Agricultural Sciences, 2019, 10, 1453-1464
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Weed Management in White Bean with Variable Doses of *S*-Metolachlor and Halosulfuron Applied Preemergence

Nader Soltani*, **Christy Shropshire**, **Peter H. Sikkema**

University of Guelph Ridgetown Campus, Ridgetown, Canada
Email: *soltanin@uoguelph.ca

How to cite this paper: Soltani, N., Shropshire, C. and Sikkema, P.H. (2019) Weed Management in White Bean with Variable Doses of *S*-Metolachlor and Halosulfuron Applied Preemergence. *Agricultural Sciences*, **10**, 1453-1464.
https://doi.org/10.4236/as.2019.1011106

Received: October 26, 2019
Accepted: November 17, 2019
Published: November 20, 2019

Abstract

Five experiments were conducted in Ontario, Canada from 2016 to 2018 to determine how doses of *S*-metolachlor and halosulfuron applied preemergence (PRE) should be adjusted to control specific weed species in white bean. *S*-metolachlor, halosulfuron, and *S*-metolachlor + halosulfuron caused minimal (1% to 4%) injury in white bean. Weed interference reduced white bean yield 54%. On average, weed interference with *S*-metolachlor and halosulfuron decreased yield 34% and 29%, respectively. In contrast, white bean seed yield was similar to the weed-free control with the *S*-metolachlor + halosulfuron tankmixes. *S*-metolachlor applied alone controlled *A. theophrasti*, *A. retroflexus*, *A. artemisiifolia*, *C. album*, *E. crus-galli* and *S. viridis* 0% to 3%, 78% to 93%, 0% to 9%, 5% to 15%, 97% to 99% and 96% to 98%, respectively. Halosulfuron applied alone controlled *A. theophrasti*, *A. retroflexus*, *A. artemisiifolia*, *C. album*, *E. crus-galli* and *S. viridis* 39% to 87%, 93% to 99%, 64% to 88%, 34% to 59%, 10% to 30% and 13% to 35%, respectively. *S*-metolachlor + halosulfuron tankmixes controlled *A. theophrasti*, *A. retroflexus*, *A. artemisiifolia*, *C. album*, E. *crus-galli* and *S. viridis* 47% to 94%, 98% to 100%, 78% to 94%, 37% to 78%, 94% to 98% and 91% to 96%, respectively. Weed density and biomass reductions with the herbicides evaluated followed the same pattern as visible weed control assessments. Results from this study indicate that doses of *S*-metolachlor and halosulfuron, when applied as a tankmix, should be adjusted based on a weed species composition in each individual white bean field.

Keywords

Biomass, Density, Dry Bean, Maturity, Seed Yield, Tolerance, Weed Control

1. Introduction

Dry bean (*Phaseolus vulgaris* L.) is popular legume crop grown in Ontario. Approximately 80% - 90% of dry bean harvested in Ontario is exported out of the province [1]. White bean has been produced in the province since the early 1900's and over the years has become the most popular dry bean market class grown [1]. In 2018, approximately 63,000 tonnes of white beans were produced from 22,000 ha in Ontario with a value of nearly $49 million [2]. Controlling weeds is one of the most important concerns for white bean production in Ontario.

Typical problem weeds for white bean producers in Ontario include *Abutilon theophrasti* Medic. (velvetleaf), *Amaranthus retroflexus* L. (redroot pigweed), *Ambrosia artemisiifolia* L. (common ragweed), *Chenopodium album* L. (common lambsquarters), *Sinapis arvensis* L. (wild mustard), *Polygonum persicaria* L. (ladysthumb), Eastern black nightshade (*Solanum ptycanthum* Dun.), *Xanthium strumarium* L. (cocklebur), *Digitaria sanguinalis* (L.) Scop. (large crabgrass), *Setaria viridis* (L.) Beauv. (green foxtail), and *Echinochloa crus-galli* (L.) P. Beauv. (barnyardgrass) [3]. These problematic weeds generally germinate early in the season and are fast growing thereby outcompeting the slower growing white bean plants for irradiance, moisture and nutrients resulting in substantial yield losses [4]. White bean seed yield losses have been reported to be 68% to 81% in white bean from weed interference [5]-[12]. There are currently few herbicide choices that producers can choose from to control these problematic weed species in white bean.

