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Tolerance of Four Dry Bean Market Classes to Pre-Emergence Applications of Sulfentrazone

Allison N. Taziar[1], Nader Soltani[1], Christy Shropshire[1], Darren E. Robinson[1], Mitch Long[2], Chris L. Gillard[1], Peter H. Sikkema[1]

[1]University of Guelph Ridgetown Campus, Ridgetown, Canada
[2]FMC Corporation, Saskatoon, Canada
Email: soltanin@uoguelph.ca

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Abstract

Ontario dry bean growers are currently limited to ALS inhibitor herbicides for soil-applied broadleaf weed control; therefore another mode of action is needed. Sulfentrazone is a PPO inhibitor herbicide that has activity on some annual grass and broadleaf weed species. Four field trials were conducted over two years (2014, 2015) to determine the tolerance of four commonly grown dry bean market classes (adzuki, kidney, small red Mexican and white bean) to PRE applications of sulfentrazone at 140, 210, 280 and 420 g·ai·ha^{-1}. Crop injury, plant height, plant density, shoot biomass, seed moisture content and yield were examined. Sulfentrazone (420 g·ai·ha^{-1}) caused up to 74%, 22%, 30%, and 57% injury in adzuki, kidney, small red Mexican and white bean, respectively. Plant density, height and yield were not reduced for kidney or small red Mexican bean. Sulfentrazone (420 g·ai·ha^{-1}) reduced white bean plant density, height and yield by 28%, 29% and 29%, respectively; and reduced adzuki bean plant density, height and yield by 51%, 34% and 57%, respectively. Overall, kidney and small red Mexican bean were the most tolerant to sulfentrazone, followed by white bean, and then adzuki. This study determined sulfentrazone applied PRE is safe for Ontario kidney bean and small red Mexican bean crops.

Keywords

Adzuki Bean, Kidney Bean, Small Red Mexican Bean, White Bean, Injury, Density, Height, Seed Moisture Content, Yield

1. Introduction

Dry beans (*Phaseolus vulgaris* L.) are an important crop for southwestern Ontario. In 2014, over 50,000 ha of white and coloured dry beans were seeded in Ontario, producing 125,000 T with an approximate value of $111,000,000 [1]. Popular market classes of dry beans grown in Ontario include black, cranberry, kidney, white (navy), otebo, small red Mexican, and adzuki (*Vigna angularis* (Willd) Ohwi & Ohashi). Weeds can significantly reduce dry bean yield as weeds can outcompete the beans for essential resources [2] [3] [4]. Studies have found 70% yield loss can occur in dry beans from competition with weeds [5].

Only two soil-applied broadleaf herbicides are registered for Ontario dry beans-imazethapyr and halosulfuron. Both are group 2, ALS inhibitor herbicides. As there are more than ten documented weed species with group 2 resistance in Ontario [6], another mode of action is needed for weed management in dry beans. Sulfentrazone is a soil-applied, protoporphyrinogen oxidase IX (PPO) inhibitor herbicide that provides residual control of many broadleaf weeds and some grasses. Sulfentrazone causes an excess of protoporphyrinogen IX in the chloroplast, which then leaks into the cytoplasm and is converted to protoporphyrin IX. As weeds emerge from the soil, the protoporphyrin IX reacts with light to produce O^+, which peroxidizes cell membranes causing cellular leakage. It controls weed species such as *Amaranthus retroflexus* L. (redroot pigweed), *Amaranthus tuberculatus* var. *rudis* (waterhemp), *Chenopodium album* L. (common lambsquarters), *Digitaria* spp. (crabgrass), *Panicum* spp. and *Setaria faberii* L. (giant foxtail) [7] [8] [9]. Sulfentrazone is registered Canada-wide for pre-emergence (PRE) use in chickpea (*Cicer arientinum* L.), soybean (*Glycine max* L.), sunflower (*Helianthus annuus* L.), and field pea (*Pisum sativum* L.). There is little information on the response of dry bean market classes to PRE applications of sulfentrazone in Ontario.

The objective of this research was to determine the tolerance of four market classes of dry bean to PRE applications of sulfentrazone at 140, 210, 280 and 420 g·ai·ha^{-1}, representing 1×, 1.5×, 2× and 3× registered rate in Ontario.

