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Effect of Halosulfuron Rate and Application Timing on Volunteer Azuki Bean Control in White Bean

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Abstract

Three field experiments were carried out during 2017-2019 at the University of Guelph Huron Research Station near Exeter, Ontario, Canada to determine the effect of halosulfuron rate (25, 37.5 or 50 g·ai·ha^{-1}) and application timing (POST 1, POST 2 and POST 3) on volunteer azuki bean control in white bean. At POST 1, halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1} controlled volunteer azuki bean 46% - 50% at 1 week after application (WAA), controlled decreased to 16% - 25% at 8 WAA. At POST 2, volunteer azuki bean controlled decreased from 34% - 39% at 1 WAA to 17% - 27% at 8 WAA. A similar trend was observed at POST 3. Halosulfuron applied POST 1 at 25, 37.5 and 50 g·ai·ha^{-1} reduced biomass 49%, 64% and 69%, respectively. Halosulfuron applied POST 2 did not reduce volunteer azuki bean biomass at 25 g·ai·ha^{-1}, but decreased biomass 51% at 37.5 g·ai·ha^{-1} and 49% at 50 g·ai·ha^{-1}. Similarly, halosulfuron applied POST 3 did not reduce volunteer azuki bean biomass at 25 g·ai·ha^{-1}, but decreased biomass 40% at 37.5 g·ai·ha^{-1} and 44% at 50 g·ai·ha^{-1}. There was as much as 19%, 22% and 25% dockage with halosulfuron applied POST 1, POST 2 and POST 3, respectively. Volunteer azuki bean interference reduced white bean yield 40%. Reduced volunteer azuki bean interference with halosulfuron applied POST 1 at 37.5 or 50 g·ai·ha^{-1} resulted in an increase in white bean yield relative to the weedy control; however white yield was less than the weed-free control. This study concludes that halosulfuron at rates and application timings evaluated does not provide adequate control of volunteer azuki bean in white bean.

Keywords

Azuki Bean, Biomass, Aboveground Dry Weight, Dockage, Injury, Weed Control, White Bean, *Phaseolus vulgaris, Vigna angularis*

1. Introduction

Azuki bean [*Vigna angularis* (Willd.) Ohwi & Ohashi] is a protein-rich small red-brown coloured bean (5 mm long) that is widely grown in East Asia, mostly in China and Japan [1] [2] [3]. In recent years, azuki bean production has become popular among dry bean producers in Ontario as it can bring in up to three times the price of soybean on a tonnage basis [4]. Azuki bean production is so popular with dry bean growers in Ontario that their contracts are often filled months in advance [4]. Most of the azuki bean produced in Ontario is exported to Japan where it is used in confectionery products including pastry, soft drinks and chocolate bars [5]. One of the main concerns with azuki bean production is volunteer azuki bean in subsequent crops in the rotation. Azuki bean has a hardy seed that can survive and germinate up to 20 years after seed shed [6]. Studies have shown greater than 95% seed viability of azuki bean after 10 years [3].

White navy bean (*Phaseolus vulgaris* L.) is the largest market class of dry bean grown in Ontario. Volunteer azuki bean can be a serious challenge if white bean is grown after azuki bean as seeds from shattering losses of azuki bean during harvest operations can germinate and interfere with the white bean crop. Effective volunteer azuki bean control is essential for white bean growers as there is a significant downgrading and premium losses due to azuki bean seed contamination in white bean [7] [8]. The presence of volunteer azuki bean plants at white bean harvest can also decrease harvesting efficiency and lower seed quality. Azuki bean seeds are only marginally smaller than the white bean and are hard to separate from white bean. Yield losses of 31% have been reported when azuki bean was not controlled in white bean [9]. More research is needed to assess new herbicide programs that are safe for use in white bean and provide control of volunteer azuki bean.

Halosulfuron is a recently registered herbicide at the rate of 25 to 50 g·ai·ha^{-1} in *Phaseolus vulgaris* species including white bean in Ontario [10]. Halosulfuron is a Group 2 sulfonylurea herbicide that binds to the ALS enzyme which disrupts the synthesis of key amino acids [11]. Sulfonylurea herbicides are popular among growers as they have low mammalian toxicity, low use rates, can be tank-mixed with many other herbicides, and they provide effective control of a broad spectrum of weeds; although herbicide activity is active ingredient specific. Azuki bean is very sensitive to halosulfuron applied postemergence (POST); halosulfuron at 35 or 70 g·ai·ha^{-1} applied POST reduced azuki bean biomass reduction of 93% [12]. In addition to its activity on volunteer azuki bean, halosulfuron controls a wide range of common annual broadleaf weeds that occur in Ontario including Amaranthus species, common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemesiifolia* L.), velvetleaf (*Abutilon theophrasti* Medic.), wild mustard (*Sinapis arvensis* L.), ladysthumb [*Persicaria maculosa* (Gray)], common chickweed [*Stellaria media* (L.) Vill.], jimsonweed (*Datura stramonium* L.) and flower-of-an-hour (*Hibiscus trionum* L.).