Halosulfuron is a recently registered sulfonyl-urea herbicide for broadleaved weed control in white bean in Ontario (OMAFRA 2018). Major weeds controlled with halosulfuron includes *A. theophrasti*, *C. album*, *S. arvensis*, *P. persicaria*, *A. retroflexus* and *X. strumarium*, including biotypes that are resistant to Group 5 (triazine) herbicides [13] [14]. There is little activity with halosulfuron against grass weed species at doses registered in white bean (OMAFRA 2018). Therefore, halosulfuron needs to be used along with a graminicide to provide broad-spectrum control of problematic weeds in white bean [3].

S-metolachlor (the active of isomer of metolachlor) is a chloroacetanilide herbicide that is registered in white bean to control of key weeds in Ontario including *Echinochloa* spp., *Setaria* spp., *Panicum* spp., *Digitaria* spp., *Solanum spp.* and *Amaranthus* spp. [15]. *S*-metolachlor tank mixed with halosulfuron can control troublesome grass and broadleaved weeds (including Group 5 resistant biotypes) in white bean.

The *S*-metolachlor label has a dose range of 1050 to 1600 $g \cdot ai \cdot ha^{-1}$ and the halosulfuron label has a dose range of 25 to 50 $g \cdot ai \cdot ha^{-1}$. Earlier research has primarily focused on halosulfuron at 35 $g \cdot ai \cdot ha^{-1}$ for weed control in white bean [6] [9] [10] [16]. Limited information exists on the effect of *S*-metolachlor plus lower doses of halosulfuron particularly at the lowest labelled dose of 25 $g \cdot ai \cdot ha^{-1}$ for weed control in white bean. Studies are needed to determine the appropriate application dose of halosulfuron alone or in tankmix with *S*-metolachlor for broad and comprehensive weed control in white bean. This information will allow producers to reduce their input costs and minimize crop losses from weed interference in white bean.

The purpose of this research was to evaluate how doses of *S*-metolachlor and halosulfuron should be adjusted to control specific problematic weeds in white bean production.

2. Materials and Methods

Field experiments (total of 5) were established at the University of Guelph Research Station near Exeter (43˚19'1.2108"N, 81˚30'3.8736"E) in 2016 and 2017 and at the University of Guelph Ridgetown Campus near Ridgetown (42˚26'41.46"N, 81˚52'44.472"W) during 2016 to 2018. The experimental design was a randomized complete block design (RCBD) with 4 replications. Treatments included a weedy control, weed-free control, *S*-metolachlor at 1050 and 1600 g·ai·ha^{-1}, halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1}, *S*-metolachlor at 1050 g·ai·ha^{-1} + halosulfuron at 25, 37.5 or 50 g·ai·ha^{-1}, and *S*-metolachlor at 1600 g·ai·ha^{-1} + halosulfuron at 25, 37.5 or 50 g·ai·ha^{-1}. Plots within each experiment included four rows of white bean ("T9905") spaced 75 cm apart and were 8 m long at Ridgetown and 10 m long at Exeter. White bean was seeded 3.5 to 4.5 cm deep at a rate of approximately 240,000 seeds ha^{-1} in late May to early June of each year.

Herbicides were sprayed preemergence (PRE) one to two days after seeding with a backpack sprayer which was pressurized with CO_2 and was calibrated to deliver 200 L·ha^{-1} of water at 240 kPa.

Injury in white bean was assessed visually 2 and 4 weeks after white bean emergence (WAE) and weed control assessments was made 4 and 8 WAE based on a rating of 0 to 100 where 0 represented no injury or weed control and 100 represented total bean or weed necrosis. Weed density (counts) and weed shoot dry weight (biomass) were evaluated 8 WAE by harvesting weeds from two 0.25 m^{-2} quadrats (counted and dried at 60˚C in a paper bag for at least 72 hours) within each experimental plot. White bean in each experimental plot was harvested during September/October of each year.

