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Efficacy of Trifluralin Compared to Ethalfluralin Applied Alone and Co-Applied with Halosulfuron for Weed Management in White Bean

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Abstract

There are a limited number of herbicides registered for weed management in white bean production in Ontario, Canada. Five field experiments were completed in Ontario from 2016 to 2018 to compare the efficacy of trifluralin and ethalfluralin applied alone and in combination with halosulfuron, applied preplant incorporated (PPI), for weed control efficacy and white bean tolerance and seed yield. At 2 and 4 WAE, there was no white bean injury from the herbicide treatments evaluated. Trifluralin applied PPI provided up to 32%, 99%, 13%, 99%, 27%, 99% and 99% control of velvetleaf, redroot pigweed, common ragweed, common lambsquarters, wild mustard, barnyardgrass and green foxtail, respectively. Trifluralin and ethalfluralin provide similar control of velvetleaf, redroot pigweed, barnyardgrass and green foxtail control, however, ethalfluralin is slightly more efficacious on common ragweed, common lambsquarters and wild mustard. Halosulfuron (35 g·ai·ha^{-1}), applied PPI, provided as much as 76%, 98%, 96%, 96%, 100%, 19% and 23% control of velvetleaf, redroot pigweed, common ragweed, common lambsquarters, wild mustard, barnyardgrass and green foxtail, respectively. Trifluralin (600 or 1155 g·ai·ha^{-1}) + halosulfuron (35 g·ai·ha^{-1}), applied PPI, provided up to 88%, 100%, 98%, 100%, 100%, 99% and 98% control of velvetleaf, redroot pigweed, common ragweed, common lambsquarters, wild mustard, barnyardgrass and green foxtail, respectively. Ethalfluralin (810 or 1080 ai·ha^{-1}) + halosulfuron (35 g·ai·ha^{-1}) provided similar control. Weed interference decreased white bean seed yield 44% - 45% with trifluralin, 30% - 41% with ethalfluralin and 34% with halosulfuron. However, decreased weed interference with trifluralin and ethalfluralin applied in combination with halosulfuron resulted white bean seed yield that was similar to the weed-free control. Trifluralin or ethalfluralin co-applied with halosulfuron can be safely used in white bean production for the control of common annual grass and broadleaf weeds in Ontario.

Keywords

ALS Inhibitor Herbicides, Crop Injury, Dinitroanaline Herbicides, Navy Bean, *Phaseolus vulgaris*, Sulfonylurea Herbicides

1. Introduction

Canada is one of the major dry bean (*Phaseolus vulgaris* L.) producing countries in the world [1]. White (navy) bean is the largest market class of dry bean grown in Canada [2]. Most of the white bean produced in Canada is grown in Ontario. On an annual basis, white bean growers in Ontario harvest approximately 26,000 hectares and produce 58,000 tonnes of white bean with a farm gate value of $36,000,000 [2]. Weeds management is a critical component of successful white bean production as weed interference can reduce seed yield as much as 81% [1] [3] [4] [5] [6]. There are a limited number of herbicides registered for weed management in white bean production in Ontario [7]. New herbicides/tank mixes are needed to effectively control common annual grass and broadleaf weeds in white bean production.

Halosulfuron [methyl 3-chloro-5-[(4,6-dimethoxypyrimidin-2-yl)carbamoyl-sulfamoyl]-1-methylpyrazole-4-carboxylate] is a Group 2 sulfonylurea herbicide that inhibits the acetolactate synthase (ALS) enzyme which is crucial for the production of isoleucine, valine and leucine, three branched-chain amino acids needed for protein synthesis within plants [8] [9]. Halosulfuron, provides residual control of annual broadleaf weeds including redroot pigweed (*Amaranthus retroflexus* L.), jimsonweed (*Datura stramonium* L.), ladysthumb (*Persicaria maculosa* Gray.), common lambsquarters (*Chenopodium album L.*), wild mustard (*Sinapis arvensis* L.), velvetleaf (*Abutilon theophrasti* Medic.) and common ragweed (*Ambrosia artemesiifolia* L.) [7] [8]. However, halosulfuron applied alone does not adequately control grass weed species and needs a grass herbicide partner for broad-spectrum weed control [7] [8].