There is limited information on the efficacy of halosulfuron applied POST at various rates and application timings for the control of volunteer azuki bean in white bean under Ontario environmental conditions. Preliminary studies have shown that halosulfuron (35 g a.i. ha^{-1}) applied preemergence (PRE) does not provide adequate control for volunteer azuki bean in white bean, but halosulfuron applied POST has the potential to provide some control of volunteer azuki bean in white bean [9]. Increasing the application rate of halosulfuron and adjusting the application timing may improve volunteer azuki bean in white bean.

The purpose of this study was to determine the effect of halosulfuron rate (25, 37.5 or 50 g·ha^{-1}) and postemergence application timing [V1 (POST 1), V3 (POST 2) or V5 (POST 3) leaf stage] on the control of volunteer azuki bean in white bean.

2. Materials and Methods

Three field experiments were carried out over a three-year period (2017, 2018, and 2019) at the University of Guelph Huron Research Station near Exeter, Ontario, Canada. Seedbed was prepared with moldboard plowing in the autumn followed by two passes with a field cultivator (depth of 10 cm) with rolling basket harrows in the spring. For uniform distribution of volunteer azuki bean seeds in the experimental plots, azuki bean seeds "Erimo" were distributed using a seed spreader at the rate of approximately 55 kg·ha^{-1} before cultivation in the spring.

The experiment design was a randomized complete block design with four replications. Treatments included a non-treated weedy control, weed-free control and halosulfuron applied POST 1 (V1 leaf stage), POST 2 (V3 leaf stage), and POST 3 (V5 leaf stage) at the rate of 25, 37.5 and 50 g·ai·ha^{-1}. Plots were 3 m wide (4 rows spaced 75 cm apart) and 10 m long. White bean "T9905" was seeded at a rate of approximately 250,000 seeds ha^{-1} to a depth of approximately 4 cm.

Halosulfuron treatments which included a nonionic surfactant (Agral 90®) at 0.25% v/v were applied when the volunteer azuki bean was at V1 (POST 1), V3 (POST 2) and V5 (POST 3). Halosulfuron was applied with a backpack (CO_2-pressurized) sprayer adjusted to deliver 200 L ha^{-1} at 207 kPa. The boom had four Ultra Lo-Drift (ULD 120-02) spray nozzles spaced 50 cm apart, producing a spray width of 2.0 m. Percent volunteer azuki bean control was estimated visually on a scale of 0% to 100% (0 = no control and 100 = total control) at 1, 2, 4 and 8 weeks after application (WAA). At 4 weeks after POST 3 application, density (plant counts) and biomass (shoot dry weight dried at 60˚C) of volunteer azuki bean were determined from two 0.25 m^2 quadrats in each plot. Seed moisture content, dockage, and seed yield of white bean were measured at maturity. Dockage represented percent contamination in harvested white beans with volunteer azuki bean. White bean yield was adjusted to 18% seed moisture content.

Data was analyzed using the GLIMMIX procedure in SAS [13]. The treatments were replicated 4 times in a randomized complete block design. The fixed effect was herbicide treatment and random effects were year-location combinations (environment), replicate within environment and the environment by treatment interaction. The Shapiro-Wilk statistic, fit statistics, residual plots and the potential distributions were used to identify the best distribution and associated link function for each parameter. Least square means (LSMEANS) were calculated on the data scale by using the inverse link function, and pairwise comparisons were subjected to Tukey's adjustment before determining treatment differences at $P < 0.05$. The normal distribution and identity link was used for percent azuki bean control at 1, 2, 4 and 8 WAT, azuki bean density and dry weight, as well as white bean moisture and yield at harvest. Percent dockage was analyzed using the lognormal distribution and identity link. The weedy control was assigned a value of 0 for weed control, and the weed-free control was assigned a value of 0 for weed density, biomass and dockage, or 100 for weed control and was 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.

3. Results and Discussion

At 1 WAA, there was no effect of halosulfuron rate (25, 37.5 and 50 g·ai·ha^{-1}) on volunteer azuki bean control in white bean. Halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1} controlled volunteer azuki bean 46%, 49% and 50% when applied POST 34%, 36% and 39% when applied POST 2; and 26%, 30% and 31% when applied POST 3, respectively (Table 1). Halosulfuron applied POST 1 at 25, 37.5 and 50 g·ai·ha^{-1} provided greater control of volunteer azuki bean than when applied POST 3 at the same rates (Table 1).

