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Response of Four Market Classes of Dry Beans to Halosulfuron Applied Postemergence at Five Application Timings

Nader Soltani*, Christy Shropshire, Peter H. Sikkema

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

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Abstract

Six field trials were conducted over a three-year period (2011, 2012, 2013) at the Huron Research Station, Exeter, Ontario and University of Guelph Ridgetown Campus, Ridgetown, Ontario to determine the effect of five postemergence (POST) application timings (1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod stage) of halosulfuron (35 and 70 g·ai·ha^{-1}) on the tolerance of adzuki, black, white and kidney beans. All treatments including the non-treated control were maintained weed free during the growing season. Halosulfuron applied POST in black, white and kidney bean caused as much as 8%, 8%, 7%, 4% and 2% injury 1 WAA and 4%, 4%, 2%, 2% and 1% injury 2 WAA at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod stage application timings, respectively. The injury observed was transient with 1% or less injury 4 WAA and there was no adverse effect on the shoot dry weight, plant height, seed moisture content and yield of black, white and kidney bean. Injury was substantially higher in adzuki bean at all application timings. Halosulfuron applied POST caused as much as 66%, 47%, 50%, 39% and 36% injury 1 WAA; 77%, 68%, 64%, 51% and 42% 2 WAA; and 69%, 51%, 47%, 40% and 29% 4 WAA at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod stage application timings, respectively. Halosulfuron POST decreased shoot dry weight as much as 69%, 57%, 43%, 41% and 34%; plant height as much as 17%, 15%, 14%, 13% and 10%; and seed yield as much as 47%, 46%, 45%, 56% and 55% at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod stages, respectively. Based on these results, there is an adequate margin of crop safety for halosulfuron POST in black, white and kidney beans. However, there is not an adequate margin of crop safety for halosulfuron POST in adzuki bean at the application timings evaluated.

Keywords

Adzuki Bean, Black Bean, Kidney Bean, White Bean, *Phaseolus vulgaris* L.

*Corresponding author.

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1. Introduction

Edible dry beans (*Phaseolus vulgaris* L.) are a short season crop with short physical stature and therefore are very sensitive to weed interference [1]-[3]. Beans are more susceptible to yield losses due to weed interference than the other major field crops grown in Ontario. Bean seed yield has been reduced an average of 59% in research studies conducted in Ontario. This is greater than the other major field crops: corn (52), soybean (38%), spring cereals (12%) and winter wheat (3%). In addition, presence of weeds in beans at harvest can also cause seed staining and interfere with harvesting efficiency [4]-[6]. There are numerous broadleaf herbicides registered for use in soybean, but most of them cannot be used in edible beans because of crop injury. Consequently there is only one registered soil applied broadleaf herbicide-imazethapyr, and two postemergence (POST) broadleaf herbicides-bentazon and fomesafen. In contrast, Identity Preserved soybean producers have at least 12 broadleaf herbicides to choose from-acifluorfen, bentazon, chlorimuron, clomazone, cloransulam, flumetsulam, flumioxazin, fomesafen, imazethapyr, linuron, metribuzin and thifensulfuron [7]. Even with the wide array of herbicides registered for use in IP soybeans broadleaf weed control is still a challenge! This highlights the difficulty facing Ontario edible bean producers. Clearly, there is a lack of weed management tools for broadleaf weed control in edible beans. More research is needed to find new herbicide options that have an adequate margin of crop safety, provide consistent broad spectrum weed control, have low environmental impact and maximize bean yield and net returns.

Halosulfuron is a newly registered sulfonylurea herbicide in Ontario that inhibits the acetolactate synthase enzyme and blocks biosynthesis of key amino acids valine, leucine and isoleucine which are required for cell growth [8]. It is absorbed by roots, emerging shoots and foliage and is translocated in both xylem and phloem. Halosulfuron controls troublesome weeds including yellow nutsedge (*Cyperus esculentus* L.), velvetleaf (*Abutilon theophrasti* Medic.), redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), ladysthumb (*Polygonum persicaria* L.), cocklebur (*Xanthium strumarium* L.) and wild mustard (*Sinapis arvensis* L.), including triazine resistant biotypes [7] [8]. Halosulfuron is active at low doses, has low mammalian toxicity, is relatively soil immobile and degrades rapidly, therefore has low potential to contaminate groundwater and the environment [8].