The GLIMMIX procedure in SAS [17] was used to analyze the data. In the analysis, herbicide treatment was the fixed effect and environment (year-location combinations), replicate within the environment and the environment-treatment interaction were the random effects. The best distribution and associated link function for each parameter was chosen by comparing fit statistics, residual plots and the Shapiro-Wilk statistic among the potential distributions. LSMEANS were calculated by using the inverse link function, and pairwise comparisons were subjected to Tukey's adjustment before determining treatment differences at $P < 0.05$. The Gaussian distribution and identity link were used for percent visible white bean injury 2 and 4 WAE, percent visible weed control of *A. theophrasti* and *C. album* 8 WAE, *E. crus-galli* dry weight and white bean yield.

Percent visible weed control of all remaining weed species at 2 and 4 WAE were analyzed using arcsine square root distribution and identity link. Weed density and weed shoot dry weight were analyzed using the lognormal distribution and identity link. The weedy control (assigned a value of 0 for injury and weed control) and weed-free control (assigned a value of 0 for injury, weed density and biomass, or 100 for weed control) were excluded from the analysis due to zero variance. Comparisons were still possible between the other treatments and the value zero using the LSMEANS output and differences were identified. Arcsine square root and lognormal distributions were back-transformed for presentation of results.

3. Results and Discussion

3.1. White Bean Injury and Yield

Visible white bean injury from the herbicides evaluated was minimal. *S*-metolachlor, halosulfuron, and *S*-metolachlor + halosulfuron, applied PRE, caused < 5% injury in white bean 2 and 4 WAE (**Table 1**). The level of injury is consistent with other research that have shown minimal, and transient, injury in white bean with *S*-metolachlor and halosulfuron [6] [9] [10] [16].

Weed interference delayed maturity (as indicated by seed moisture content at harvest) and reduced white bean seed yield 54%. Interference from weeds with

Table 1. Visible injury 2 and 4 WAE, percent moisture at maturity and yield of white bean treated with *S*-metolachlor and halosulfuron applied PRE at Exeter and Ridgetown (2016-2018)[a,b].

Treatment	Dose ($g·ai·ha^{-1}$)	Injury (%)		Seed Moisture	Yield ($T·ha^{-1}$)
		2 WAE	4 WAE		
Weedy control		0^{a}	0^{a}	19.48^{d}	1.1^{e}
Weed-free control		0^{a}	0^{a}	18.02^{a}	2.4^{a}
S-metolachlor	1050	2^{b}	2^{a}	19.23^{bcd}	1.3^{de}
S-metolachlor	1600	3^{b}	4^{a}	19.39^{cd}	1.4^{de}
Halosulfuron	25	1^{a}b	1^{a}	18.79^{abcd}	1.6^{cd}
Halosulfuron	37.5	2^{b}	2^{a}	18.38^{a}	1.8^{bcd}
Halosulfuron	50	2^{b}	3^{a}	18.53^{ab}	1.7^{bcd}
S-metolachlor + halosulfuron	1050 + 25	2^{b}	2^{a}	18.57^{abc}	2.2^{ab}
S-metolachlor + halosulfuron	1050 + 37.5	3^{b}	3^{a}	18.34^{a}	2.1^{abc}
S-metolachlor + halosulfuron	1050 + 50	4^{b}	4^{a}	18.35^{a}	2.1^{abc}
S-metolachlor + halosulfuron	1600 + 25	3^{b}	3^{a}	18.55^{ab}	2.1^{abc}
S-metolachlor + halosulfuron	1600 + 37.5	4^{b}	4^{a}	18.30^{a}	2.1^{abc}
S-metolachlor + halosulfuron	1600 + 50	4^{b}	3^{a}	18.15^{a}	2.0^{abc}

[a]Abbreviations: PRE, preemergence; 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 $P < 0.05$.

S-metolachlor and halosulfuron applied alone reduced white bean seed yield as much as 46% and 33%, respectively (**Table 1**). White bean seed yield with the *S*-metolachlor + halosulfuron tankmixes at all doses evaluated was similar to the weed-free control. Results are consistent with other studies that have shown minimal crop injury in white bean with *S*-metholachlor (1600 g·ai·ha^{-1}), halosulfuron (35 g·ai·ha^{-1}), and *S*-metolachlor + halosulfuron (1050 + 35 g·ai·ha^{-1}) [6] [7] [9] [10].