At 2 WAA, there was no effect of halosulfuron rate (25, 37.5 and 50 g·ai·ha^{-1}) on volunteer azuki bean control in white bean. Halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1} controlled volunteer azuki bean 58%, 64% and 70% when applied POST 1; 45%, 52% and 55% when applied POST 2; and 45%, 51% and 56% when applied POST 3, respectively (Table 1). Halosulfuron applied POST 1 at 50 g·ai·ha^{-1} provided greater volunteer azuki bean control than the same rate at POST 2.

At 4 WAA, there was no effect of halosulfuron rate (25, 37.5 and 50 g·ai·ha^{-1}) or application timing (POST 1, POST 2 or POST 3) on volunteer azuki bean control in white bean. Halosulfuron at 25, 37.5 and 50 g·ai·ha^{-1} controlled volunteer azuki bean 31%, 39% and 47% when applied POST 1; 32%, 36% and 42% when applied POST 2; and 33%, 43% and 50% when applied POST 3, respectively (Table 1).

Volunteer azuki bean control was lower at 8 WAA. There was generally no effect of halosulfuron rate (25, 37.5 and 50 g·ai·ha^{-1}) or application timing (POST 1, POST 2 or POST 3) on volunteer azuki bean control in white bean. Across the three rates, halosulfuron applied at POST 1, POST 2 and POST 3 controlled volunteer azuki bean only 16% - 25%, 17% - 27% and 18% - 32%, respectively. Results are similar to another study in which halosulfuron (30 g·ai·ha^{-1}) applied

PRE or POST controlled volunteer azuki bean 12 and 60%, respectively in white bean [9]. In contrast, another study has shown that halosulfuron applied POST at 35 g·ai·ha^{-1} can cause up to 81% injury in azuki bean [14]. Additionally, Stewart *et al.* [12] found up to 86% azuki bean injury with halosulfuron applied POST at 70 g·ai·ha^{-1}. Soltani *et al.* [14] reported up to 73% injury to azuki bean with halosulfuron applied POST at 35 and 70 g·ai·ha^{-1}.

At 4 weeks after POST 3 application, there was no effect of halosulfuron rate (25, 37.5 and 50 g·ai·ha^{-1}) or application timing (POST 1, POST 2 and POST 3) on volunteer azuki bean density in white bean. There was a trend for decreased volunteer azuki bean biomass as the rate of halosulfuron increased at various application timings. Halosulfuron applied POST 1 at 25, 37.5 and 50 g·ai·ha^{-1} reduced biomass 49%, 64% and 69%, respectively (**Table 1**). Halosulfuron applied POST 2 did not reduce volunteer azuki bean biomass at 25 g·ai·ha^{-1}, but decreased biomass 51% at 37.5 g·ai·ha^{-1} and 49% at 50 g·ai·ha^{-1}. Similarly, halosulfuron applied POST 3 did not reduce volunteer azuki bean biomass at 25 g·ai·ha^{-1}, but decreased biomass 40% at 37.5 g·ai·ha^{-1} and 44% at 50 g·ai·ha^{-1} (**Table 1**). Results are similar to another study in which halosulfuron applied POST at 30 g·ai·ha^{-1} reduced volunteer azuki bean biomass 38% in white bean [9]. In contrast, Stewart *et al.* [12] reported up to 93% reduction in azuki bean biomass with halosulfuron applied POST at 70 g·ai·ha^{-1}. Soltani *et al.* [14] found up to 68% reduction in azuki bean biomass with halosulfuron applied POST at 35 or 70 g·ai·ha^{-1}.

Table 1. Percent control, density and biomass of azuki bean as well as percent dockage, seed moisture content at maturity and yield of white bean (2017-2019) treated with halosulfuron at three rates at three POST timings. Means followed by a different letter within a column are significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$.[a]

