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Weed Management in White Beans with Soil-Applied Grass Herbicides plus Halosulfuron

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Abstract

There are a limited number of soil-applied herbicides available for broad-spectrum weed control in dry bean production in Ontario, Canada. Four experiments were conducted from 2017 to 2019 in southwestern Ontario to compare the efficacy of six soil-applied grass herbicides [trifluralin (600 g ai ha^{-1}), ethalfluralin (810 g ai ha^{-1}), pendimethalin (1080 g ai ha^{-1}), S-metolachlor (1050 g ai ha^{-1}), dimethenamid-p (544 g ai ha^{-1}) and EPTC (3400 g ai ha^{-1})] and halosulfuron (35 g ai ha^{-1}) applied alone and in combination, applied preplant incorporated (PPI), on white bean tolerance and yield, and weed control efficacy. There was no white bean injury from the herbicide treatments evaluated. Grass herbicides (trifluralin, ethalfluralin, pendimethalin, S-metolachlor dimethenamid-P and EPTC) controlled velvetleaf 0% - 82%, pigweeds 87% - 99%, common ragweed 0% - 93%, common lambsquarters 81% - 99%, wild mustard 0% - 71%, barnyardgrass 98% - 100% and green foxtail 98% - 99%. Halosulfuron controlled velvetleaf 98%, pigweeds 94%, common ragweed 90% - 94%, common lambsquarters 97%, wild mustard 98% - 100%, barnyardgrass 19% - 24% and green foxtail 20% - 25%. Tankmixes of halosulfuron with soil-applied grass herbicides provided ≥93% control of the weed species evaluated. Reduction in density and biomass generally followed the same trend as visible control with herbicide treatments evaluated. Weed interference reduced white bean seed yield 70%. Seed yield was 53% - 66% of the weed-free control with trifluralin, ethalfluralin, pendimethalin, S-metolachlor and dimethenamid-P, 81% of the weed-free control with EPTC, 58% of the weed-free control with halosulfuron, and 87% - 95% of the weed-free control with halosulfuron tankmixes with the grass herbicides evaluated. Based on these results, halosulfuron in combination with trifluralin, ethalfluralin, pendimethalin, S-metolachlor, dimethenamid-p and EPTC, applied PPI at rates evaluated, can be used to effectively control common annual grass and broadleaf weeds in white beans.

Keywords

Weed Density, Weed Biomass, Seed Moisture, Seed Yield, Visible Control, *Phaseolus vulgaris*

1. Introduction

Dry bean (*Phaseolus vulgaris* L.) is an important field crop grown in southwestern Ontario that fits well in a typical Ontario crop rotation of corn, soybean and wheat. Dry bean growers produced over 120,000 tonnes of dry beans on nearly 52,000 hectares with a farm gate value of nearly $115,000,000 in 2017 [1]. Weeds can interfere with dry bean growth and development and cause substantial losses in seed yield and quality if not adequately controlled [2] [3] [4]. White navy bean is the most commonly grown market class of dry beans in Ontario. A limited number of soil-applied herbicides are available for weed control in white bean production in Ontario. Currently, only two soil-applied herbicides are available for broadleaf weed control in white bean production in Ontario, imazethapyr and halosulfuron [5]. Although imazethapyr is a very efficacious soil-applied broadleaf herbicide, it has a narrow margin of crop safety, especially in the small-seeded market classes of beans, specifically white and black beans. New research is needed to identify new soil-applied herbicides/tankmixes for efficacious broad-spectrum weed control in white beans.

Halosulfuron is a Group 2 soil and foliar applied sulfonylurea herbicide that was recently registered at 25 to 50 g ai ha^{-1} for use in dry beans and has become a popular herbicide option for the control of common annual broadleaf weeds in Ontario [5]. Halosulfuron inhibits the acetolactate synthase (ALS) enzyme which is needed for synthesis of branched-chain amino acids including isoleucine, leucine and valine [6]. Halosulfuron controls common annual broadleaf weeds in Ontario such as redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), wild mustard (*Sinapis arvensis* L.) and velvetleaf (*Abutilon theophrasti* Medic.). However, halosulfuron does not adequately control grasses and needs to be tankmixed with a selective grass herbicide to provide broad-spectrum control of common annual weeds in dry bean production in Ontario [7] [8] [9].