3.2. Weed Control

Weeds selected for analysis needed to be present in at least 2 out of the 5 environments. Major weed species present on study sites included *A. theophrasti*, *A. retroflexus*, *C. album*, *A. artemisiifolia*, *E. crus-galli* and *S. viridis.*

3.2.1. *Abutilon theophrasti*

S-metolachlor at doses evaluated controlled *A. theophrasti* ≤ 3% (**Table 2**). Halosulfuron at the doses evaluated controlled *A. theophrasti* 39% to 87%. *S*-metolachlor (1050 g·ai·ha^{-1}) + halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1} provided as much as 64%, 78% and 89% control of *A. theophrasti*, respectively. *S*-metolachlor (1600 g·ai·ha^{-1}) + halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1} provided as much as 80%, 88% and 94% control of *A. theophrasti*, respectively. All herbicide treatments resulted in *A. theophrasti* density and shoot dry weight that was comparable to the weedy control (**Table 2**).

Table 2. Percent visible control 4 and 8 WAE, density and dry weight of *Abutilon theophrasti* treated with *S*-metolachlor and halosulfuron applied PRE at Ridgetown (2016-2018)[a,b].

Treatment	Dose (g·ai·ha^{-1})	Control (%)		Density (no. m^{-2})	Dry weight (g·m^{-2})
		4 WAE	8 WAE		
Weedy control		0^{c}	0^{d}	7.4^{b}	6.0^{b}
Weed-free control		100	100	0.0^{a}	0.0^{a}
S-metolachlor	1050	1^{c}	0^{d}	5.8^{b}	7.6^{b}
S-metolachlor	1600	3^{c}	2^{d}	5.1^{b}	8.2^{b}
Halosulfuron	25	57^{b}	39^{c}	3.0^{b}	2.7^{b}
Halosulfuron	37.5	74^{ab}	61^{abc}	4.2^{b}	2.7^{b}
Halosulfuron	50	87^{ab}	74^{ab}	3.0^{b}	1.7^{b}
S-metolachlor + halosulfuron	1050 + 25	64^{b}	47^{c}	3.9^{b}	3.1^{b}
S-metolachlor + halosulfuron	1050 + 37.5	78^{ab}	61^{abc}	3.9^{b}	4.0^{b}
S-metolachlor + halosulfuron	1050 + 50	89^{ab}	79^{ab}	3.0^{b}	1.9^{b}
S-metolachlor + halosulfuron	1600 + 25	80^{ab}	59^{bc}	2.2^{b}	2.0^{b}
S-metolachlor + halosulfuron	1600 + 37.5	88^{ab}	76^{ab}	3.2^{b}	3.6^{b}
S-metolachlor + halosulfuron	1600 + 50	94^{a}	86^{a}	2.4^{b}	1.1^{ab}

[a]Abbreviations: PRE, preemergence; 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 $P < 0.05$.

3.2.2. *Amaranthus retroflexus*

S-metolachlor and halosulfuron applied alone at doses evaluated controlled *A. retroflexus* 78% to 93% and 93% to 99%, respectively (Table 3). *S*-metolachlor (1050 or 1600 g·ai·ha^{-1}) + halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1} provided excellent (98% to 100%) control of *A. retroflexus*. Increasing the dose of *S*-metolachlor or halosulfuron did not significantly increase *A. retroflexus* control.

A. retroflexus density and dry weight reductions with herbicides evaluated were consistent with the visible control assessments (Table 3). *S*-metolachlor, halosulfuron, and *S*-metolachlor + halosulfuron reduced *A. retroflexus* density as much as 87%, 97% and 98% and *A. retroflexus* dry weight as much as 95%, 99% and 100%, respectively (Table 3).

Other studies have similarly shown 84% to 95% control of *A. retroflexus* with *S*-metolachlor and 83% to 100% control of *A. retroflexus* with halosulfuron in white bean [7] [9]. Brown and Masiunas [19] also reported 94% and 98% *A. retroflexus* control with halosulfuron at 3 and 6 weeks after application (WAA), respectively. Other studies have also reported as much as 96% to 100% *A. retroflexus* control with *S*-metolachlor and halosufuron tankmix in white bean [6] [7] [9] [18]. Li *et al.* [7] found 100% *A. retroflexus* control in white bean with *S*-metolachlor + halosulfuron at 1050 + 35 g·ai·ha^{-1}.