Ethalfluralin [N-ethyl-N-(2-methylprop-2-enyl)-2,6-dinitro-4-(trifluoromethyl)aniline] is a Group 3 dinitroanaline herbicide that can control/suppress problematic grassy weeds such as barnyardgrass (*Echinochloa crusgalli* (L.) Beauv.), green foxtail (*Setaria viridis* L.), yellow foxtail (*Setaria pumila* L.), volunteer barley (*Hordeum vulgare* L.), volunteer wheat (*Triticum aestivum* L.) and wild oats (*Avena sativa* L.) [9] [10]. Ethalfluralin can also control/suppress broadleaf weeds such as kochia (*Bassia scoparia* subsp. densiflora), wild buckwheat (*Polygonum convolvulus* L.), redroot pigweed and common lambsquarters [10] [11]. Ethalfluralin, a Group 3 herbicide, can be one component of a diversified herbicide resistance management program to reduce the selection pressure for the evolution of herbicide-resistant weeds including wild oats, green foxtail and kochia [10]. Ethalfluralin is a microtubule polymerization inhibitor that reduces root elongation, causes swollen root tips, swelling of stems, and dark green or purpling of tissues in susceptible weeds [10]. Ethalfluralin does not control emerged weeds and should be applied preplant (PP), preplant incorporated (PPI) or preemergence (PRE) for the control of susceptible weeds. When applied PP, PPI or PRE, ethalfluralin controls susceptible weed species prior to emergence [10].

Trifluralin [2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)aniline] is another Group 3 dinitroanaline herbicide that controls most annual grasses and small-seeded annual broadleaf weeds such as redroot pigweed and common lambsquarters, including the triazine-tolerant biotypes [7] [8]. Trifluralin is registered as a soil-applied herbicide in many crops including soybean, dry bean, snap bean and lima bean [7] [12]. Halosulfuron has been recently registered at 25 to 50 g·ai·ai·ha^{-1} for use in white bean production [7]. Ethalfluralin is not currently registered for use in any market class of dry bean in Ontario. Ethalfluralin has been reported to be a more active herbicide than trifluralin [10]. Ethalfluralin and trifluralin co-applied with halosulfuron can provide effective broad-spectrum control of common annual grass and broadleaf weeds in white bean production in Ontario. However, limited information is available on comparing the efficacy of trifluralin and ethalfluralin applied alone and in combination with halosulfuron for weed management in white bean under Ontario environmental conditions.

The purpose of this study was to compare the efficacy of trifluralin and ethalfluralin applied alone and in combination with halosulfuron, applied PPI, on white bean tolerance and yield, and weed control efficacy.

2. Materials and Methods

2.1. Experimental Methods

Field experiments (total of 5) were carried out at the University of Guelph Ridgetown Campus, Ridgetown, ON, in 2016, 2017 and 2018, and at the Huron Research Station, University of Guelph, Exeter, ON, in 2017 and 2018. Each experiment was arranged in a randomized complete block design (RCBD) with 4 replications. Treatments evaluated are presented in **Tables 1-8**. The experimental plots were 3.0 m wide and 8 or 10 m long depending on lacation. White bean "T9905" was seeded approximately 4 cm deep at the rate of approximately 250,000 seeds ha^{-1} in rows that were spaced 75 cm apart in late May to early June.

Herbicides treatments were applied 1 - 2 days before seeding and incorporated within one day with two passes of a field cultivator with rolling basket harrows in opposite directions. Herbicides were applied with a CO_2-pressurized backpack sprayer calibrated to deliver 200 L·ha^{-1} at 240 kPa. The spray boom was 1.5 m

Table 1. Percent seed moisture content at maturity and yield for white bean treated with trifluralin or ethalfluralin and halosulfuron applied PPI at Exeter (2017-2018) and Ridgetown, ON, Canada (2016-2018).[a,b]

Treatment	Rate ($g \cdot ai \cdot ha^{-1}$)	Moisture (%)	Yield ($T \cdot ha^{-1}$)
Weed-free control		18.7 a	2.63 ab
Weedy control		20.1 b	0.74 e
Trifluralin	600	19.4 ab	1.48 de
Trifluralin	1155	19.4 ab	1.44 de
Ethalfluralin	810	19.3 ab	1.56 de
Ethalfluralin	1080	18.9 a	1.84 bcd
Halosulfuron	35	19.1 ab	1.74 cd
Trifluralin + halosulfuron	600 + 35	18.9 a	2.70 a
Trifluralin + halosulfuron	1155 + 35	18.8 a	2.49 abc
Ethalfluralin + halosulfuron	810 + 35	18.7 a	2.55 abc
Ethalfluralin + halosulfuron	1080 + 35	18.7 a	2.60 ab

[a]Abbreviations: PPI, preplant incorporated; WAE, weeks after white bean emergence. [b]Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.