2. Materials and Methods

2.1. Experimental Design

Four field trials were conducted over a two-year period (2014, 2015) at the Huron Research Station near Exeter, Ontario and University of Guelph Ridgetown Campus in Ridgetown, Ontario, Canada. In 2014, the soil in Ridgetown was a loam with 40% sand, 35% silt and 25% clay, organic matter content of 7.1% and pH of 6.6. In 2015, Ridgetown soil was a sandy clay loam with 53% sand, 27% silt, 20% clay, organic matter content of 5.3% and pH of 7.0. Exeter Site A was a silty clay loam with 18%, 46%, and 36% sand, silt and clay, respectively, with an organic matter content of 4.7% and pH of 7.5. Site B was a loam with 35% sand, 43% silt, 22% clay, organic matter content of 3.6% and pH of 7.6. Seedbeds were prepared by moldboard ploughing in the fall and two passes with a cultivator with rolling basket harrows in the spring.

The experiments were arranged in split-plot design with 4 replicates. Main plots were herbicide rate and subplots were four commonly grown dry bean market classes (adzuki, kidney, small red Mexican and white bean). Plots were 6 m wide (2 rows of each market class spaced 0.75 m apart) by 8 m long in Ridgetown and 3 m (1 row of each market class spaced 0.75 m apart) by 10 m long in Exeter. Dry beans were seeded to a depth of 4 to 5 cm in late May to early June. Different discs were used to adjust the seeding population depending on market class and location as per provincial agronomic recommendations. In Ridgetown, adzuki, small red Mexican and white bean were seeded at a rate of 232,900 seeds·ha^{-1} and kidney beans were seeded at 175,500 seeds·ha^{-1}. At the Exeter locations, adzuki bean was seeded at 272,000 seeds·ha^{-1}, white bean was seeded at 254,000 seeds·ha^{-1}, and kidney and small red Mexican beans were seeded at 212,000 seeds·ha^{-1}. Herbicide treatments included an untreated control and four rates of sulfentrazone (140, 210, 280 and 420 g·ai·ha^{-1}). Herbicides were applied using a CO_2 pressurized backpack sprayer and a 1.0 m handheld boom with three ULD 110-02 nozzles (Hypro, New Brighton, MN) spaced 0.5 m apart, calibrated to deliver 200 L·ha^{-1} at 240 kPa. Plots were maintained weed-free by hand-hoeing for the entire growing season to eliminate the confounding factor of weed interference.

Crop injury was visually assessed at 1, 2, 3, 4, 6, and 8 weeks after crop emergence (WAE). At 3 WAE, plant density was determined by counting the number of plants in a metre of row for each market class. A metre of row for each market class was then harvested at ground level, placed in separate paper bags, and dried in a kiln. Once dry, the plants were weighed to determine dry shoot weight. At 6 WAE, 10 plants from each treatment were randomly selected for height measurement, and their heights were averaged for each market class. Seed moisture content and yield—adjusted to 15% moisture for adzuki and 18% moisture for kidney, small red Mexican and white bean—were determined at maturity.

2.2. Statistical Analysis

All analyses were conducted in SAS version 9.4 (SAS Institute Inc., NC). Fixed effects for the analysis included sulfentrazone rate, bean market class, and their interaction; and their significance was determined with the F-test. Random effects included environment (year-location combination), block nested within environment, rate by environment interaction, market class by environment interaction, and rate by market class by environment interaction. Their significance was determined with the Z-test. The assumptions of normality and homogeneity of the residuals were tested with the UNIVARIATE procedure under various transformations of the data. The transformation that produced the highest Shapiro-Wilk statistic for each data set was selected for the analysis. Data were then subjected to analysis of variance using the MIXED procedure and Fisher's Protected LSD test with a significance level of 0.05. Data were transformed back to the original scale for presentation.

3. Results and Discussions

Statistical analyses determined that the market class by environment interaction was significant for most data sets. This is likely due to the beans responding to the different soil types and weather conditions. However, there were no significant environment, rate by environment interaction, or rate by market class by environment interaction effects, and so data were pooled for the analysis. Analyses revealed that sulfentrazone rate was significant for all assessments, and bean market class was significant for injury at 2, 3, 4, 6 and 8 WAE, plant density, height, shoot dry weight, seed moisture content and yield (Table 1). Rate by market class interaction was significant for injury 3, 4, 6 and 8 WAE, plant density, height, and yield (Table 1).