Table 3. Percent visible control 4 and 8 WAE, density and dry weight of *Amaranthus retroflexus* treated with *S*-metolachlor and halosulfuron applied PRE at Exeter (2016-2017) and Ridgetown (2017).

Treatment	Dose (g·ai·ha^{-1})	Control		Density (no. m^{-2})	Dry weight (g·m^{-2})
		4 WAE	8 WAE		
Weedy control		0[c]	0[c]	28.6[c]	36.0[d]
Weed-free control		100	100	0[a]	0[a]
S-metolachlor	1050	81.9[b]	78.4[b]	4.0[b]	2.3[c]
S-metolachlor	1600	92.9[ab]	92.7[ab]	3.7[b]	1.7[bc]
Halosulfuron	25	95.2[ab]	95.2[ab]	1.7[ab]	0.6[abc]
Halosulfuron	37.5	95.9[ab]	92.6[ab]	2.5[ab]	0.9[abc]
Halosulfuron	50	98.8[ab]	97.9[a]	0.9[ab]	0.4[abc]
S-metolachlor + halosulfuron	1050 + 25	98.9[ab]	97.9[a]	1.8[ab]	0.6[abc]
S-metolachlor + halosulfuron	1050 + 37.5	99.2[a]	99.3[a]	1.4[ab]	0.3[abc]
S-metolachlor + halosulfuron	1050 + 50	98.9[ab]	98.7[a]	0.8[ab]	0.5[abc]
S-metolachlor + halosulfuron	1600 + 25	99.2[a]	98.3[a]	1.1[ab]	0.4[abc]
S-metolachlor + halosulfuron	1600 + 37.5	99.6[a]	99.6[a]	1.9[ab]	0.7[abc]
S-metolachlor + halosulfuron	1600 + 50	99.7[a]	99.8[a]	0.6[ab]	0.1[abc]

[a]Abbreviations: PRE, preemergence; 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 $P < 0.05$.

3.2.3. *Ambrosia artemisiifolia*

S-metolachlor alone at doses evaluated provided only 0% to 9% control of *A. artemisiifolia* (**Table 4**). However, halosulfuron alone at doses evaluated controlled *A. artemisiifolia* 64% to 88%. *S*-metolachlor (1050 g·ai·ha^{-1}) + halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1} controlled *A. artemisiifolia* 78% to 91%. Similarly, *S*-metolachlor (1600 g·ai·ha^{-1}) + halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1} provided 83% to 94% *A. artemisiifolia* control.

S-metolachlor provided no reduction in density or dry weight of *A. artemisiifolia* at the doses evaluated (**Table 4**). However, halosulfuron and *S*-metolachlor + halosulfuron treatments reduced *A. artemisiifolia* density or dry weight as much as 95% (**Table 4**).

Other research has shown only 13% to 40% control of *A. artemisiifolia* with *S*-metolachlor and 95% to 99% control of *A. artemisiifolia* with halosulfuron in white bean [7] [9]. Li *et al.* [7] reported 95% to 98% *A. artemisiifolia* control in white bean with *S*-metolachlor + halosulfuron at 1050 + 35 g·ai·ha^{-1}.

3.2.4. *Chenopodium album*

S-metolachlor applied alone at the doses evaluated provided poor (5% to 15%) control of *C. album* (**Table 5**). Halosulfuron alone at doses evaluated controlled *C. album* only 34% to 59%. *S*-metolachlor + halosulfuron at doses evaluated also provided less than adequate control (37% to 78%) of *C. album*. Increasing the

Table 4. Percent visible control 4 and 8 WAE, density and dry weight of *Ambrosia artemisiifolia* treated with *S*-metolachlor and halosulfuron applied PRE at Exeter (2017) and Ridgetown (2016-2018)[a,b].