Table 2. Percent visible control 4, 8 and 12 WAE of velvetleaf treated with trifluralin or ethalfluralin and halosulfuron applied PPI at Ridgetown, ON, Canada (2016-2018).[a,b]

Treatment	Rate ($g \cdot ai \cdot ha^{-1}$)	Velvetleaf control (%)		
		4 WAE	8 WAE	12 WAE
Weed-free control		100	100	100
Weedy control		0 c	0 d	0 c
Trifluralin	600	15 b	2 cd	2 bc
Trifluralin	1155	32 b	27 b	25 b
Ethalfluralin	810	13 b	6 bcd	5 bc
Ethalfluralin	1080	18 b	14 bc	11 bc
Halosulfuron	35	76 a	74 a	69 a
Trifluralin + halosulfuron	600 + 35	83 a	76 a	69 a
Trifluralin + halosulfuron	1155 + 35	88 a	84 a	76 a
Ethalfluralin + halosulfuron	810 + 35	88 a	76 a	67 a
Ethalfluralin + halosulfuron	1080 + 35	88 a	79 a	71 a

[a]Abbreviations: PPI, preplant incorporated; WAE, weeks after white bean emergence. [b]Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.

Table 3. Percent visible control 4, 8 and 12 WAE of redroot pigweed treated with trifluralin or ethalfluralin and halosulfuron applied PPI at Exeter (2017) and Ridgetown, ON, Canada (2017).[a,b]

Treatment	Rate ($g \cdot ai \cdot ha^{-1}$)	Redroot pigweed control (%)		
		4 WAE	8 WAE	12 WAE
Weed-free control		100	100	100
Weedy control		0 b	0 b	0 b
Trifluralin	600	98 a	98 a	96 a
Trifluralin	1155	98 a	99 a	99 a
Ethalfluralin	810	99 a	99 a	99 a
Ethalfluralin	1080	99 a	99 a	99 a
Halosulfuron	35	98 a	97 a	97 a
Trifluralin + halosulfuron	600 + 35	99 a	99 a	99 a
Trifluralin + halosulfuron	1155 + 35	100 a	100 a	99 a
Ethalfluralin + halosulfuron	810 + 35	99 a	99 a	99 a
Ethalfluralin + halosulfuron	1080 + 35	100 a	100 a	99 a

[a]Abbreviations: PPI, preplant incorporated; WAE, weeks after white bean emergence. [b] Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.

Table 4. Percent visible control 4, 8 and 12 WAE of common ragweed treated with trifluralin or ethalfluralin and halosulfuron applied PPI at Exeter (2017-2018) and Ridgetown, ON, Canada (2016-2018).[a,b]

Treatment	Rate ($g \cdot ai \cdot ha^{-1}$)	Common ragweed control (%)		
		4 WAE	8 WAE	12 WAE
Weed-free control		100	100	100
Weedy control		0 c	0 c	0 c
Trifluralin	600	0 c	2 b	13 b
Trifluralin	1155	7 b	7 b	10 b
Ethalfluralin	810	14 b	6 b	12 b
Ethalfluralin	1080	20 b	13 b	13 b
Halosulfuron	35	96 a	95 a	95 a
Trifluralin + halosulfuron	600 + 35	97 a	95 a	94 a
Trifluralin + halosulfuron	1155 + 35	98 a	97 a	97 a
Ethalfluralin + halosulfuron	810 + 35	98 a	97 a	97 a
Ethalfluralin + halosulfuron	1080 + 35	99 a	97 a	97 a

[a]Abbreviations: PPI, preplant incorporated; WAE, weeks after white bean emergence. [b]Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.