Grass herbicides available in Ontario that have the potential to be used with halosulfuron include trifluralin, ethalfluralin, pendimethalin, S-metolachlor, dimethenamid-P and EPTC. Trifluralin is a Group 3 dinitroaniline herbicide that controls most grasses and some annual broadleaf weeds such as common lambsquarters and pigweeds [5]. Ethalfluralin is another Group 3 dinitroanaline herbicide that controls most grasses and some broadleaf weeds such as pigweeds, common lambsquarters, ladysthumb, Russian thistle (*Salsola tragus* L.), kochia (*Brassia scoparia* subsp. densiflora) and wild buckwheat (*Polygonum convolvulus* L.) [5] [10]. Ethalfluralin is not currently registered for use in white bean or any other market class of dry beans in Ontario [5]. Pendimethalin is a Group 3 dinitroaniline herbicide that controls grasses such as barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], foxtail species (*Setaria* spp.), crabgrass species (*Digitaria* spp.), fall panicum (*Panicum dichotomiflorum* Michx.) and broadleaf weeds such as common lambsquarters and pigweed species [5]. S-metolachlor is a Group 15 chloroacetanilide herbicide that control crabgrass, witchgrass (*Panicum capillare* L.), barnyardgrass, foxtails, nightshades (*Solanum* spp.), pigweeds and waterhemp [5]. Dimethenamid-P is another Group 15 chloroacetamide grass herbicide that controls barnyardgrass, foxtails, crabgrass and broadleaf weeds such as pigweeds, nightshades, and waterhemp (*Amaranthus rudis* Sauer) [5] [10]. EPTC is a Group 15 thiocarbamate herbicide that controls annual grasses such as barnyardgrass, foxtails, fall panicum, and wild oats (*Avena fatua* L.), plus yellow nutsedge (*Cyperus esculentus*) and some annual broadleaf weeds such as common ragweed, pigweed species, chickweed (*Stellaria media* L.) and nightshades [5] [10].

It is critical to determine the appropriate partner grass herbicide for halosulfuron based on weed species composition in each individual field for further adoption of halosulfuron in white bean production in Ontario. To our knowledge, no study has cumulatively compared the tolerance and efficacy of trifluralin, ethalfluralin, pendimethalin, S-metolachlor, dimethenamid-P, EPTC, halosulfuron, trifluralin + halosulfuron, ethalfluralin + halosulfuron, pendimethalin + halosulfuron, S-metolachlor + halosulfuron, dimethenamid-P + halosulfuron, and EPTC + halosulfuron, applied preplant incorporated (PPI), for broad-spectrum weed control in white beans.

The purpose of this study was to compare the efficacy of six soil-applied grass herbicides [trifluralin (600 g ai ha^{-1}), ethalfluralin (810 g ai ha^{-1}), pendimethalin (1080 g ai ha^{-1}), S-metolachlor (1050 g ai ha^{-1}), dimethenamid-P (544 g ai ha^{-1}) and EPTC (3400 g ai ha^{-1})] and halosulfuron (35 g ai ha^{-1}) applied alone and in combination, applied PPI, on white bean tolerance and yield, and weed control efficacy.

2. Materials and Methods

Field experiments (total of 4) were conducted in 2018 and 2019 at the University of Guelph Ridgetown Campus, Ridgetown, Ontario, Canada and in 2017 and 2019 at the Huron Research Station, Exeter, Ontario, Canada. Seedbed preparation at all sites consisted of fall moldboard plowing followed by two passes with a field cultivator with rolling basket harrows in the spring.

The experiment was arranged in a randomized block design with treatments replicated four times. Treatments included a weedy and weed-free control and trifluralin (600 g ai ha^{-1}), ethalfluralin (810 g ai ha^{-1}), pendimethalin (1080 g ai ha^{-1}), S-metolachlor (1050 g ai ha^{-1}), dimethenamid-P (544 g ai ha^{-1}), EPTC (3400 g ai ha^{-1}), halosulfuron (35 g ai ha^{-1}), trifluralin + halosulfuron (600 + 35 g ai ha^{-1}), ethalfluralin + halosulfuron (810 + 35 g ai ha^{-1}), pendimethalin + halosulfuron (1080 + 35 g ai ha$^{−1}$), S-metolachlor + halosulfuron (1050 + 35 g ai ha$^{−1}$), dimethenamid-P + halosulfuron (544 + 35 g ai ha$^{−1}$) and EPTC + halosulfuron (3400 + 35 g ai ha$^{−1}$). Each plot was 3.0 m wide and consisted of 4 rows of "T9905" white beans spaced 0.75 m apart in rows that were 10 m long at Exeter and 8 m long at Ridgetown. White bean was planted at a rate of approximately 233,000 seeds ha$^{−1}$ in late May to early June of each year.