Treatment	Dose (g·ai·ha^{-1})	Control (%)		Density (no. m^{-2})	Dry weight (g·m^{-2})
		4 WAE	8 WAE		
Weedy control		0[c]	0[d]	43.1[c]	50.2[c]
Weed-free control		100	100	0[a]	0[a]
S-metolachlor	1050	7[b]	0[d]	33.7[c]	63.1[c]
S-metolachlor	1600	9[b]	0[d]	27.8[c]	51.0[c]
Halosulfuron	25	78[a]	64[c]	5.9[b]	7.3[b]
Halosulfuron	37.5	81[a]	72[bc]	4.6[b]	6.5[b]
Halosulfuron	50	88[a]	81[abc]	4.5[b]	4.9[b]
S-metolachlor + halosulfuron	1050 + 25	86[a]	78[abc]	5.6[b]	6.0[b]
S-metolachlor + halosulfuron	1050 + 37.5	91[a]	84[ab]	5.5[b]	8.0[b]
S-metolachlor + halosulfuron	1050 + 50	91[a]	85[ab]	3.3[b]	5.4[b]
S-metolachlor + halosulfuron	1600 + 25	89[a]	83[abc]	3.5[b]	6.1[b]
S-metolachlor + halosulfuron	1600 + 37.5	93[a]	89[a]	2.8[b]	5.2[b]
S-metolachlor + halosulfuron	1600 + 50	94[a]	88[ab]	2.2[b]	2.5[b]

[a]Abbreviations: PRE, preemergence; 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 and 8 WAE, density and dry weight of *Chenopodium album*treated with *S*-metolachlor and halosulfuron applied PRE at Exeter and Ridgetown (2016-2018)[a,b].

Treatment	Dose (g·ai·ha^{-1})	Control (%)		Density (no. m^{-2})	Dry weight (g·m^{-2})
		4 WAE	8 WAE		
Weedy control		0^{c}	0^{d}	30.9^{f}	13.2^{c}
Weed-free control		100	100	0^{a}	0^{a}
S-metolachlor	1050	5^{c}	14^{cd}	10.5^{e}	10.7^{bc}
S-metolachlor	1600	6^{c}	15^{cd}	8.2^{de}	10.4^{bc}
Halosulfuron	25	35^{b}	34^{bc}	3.2^{bc}	3.7^{bc}
Halosulfuron	37.5	49^{ab}	45^{ab}	3.3^{cd}	2.7^{bc}
Halosulfuron	50	59^{ab}	48^{ab}	2.0^{bc}	3.5^{bc}
S -metolachlor + halosulfuron	1050 + 25	47^{ab}	37^{abc}	2.7^{bc}	4.1^{bc}
S-metolachlor + halosulfuron	1050 + 37.5	54^{ab}	48^{ab}	1.9^{bc}	2.4^{bc}
S-metolachlor + halosulfuron	1050 + 50	64^{ab}	61^{a}	1.0^{bc}	2.8^{bc}
S-metolachlor + halosulfuron	1600 + 25	66^{ab}	46^{a}b	2.1^{bc}	5.3^{bc}
S-metolachlor + halosulfuron	1600 + 37.5	71^{a}	62^{a}	1.0^{b}	1.8^{b}
S-metolachlor + halosulfuron	1600 + 50	78^{a}	61^{a}	1.2^{bc}	2.0^{b}

[a]Abbreviations: PRE, preemergence; 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.

dose of *S*-metolachlor or halosulfuron did not significantly increase the control of *C. album*.

S-metolachlor, halosulfuron, and *S*-metolachlor + halosulfuron reduced *C. album* density as much as 73%, 94% and 97%, respectively. However, shoot weight was not different than the weedy control with all herbicide treatments except for *S*-metolachlor (1600 g·ai·ha^{-1}) + halosulfuron at 37.5 and 50 g·ai·ha^{-1} which reduced *C. album* dry weight 86% and 85%, respectively (Table 5).

In other research, *S*-metolachlor applied alone provided 19% to 82% *C. album* control in white bean [7] [9]. Brown and Masiunas [19] reported 90% to 98% *C. album* control with halosulfuron at 3 to 6 WAA. Other studies have also reported 96% to 100% *C. album* control with halosulfuron in white bean [7] [9]. Li *et al.* [7] reported 99% to 100% *C. album* control with *S*-metolachlor + halosulfuron at 1050 + 35 g·ai·ha^{-1}.