Halosulfuron will be available for the first time in Ontario in 2014. Halosulfuron will provide Ontario dry bean growers with a new, low-use-rate herbicide that provides full-season control of annual broadleaf weeds and specific troublesome weeds such as yellow nutsedge. There is little information available on the sensitivity of *Phaseolus vulgaris* (common bean) and *Vigna angularis* (adzuki bean) species to halosulfuron applied postemergence. Earlier studies have shown that halosulfuron applied POST at 2 - 3 trifoliate can cause as much as 86% injury in adzuki bean and as much as 13% injury in common bean [9]-[11]. There is little information with halosulfuron applied POST beyond the 3 trifoliate leaf stage in adzuki and common beans. Delaying application timing may reduce injury and provide an adequate crop safety for use of halosulfuron in dry bean.

The objective of this study was to evaluate the effect of halosulfuron applied postemergence at 35 and 70 $g \cdot ai \cdot ha^{-1}$ at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod application timings in adzuki, black, white and kidney beans.

2. Materials and Methods

Six field trials were conducted over a three-year period (2011, 2012, and 2013) at the Huron Research Station, Exeter, Ontario (43˚19'1.21"N, 81˚30'3.87"E) and University of Guelph Ridgetown Campus, Ridgetown, Ontario (42˚26'26"N, 81˚53'3"W). The soil at Exeter was a Brookston clay loam (Orthic Humic Gleysol, mixed, mesic, and poorly drained) with 32% sand, 42% silt, 26% clay, 3.7% organic matter and pH 7.8 in 2011; 41% sand, 35% silt, 24% clay, 3.2% organic matter and pH 7.9 in 2012; and 29% sand, 44% silt, 27% clay, 3.6% organic matter and pH 7.7 in 2013. The soil at the Ridgetown location was a Watford/Brady sandy loam composed of 48% sand, 28% silt, 24% clay, and 6.7% organic matter with a pH of 6.6 in 2011; 49% sand, 31% silt, 20% clay, 6.0% organic matter and pH 6.5 in 2012; and 52% sand, 28% silt, 20% clay, 5.9% organic matter and pH 6.4 in 2013. Seedbed preparation at all sites consisted of fall moldboard plowing followed by three passes with a field cultivator with rolling basket harrows in the spring.

The experiments were established as a two-way factorial in a completely randomized block design with four replications. Factor one was market class of dry bean (black, "Black Velvet"; white, "T9905"; adzuki, "Erimo"; and kidney, "Red Hawk") and Factor 2 was herbicide treatment (Halosulfuron applied POST at 35 $g \cdot ai \cdot ha^{-1}$ or sprayed twice to simulate a spray overlap at each application timing: 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower, 1st pod stage plus a non-treated control). Halosulfuron treatments included a non-ionic surfactant at 0.25% v/v. Plots were 6 m wide (8 rows spaced 0.75 m apart) and 10 m long at Exeter and 8 m long at Ridgetown. Within each plot there were two rows of black, "Black Velvet"; white, "T9905"; adzuki, "Erimo"; and kidney, "Red Hawk" beans. Beans were planted 3 cm deep at the rate of 175,000 seed·ha^{-1} for kidney bean and 230,000 seed·ha^{-1} for black, white and adzuki bean in late May to early June of each year.

Herbicide applications at each timing (1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower, 1st pod) were made with a CO_2-pressurized backpack sprayer calibrated to deliver 200 L·ha^{-1} of spray solution at a pressure of 200/241 kPa using low drift nozzles (ULD120-02, Spraying Systems Co., P.O. Box 7900. Wheaton, IL 60188). The boom was 2.5 m wide with six nozzles spaced 0.5 m apart. Plots were maintained weed free by cultivation and hand hoeing as required to eliminate the confounding effect of weed interference.

Crop injury was evaluated visually 1, 2 and 4 weeks after each treatment application (WAA) using a scale of 0% to 100% where a rating of 0 was defined as no visible plant injury and a rating of 100 was defined as plant death. At 2 WAA, a 1 m section of row for each cultivar was hand harvested at the ground level, oven dried at 60˚C to constant moisture and the dry weight was recorded. Ten plants per plot were randomly selected and the height from the soil surface to the highest growing point was measured 5 WAA. Yield and seed moisture content were measured at crop maturity by harvesting the remaining 9 m from each plot at Exeter and 7 m from each plot at Ridgetown with a plot combine. Crops were considered physically mature when 90% of pods in the untreated plots of each cultivar had turned from green to a golden colour. All yields were adjusted to 18% moisture.

