI treated with a PRE, EPOST or 2-pass herbicide programs at Exeter, Ontario in 2021 (n = 1) and Ridgetown, Ontario in 2021 and 2022 (n = 5) [a]

Herbicide treatment	Rate	Timing	SETVI control			SETVI density	SETVI dry biomass
			2 WAE	4 WAT	8 WAT		
	g ai ha^{-1}		----------------- % -----------------			plants m^{-2}	g m^{-2}
Weed-free control			100	100	100	0 a	0.0 a
Non-treated control			0 c	0 d	0 e	138 d	62.6 e
S-metolachlor/metribuzin	1943	PRE	55 a	62 c	62 d	33 c	13.4 d
Pyroxasulfone/sulfentrazone	300	PRE	72 a	71 bc	68 cd	40 c	20.3 d
Flumi/metribuzin/imazethapyr	630	PRE	95 a	95 ab	93 abc	16 b	2.4 bc
Imazethapyr + bentazon + UAN	75 + 840 + 2 L ha^{-1}	EPOST	-	82 abc	79 bcd	47 c	5.1 cd
S-metolachlor/metribuzin + bent + fom + quiz + SM	1943 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	98 a	97 ab	7 b	1.1 abc
Pyroxasulfone/sulfentrazone + bent + fom + quiz + SM	300 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	97 a	96 ab	8 b	1.5 abc
Flumi/metribuzin/imazethapyr + bent + fom + quiz + SM	630 + 840 + 240 + 48 + 0.5% v/v	PRE + LPOST	-	99 a	99 a	4 b	0.2 ab
Contrasts							
PRE vs EPOST			-	78 vs 82	76 vs 79	29 vs 47*	12.0 vs 5.1
PRE vs 2-pass			-	78 vs 98**	76 vs 98**	29 vs 7**	12.0 vs 0.9**
EPOST vs 2-pass			-	82 vs 98*	79 vs 98*	47 vs 7**	5.1 vs 0.9**

Note. Means within a column followed by the same lowercase letter do not differ significantly according to Tukey's HSD at P < 0.05.

* and ** denote significance at P < 0.05 and P < 0.001, respectively.

[a] Abbreviations: Bent, bentazon; Flumi, flumioxazin; Fom, fomesafen; EPOST, postemergence up to 2.5 cm weeds; LPOST, postemergence up to 5 cm weed escapes and prior to V5 soybean; PRE, preemergence; Quiz, quizalofop-p-ethyl; SETVI, green foxtail; SM, Sure-Mix; UAN, urea ammonium nitrate; WAE, weeks after crop emergence; WAT, weeks after LPOST herbicide application.

At 4 and 8 WAT, *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr applied PRE provided 62, 68-71, and 93-95% control of green foxtail, respectively (Table 7). Imazethapyr + bentazon applied EPOST provided 79-82% control of green foxtail. *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST provided up to 98, 97, and 99% control of green foxtail, respectively (Table 7). Orthogonal contrasts was no difference between PRE treatments and EPOST at 4 and 8 WAT (Table 7). The PRE fb LPOST treatments provided 20 and 22% greater control of green foxtail in comparison to the PRE treatments, at 4 and 8 WAT, respectively The PRE fb LPOST treatments provided 16 and 19% greater control of green foxtail in comparison to the EPOST treatments, at 4 and 8 WAT, respectively (Table 7).

S-metolachlor/metribuzin, pyroxasulfone/sulfentrazone and flumioxazin/metribuzin/imazethapyr applied PRE reduced green foxtail density 76, 71, and 88%, respectively (Table 7). Imazethapyr + bentazon applied EPOST reduced green foxtail density 66% (Table 4). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced green foxtail density 95, 94, and 97%, respectively (Table 7). Orthogonal contrasts indicated that PRE treatments reduced green foxtail density 38% greater than EPOST treatments alone, two-pass treatments reduced green foxtail density 76% greater than PRE treatments, and two-pass treatments reduced green foxtail density 85% more than EPOST (Table 7).

S-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr applied PRE reduced green foxtail biomass 79, 68, and 96%, respectively (Table 7). Imazethapyr + bentazon applied EPOST reduced green foxtail biomass 92% (Table 7). *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST reduced green foxtail biomass 98, 98, and 100%, respectively (Table 7). Orthogonal contrasts indicated that there was no difference between PRE vs EPOST treatments on green foxtail biomass. The two-pass treatments reduced green foxtail biomass 93% more than the PRE treatments and the two-pass program reduced green biomass 82% more than the EPOST (Table 7).

Results are similar to Stewart et al. (2014) findings that showed 99-100% control of green foxtail with the sequential application of PRE herbicides such as imazethapyr, *S*-metolachlor + metribuzin and flumetsulam/*S*-metolachlor followed by an application of glyphosate in GR soybean. Similarly, Soltani et al. (2014) observed that the sequential application of a PRE herbicide followed by an application of glyphosate LPOST provided 99-100% control of green foxtail in GR soybean. Gonzini et al. (1999) reported that giant foxtail control was increased by 2-15% when PRE herbicides such as chlorimuron + metribuzin, cloransulam-methyl, or sulfentrazone were applied sequentially with glyphosate LPOST.

4. Conclusions

Weed control with the herbicide programs evaluated was weed species-specific. Velvetleaf was controlled the best with flumioxazin/metribuzin/imazethapyr applied PRE, imazethapyr + bentazon applied EPOST, and pyroxasulfone/sulfentrazone or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST.

Green pigweed was best controlled with pyroxasulfone/sulfentrazone and flumioxazin/metribuzin/imazethapyr applied PRE, imazethapyr + bentazon applied EPOST, and *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE followed by bentazon + fomesafen + quizalofop applied LPOST.

Common ragweed was best controlled with *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE followed by bentazon + fomesafen + quizalofop applied LPOST.

Common lambsquarters was best controlled with flumioxazin/metribuzin/imazethapyr applied PRE, imazethapyr + bentazon applied EPOST, and *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE followed by bentazon + fomesafen + quizalofop applied LPOST.

Barnyardgrass was best controlled with *S*-metolachlor/metribuzin and flumioxazin/metribuzin/imazethapyr applied PRE, and *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr applied PRE followed by bentazon + fomesafen + quizalofop applied LPOST.

Green foxtail was best controlled with flumioxazin/metribuzin/imazethapyr applied PRE, and *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE followed by bentazon + fomesafen + quizalofop applied LPOST.

All PRE or EPOST herbicide treatments applied alone caused minimal and transient injury in soybean, but *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, or flumioxazin/metribuzin/imazethapyr applied PRE fb bentazon + fomesafen + quizalofop LPOST caused 20-22% injury in soybean.

Weed interference reduced soybean yield 40%. Among various treatments evaluated, weed interference with *S*-metolachlor/metribuzin and pyroxasulfone/sulfentrazone applied PRE reduced soybean yield 25 and 31%, respectively, but all other PRE, EPOST or PRE fb LPOST treatments evaluated resulted in soybean yield that was similar to the weed-free control.

This study concludes that the two-pass programs of *S*-metolachlor/metribuzin, pyroxasulfone/sulfentrazone, and flumioxazin/metribuzin/imazethapyr applied PRE followed by bentazon + fomesafen + quizalofop applied LPOST provides broad spectrum control of common annual broadleaf and grass weeds in Ontario. Two-pass herbicide programs combine herbicides with different modes of action and have the potential to reduce the selection pressure for the evolution of herbicide-resistant weeds in Ontario.

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Drs. Peter Sikkema and Nader Soltani were responsible for the study design and writing of this manuscript. Christy Shropshire conducted the statistical analysis of the data collected.

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