Herbicide treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 200 L·ha$^{−1}$ aqueous solution at 240 kPa. The boom was 1.5 m long with four 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. Herbicide treatments were applied 1 - 2 days before planting and were immediately incorporated into the soil with two passes (in opposite directions) of an S-tine cultivator with rolling basket harrows. Weed-free plots were maintained weed-free during the growing season with trifluralin + halosulfuron (600 + 25 g ai ha$^{−1}$) applied PPI, hand hoeing, and hand weeding as required.

Crop injury was rated visually 2 and 4 weeks after white bean emergence (WAE) and weed control was assessed 4 and 8 WAE on a scale of 0% to 100% where a rating of 0 was defined as no injury/weed control and 100 was total crop/weed death. Weed density and shoot dry weight (biomass) were measured 8 WAE from two 0.25 m^2 quadrats placed between the center two rows from each plot. White bean seed yield was measured at crop maturity by harvesting the middle two rows of each plot with a small-plot combine. Seed yield was adjusted to 18% seed moisture content for analysis.

Data analysis was completed using PROC GLIMMIX (SAS Ver. 9.4, SAS Institute Inc., Cary, NC). The model specified the fixed effect as herbicide treatment and random effects as year-location combinations (environment), environment by treatment interaction and replicate within environment. Distributions in PROC GLIMMIX were evaluated using fit statistics such as AICC and Chi-square/df ratio to check for overdispersion. Normality was assessed using the Shapiro-Wilk statistic and normal probability plot generated in PROC UNIVARIATE, and studentized residual plots generated in PROC GLIMMIX were used to check for obvious deviations from the assumption of variance homogeneity. In all cases, percent visible weed control evaluations best met the assumptions for analysis when arcsine-square root transformed prior to using a Gaussian distribution and identity link. Weed densities and dry biomass were analyzed using a log-normal distribution and identity link. Analysis was performed on the model scale, but for presentation purposes treatment means were back-transformed to the data scale, with a correction for log bias for density and dry biomass means. Tukey's HSD was employed to identify treatment differences at a significance level of 0.05. In cases where a treatment had zero variance across all environments, it was excluded from the analysis; when the value of the treatment was zero, it could still be evaluated for differences with other treatments using the p-value generated in the LSMEANS output.

3. Results and Discussion

3.1. Weed Control

Weeds analyzed needed to be present in two or more sites and included velvetleaf (2/4), pigweed species (2/4), common ragweed (3/4), common lambsquarters (4/4), wild mustard (2/4), barnyardgrass (4/4) and green foxtail (4/4). For pigweed species, Ridgetown had mostly green pigweed and Exeter had mostly redroot pigweed. Data were combined for analyses.

3.1.1. Velvetleaf

Trifluralin, ethalfluralin, pendimethalin, S-metolachlor and dimethenamid-P, applied PPI at rates evaluated, provided 0% control of velvetleaf with velvetleaf density and biomass similar to the weedy control (Table 1). EPTC and halosulfuron, applied PPI at rates evaluated, controlled velvetleaf 81 - 82 and 98%, respectively; velvetleaf density and biomass were similar to the weed-free control (Table 1). EPTC provided better velvetleaf control than the other grass herbicides evaluated. Trifluralin + halosulfuron, ethalfluralin + halosulfuron, pendimethalin + halosulfuron, S-metolachlor + halosulfuron, dimethenamid-P +

Table 1. Visible percent control 4 and 8 weeks after crop emergence (WAE), density and dry biomass 8 WAE for velvetleaf (ABUTH) with herbicides applied preplant incorporated in 2018 and 2019 at Ridgetown, Ontario.

Herbicide treatment	Rate	ABUTH control		ABUTH density	ABUTH dry biomass
		4 WAE	8 WAE		
	(g ai ha^{-1})	(%)	(%)	(plants m^{-2})	(g m^{-2})
Weed-free control		100	100	0.0 a	0.0 a
Weedy control		0 c	0 c	2.8 cd	4.6 bc
Trifluralin	600	0 c	0 c	3.2 d	19.9 c
Ethalfluralin	810	0 c	0 c	3.7 d	29.1 c
Pendimethalin	1080	0 c	0 c	1.7 bcd	14.4 bc
S-metolachlor	1050	0 c	0 c	2.0 bcd	13.7 bc
Dimethenamid-P	544	0 c	0 c	1.8 bcd	11.1 bc
EPTC	3400	81 b	82 b	0.0 a	0.0 a
Halosulfuron	35	98 ab	98 ab	0.5 abc	0.6 ab
Trifluralin + halosulfuron	600 + 35	97 ab	96 ab	0.2 ab	0.2 ab
Ethalfluralin + halosulfuron	810 + 35	94 ab	93 ab	0.6 abc	1.2 b
Pendimethalin + halosulfuron	1080 + 35	98 ab	97 ab	0.5 abc	0.5 ab
S-metolachlor + halosulfuron	1050 + 35	96 ab	97 ab	0.2 ab	0.2 ab
Dimethenamid-P + halosulfuron	544 + 35	98 ab	98 ab	0.1 ab	0.2 ab
EPTC + halosulfuron	3400 + 35	100 a	100 a	0.0 a	0.0 a