3.1. Crop Injury

Crop injury symptoms in this study included leaf crinkling and cupping, reduced growth, and reduced plant stand. At 1 WAE, sulfentrazone at 140, 210, 280, and 420 $g \cdot ai \cdot ha^{-1}$ caused 2%, 4%, 11%, and 35% injury, respectively (Table 1). None of the herbicide treatments were equivalent to the control. At 2 WAE, the level of injury caused by sulfentrazone at 140, 210, 280, and 420 $g \cdot ai \cdot ha^{-1}$ was similar to 1 WAE with 1%, 5%, 10%, and 29% injury, respectively. Soltani *et al.* [10] reported a similar level of injury of

Table 1. Mean values of main effects and their interaction for crop injury, plant density, shoot dry weight, plant height, seed moisture content and yield of dry bean treated with sulfentrazone PRE at Ridgetown and Exeter, Ontario in 2014 and 2015. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at $P < 0.05$[a].

Main effects[b]	Dry Bean Injury						Plant Density	Shoot Dry Weight	Plant Height	Seed Moisture Content	Yield[c]
	1 WAE	2 WAE	3 WAE	4 WAE	6 WAE	8 WAE					
	%						# m^{-1} row	g $plant^{-1}$	cm	%	$T \cdot ha^{-1}$
Dry Bean Market Class	NS	**	**	**	*	*	*	**	**	*	**
Adzuki	10	13b	24	32	12	11	12	0.6c	33.5	15.3a	1.65
Kidney	5	4a	7	6	2	2	14	2.7a	55.2	17.1ab	2.46
Small Red Mexican	7	4a	7	5	2	1	16	2.3a	59.0	19.4b	3.39
White	12	12b	21	24	6	3	17	1.4b	49.6	18.6ab	3.35
Sulfentrazone Rate ($g \cdot ai \cdot ha^{-1}$)	**	**	**	**	**	**	**	**	**	*	**
0	0a	0a	0	0	0	0	17	1.8ab	52.2	17.0a	3.04
140	2b	1b	3	2	1	1	15	1.8a	52.4	17.2ab	2.86
210	4b	5c	7	9	2	2	15	1.7ab	50.9	17.3ab	2.80
280	11c	10d	17	19	7	5	15	1.6b	47.8	17.9ab	2.50
420	35d	29e	38	40	16	9	12	1.3c	43.0	18.2b	2.22
Interaction											
V × H	NS	NS	**	**	**	*	**	NS	**	NS	**

[a]Abbreviations: WAE, weeks after crop emergence; H, herbicide treatment; NS, not significant at $P = 0.05$; V, dry bean market class. [b]Significance at $P < 0.05$ and $P < 0.01$ denoted as * and **, respectively. Means were only separated when there was no interaction with that main effect. [c]Adjusted to 15% moisture for adzuki and 18% moisture for kidney, small red Mexican and white bean.

11% in dry bean treated with 280 g·ai·ha^{-1} sulfentrazone at 2 WAE, but Hekmat *et al.* [11] found sulfentrazone at 420 g·ai·ha^{-1} only caused an average of 12% injury across eight market classes of dry bean. Between 3 and 8 WAE, the level of injury was dependent on the bean market class and rate of sulfentrazone, and injury was highest at 4 WAE. Adzuki was the most sensitive, with sulfentrazone (140, 210, 280 and 420 g·ai·ha^{-1}) causing up to 2%, 25%, 41%, and 74% injury, respectively (**Table 2**). White bean experienced up to 4%, 13%, 33%, and 57% injury at 140, 210, 280 and 420 g·ai·ha^{-1}, respectively. Kidney and small red Mexican were the most tolerant, with sulfentrazone causing ≤10% injury at rates below 280 g·ai·ha^{-1}, while 420 g·ai·ha^{-1} caused up to 22%

Table 2. Mean visible injury (%) of four market classes of dry bean treated with sulfentrazone PRE at Ridgetown and Exeter, Ontario in 2014 and 2015. Means followed by the same letter in a row (X-Z) or column (a-d) for each rating are not significantly different according to Fisher's Protected LSD at $P < 0.05$[a].