Data were analyzed as a 2-way factorial using PROC MIXED in SAS 9.2. Fixed effects included the two treatment factors, dry bean market class and halosulfuron treatment, as well as their interaction; random effects included year-location combinations (environment), interactions between environment and the fixed effects, and replicate nested within environment. Significance of fixed effects was tested using F-tests and random effects were tested using a Z-test of the variance estimate. The UNIVARIATE procedure was used to test data for normality and homogeneity of variance. To satisfy the assumptions of the variance analyses, injury 1, 2 and 4 WAA was arcsine square root transformed, percent dry weight were square root transformed and seed moisture content at harvest was log-transformed. For all injury ratings, the untreated check (assigned a value of zero) was excluded from the analysis. However, all values were compared independently to zero to evaluate treatment differences with the untreated check. Plant stand, shoot dry weight, height and yield were converted to a percent of the untreated check for analysis. Treatment comparisons were made using Fisher's Protected LSD at a level of $P < 0.05$ and any data compared on the transformed scale were converted back to the original scale for presentation of results. When the interactions between location, year and fixed effects were not significant and the data were pooled by location and year.

3. Results and Discussion

Analysis of variance indicated that for main effects, herbicide treatment was significant for injury 1, 2 and 4 WAA, shoot dry weight, seed moisture content and yield (**Table 1**). Market class was significant for injury 1, 2 and 4 WAA, shoot dry weight, height, and yield (**Table 1**). For interactions, cultivar by treatment was significant for injury 1, 2 and 4 WAA, shoot dry weight, height, seed moisture content and yield (**Table 1**). Injury symptoms with halosulfuron included chlorosis, necrosis, stunting and death of the growing point of dry bean (**Table 1**).

3.1. Crop Injury

Halosulfuron applied POST in black, white and kidney bean caused as much as 8%, 8%, 7%, 4% and 2% injury 1 WAA and 4%, 4%, 2%, 2% and 1% injury 2 WAA at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod stage application timings, respectively (**Table 2**). However by 4 WAA, there was no injury in black and white and up to 1% injury in kidney bean with halosulfuron applied POST at all application timings (**Table 2**).

Injury was significantly higher in adzuki bean compared to black, white and kidney bean at all application timings. At 1 WAA, halosulfuron applied POST caused as much as 66%, 47%, 50%, 39% and 36% injury at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod application timings in adzuki bean, respectively (**Table 2**). Injury was persistent and did not decrease over time. Adzuki bean injury was as much as 77%, 68%,

Table 1. Main effects and interaction for percent visible injury, plant stand, height, shoot dry weight, seed moisture content and yield of dry bean treated with halosulfuron at five different timings. Plant stand, height, shoot dry weight and yield are a percent of the untreated check. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P < 0.05. Means for a main effect were separated only if there was no significant interaction involving that main effect[a].

Main effects[b]			Dry bean injury							
			1 WAA	2 WAA	4 WAA	Plant stand	Dry weight	Height	Moisture	Yield
						%				
Dry bean market class			**	**	**	NS	**	**	NS	**
Black			2	1	0	99	100	102	18.1	97
White			2	1	0	102	105	100	19.1	110
Adzuki			45	57	40	100	60	89	18.1	61
Kidney			4	2	0	108	109	104	19.4	109
Herbicide treatment[c]	Rate (g·ai·ha^{-1})	Timing	**	**	**	NS	**	NS	**	*
Untreated check			0	0	0	100	100	100	17.5	100
Halosulfuron	35	1 - 2 tri	12	11	6	97	87	98	18.1	96
Halosulfuron	70	1 - 2 tri	18	16	9	97	81	97	18.9	93
Halosulfuron	35	3 - 4 tri	9	10	4	106	94	99	18.0	98
Halosulfuron	70	3 - 4 tri	13	13	6	107	86	97	18.3	94
Halosulfuron	35	5 - 6 tri	9	8	3	103	93	100	18.2	96
Halosulfuron	70	5 - 6 tri	11	9	5	103	92	98	18.6	93
Halosulfuron	35	1st flower	5	5	3	104	100	100	18.9	94
Halosulfuron	70	1st flower	7	7	4	106	94	100	19.5	91
Halosulfuron	35	1st pod	4	4	2	101	97	100	19.6	91
Halosulfuron	70	1st pod	6	5	3	102	94	99	19.8	88
Interaction										
V × H			**	**	**	NS	**	**	**	**

[a]Abbreviations: WAA, weeks after treatment application; H, herbicide treatment; NS, not significant at P = 0.05 level; tri, trifoliate; V, dry bean market class. [b]Significance at P < 0.05 and P < 0.01 levels denoted by * and **, respectively. [c]Non-ionic surfactant included at 0.25% and 0.5% v/v with the 35 and 70 g·ai·ha^{-1} of halosulfuron, respectively.