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

halosulfuron, and EPTC + halosulfuron, applied PPI at rates evaluated controlled velvetleaf 93% - 100%; velvetleaf density and biomass were similar to the weed-free control (**Table 1**). Results are similar to other studies in which most grass herbicides evaluated did not control velvetleaf but halosulfuron controlled velvetleaf up to 98% [11].

3.1.2. Pigweed Species

Trifluralin, ethalfluralin, pendimethalin, S-metolachlor, dimethenamid-P, EPTC, halosulfuron, trifluralin + halosulfuron, ethalfluralin + halosulfuron, pendimethalin + halosulfuron, S-metolachlor + halosulfuron, dimethenamid-P + halosulfuron, and EPTC + halosulfuron, applied PPI at rates evaluated, controlled pigweeds 87% - 100% and reduced density 95% - 100% and biomass 69% - 100%, compared to the weedy control (**Table 2**). These results are similar to other studies in which pigweed species were controlled 83% - 100% with halosulfuron [9] [12] [13], 72% - 98% with trifluralin [9] [12] [14] [15], 91% - 98% with pendimethalin [9] [14] [15] [16], 84% - 95% with S-metolachlor [9] [12], 93% - 97% with dimethenamid-P [9] and 73% - 78% with EPTC applied PPI, in white beans [9] [15].

Table 2. Visible percent control 4 and 8 weeks after crop emergence (WAE), density and dry biomass 8 WAE for pigweed species (AMASS) with herbicides applied preplant incorporated in 2019 at Exeter and Ridgetown, Ontario.

Herbicide treatment	Rate	AMASS control		AMASS density	AMASS dry biomass
		4 WAE	8 WAE		
	(g ai ha^{-1})	(%)	(%)	(plants m^{-2})	(g m^{-2})
Weed-free control		100	100	0.0 a	0 a
Weedy control		0 c	0 c	46.0 e	223.7 e
Trifluralin	600	97 ab	94 ab	2.0 cd	26.4 bcd
Ethalfluralin	810	99 ab	99 a	0.1 ab	1.0 abc
Pendimethalin	1080	96 ab	96 ab	1.5 cd	43.8 cd
S-metolachlor	1050	90 b	87 b	3.1 d	70.4 d
Dimethenamid-P	544	98 ab	98 ab	1.1 bcd	21.9 bcd
EPTC	3400	93 ab	95 ab	0.4 abc	2.8 abcd
Halosulfuron	35	94 ab	94 ab	2.1 bcd	22.5 bcd
Trifluralin + halosulfuron	600 + 35	100 a	99 a	0.0 a	0.0 a
Ethalfluralin + halosulfuron	810 + 35	100 a	99 a	0.4 abc	3.5 abcd
Pendimethalin + halosulfuron	1080 + 35	100 a	100 a	0.1 ab	0.1 ab
S-metolachlor + halosulfuron	1050 + 35	99 ab	99 a	0.0 a	0.0 a
Dimethenamid-P + halosulfuron	544 + 35	99 ab	99 a	0.0 a	0.0 a
EPTC + halosulfuron	3400 + 35	100 a	100 a	0.0 a	0.0 a