Table 5. Percent visible control 4, 8 and 12 WAE of common lambsquarters treated with trifluralin or ethalfluralin and halosulfuron applied PPI at Exeter (2017-2018) and Ridgetown, ON, Canada (2016-2018).[a,b]

Treatment	Rate ($g \cdot ai \cdot ha^{-1}$)	Common lamb's-quarters control (%)		
		4 WAE	8 WAE	12 WAE
Weed-free control		100	100	100
Weedy control		0 d	0 d	0 d
Trifluralin	600	94 c	89 c	88 c
Trifluralin	1155	99 ab	98 ab	98 ab
Ethalfluralin	810	98 abc	98 ab	97 ab
Ethalfluralin	1080	100 a	100 a	100 a
Halosulfuron	35	96 bc	93 bc	90 bc
Trifluralin + halosulfuron	600 + 35	98 abc	98 ab	97 ab
Trifluralin + halosulfuron	1155 + 35	100 a	100 a	99 a
Ethalfluralin + halosulfuron	810 + 35	100 a	100 a	99 a
Ethalfluralin + halosulfuron	1080 + 35	100 a	100 a	100 a

[a]Abbreviations: PPI, preplant incorporated; WAE, weeks after white bean emergence. [b] Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.

Table 6. Percent visible control 4, 8 and 12 WAE of wild mustard treated with trifluralin or ethalfluralin and halosulfuron applied PPI at Exeter, ON, Canada (2017-2018).[a,b]

Treatment	Rate ($g \cdot ai \cdot ha^{-1}$)	Wild mustard control (%)		
		4 WAE	8 WAE	12 WAE
Weed-free control		100	100	100
Weedy control		0 d	0 d	0 e
Trifluralin	600	2 c	10 c	13 cd
Trifluralin	1155	27 b	14 c	6 d
Ethalfluralin	810	27 b	25 bc	21 c
Ethalfluralin	1080	47 b	40 b	41 b
Halosulfuron	35	96 a	98 a	100 a
Trifluralin + halosulfuron	600 + 35	99 a	99 a	99 a
Trifluralin + halosulfuron	1155 + 35	99 a	100 a	100 a
Ethalfluralin + halosulfuron	810 + 35	100 a	100 a	100 a
Ethalfluralin + halosulfuron	1080 + 35	97 a	100 a	100 a

[a]Abbreviations: PPI, preplant incorporated; WAE, weeks after white bean emergence. [b]Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.

Table 7. Percent visible control 4, 8 and 12 WAE of barnyardgrass treated with trifluralin or ethalfluralin and halosulfuron applied PPI at Exeter (2017) and Ridgetown, ON, Canada (2016 and 2018).[a,b]

Treatment	Rate ($g·ai·ha^{-1}$)	Barnyardgrass control (%)		
		4 WAE	8 WAE	12 WAE
Weed-free control		100	100	100
Weedy control		0 c	0 c	0 b
Trifluralin	600	97 a	98 a	98 a
Trifluralin	1155	99 a	99 a	99 a
Ethalfluralin	810	99 a	99 a	99 a
Ethalfluralin	1080	100 a	99 a	100 a
Halosulfuron	35	19 b	11 b	0 b
Trifluralin + halosulfuron	600 + 35	98 a	97 a	97 a
Trifluralin + halosulfuron	1155 + 35	98 a	99 a	99 a
Ethalfluralin + halosulfuron	810 + 35	98 a	97 a	98 a
Ethalfluralin + halosulfuron	1080 + 35	100 a	99 a	99 a

[a]Abbreviations: PPI, preplant incorporated; WAE, weeks after white bean emergence. [b]Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.

Table 8. Percent visible control 4, 8 and 12 WAE of green foxtail treated with trifluralin or ethalfluralin and halosulfuron applied PPI at Exeter (2017-2018) and Ridgetown, ON, Canada (2016-2018).[a,b]

Treatment	Rate ($g·ai·ha^{-1}$)	Green foxtail control (%)		
		4 WAE	8 WAE	12 WAE
Weed-free control		100	100	100
Weedy control		0 d	0 d	0 e
Trifluralin	600	96 b	96 ab	96 bc
Trifluralin	1155	99 ab	99 a	99 ab
Ethalfluralin	810	99 ab	99 a	99 ab
Ethalfluralin	1080	99 ab	99 a	100 a
Halosulfuron	35	23 c	14 c	3 d
Trifluralin + halosulfuron	600 + 35	96 b	95 b	94 c
Trifluralin + halosulfuron	1155 + 35	98 ab	98 ab	98 abc
Ethalfluralin + halosulfuron	810 + 35	98 ab	98 ab	98 abc
Ethalfluralin + halosulfuron	1080 + 35	100 a	99 a	99 ab

[a]Abbreviations: PPI, preplant incorporated; WAE, weeks after white bean emergence. [b]Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.

long equipped with 4 ultra-low drift (ULD 120-02, Pentair-Hypro, New Brighton, Minnesota) nozzles spaced 0.5 m apart producing a spray width of 2.0 m.