64%, 51% and 42% 2 WAA and 69%, 51%, 47%, 40% and 29% 4 WAA at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod application timings, respectively (**Table 2**).

In other studies, halosulfuron applied POST at 2 - 3 trifoliate caused as much as 73%, 7%, 13%, 12%, 12%, 11%, 11% and 9% injury in adzuki, black, cranberry, kidney, otebo, pinto, small red Mexican and white beans, respectively [9] [10]. Stewart *et al.* [10] found as much as 67% and 86% injury when halosulfuron was applied POST at 35 g·ai·ha^{-1} and 70 g·ai·ha^{-1} in adzuki bean, respectively. Wall [12] also reported as much as 50% injury in white bean with halosulfuron applied POST. Silvey *et al.* [13] reported 5% injury from halosulfuron POST in snap bean. Other sulfonylurea herbicides such as thifensulfuron have been shown to cause up to 67% injury in some market classes of beans [10].

3.2. Shoot Dry Weight

Halosulfuron applied POST at 35 and 70 g·ai·ha^{-1} had no adverse effect on the shoot dry weight of black, white and kidney bean at all application timings (**Table 3**). However, it decreased adzuki bean shoot dry weight as much as 69%, 57%, 43%, 41% and 34% at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod

Table 2. Percent visible injury 1, 2 and 4 WAA for four dry bean market classes treated with halosulfuron at five different timings. Means followed by the same letter within a column (a-g) or row (Y-Z) are not significantly different according to Fisher's Protected LSD at P < 0.05[a].

Herbicide treatment[b]	Rate ($g·ai·ha^{-1}$)	Timing	Black			White			Adzuki			Kidney		
Injury 1 *WAA*								%						
Untreated check			0	a		0	a		0	a		0	a	
Halosulfuron	35	1 - 2 tri	3	cd	Z	4	cde	Z	60	fg	Y	3	bc	Z
Halosulfuron	70	1 - 2 tri	6	d	Z	8	e	Z	66	g	Y	6	cd	Z
Halosulfuron	35	3 - 4 tri	2	bc	Z	3	bcd	Z	40	bcd	Y	4	bcd	Z
Halosulfuron	70	3 - 4 tri	4	cd	Z	6	de	Z	47	de	Y	8	d	Z
Halosulfuron	35	5 - 6 tri	1	abc	Z	2	bc	Z	46	cde	Y	5	cd	Z
Halosulfuron	70	5 - 6 tri	2	bc	Z	3	bcd	Z	50	ef	Y	7	cd	Z
Halosulfuron	35	1st flower	0	ab	Z	0	a	Z	34	b	Y	3	bc	Z
Halosulfuron	70	1st flower	1	abc	Z	2	bc	Z	39	bcd	Y	4	bcd	Z
Halosulfuron	35	1st pod	0	ab	Z	0	a	Z	31	b	Y	1	b	Z
Halosulfuron	70	1st pod	0	ab	Z	1	ab	Z	36	bc	Y	2	bc	Z
Injury 2 *WAA*								%						
Untreated check			0	a		0	a		0	a		0	a	
Halosulfuron	35	1 - 2 tri	1	ab	Z	2	bc	Z	71	fg	Y	1	b	Z
Halosulfuron	70	1 - 2 tri	3	b	Z	4	c	Z	77	g	Y	3	bc	Z
Halosulfuron	35	3 - 4 tri	1	ab	Z	1	ab	Z	59	de	Y	3	bc	Z
Halosulfuron	70	3 - 4 tri	2	b	Z	3	bc	Z	68	f	Y	4	c	Z
Halosulfuron	35	5 - 6 tri	0	a	Z	1	ab	Z	56	de	Y	2	bc	Z
Halosulfuron	70	5 - 6 tri	1	ab	Z	1	ab	Z	64	ef	Y	2	bc	Z
Halosulfuron	35	1st flower	0	a	Z	0	a	Z	42	bc	Y	1	b	Z
Halosulfuron	70	1st flower	0	a	Z	1	ab	Z	51	cd	Y	2	bc	Z
Halosulfuron	35	1st pod	0	a	Z	0	a	Z	34	b	Y	1	b	Z
Halosulfuron	70	1st pod	0	a	Z	1	ab	Z	42	bc	Y	1	b	Z
Injury 4 *WAA*								%						
Untreated check			0	a		0	a		0	a		0	a	
Halosulfuron	35	1 - 2 tri	0	a	Z	0	a	Z	47	ef	Y	1	b	Z
Halosulfuron	70	1 - 2 tri	0	a	Z	0	a	Z	69	g	Y	1	b	Z
Halosulfuron	35	3 - 4 tri	0	a	Z	0	a	Z	35	cd	Y	0	a	Z
Halosulfuron	70	3 - 4 tri	0	a	Z	0	a	Z	51	f	Y	1	b	Z
Halosulfuron	35	5 - 6 tri	0	a	Z	0	a	Z	36	cd	Y	0	a	Z
Halosulfuron	70	5 - 6 tri	0	a	Z	0	a	Z	47	ef	Y	0	a	Z
Halosulfuron	35	1st flower	0	a	Z	0	a	Z	29	bc	Y	0	a	Z
Halosulfuron	70	1st flower	0	a	Z	0	a	Z	40	de	Y	0	a	Z
Halosulfuron	35	1st pod	0	a	Z	0	a	Z	23	b	Y	0	a	Z
Halosulfuron	70	1st pod	0	a	Z	0	a	Z	29	bc	Y	0	a	Z