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

3.1.3. Common Ragweed

Trifluralin, ethalfluralin, pendimethalin, S-metolachlor and dimethenamid-P, applied PPI at rates evaluated, controlled common ragweed only 0% - 41%; common ragweed density and biomass were similar to the weedy control (Table 3). EPTC and halosulfuron, applied PPI at rates evaluated, provided 85% - 93% and 90% - 94% control of common ragweed and reduced density 78% and 94% and biomass 85 and 93%, respectively (Table 3). EPTC provided better control of common ragweed than the other grass herbicides evaluated. Trifluralin + halosulfuron, ethalfluralin + halosulfuron, pendimethalin + halosulfuron, S-metolachlor + halosulfuron, dimethenamid-P + halosulfuron and EPTC + halosulfuron, applied PPI at rates evaluated, controlled common ragweed 88% - 99% and reduced common ragweed density 92% - 97% and biomass 60% - 98%, compared to the weedy control (Table 3). In other studies, common ragweed was controlled 95% - 99% with halosulfuron [9] [12], 9% - 28% with trifluralin [9] [12] [14] [15] [17], 1% - 13% with pendimethalin [9] [14] [15] [16], 13% - 40% with S-metolachlor [9] [12], 41% - 56% with dimethenamid-P [8] and 52% - 71% with EPTC [9] [15], applied PPI, in white beans.

Table 3. Visible percent control 4 and 8 weeks after crop emergence (WAE), density and dry biomass 8 WAE for common ragweed (AMBEL) with herbicides applied preplant incorporated in 2019 at Exeter and 2018 and 2019 at Ridgetown, Ontario.

Herbicide treatment	Rate	AMBEL control		AMBEL density	AMBEL dry biomass
		4 WAE	8 WAE		
	(g ai ha^{-1})	(%)	(%)	(plants m^{-2})	(g m^{-2})
Weed-free control		100	100	0 a	0 a
Weedy control		0 d	0 c	31.1 e	101.5 e
Trifluralin	600	2 c	0 c	27.2 e	212.3 e
Ethalfluralin	810	2 cd	1 c	31.0 e	150.7 e
Pendimethalin	1080	9 c	0 c	26.4 de	197.0 e
S-metolachlor	1050	7 c	3 bc	24.8 de	176.7 e
Dimethenamid-P	544	41 b	25 b	19.0 cde	99.6 de
EPTC	3400	93 a	85 a	6.8 bcd	15.0 bcd
Halosulfuron	35	94 a	90 a	1.9 ab	6.6 bc
Trifluralin + halosulfuron	600 + 35	94 a	93 a	1.2 ab	9.4 bc
Ethalfluralin + halosulfuron	810 + 35	92 a	90 a	2.5 bc	16.9 bcd
Pendimethalin + halosulfuron	1080 + 35	92 a	88 a	1.9 ab	40.7 cd
S-metolachlor + halosulfuron	1050 + 35	96 a	91 a	2.2 bc	49.1 cd
Dimethenamid-P + halosulfuron	544 + 35	97 a	94 a	1.0 ab	6.3 bc
EPTC + halosulfuron	3400 + 35	99 a	98 a	0.9 ab	2.5 ab

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

3.1.4. Common Lambsquarters

Trifluralin, ethalfluralin, pendimethalin, S-metolachlor, dimethenamid-P, EPTC and halosulfuron, applied PPI at rates evaluated, controlled common lambsquarters 81% - 99% and reduced density 75% - 100% and biomass 71% - 100% (**Table 4**). Trifluralin + halosulfuron, ethalfluralin + halosulfuron, pendimethalin + halosulfuron, S-metolachlor + halosulfuron, dimethenamid-P + halosulfuron, and EPTC + halosulfuron, applied PPI at rates evaluated, controlled common lambsquarters 99% - 100% and reduced common lambsquarters density 98% - 100% and biomass 97% - 100%, compared to the weedy control (**Table 4**). Results are similar to other studies in which common lambsquarters was controlled 96% - 100% with halosulfuron [9] [12] [13], 60% - 92% with trifluralin [9] [12] [13] [14] [15] [17], 56% - 97% with pendimethalin [9] [14] [15] [16], 19% - 82% with S-metolachlor [9] [12], 55% - 72% with dimethenamid-P [9] and 77% - 85% with EPTC [9] [15], applied PPI, in white beans.

3.1.5. Wild Mustard

Trifluralin, ethalfluralin, pendimethalin, S-metolachlor and dimethenamid-P, applied PPI at rates evaluated, controlled wild mustard 0% - 46%; wild mustard

Table 4. Visible percent control 4 and 8 weeks after crop emergence (WAE), density and dry biomass 8 WAE for common lambsquarters (CHEAL) with herbicides applied preplant incorporated in 2017 and 2019 at Exeter and 2018 and 2019 at Ridgetown, Ontario.