White bean visible injury was assessed 2, 4 and 8 weeks after emergence (WAE) and weed control efficacy was assessed visually on a scale of 0 (no injury/control) to 100% (total plant necrosis/weed control) 4, 8 and 12 WAE. White bean yield was determined by harvesting the middle two rows of each plot with a plot combine at maturity. White bean yield was adjusted to 18% seed moisture content.

2.2. Statistical Analyses

The GLIMMIX procedure in SAS [13] was utilized for data analysis, with herbicide treatment as the fixed effect and year-location combinations, replicate within environment and environment by treatment interaction as the random effects. Potential distributions were assessed using residual plots, fit statistics and the Shapiro-Wilk statistic to find the most appropriate distribution or transformation. Analysis was performed on the model scale, with least square means presented on the data scale. Treatment differences were determined at a significance level of 0.05, after pairwise comparisons were subjected to Tukey's adjustment. The Gaussian distribution and identity link were used for percent control of velvetleaf (4, 8 and 12 WAE), wild mustard (12 WAE), white bean moisture at harvest and yield. All other percent weed control data were arcsine square-root transformed prior to analysis, and back-transformed for presentation. Treatments with zero variance were excluded from the analysis and included the weedy control (assigned a value of zero) and the weed-free control (assigned a value of 100) for percent weed control. Comparisons of each treatment with the value zero were still conducted and differences identified using the P values from the LSMEANS output.

3. Results and Discussion

3.1. Crop Injury

At 2, 4 and 8 WAE, there was no white bean injury from the herbicide treatments evaluated (data not presented). There was a delay in white bean maturity due to weed interference as indicated by increased seed moisture content at harvest (**Table 1**). Weeds interference decreased white bean seed yield 72% (**Table 1**). Generally, white bean yield reflected the level of weed control provided by the herbicide treatments evaluated. There was no difference in white bean seed yield between trifluralin and ethalfluralin. Weed presence decreased seed yield 44% - 45% with trifluralin and 30% - 41% with ethalfluralin (**Table 1**). Weed interference with halosulfuron applied alone decreased seed yield 34% (**Table 1**). In contrast, decreased weed interference with trifluralin and ethalfluralin applied in combination with halosulfuron resulted in white bean seed yield that was similar to the weed-free control.

These results are similar to other studies that have shown little white bean injury with trifluralin and trifluralin + halosulfuron in white bean. Soltani *et al.* 2014 [4] found no injury with trifluralin applied PPI alone and 1% injury with trifluralin + halosulfuron applied PPI in white bean [4]. In other studies, halosulfuron, applied PPI was shown to be safe for use on most market classes of dry beans except for azuki, mung, and snap bean [14] [15] [16] [17]. In another study, halosulfuron caused 8% injury and reduced seed yield 7% in snap bean [14].

3.2. Weed Control

Trifluralin (600 g·ai·ha^{-1}), applied PPI, provided 2% - 15%, 96% - 98%, 0% - 13%, 88% - 94%, 2% - 13%, 97% - 98% and 96% control of velvetleaf, redroot pigweed, common ragweed, common lambsquarters, wild mustard, barnyardgrass and green foxtail, respectively (**Tables 2-8**). Ethalfluralin (810 g·ai·ha^{-1}) provided similar control of velvetleaf, redroot pigweed, barnyardgrass and green foxtail and better control of common lambsquarters at 8 and 12 WAE, common ragweed at 4 WAE, and wild mustard at 4 WAE (**Tables 2-8**).