Sulfentrazone rate (g·ai·ha^{-1})	Adzuki Bean			Kidney Bean			Small Red Mexican Bean			White Bean		
Injury 3 WAE						%						
0	0	a		0	a		0	a		0	a	
140	2	b	Z	2	b	Z	2	b	Z	4	b	Z
210	16	c	Z	3	b	Z	2	b	Z	12	bc	Z
280	35	cd	Y	6	bc	Z	7	bc	Z	29	cd	YZ
420	64	d	Y	22	c	Z	21	c	Z	54	d	YZ
Injury 4 WAE						%						
0	0	a		0	a		0	a		0	a	
140	2	b	Z	1	ab	Z	1	ab	Z	4	b	Z
210	25	c	Z	2	b	Z	2	bc	Z	13	bc	Z
280	41	c	X	5	bc	Z	6	bc	YZ	33	cd	XY
420	74	d	Y	19	c	Z	15	c	Z	57	d	Y
Injury 6 WAE						%						
0	0	a		0	a		0	a		0	a	
140	1	ab	Z	1	ab	Z	0	ab	Z	1	ab	Z
210	8	bc	Z	1	ab	Z	1	b	Z	2	bc	Z
280	27	cd	Y	2	b	Z	3	b	Z	10	cd	YZ
420	58	d	X	6	b	YZ	5	b	Z	33	d	XY
Injury 8 WAE						%						
0	0	a		0	a		0	a		0	a	
140	1	ab	Z	1	ab	Z	0	ab	Z	0	ab	Z
210	8	bc	Z	1	ab	Z	1	ab	Z	2	bc	Z
280	17	cd	Y	3	b	YZ	2	b	Z	5	bc	YZ
420	49	d	Y	5	b	Z	2	b	Z	12	c	YZ

[a]Abbreviations: WAE, weeks after crop emergence.

injury. Soltani *et al.* [10] also found kidney bean was more tolerant to sulfentrazone than white bean. In other studies examining PPO inhibitors on dry beans, flumioxazin applied PRE at 140 g·ai·ha^{-1} caused up to 34% injury in black, kidney, cranberry and white bean [12]. Fomesafen caused 5% injury or less in black, cranberry, great northern, kidney, pink, pinto and white bean [13] [14]. Saflufenacil applied PRE at 50 g·ai·ha^{-1} caused up to 31% injury in adzuki, black, kidney and white bean [15] [16].

3.2. Plant Density

Small red Mexican bean and kidney bean densities were not reduced by any of the herbicide treatments compared to the control (**Table 3**). White bean had densities equivalent to the control at up to 280 g·ai·ha^{-1} of sulfentrazone. Sulfentrazone at 420 g·ai·ha^{-1} reduced white bean density by 28%. Sulfentrazone at 140 and 210 g·ai·ha^{-1} did not reduce adzuki bean density relative to the control, but sulfentrazone at 280 and 420 g·ai·ha^{-1} reduced density by 34% and 51%, respectively. Soltani *et al.* [15] found saflufenacil applied PRE reduced plant density by 53% in black bean, 38% in kidney bean and 70% in white bean.

Table 3. Mean plant density, plant height, and yield as a percentage of the untreated control (0 g·ai·ha^{-1}) of four market classes of dry bean treated with sulfentrazone PRE at Ridgetown and Exeter, Ontario in 2014 and 2015. Means followed by the same letter in a row (X-Z) or column (a-d) for each variable are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

Sulfentrazone rate (g·ai·ha^{-1})	Adzuki Bean			Kidney Bean			Small Red Mexican Bean			White Bean		
Plant Density							%					
0	100	a	Z	100	a	Z	100	a	Z	100	a	Z
140	96	a	Z	84	a	Z	92	a	Z	96	ab	Z
210	78	ab	Z	100	a	Z	91	a	Z	92	ab	Z
280	66	b	Y	98	a	YZ	99	a	Z	87	ab	YZ
420	49	b	Y	78	a	YZ	86	a	Z	72	b	YZ
Plant Height							%					
0	100	a	Y	100	a	Z	100	a	Z	100	a	Z
140	103	a	Y	102	a	Z	102	a	Z	95	ab	Z
210	98	a	Y	99	a	Z	101	a	Z	92	ab	Z
280	86	ab	Y	97	a	Z	99	a	Z	83	bc	Z
420	66	b	X	93	a	YZ	94	a	Z	71	c	Y
Yield							%					
0	100	a	Y	100	a	YZ	100	a	Z	100	a	Z
140	91	ab	Y	99	a	YZ	95	a	Z	92	a	Z
210	89	ab	Y	96	a	YZ	93	a	Z	90	a	Z
280	72	b	Y	89	a	YZ	83	a	Z	83	ab	Z
420	43	c	Y	87	a	Z	87	a	Z	71	b	Z