Herbicide treatment	Rate	CHEAL control		CHEAL density	CHEAL dry biomass
		4 WAE	8 WAE		
	(g ai ha^{-1})	(%)	(%)	(plants m^{-2})	(g m^{-2})
Weed-free control		100	100	0 a	0 a
Weedy control		0 d	0 d	25.3 e	88.3 b
Trifluralin	600	97 ab	98 ab	0.7 abc	9.5 ab
Ethalfluralin	810	99 a	99 a	0.1 ab	0.1 a
Pendimethalin	1080	97 ab	99 a	1.1 bc	12.7 ab
S-metolachlor	1050	81 c	83 c	6.2 d	25.6 b
Dimethenamid-P	544	88 bc	88 bc	3.6 cd	3.8 ab
EPTC	3400	98 a	97 ab	0.8 abc	0.2 a
Halosulfuron	35	97 ab	97 ab	1.8 bcd	15.7 ab
Trifluralin + halosulfuron	600 + 35	99 a	100 a	0.4 abc	3.0 ab
Ethalfluralin + halosulfuron	810 + 35	100 a	100 a	0.1 ab	0.0 a
Pendimethalin + halosulfuron	1080 + 35	100 a	100 a	0.2 ab	0.0 a
S-metolachlor + halosulfuron	1050 + 35	99 a	99 a	0.1 ab	0.1 a
Dimethenamid-P + halosulfuron	544 + 35	100 a	100 a	0.2 ab	0.0 a
EPTC + halosulfuron	3400 + 35	100 a	100 a	0.0 a	0.0 a

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

density and biomass were similar to the weedy control (Table 5). EPTC provided better control of wild mustard than the other grass herbicides evaluated. EPTC applied PPI at the rate evaluated provided 71% control of wild mustard; wild mustard density and biomass were similar to the weed-free control (Table 5). Halosulfuron alone or in combination with trifluralin, ethalfluralin, pendimethalin, S-metolachlor, dimethenamid-P and EPTC, applied PPI at rates evaluated, controlled wild mustard 97% - 100% and reduced density 98% - 100% and biomass 99% - 100% (Table 5). In other studies, wild mustard was controlled 99% - 100% with halosulfuron [9] [12] [13], 11% - 44% with trifluralin [9] [12] [14] [15], 0% - 23% with pendimethalin [9] [12] [15] [16], 11% - 55% with S-metolachlor [9] [12], 27% - 70% with dimethenamid-P [9] and 24% - 68% with EPTC [9] [15], applied PPI in white beans.

3.1.6. Barnyardgrass

Trifluralin, ethalfluralin, pendimethalin, S-metolachlor, dimethenamid-P and EPTC, applied PPI at rates evaluated, controlled barnyardgrass 98% - 100% and reduced density 95% - 99% and biomass 98% - 100% (Table 6). Halosulfuron controlled barnyardgrass up to 24%; density and biomass were similar to the

Table 5. Visible percent control 4 and 8 weeks after crop emergence (WAE), density and dry biomass 8 WAE for wild mustard (SINAR) with herbicides applied preplant incorporated in 2017 and 2019 at Exeter, Ontario.

Herbicide treatment	Rate	SINAR control		SINAR density	SINAR dry biomass
		4 WAE	8 WAE		
	(g ai ha^{-1})	(%)	(%)	(plants m^{-2})	(g m^{-2})
Weed-free control		100	100	0 a	0 a
Weedy control		0 e	0 c	128.0 de	135.3 c
Trifluralin	600	11 d	3 c	136.2 de	181.0 c
Ethalfluralin	810	16 cd	8 bc	115.6 bcde	164.8 c
Pendimethalin	1080	0 e	0 c	127.4 cde	224.2 c
S-metolachlor	1050	20 cd	3 c	156.2 e	176.1 c
Dimethenamid-P	544	46 bc	8 bc	85.1 bcde	69.8 c
EPTC	3400	71 b	71 ab	97.3 bcde	54.5 bc
Halosulfuron	35	98 a	100 a	0.1 ab	0.0 a
Trifluralin + halosulfuron	600 + 35	97 a	100 a	0.2 ab	0.0 a
Ethalfluralin + halosulfuron	810 + 35	98 a	99 a	0.4 abc	0.5 ab
Pendimethalin + halosulfuron	1080 + 35	99 a	100 a	0.0 a	0.0 a
S-metolachlor + halosulfuron	1050 + 35	99 a	100 a	0.0 a	0.0 a
Dimethenamid-P + halosulfuron	544 + 35	99 a	100 a	2.0 abcd	1.3 ab
EPTC + halosulfuron	3400 + 35	99 a	100 a	1.3 abcd	0.3 ab

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

Table 6. Visible percent control 4 and 8 weeks after crop emergence (WAE), density and dry biomass 8 WAE for barnyardgrass (ECHCG) with herbicides applied preplant incorporated in 2017 and 2019 at Exeter and 2018 and 2019 at Ridgetown, Ontario.