3.2.5. *Echinochloa crus-galli*

All treatments that included *S*-metolachlor provided excellent *E. crus-galli* control (Table 6). *S*-metolachlor applied alone at the doses evaluated controlled *E. crus-galli* 97% to 99% (Table 6). In contrast, halosulfuron applied at 25, 37.5 and 50 g·ai·ha^{-1} controlled *E. crus-galli* only 10% to 30% in white bean (Table 6). *S*-metolachlor (1050 g·ai·ha^{-1}) + halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1}

Table 6. Percent visible control 4 and 8 WAE, density and dry weight of *Echinochloa crus-galli* treated with *S*-metolachlor and halosulfuron applied PRE at Exeter (2017) and Ridgetown (2018)[a,b].

Treatment	Dose ($g·ai·ha^{-1}$)	Control (%)		Density (no. m^{-2})	Dry weight ($g·m^{-2}$)
		4 WAE	8 WAE		
Weedy control		0^{c}	0^{c}	21.8^{d}	26.3^{bc}
Weed-free control		100	100	0 a	0^{a}
S-metolachlor	1050	97^{a}	98^{a}	2.5^{b}	1.1^{b}
S-metolachlor	1600	99^{a}	99^{a}	2.2^{b}	1.0^{b}
Halosulfuron	25	26^{b}	21^{b}	28.2^{d}	39.2^{c}
Halosulfuron	37.5	28^{b}	25^{b}	15.1^{cd}	28.0^{bc}
Halosulfuron	50	30^{b}	10^{b}	27.5^{d}	23.7^{bc}
S-metolachlor + halosulfuron	1050 + 25	94^{a}	97^{a}	4.0^{bc}	3.5^{b}
S-metolachlor + halosulfuron	1050 + 37.5	97^{a}	98^{a}	3.6^{bc}	1.8^{b}
S-metolachlor + halosulfuron	1050 + 50	94^{a}	96^{a}	5.0^{bc}	2.1^{b}
S-metolachlor + halosulfuron	1600 + 25	98^{a}	98^{a}	2.7^{b}	1.0^{b}
S-metolachlor + halosulfuron	1600 + 37.5	95^{a}	98^{a}	2.7^{b}	0.9^{b}
S-metolachlor + halosulfuron	1600 + 50	98^{a}	98^{a}	2.4^{b}	10.4^{bc}

[a]Abbreviations: PRE, preemergence; 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 $P < 0.05$.

provided 97%, 98% and 96% control of *E. crus-galli* in white bean, respectively 8 WAE. Similarly, *S*-metolachlor (1600 $g·ai·ha^{-1}$) + halosulfuron at 25, 37.5, and 50 $g·ai·ha^{-1}$ controlled *E. crus-galli* as much as 98% in white bean.

S-metolachlor and *S*-metolachlor + halosulfuron reduced density of *E. crus-galli* as much as 90% and 89%, respectively. However, *E. crus-galli* density and shoot dry weight was not different than the weedy control with halosulfuron (Table 6).

3.2.6. *Setaria viridis*

All treatments that included *S*-metolachlor provided excellent *S. viridis* control (Table 7). *S*-metolachlor applied alone at the doses evaluated provided 96% to 98% *S. viridis* control (Table 7). Halosulfuron alone provided poor *S. viridis* control. Halosulfuron (25, 37.5, and 50 $g·ai·ha^{-1}$) provided a maximum *S. viridis* control of 35% in white bean (Table 7). *S*-metolachlor (1050 or 1600 $g·ai·ha^{-1}$) + halosulfuron (25, 37.5, and 50 $g·ai·ha^{-1}$) controlled *S. viridis* 91% to 96% in white bean.

Halosolfuron alone at doses evaluated did not reduce *S. viridis* density or dry weight (Table 7). However, *S*-metolachlor and *S*-metolachlor + halosulfuron reduced *S. viridis* density as much as 89% and 86% and *S. viridis* dry weight as much as 94% and 93%, respectively (Table 7).