[a]Abbreviations: WAA, weeks after treatment application; tri, trifoliate. [b]Non-ionic surfactant included at 0.25% and 0.5% v/v with the 35 and 70 $g·g·ai·ha^{-1}$ of halosulfuron, respectively.

Table 3. Shoot dry weight (2 WAA) and height (5 WAA), both as a percent of the untreated check, for four dry bean market classes treated with halosulfuron at five different timings. Means followed by the same letter within a column (a-g) or row (X-Z) are not significantly different according to Fisher's Protected LSD at $P < 0.05$[a].

Herbicide treatment[b]	Rate ($g \cdot ai \cdot ha^{-1}$)	Timing	Black			White			Adzuki			Kidney		
Shoot dry weight									%					
Untreated check			100	a		100	a		100	a		100	b	
Halosulfuron	35	1 - 2 tri	101	a	Z	101	a	Z	50	ef	Z	104	b	Z
Halosulfuron	70	1 - 2 tri	96	a	Z	105	a	Z	31	g	Z	106	ab	Z
Halosulfuron	35	3 - 4 tri	100	a	Z	111	a	Z	61	cde	Z	111	ab	Z
Halosulfuron	70	3 - 4 tri	98	a	Z	105	a	Z	43	f	Z	108	ab	Z
Halosulfuron	35	5 - 6 tri	103	a	Z	102	a	Z	64	bcd	Z	108	ab	Z
Halosulfuron	70	5 - 6 tri	99	a	Z	105	a	Z	57	de	Z	114	ab	Z
Halosulfuron	35	1st flower	107	a	Z	110	a	Z	70	bc	Z	116	ab	Z
Halosulfuron	70	1st flower	98	a	Y	102	a	Y	59	cde	X	121	a	Z
Halosulfuron	35	1st pod	96	a	Z	108	a	Z	77	b	Z	108	ab	Z
Halosulfuron	70	1st pod	105	a	Z	104	a	Z	66	bcd	Z	106	ab	Z
Height									%					
Untreated check			100	a	Z	100	a	Z	100	a	Z	100	c	Z
Halosulfuron	35	1 - 2 tri	101	a	Z	99	a	Z	88	cde	Z	102	abc	Z
Halosulfuron	70	1 - 2 tri	101	a	Z	100	a	Z	83	e	Z	104	abc	Z
Halosulfuron	35	3 - 4 tri	100	a	Z	99	a	Z	90	bcd	Z	105	ab	Z
Halosulfuron	70	3 - 4 tri	103	a	Z	101	a	Z	85	e	Z	101	bc	Z
Halosulfuron	35	5 - 6 tri	103	a	Z	101	a	Z	91	bc	Z	104	abc	Z
Halosulfuron	70	5 - 6 tri	102	a	Z	100	a	Z	86	de	Z	105	ab	Z
Halosulfuron	35	1st flower	103	a	Z	102	a	Z	91	bc	Z	105	ab	Z
Halosulfuron	70	1st flower	103	a	Z	101	a	Z	87	cde	Z	107	a	Z
Halosulfuron	35	1st pod	103	a	Z	100	a	YZ	92	b	Y	103	abc	Z
Halosulfuron	70	1st pod	101	a	Z	99	a	Z	90	bcd	Z	105	ab	Z