Herbicide treatment	Rate	ECHCG control		ECHCG density	ECHCG dry biomass
		4 WAE	8 WAE		
	(g ai ha^{-1})	(%)	(%)	(plants m^{-2})	(g m^{-2})
Weed-free control		100	100	0 a	0 a
Weedy control		0 c	0 c	22.0 c	152.8 c
Trifluralin	600	99 a	99 a	1.0 b	2.7 ab
Ethalfluralin	810	99 a	99 a	0.3 ab	1.2 ab
Pendimethalin	1080	99 a	99 a	0.7 ab	2.3 ab
S-metolachlor	1050	99 a	99 a	0.9 ab	1.8 ab
Dimethenamid-P	544	98 a	99 a	0.9 ab	1.6 ab
EPTC	3400	100 a	100 a	0.3 ab	0.7 ab
Halosulfuron	35	19 b	24 b	19.0 c	135.4 c
Trifluralin + halosulfuron	600 + 35	99 a	98 a	0.5 ab	6.3 ab
Ethalfluralin + halosulfuron	810 + 35	99 a	99 a	1.6 b	10.9 b
Pendimethalin + halosulfuron	1080 + 35	98 a	99 a	1.2 b	3.2 ab
S-metolachlor + halosulfuron	1050 + 35	97 a	98 a	0.9 ab	6.7 ab
Dimethenamid-P + halosulfuron	544 + 35	99 a	99 a	1.5 b	4.1 ab
EPTC + halosulfuron	3400 + 35	99 a	99 a	1.6 b	1.0 ab

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

weedy control (Table 6). However, halosulfuron in combination with trifluralin, ethalfluralin, pendimethalin, S-metolachlor, dimethenamid-P or EPTC, applied PPI at rates evaluated, provided 97% - 99% control of barnyardgrass and reduced density 93% - 98% and biomass 93% - 99% (Table 6). In other studies, soil application of trifluralin provided excellent control (>90%) of barnyardgrass, but pendimethalin provided only 58% control of barnyardgrass in white beans [9] [14].

3.1.7. Green Foxtail

Trifluralin, ethalfluralin, pendimethalin, S-metolachlor, dimethenamid-P and EPTC, applied PPI at rates evaluated, controlled green foxtail 98% - 99% and reduced density 95% - 99% and biomass 88% - 99% (Table 7). Halosulfuron, applied PPI at the rate evaluated, provided only up to 25% control of green foxtail; density and biomass were similar to the weedy control (Table 7). Trifluralin + halosulfuron, ethalfluralin + halosulfuron, pendimethalin + halosulfuron, S-metolachlor + halosulfuron, dimethenamid-P + halosulfuron, and EPTC + halosulfuron, applied PPI at rates evaluated, provided 94% - 99% control of green foxtail and reduced green foxtail density 89% - 97% and biomass 53% -

Table 7. Visible percent control 4 and 8 weeks after crop emergence (WAE), density and dry biomass 8 WAE for green foxtail (SETVI) with herbicides applied preplant incorporated in 2017 and 2019 at Exeter and 2018 and 2019 at Ridgetown, Ontario.

Herbicide treatment	Rate	SETVI control		SETVI density	SETVI dry biomass
		4 WAE	8 WAE		
	(g ai ha^{-1})	(%)	(%)	(plants m^{-2})	(g m^{-2})
Weed-free control		100	100	0 a	0 a
Weedy control		0 c	0 c	129.2 e	184.6 e
Trifluralin	600	98 a	98 a	5.8 bcd	22.1 bcd
Ethalfluralin	810	99 a	99 a	0.7 ab	1.0 ab
Pendimethalin	1080	98 a	98 a	4.1 bc	19.9 bcd
S-metolachlor	1050	98 a	98 a	6.7 cd	10.2 bcd
Dimethenamid-P	544	99 a	99 a	5.4 bcd	7.6 bc
EPTC	3400	99 a	98 a	6.4 bcd	3.2 bc
Halosulfuron	35	25 b	20 b	65.5 e	140.7 e
Trifluralin + halosulfuron	600 + 35	95 a	95 a	11.2 cd	79.2 cd
Ethalfluralin + halosulfuron	810 + 35	98 a	99 a	4.2 bc	3.0 abc
Pendimethalin + halosulfuron	1080 + 35	96 a	97 a	7.3 bcd	11.5 bcd
S-metolachlor + halosulfuron	1050 + 35	95 a	94 a	14.2 d	87.4 d
Dimethenamid-P + halosulfuron	544 + 35	97 a	97 a	6.0 bcd	6.9 bcd
EPTC + halosulfuron	3400 + 35	98 a	97 a	8.2 bcd	11.5 bcd