3.3. Shoot Dry Weight

Shoot dry weight was not affected by sulfentrazone at 140 or 210 g·ai·ha^{-1} (Table 1). Shoot dry weight was reduced by 11% at 280 g·ai·ha^{-1} and 28% at 420 g·ai·ha^{-1}. In contrast, Hekmat *et al.* [11] did not observe a decrease in dry bean shoot dry weight when treated with 420 g·ai·ha^{-1} of sulfentrazone. Flumioxazin applied PRE reduced shoot dry weight for black and white bean, but not for cranberry or kidney bean [12]. Saflufenacil reduced black and white bean shoot dry weight by up to 41%, but did not reduce adzuki or kidney bean shoot dry weight [15].

3.4. Plant Height

Shorter plant heights can cause reduced yield at harvest due to harvest losses at the cutter bar of the combine. Kidney bean and small red Mexican bean height were not reduced by any of the sulfentrazone rates evaluated (Table 3). Adzuki bean height was reduced at 420 g·ai·ha^{-1} by 34%, while white bean height was reduced by 17% at 280 g·ai·ha^{-1} and 29% at 420 g·ai·ha^{-1}. These results both agree and conflict with a study by Hekmat *et al.* [11]. In Hekmat *et al.* [11], sulfentrazone at 420 g·ai·ha^{-1} also did not reduce kidney bean height, but white bean ("OAC Thunder") height was equivalent to the control, which may indicate some differential cultivar sensitivity to sulfentrazone. In other studies, saflufenacil did not reduce adzuki or kidney bean height [15]. Flumioxazin did not reduce cranberry or kidney bean height relative to the control, but black bean height was reduced by 24% and white bean height was reduced by 29% [12].

3.5. Seed Moisture Content and Yield

Herbicide injury can cause delayed maturity of the crop which can cause seed damage from delayed harvest and storage problems. Delayed maturity is indicated by elevated seed moisture content. In this study, sulfentrazone at 140, 210 and 280 g·ai·ha^{-1} did not increase seed moisture content compared to the untreated control, but seed moisture was 1.2% higher for the beans treated with 420 g·ai·ha^{-1} (Table 1). Kidney bean and small red Mexican bean yields were not significantly reduced by any of the rates evaluated (Table 3). Adzuki bean yield was not affected by sulfentrazone at 140 and 210 g·ai·ha^{-1}, yielding 91% and 89% of the control, respectively. In contrast, sulfentrazone at 280 g·ai·ha^{-1} reduced adzuki yield by 28% and 420 g·ai·ha^{-1} reduced yield by 57%. Soltani *et al.* [1] found saflufenacil reduced adzuki bean yield by 56%. White bean yield was not reduced compared to the control by rates up to 280 g·ai·ha^{-1}, but was reduced by 29% at 420 g·ai·ha^{-1}. In contrast, Hekmat *et al.* [11] found white bean yield was equivalent to the untreated control but was numerically reduced by 17% by sulfentrazone (420 g·ai·ha^{-1}). This difference could be attributed to a different cultivar used in that study. Soltani *et al.* (2014a) did not find a decrease in yield in black, cranberry, kidney or white bean treated with sulfentrazone at rates up to 280 g·ai·ha^{-1}.

4. Conclusion

In this study, kidney bean and small red Mexican bean demonstrated the highest tolerance to PRE applications of sulfentrazone; plant density, height, and yield were not affected at any of the rates evaluated, and there was an acceptable margin of crop safety for rates up to 280 g·ai·ha^{-1}. White bean had the next best tolerance, with plant density and yield only affected at 420 g·ai·ha^{-1}, and a narrow margin of crop safety at rates up to 210 g·ai·ha^{-1}. Adzuki bean had the poorest tolerance of the market classes evaluated, with plant density and yield reduced by 280 and 420 g·ai·ha^{-1}, and unacceptable injury at 210 g·ai·ha^{-1} and above. Based on these results, PRE applications of sulfentrazone are safe for kidney and small red Mexican bean production in Ontario.

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