Table 7. Percent visible control 4 and 8 WAE, density and dry weight of *Setaria viridis*treated with *S*-metolachlor and halosulfuron applied PRE at Exeter and Ridgetown (2016-2018)[a,b].

Treatment	Dose ($g \cdot ai \cdot ha^{-1}$)	Control (%)		Density (no. m^{-2})	Dry weight ($g \cdot m^{-2}$)
		4 WAE	8 WAE		
Weedy control		0^{c}	0^{c}	57.7^{c}	58.1^{c}
Weed-free control		100	100	0^{a}	0^{a}
S-metolachlor	1050	96^{a}	96^{a}	6.6^{b}	3.8^{b}
S-metolachlor	1600	98^{a}	98^{a}	6.4^{b}	3.2^{b}
Halosulfuron	25	21^{b}	13^{b}	47.9^{c}	36.7^{c}
Halosulfuron	37.5	25^{b}	19^{b}	45.7^{c}	29.9^{c}
Halosulfuron	50	35^{b}	25^{b}	40.2^{c}	31.1^{c}
S-metolachlor + halosulfuron	1050 + 25	92^{a}	91^{a}	12.4^{b}	9.1^{b}
S-metolachlor + halosulfuron	1050 + 37.5	92^{a}	94^{a}	12.1^{b}	8.4^{b}
S-metolachlor + halosulfuron	1050 + 50	92^{a}	92^{a}	9.6^{b}	5.8^{b}
S-metolachlor + halosulfuron	1600 + 25	96^{a}	95^{a}	8.0^{b}	5.9^{b}
S-metolachlor + halosulfuron	1600 + 37.5	96^{a}	95^{a}	8.5^{b}	5.2^{b}
S-metolachlor + halosulfuron	1600 + 50	96^{a}	96^{a}	8.3b	3.9b

[a]Abbreviations: PRE, preemergence; 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 $P < 0.05$.

Other studies have similarly shown 93% to 97% *S. viridis* control with *S*-metolachlor [6] [20] and 47% to 59% *S. viridis* control with halosufuron in white bean [7] [9]. Li *et al.* [7] found up to 94% *S. viridis* control with *S*-metolachlor + halosulfuron at 1050 + 35 $g \cdot ai \cdot ha^{-1}$.

4. Conclusions

There is an adequate margin of crop safety in white bean for use of *S*-metolachlor, halosulfuron and *S*-metolachlor + halosulfuron applied PRE. *S*-metolachlor alone provided poor control of *A. artemisiifolia, C. album* and *A. theophrasti*, fair control of *A. retroflexus* and excellent control of *S. viridis* and *E. crus-galli*. Halosulfuron alone provided poor control of *C. album*, *A. theophrasti*, *E. crus-galli* and *S. viridis*, fair control of *A. artemisiifolia* and excellent control of *A. retroflexus*. *S*-metolachlor + halosulfuron tankmixes provided poor control of *C. album*, fair control of *A. theophrasti*, good control of *A. artemisiifolia* and excellent control of *A. retroflexus*, *E. crus-galli* and *S. viridis*. There was a trend for better control of *A. artemisiifolia, C. album* and *A. theophrasti* with the higher doses of halosulfuron. White bean yield with *S*-metolachlor + halosulfuron tankmixes was similar to the weed-free control.

Results also show that the dose of *S*-metolachlor and halosulfuron when applied as a tankmix should be adjusted depending on weeds that exist in the field.

For fields with *A. theophrasti*, there was a trend for improved control with the higher doses of halosulfuron. For fields with *A. artemisiifolia*, there was a trend for improved control with the higher doses of halosulfuron when applied as a tankmix with the low dose of *S*-metolachlor, however, there was no need to increase the halosulfuron dose when applied as a tankmix with the high dose of *S*-metolachlor. For fields with *A. retroflexus* species, *E. crus-galli* and *S. viridis*, a tankmix of *S*-metolachlor + halosulfuron at the low dose was sufficient to provide excellent weed control. Using this information, white bean producers can maximize crop yield and reduce input costs while reducing unnecessary loading of herbicides into the environment by adjusting herbicide doses depending on weed species present in their land.

Acknowledgements

This study was funded in part by Ontario Bean Growers (OBG).

Conflicts of Interest

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

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