American Journal of Plant Sciences, 2014, 5, 3288-3294
Published Online October 2014 in SciRes. http://www.scirp.org/journal/ajps
http://dx.doi.org/10.4236/ajps.2014.521343

Sensitivity of Dry Bean to Dimethenamid-p, Saflufenacil and Dimethenamid-p/Saflufenacil

Nader Soltani*, Christy Shropshire, Peter H. Sikkema

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

Received 4 August 2014; revised 19 September 2014; accepted 21 October 2014

Abstract

There is limited information on the sensitivity of dry bean to dimethenamid-p, saflufenacil and a preformulated mixture of dimethenamid-p/saflufenacil. Field trials were conducted at Exeter and Ridgetown, ON, Canada in 2012 and 2013 to evaluate the tolerance of four market classes of dry bean to dimethenamid-p, saflufenacil and dimethenamid-p/saflufenacil applied preemergence (PRE) at the 1X and 2X manufacturer's recommended rate in soybean. Dimethenamid-p, saflufenacil and dimethenamid-p/saflufenacil applied PRE caused 0% - 2%, 20% - 31% and 34% - 45% injury in dry bean, respectively. Dimethenamid-p (220 and 440 g ai ha^{-1}) caused no adverse effect on plant stand, shoot dry weight, height and yield of black, white, adzuki and kidney bean. Saflufenacil (25 and 50 g ai ha^{-1}) or dimethenamid-p/saflufenacil (245 and 490 g ai ha^{-1}) reduced plant stand 53% - 70%, shoot dry weight 61% - 81%, height 26% - 48% and yield 40% - 61% of black and white bean. However, saflufenacil applied alone or in combination with dimethenamid-p at the 1X or 2X rates caused no adverse effect on plant stand, shoot dry weight, height and yield of adzuki and kidney bean except with dimethenamid-p/saflufenacil at the 2X rate which reduced plant stand 38% in kidney bean, shoot dry weight 46% in adzuki bean and 42% in kidney bean, and yield 29% in kidney bean. Based on these results, saflufenacil and dimethenamid-p/saflufenacil applied PRE at the proposed rate of 25 and 245 g ai ha^{-1}, respectively does have an adequate margin of crop safety for weed management in black and white bean. Further research is needed to ascertain the margin of crop safety in kidney and adzuki bean.

Keywords

Adzuki Bean, Black Bean, Kidney Bean, White Bean, Sensitivity, Tolerance

*Corresponding author.

How to cite this paper: Soltani, N., Shropshire, C. and Sikkema, P.H. (2014) Sensitivity of Dry Bean to Dimethenamid-p, Saflufenacil and Dimethenamid-p/Saflufenacil. *American Journal of Plant Sciences*, **5**, 3288-3294.
http://dx.doi.org/10.4236/ajps.2014.521343

1. Introduction

Dry beans such as adzuki bean (*Vigna angularis* L.), black bean (*Phaseolus vulgaris* L.), kidney bean (*Phaseolus vulgaris* L.) and white bean (*Phaseolus vulgaris* L.) are important cash crops grown in southwestern Ontario. Short physical stature of these crops makes them not very competitive against weeds. Weed interference has been shown to reduce seed yield of dry bean as much as 70% [1]. Common annual weeds in dry bean production in Ontario include redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), velvetleaf (*Abutilon theophrasti* Medicus), ladysthumb (*Polygonum persicaria* L.), eastern black nightshade (*Solanum ptycanthum* Dun.), and annual grasses such as *Setaria*, *Digitaria*, *Echinochloa*, and *Panicum* species [2].