Treatment[b]	Rate	Trt. Timing[c]	Volunteer azuki bean control (%)				Volunteer azuki bean density	Volunteer azuki biomass	White bean dockage	White bean moisture	White bean yield
			1 WAA	2 WAA	4 WAA	8 WAA	(Plants·m^{-2})	(g·m^{-2})	(%)	(%)	(T·ha^{-1})
Weed-Free			100	100	100	100	0^{a}	0^{a}	0^{a}	17·5	3·0^{a}
Weedy			0^{d}	0^{d}	0^{b}	0^{c}	32^{b}	106·8^{e}	31^{c}	17·3	1·8^{c}
Halosulfuron	25	POST 1	46^{ab}	58^{abc}	31^{a}	16^{b}	34^{b}	54·2^{bcd}	19^{bc}	18·4	2·1^{bc}
Halosulfuron	37.5	POST 1	49^{a}	64^{ab}	39^{a}	18^{ab}	28^{b}	38·0^{bcd}	9^{b}	18·3	2·4^{b}
Halosulfuron	50	POST 1	50^{a}	70^{a}	47^{a}	25^{ab}	28^{b}	33·0^{b}	10^{b}	19·0	2·4^{b}
Halosulfuron	25	POST 2	34^{abc}	45^{c}	32^{a}	17^{ab}	41^{b}	72·8^{cde}	19^{bc}	18·2	2·1^{bc}
Halosulfuron	37.5	POST 2	36^{abc}	52^{bc}	36^{a}	22^{ab}	30^{b}	51·9^{bcd}	22^{bc}	17·9	2·1^{bc}
Halosulfuron	50	POST 2	39^{abc}	55^{bc}	42^{a}	27^{ab}	31^{b}	54·9^{bcd}	18^{bc}	18·5	2·2^{bc}
Halosulfuron	25	POST 3	26^{c}	45^{c}	33^{a}	18^{ab}	33^{b}	78·4de	25^{bc}	18·3	2·2^{bc}
Halosulfuron	37.5	POST 3	30^{bc}	51^{bc}	43^{a}	26^{ab}	37^{b}	64·1^{bcd}	17^{b}	19·1	2·1^{bc}
Halosulfuron	50	POST 3	31^{bc}	56^{abc}	50^{a}	32^{a}	27^{b}	59·3^{bcd}	12^{b}	18·3	2·2^{bc}

[a]Abbreviations: WAA, weeks after application; POST, postemergence; Trt, treatment. [b]Halosulfuron treatments included 0.25% v/v Agral 90. [c]POST 1, 2 and 3 applications were made at V1, V3 and V5 azuki bean, respectively.

There was a 31% dockage due to volunteer azuki bean in white bean (Table 1). The dockage was as much as 19%, 22% and 25% with the halosulfuron applied POST 1, POST 2 and POST 3, respectively (Table 1).

White bean seed moisture content at harvest time ranged from 17.3% - 19.1% (Table 1). There was no effect of halosulfuron rate (25, 37.5 and 50 g·ai·ha^{-1}) or application timing (POST 1, POST 2 and POST 3) on white bean seed moisture content (Table 1). This is similar to another study in which halosulfuron applied PRE or POST at 30 g·ai·ha^{-1} for volunteer azuki bean control did not have an effect on white bean maturity as measured by seed moisture content [9].

Volunteer azuki bean interference reduced white bean yield 40% (Table 1). Volunteer azuki bean interference with halosulfuron treatments reduced white bean yield 20% - 30%. Most of the halosulfuron treatments resulted in white bean yield that was similar to the weedy control. Halosulfuron applied POST 1 at 37.5 or 50 g·ai·ha^{-1} were the only herbicide treatments that resulted in white bean yield that was greater than the weedy control (Table 1). In other studies, reduce volunteer azuki bean interference with halosufuron applied POST at 30 g·ai·ha^{-1} resulted in an increase in white bean yield of 31% [9].

4. Conclusion

Generally, there was generally no effect of halosulfuron rate on volunteer azuki bean control in white bean. There was a trend for reduced volunteer azuki bean control as the application timing was delayed although results were not always statistically significant. Halosulfuron at rates evaluated controlled volunteer azuki bean up to 70% when applied POST 1; 55% when applied POST 2; and 56% when applied POST 3. Similarly, volunteer azuki bean biomass was reduced only 69%, 49% and 44% with halosulfuron applied POST 1, POST 2 and POST 3 at the highest registered rate (50 g·ai·ha^{-1}), respectively. Volunteer azuki bean interference with halosulfuron treatments caused 19% - 25% dockage in white bean. Additionally, volunteer azuki bean interference with halosulfuron treatments reduced white bean yield 20% - 30%. Reduced volunteer azuki bean interference with halosulfuron applied POST 1 at 37.5 or 50 g·ai·ha^{-1} were the only herbicide treatments that resulted in white bean yield greater than the weedy control. Based on these results, halosulfuron applied POST 1, POST 2 or POST 3 at 25, 37.5 and 50 g·ai·ha^{-1} does not provide adequate volunteer azuki bean control in white bean. Further research is required to assess the safety and efficacy of halosulfuron plus new tank-mix partners for the control of volunteer azuki bean in white bean production.

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Conflicts of Interest

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

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