At 4, 8 and 12 WAE, trifluralin (1155 g·ai·ha^{-1}), applied PPI, provided 25% - 32%, 98% - 99%, 7% - 10%, 98% - 99%, 6% - 27%, 99% and 99% control of velvetleaf, redroot pigweed, common ragweed, common lambsquarters, wild mustard, barnyardgrass and green foxtail, respectively. Ethalfluralin (1080 g·ai·ha^{-1}) provided similar control of velvetleaf, redroot pigweed, common ragweed, common lambsquarters, barnyardgrass and green foxtail and better control of wild mustard at 8 and 12 WAE (**Tables 2-8**).

At 4, 8 and 12 WAE, halosulfuron (35 g·ai·ha^{-1}), applied PPI, provided 69% - 76%, 97% - 98%, 95% - 96%, 90% - 96%, 96% - 100%, 0% - 19% and 3% - 23% control of velvetleaf, redroot pigweed, common ragweed, common lambsquarters, wild mustard, barnyardgrass and green foxtail, respectively (**Tables 2-8**).

At 4, 8 and 12 WAE, trifluralin (600 g·ai·ha^{-1}) + halosulfuron (35 g·ai·ha^{-1}), applied PPI, provided 69% - 83%, 99%, 94% - 97%, 97% - 98%, 99%, 97% - 98% and 94% - 96% control of velvetleaf, redroot pigweed, common ragweed, common lambsquarters, wild mustard, barnyardgrass and green foxtail, respectively (**Tables 1-7**). Ethalfluralin (810 g·ai·ha^{-1}) + halosulfuron (35 g·ai·ha^{-1}) provided similar control of the same weed species (**Tables 2-8**).

At 4, 8 and 12 WAE, trifluralin (1155 g·ai·ha^{-1}) + halosulfuron (35 g·ai·ha^{-1}), applied PPI, provided 76% - 88%, 99% - 100%, 97% - 98%, 99% - 100%, 99% - 100%, 98% - 99% and 98% control of velvetleaf, redroot pigweed, common ragweed, common lambsquarters, wild mustard, barnyardgrass and green foxtail, respectively. Ethalfluralin (1080 g·ai·ha^{-1}) + halosulfuron (35 g·ai·ha^{-1}) provided similar control of the same weed species (**Tables 2-8**).

The results from this study are similar to other research in which trifluralin applied PPI controlled redroot pigweed 72% - 98%, common ragweed 9% - 28%, common lambsquarters 60% - 92%, wild mustard 11% - 44%, and green foxtail

94% - 100% in dry bean [4] [5] [15] [18]. In other studies, halosulfuron applied PPI controlled redroot pigweed 83% - 100%, common ragweed 95% - 99%, common lambsquarters 96% - 100%, wild mustard 99% - 100%, and green foxtail 47% - 59% [4] [5] [18].

4. Conclusions

Trifluralin and ethalfluralin applied PPI alone or in combination with halosulfuron caused no visible injury in white bean at rates evaluated. There was delayed white bean maturity due to weed interference as indicated by increased seed moisture content at harvest. Weeds presence decreased white bean seed yield 72%. Generally, white bean yield reflected the level of weed control provided by the herbicide treatments evaluated. There was no difference in white bean seed yield between trifluralin and ethalfluralin. Decreased weed interference with trifluralin and ethalfluralin applied in combination with halosulfuron resulted in white bean seed yield that was similar to the weed-free control. Trifluralin and ethalfluralin applied PPI alone did not provide adequate control of velvetleaf, common ragweed and wild mustard, but provided good to excellent control of redroot pigweed, common lambsquarters, barnyardgrass and green foxtail. Trifluralin and ethalfluralin provide similar control of velvetleaf, redroot pigweed, barnyardgrass and green foxtail control, however, ethalfluralin is slightly more efficacious on common ragweed, common lambsquarters and wild mustard. Halosulfuron applied PPI alone provided inadequate control of barnyardgrass and green foxtail, fair control of velvetleaf and good to excellent control of redroot pigweed, common ragweed, common lambsquarters and wild mustard. Trifluralin and ethalfluralin applied PPI in combination with halosulfuron provided good to excellent control of velvetleaf, redroot pigweed, common ragweed, common lambsquarters, wild mustard, barnyardgrass and green foxtail. This study concludes that trifluralin or ethalfluralin co-applied with halosulfuron can be safely used for broad-spectrum control of annual grass and broadleaf weeds in white bean production in Ontario.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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