Saflufenacil is a new herbicide developed by BASF for burndown and residual broadleaf weed control in corn, soybean, and other crops applied prior to crop emergence. Saflufenacil is a pyrimidinedione that inhibits the protoporphyrinogen-IX-oxidase (PPO) enzyme which is critical for chlorophyll synthesis. Saflufenacil is absorbed by both roots and foliage of plants. Saflufenacil is mainly translocated in the xylem and has limited mobility in the phloem. Plants susceptible to saflufenacil show injury symptoms within a few hours and die in 1 to 3 days after treatment (Anonymous 2008). Saflufenacil is applied at relatively low doses and has low environmental, toxicological and eco-toxicological impact with minimal residual carryover as the herbicide does not persist in the soil [3]. Saflufenacil effectively controls several broadleaf weeds in Ontario including redroot pigweed, common ragweed, common lambsquarters, velvetleaf, common cocklebur (*Xanthium strumarium* L.), giant ragweed (*Ambrosia trifida* L.) and common waterhemp (*Amaranthus rudis* Sauer) including triazine-, acetolactate synthase- and glyphosate-resistant biotypes [3] [4]. Saflufenacil is not very efficacious on annual grasses such as *Setaria*, *Digitaria*, *Echinochloa*, and *Panicum* species.

Dimethenamid-p is a chloroacetanilide herbicide that controls annual grasses such as green foxtail, yellow foxtail [*Setaria glauca* auct., *non* (L.) P. Beauv.], giant foxtail (*Setaria faberi* R.A.W. Herrm.), barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], witchgrass (*Panicum capillare* L.), fall panicum (*Panicum dichotomiflorum* Michx.), smooth crabgrass [*Digitaria ischaemum* (Schreb.) *ex* Muhl.], and large crabgrass [*Digitaria sanguinalis* (L.) Scop.] and some small-seeded broadleaf weeds such as redroot pigweed and eastern black nightshade including triazine- and acetolactate synthase-resistant biotypes [5]-[7].

Saflufenacil/dimethenamid-p is a new pre-packaged herbicide mixture available for use in soybean at a maximum dose of 245 g ai ha^{-1} (25:220 g ai ha^{-1} of saflufenacil:dimethenamid-p), in Ontario [2]. Saflufenacil used at a rate of 100 or 200 g ai ha^{-1} in Ontario has been shown to cause significant injury in some market classes of dry bean [8]. Dimethenamid-p and other chloroacetamide herbicides have been shown to have an adequate margin of crop safety in various market classes of dry beans [5] [9]-[11].

There is little information on the tolerance of black, white, adzuki and kidney beans to saflufenacil/dimethenamid-p herbicide mixture under Ontario environmental conditions. Saflufenacil at the proposed reduced rate of 25 g ai ha^{-1} in mixture with dimethenamid (220 g ai ha^{-1}) may be an effective option for broad-spectrum control of annual grass and broadleaf weeds in dry beans.

The objective of this research was to evaluate the sensitivity of black, white, adzuki and kidney bean to saflufenacil/dimethenamid-p applied preemergence at the 1X and 2X manufacturer's recommended rates for soybean under Ontario environmental conditions.

2. Materials and Methods

Field trials were conducted at the Huron Research Station at Exeter, ON, Canada and at Ridgetown Campus of the University of Guelph at Ridgetown, ON, Canada in 2012 and 2013. The soil at Exeter was a Brookston clay loam (Orthic Humic Gleysol, mixed, mesic, and poorly drained) with 41% sand, 35% silt, 24% clay, 3.2% organic matter and pH of 7.9 in 2012 and 29% sand, 44% silt, 27% clay, 3.6% organic matter and pH of 7.7 in 2013. The soil at Ridgetown was a Watford (Grey to Brown Brunisolic, mixed, mesic, sandy, and imperfectly drained)-Brady (Gleyed Brunisolic Grey to Brown Luvisol, mixed, mesic, sandy, and imperfectly drained) sandy loam with 56% sand, 27% silt, 17% clay, 5.4% organic matter and pH of 6.7 in 2012 and 52% sand, 28% silt, 20% clay, 5.9% organic matter and pH of 6.4 in 2013. Seedbed preparation at all sites consisted of fall moldboard plowing followed by two passes with a field cultivator with rolling basket harrows in the spring.