[a]Abbreviations: WAA, weeks after treatment application; tri, trifoliate. [b]Non-ionic surfactant included at 0.25% and 0.5% v/v with the 35 and 70 $g \cdot ai \cdot ha^{-1}$ of halosulfuron, respectively.

application timings, respectively (**Table 3**). In other studies, halosulfuron applied POST at 2 - 3 trifoliate reduced shoot dry weight of otebo bean 12%, small red Mexican bean 12% and adzuki bean 68% but had no effects on shoot dry weight of black, cranberry, kidney, pinto and white beans at 35 and 70 $g \cdot ai \cdot ha^{-1}$ [9]. In another study, significant shoot dry weight reduction was seen with halosulfuron and thifensulfuron applied POST in adzuki bean [10]. Other sulfonylurea herbicides such as thifensulfuron and chorimuron applied POST have been shown to reduce shoot dry weight 27% - 64% in dry bean [14].

3.3. Plant Height

Height of beans is critical as beans are commonly direct harvested by combines and shorter plants tend to have greater shatter loss at the cutter bar of the combine resulting in reduced harvested seed yield.

Halosulfuron applied POST at 35 and 70 $g \cdot ai \cdot ha^{-1}$ had no adverse effect on the height of black, white and kidney bean at all application timings (**Table 3**). However, it decreased adzuki bean height as much as 17%, 15%, 14%, 13% and 10% at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod application timings, respectively (**Table 3**). In other studies, halosulfuron applied POST at 2 - 3 trifoliate reduced adzuki bean height as much as 60% and 70% at 35 and 70 g·ai·ha^{-1}, respectively but had no effect on the height of black, cranberry, kidney, otebo, pinto, small red Mexican and white beans [9]. This is in contrast to previous studies that have shown significant plant height reduction from sulfonylurea herbicides in dry bean. Thifensulfuron and halosulfuron caused significant reduction in height of adzuki bean [10]. Thifensulfuron applied POST decreased plant height 15% to 57% in dry bean [14]. Chlorimuron applied POST also decreased plant height as much as 36% in white bean [14].

3.4. Seed Moisture Content

Quality of dry bean seeds can be affected by seed moisture content at harvest time as seeds coats can split when seed moisture is less than 18% and seeds can have increased respiration and be prone to spoilage at greater than 18% seed moisture content.

Halosulfuron applied POST at 35 and 70 g·ai·ha^{-1} had no effect on the seed moisture content of black, white and kidney bean at all application timings (**Table 4**). However, it increased adzuki bean seed moisture content as

Table 4. Seed moisture content at harvest, and yield as a percent of the untreated check for four dry bean market classes treated with halosulfuron at five different timings. Means followed by the same letter within a column (a-g) or row (X-Z) are not significantly different according to Fisher's Protected LSD at $P < 0.05$[a].