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

98% (Table 7). Results are similar to other studies in which halosulfuron, trifluralin, pendimethalin, S-metolachlor, dimethenamid-P and EPTC, applied PPI, provided 47% - 59% [9] [12], 94% - 100% [9] [12] [14] [15] [17], 92% - 98% [9] [16], 93% - 97% [9] [12], 95% - 96% [9] and 94% - 99% [9] [15] control of green foxtail in white beans, respectively.

3.2. Crop Injury and Seed Yield

White bean injury for all treatments evaluated was zero and was not analyzed (data not shown). Weed interference reduced white bean seed yield by 70% (Table 8). White bean seed yield was 53% - 66% of the weed-free control with trifluralin, ethalfluralin, pendimethalin, S-metolachlor and dimethenamid-P (Table 8). White bean seed yield was 81% and 58% of the weed-free control with EPTC and halosulfuron, applied PPI, respectively (Table 8). Trifluralin + halosulfuron, ethalfluralin + halosulfuron, pendimethalin + halosulfuron, S-metolachlor + halosulfuron, dimethenamid-P + halosulfuron, and EPTC + halosulfuron, applied PPI at rates evaluated, resulted in white bean seed yield that was 87% - 95% of the weed-free control (Table 8). There was no herbicide treatment effect on the seed moisture content which indicates no delay in white

Table 8. White bean moisture at harvest and yield with herbicide treatments applied preplant incorporated in 2017 and 2019 at Exeter and 2018 and 2019 at Ridgetown, Ontario.

Herbicide treatment	Rate	White bean moisture	White bean yield
	(g ai ha^{-1})	(% of weed-free control)	
Weedy control		104 a	30 e
Trifluralin	600	103 a	53 de
Ethalfluralin	810	103 a	56 cd
Pendimethalin	1080	104 a	53 de
S-metolachlor	1050	102 a	58 cd
Dimethenamid-P	544	103 a	66 bcd
EPTC	3400	99 a	81 abc
Halosulfuron	35	102 a	58 cd
Trifluralin + halosulfuron	600 + 35	100 a	88 ab
Ethalfluralin + halosulfuron	810 + 35	102 a	89 ab
Pendimethalin + halosulfuron	1080 + 35	101 a	91 ab
S-metolachlor + halosulfuron	1050 + 35	101 a	87 ab
Dimethenamid-P + halosulfuron	544 + 35	103 a	94 a
EPTC + halosulfuron	3400 + 35	102 a	95 a

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

bean maturity with any of the herbicide treatments evaluated (**Table 8**). Results are similar to other studies in which weed interference with halosulfuron, pendimethalin, dimethenamid-P and S-metolachlor herbicide treatments reduced white bean seed yield 20%, 66%, 72% and 62%, respectively [9] [10].

4. Conclusion

Results indicate that halosulfuron provides excellent control of velvetleaf, pigweed species, common ragweed, common lambsquarters, and wild mustard and minimal control of barnyardgrass and green foxtail. Trifluralin, ethalfluralin, pendimethalin, S-metolachlor and dimethenamid-P provide minimal control of velvetleaf, common ragweed, wild mustard and good to excellent control of pigweed species, common lambsquarters, barnyardgrass and green foxtail. EPTC provides fair to good control of velvetleaf and wild mustard and good to excellent control of pigweeds, common ragweed, common lambsquarters, barnyardgrass and green foxtail. EPTC provides better control of velvetleaf, common ragweed and wild mustard than the other grass herbicides evaluated. Halosulfuron tankmixed with trifluralin, ethalfluralin, pendimethalin, S-metolachlor, dimethenamid-P and EPTC provides excellent control of velvetleaf, pigweeds, common ragweed, common lambsquarters, wild mustard, barnyardgrass and green foxtail. Ethalfluralin provides comparable weed control as the other grass herbicides evaluated, and has potential to be registered for the control of grass weed species in white beans. Based on these results, halosulfuron in combination with any of the grass herbicides evaluated can provide effective broad-spectrum control of common annual grass and broadleaf weeds in dry bean production in Ontario, Canada.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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