The study was established as a split-plot in a randomized complete block design with four replications. Main plots consisted of untreated check, dimethenamid-p (220 g ai ha^{-1}), dimethenamid-p (440 g ai ha^{-1}), saflufenaci

(25 g ai ha^{-1}), saflufenacil (50 g ai ha^{-1}), dimethenamid-p/saflufenacil (220 + 25 g ai ha^{-1}), and dimethenamid-p/saflufenacil (440 + 50 g ai ha^{-1}) and sub-plots were market classes of dry bean which consisted of one row each of black bean ("Black Velvet"), white bean ("T9905"), adzuki bean ("Erimo") and kidney bean ("Red Hawk") spaced 0.75 m apart. Plots were 3 m wide at both locations and 8 m long at Ridgetown and 10 m long at Exeter. Black, white, and adzuki bean were seeded at 250,000 seeds ha^{-1} and kidney bean was seeded at 200,000 seeds ha^{-1} using different seed disks at a depth of 5 cm in late May to early June.

Herbicide treatments were applied PRE to the soil surface one or two days after seeding. Herbicide treatments were applied 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. All plots including the non-treated control were kept weed-free by inter-row cultivation and hand weeding as required.

Estimates of crop injury were evaluated 1, 2, and 4 weeks after emergence (WAE) using a scale of 0% to 100%, where a rating of 0 was no plant injury and a rating of 100 was plant death. At 3 WAE, a 1 m section of row for each plot was hand harvested at the ground level, oven dried and the shoot dry weight was recorded. Plant stand was also counted at 3 WAE. At 6 WAE, ten plants from each plot were randomly selected and the height from the soil surface to the highest growing point was measured with a measuring stick and recorded as plant height. Yield was measured at maturity for each crop by combining the remaining 9 m from each plot at Exeter and 7 m from each plot at Ridgetown. Seed moisture content was adjusted to 18% for black, white and kidney bean and 13% for adzuki bean.

Data were analyzed as a 2-way factorial using PROC MIXED in SAS 9.2. Fixed effects included dry bean market class and herbicide 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 were 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 WAE were arcsine square root transformed, percent plant stand, percent dry weight and percent yield 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, 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.

3. Results and Discussion

Statistical analysis indicated that for main effects of market class was significant for seed moisture content (**Table 1**). Also, herbicide treatment was significant for injury 1, 2 and 4 WAE, plant stand, dry weight, height, seed moisture content and yield (**Table 1**). Market class by treatment interaction was also significant for plant stand, dry weight, height and yield (**Table 1**).

3.1. Crop Injury

Injury symptoms caused by saflufenacil included leaf chlorosis followed by complete necrosis, decreased growth and reduced plant stand. Dimethenamid-p, saflufenacil and dimethenamid-p/saflufenacil applied PRE at the rates evaluated caused 0% - 2%, 7% - 31% and 13% - 45% injury in dry beans, respectively (**Table 1**). In other studies saflufenacil applied PRE at 100 and 200 g ai ha^{-1} caused greater than 90% injury in cranberry bean, lima bean, snap bean, and white bean [8]. Adzuki bean was not as sensitive as cranberry, lima, snap, or white bean to saflufenacil but was injured 51% and 88% at 100 and 200 g ai ha^{-1}, respectively [8]. The levels of injury observed in this study with saflufenacil or dimethanamid-p/saflufenacil was substantially higher than the level of injury observed with other PPO inhibitors such as fomesafen, flumioxazin and sulfentrazone in dry beans [12]-[16]. Sikkema *et al*. [13] found only 1% or less injury in dry bean with fomesafen applied PRE. Sulfentrazone caused up to 30% injury in black, brown, cranberry, kidney, otebo, pinto, white and yellow eye bean [12]. Flumioxazin caused as much as 34% injury in black, cranberry, kidney, and white bean [14].