Herbicide treatment[b]	Rate (g ai ha^{-1})	Timing	Black			White			Adzuki			Kidney		
Moisture								%						
Untreated check			18.2	a	Y	19.2	a	Y	14.0	a	Z	19.1	a	Y
Halosulfuron	35	1 - 2 tri	18.1	a	YZ	19.0	a	Y	16.3	b	Z	19.3	a	Y
Halosulfuron	70	1 - 2 tri	18.2	a	Z	19.5	a	Z	18.4	de	Z	19.5	a	Z
Halosulfuron	35	3 - 4 tri	17.7	a	YZ	19.0	a	Y	16.2	b	Z	19.1	a	Y
Halosulfuron	70	3 - 4 tri	18.1	a	Z	19.2	a	Z	17.0	bcd	Z	19.2	a	Z
Halosulfuron	35	5 - 6 tri	17.7	a	Z	18.9	a	Z	16.6	bc	Z	19.7	a	Z
Halosulfuron	70	5 - 6 tri	18.3	a	Z	18.9	a	Z	18.1	cde	Z	19.2	a	Z
Halosulfuron	35	1st flower	18.0	a	Z	19.0	a	Z	19.5	ef	Z	19.2	a	Z
Halosulfuron	70	1st flower	18.2	a	Z	19.3	a	YZ	21.3	fg	Y	19.4	a	YZ
Halosulfuron	35	1st pod	18.5	a	Z	19.3	a	Z	20.7	f	Z	20.0	a	Z
Halosulfuron	70	1st pod	18.2	a	Z	19.2	a	Z	22.7	g	Y	19.5	a	Z
Yield								%						
Untreated check			100	a		100	b		100	a		100	b	
Halosulfuron	35	1 - 2 tri	98	a	Y	112	a	Z	66	bc	X	109	ab	YZ
Halosulfuron	70	1 - 2 tri	96	a	Y	112	a	Z	53	de	X	112	a	Z
Halosulfuron	35	3 - 4 tri	99	a	Z	114	a	Z	69	b	Y	108	ab	Z
Halosulfuron	70	3 - 4 tri	98	a	Z	113	a	Z	54	de	Y	112	a	Z
Halosulfuron	35	5 - 6 tri	97	a	Y	115	a	Z	63	bcd	X	110	ab	YZ
Halosulfuron	70	5 - 6 tri	95	a	Y	111	a	Z	55	de	X	113	a	Z
Halosulfuron	35	1st flower	100	a	Z	110	ab	Z	59	bcd	Y	106	ab	Z
Halosulfuron	70	1st flower	99	a	Y	105	ab	YZ	44	e	X	116	a	Z
Halosulfuron	35	1st pod	95	a	Z	106	ab	Z	57	cd	Y	107	ab	Z
Halosulfuron	70	1st pod	94	a	Z	108	ab	Z	45	e	Y	106	ab	Z

[a]Abbreviations: tri, trifoliate. [b]Non-ionic surfactant included at 0.25% and 0.5% v/v with the 35 and 70 g·ai·ha^{-1} of halosulfuron, respectively.

much as 4.4%, 3.0%, 4.1%, 7.3% and 8.7% at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod application timings, respectively (**Table 4**). In other studies halosulfuron applied POST at 2 - 3 trifoliate increased seed moisture content by 1.8% - 3% in adzuki, cranberry and kidney bean but had no effect on the seed moisture content of black, otebo, pinto, small red Mexican and white beans [9].

3.5. Seed Yield

Halosulfuron applied POST at 35 and 70 g·ai·ha^{-1} had no adverse effect on seed yield of black, white and kidney bean at all application timings (**Table 3**). However, it decreased adzuki bean seed yield as much as 47%, 46%, 45%, 56% and 55% at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod application timings, respectively (**Table 4**). In other studies halosulfuron applied POST at 2 - 3 trifoliate reduced seed yield of adzuki bean as much as 68% and white bean as much as 9% but had no adverse effect on seed yield of black, cranberry, kidney, otebo, pinto and small red Mexican beans [9]. Sulfonylurea herbicides such as thifensulfuron applied POST caused as much as 89% yield reduction in yield and chlorimuron applied POST decreased seed yield as much as 93% in dry bean [14].

4. Conclusion

Halosulfuron applied POST at the proposed manufacturer's rate of 35 g·ai·ha^{-1} or twice that rate caused significant injury 1WAA in black, kidney and white beans. Generally, the injury decreased as the application timing was delayed from 1 - 2 trifoliate to 1st pod stage. Crop injury was transient with minimal injury 4 WAA and no adverse effect on the shoot dry weight, plant height, seed moisture content and yield of black, white and kidney bean. Injury was significantly higher in adzuki bean compared to black, white and kidney bean at all application timings. Halosulfuron applied POST to adzuki bean at 1 - 2 trifoliate, 3 - 4 trifoliate, 5 - 6 trifoliate, 1st flower and 1st pod application timings caused severe injury, plant height reduction, shoot dry weight reduction, seed moisture content elevation, and seed yield reduction. Based on these results, there is potential for halosulfuron applied POST at 35 g·ai·ha^{-1} after 3 - 4 trifoliate stage in black, white and kidney beans. However, there is not an adequate margin of crop safety for halosulfuron applied POST in adzuki bean at any of the application timings evaluated.

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