Table 1. Main effects and interaction for percent visible injury, plant stand, dry weight, height, seed moisture content and seed yield of dry bean treated with dimethenamid-p and saflufenacil alone and in combination at Exeter and Ridgetown Ontario in 2012 and 2013. Plant stand, height, 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 WAE		2 WAE		4 WAE		Plant Stand	Shoot Dry Weight	Plant Height	Seed Moisture Content		Seed Yield
		%								%			
Dry bean market class		NS		NS		NS		NS	NS	NS	**		NS
Black		17		18		16		77	71	91	18.4	b	83
White		15		20		21		71	65	86	21.0	b	83
Adzuki		6		8		7		92	86	99	13.8	a	114
Kidney		5		7		6		89	84	96	19.8	b	96
Herbicide treatment	**Rate ($g\ ai\ ha^{-1}$)**	*		**		**		**	**	**	**		**
Untreated check		0	a	0	a	0	a	100	100	100	17.6	a	100
Dimethenamid-p	220	1	a	0	a	0	a	109	106	102	17.5	a	106
Dimethenamid-p	440	2	ab	1	ab	0	a	98	95	105	17.1	a	109
Saflufenacil	25	7	ab	11	bc	11	b	81	74	97	17.8	ab	104
Saflufenacil	50	20	bc	30	cd	31	bc	60	53	79	18.8	bc	75
Dimethenamid-p/saflufenacil	220 + 25	13	abc	18	cd	14	b	83	77	95	18.1	ab	99
Dimethenamid-p/saflufenacil	440 + 50	34	c	44	d	45	c	51	40	73	19.6	c	66
Interaction													
V × H		NS		NS		NS		**	**	**	NS		**

[a]Abbreviations: WAE, weeks after emergence; H, herbicide treatment; NS, not significant at P = 0.05 level; V, dry bean market class. [b]Significance at P < 0.05 and P < 0.01 levels denoted by * and **, respectively.

3.2. Plant Stand

Dimethenamid-p at the 1X or 2X rate caused no adverse effect on plant stand of black, white, adzuki and kidney bean (**Table 2**). Saflufenacil applied alone or in combination with dimethenamid-p reduced plant stand as much as 53% in black bean, 70% in white bean and 38% in kidney bean but had no adverse effect on plant stand of adzuki bean (**Table 2**).

3.3. Shoot Dry Weight

Dimethenamid-p at 1X or 2X rate caused no adverse effect on shoot dry weight of black, white, adzuki and kidney bean (**Table 2**). Saflufenacil applied alone or in combination with dimethenamid-p reduced shoot dry weight as much as 63% in black bean and 81% in white bean but caused no adverse effect on shoot dry weight of adzuki or kidney bean except with dimethenamid-p/saflufenacil at 2X rate which reduced shoot dry weight 46% in adzuki bean and 42% in kidney bean (**Table 2**).

In other studies saflufenacil applied PRE at 100 and 200 $g\ ai\ ha^{-1}$ reduced shoot dry weight 92% to 99% in adzuki, cranberry, lima, snap and white bean, averaged over application rates [8]. Shoot dry weight was reduced greater in cranberry, snap, white, and lima bean compared to adzuki bean [8]. Results in this study are consistent with other studies that have shown 0% to 40% shoot dry weight reductions with PPO herbicides such as fomesafen, flumioxazin and sulfentrazone [12]-[14].

3.4. Plant Height

Plant height is critical to dry bean producers as shorter plants at harvest can result in greater losses at the cutter

Table 2. Plant stand, shoot dry weight, height and yield (both as a percent of the untreated check), for four dry bean market classes treated with dimethenamid-p and saflufenacil alone and in combination at Exeter and Ridgetown Ontario in 2012 and 2013. Means followed by the same letter within a column (a-c) or row (X-Z) are not significantly different according to Fisher's Protected LSD at P < 0.05.

Herbicide Treatment	Rate (g ai ha^{-1})	Black Bean			White Bean			Adzuki Bean			Kidney Bean		
Plant Stand						%							
Untreated check		100	ab	Z	100	a	Z	100	a	Z	100	a	Z
Dimethenamid-p	220	123	a	Z	108	a	Z	100	a	Z	105	a	Z
Dimethenamid-p	440	121	a	Z	98	a	YZ	94	a	YZ	81	ab	Y
Saflufenacil	25	59	c	Y	72	a	YZ	99	a	Z	99	ab	Z
Saflufenacil	50	47	c	Y	33	b	Y	90	a	Z	77	ab	Z
Dimethenamid-p/saflufenacil	220 + 25	65	bc	Y	77	a	YZ	91	a	YZ	102	a	Z
Dimethenamid-p/saflufenacil	440 + 50	47	c	YZ	30	b	Y	69	a	Z	62	b	Z
Shoot Dry Weight						%							
Untreated check		100	a	Z	100	ab	Z	100	a	Z	100	a	Z
Dimethenamid-p	220	117	a	Z	113	a	Z	98	a	Z	98	a	Z
Dimethenamid-p	440	107	a	Z	104	ab	Z	87	ab	Z	84	ab	Z
Saflufenacil	25	55	b	Y	59	c	Y	100	a	Z	86	ab	YZ
Saflufenacil	50	39	b	Y	26	d	Y	81	ab	Z	74	ab	Z
Dimethenamid-p/saflufenacil	220 + 25	62	b	Z	71	bc	Z	87	ab	Z	90	ab	Z
Dimethenamid-p/saflufenacil	440 + 50	37	b	YZ	19	d	Y	54	b	Z	58	b	Z
Height						%							
Untreated check		100	a	Z	100	ab	Z	100	ab	Z	100	a	Z
Dimethenamid-p	220	100	a	Z	104	ab	Z	103	ab	Z	102	a	Z
Dimethenamid-p	440	107	a	Z	108	a	Z	103	ab	Z	102	a	Z
Saflufenacil	25	93	a	Z	91	ab	Z	105	a	Z	98	a	Z
Saflufenacil	50	74	b	XY	59	c	X	94	ab	Z	90	a	YZ
Dimethenamid-p/saflufenacil	220 + 25	95	a	Z	87	b	Z	102	ab	Z	95	a	Z
Dimethenamid-p/saflufenacil	440 + 50	69	b	XY	52	c	X	86	b	Z	85	a	YZ
Seed Yield						%							
Untreated check		100	a	Z	100	a	Z	100	a	Z	100	abc	Z
Dimethenamid-p	220	99	a	Z	115	a	Z	105	a	Z	106	ab	Z
Dimethenamid-p	440	101	a	Z	113	a	Z	107	a	Z	115	a	Z
Saflufenacil	25	88	ab	Z	99	a	Z	124	a	Z	106	ab	Z
Saflufenacil	50	60	bc	XY	46	b	X	129	a	Z	78	bc	Y
Dimethenamid-p/saflufenacil	220 + 25	89	ab	Z	90	a	Z	120	a	Z	99	abc	Z
Dimethenamid-p/saflufenacil	440 + 50	53	c	XY	39	b	X	114	a	Z	71	c	Y

bar of the combine and reduce seed yield. Dimethenamid-p at 1X or 2X rate caused no adverse effect on height of black, white, adzuki and kidney bean (**Table 2**). Saflufenacil applied alone or in combination with dimethenamid-p at 1X rate had no adverse effect on plant height but at 2X rate reduced plant height as much as 31% in black bean and 48% in white bean (**Table 2**). Saflufenacil applied alone or in combination with dimethenamid-p at 1X or 2X rate caused no adverse effect on height of adzuki or kidney bean (**Table 2**).

In other studies saflufenacil applied PRE reduced plant height > 65% at 100 g ai ha^{-1} and 63% to 93% at 200 g ai ha^{-1} in cranberry, lima, snap, and white bean and 25% in adzuki bean [8]. Plant height reductions in this study are consistent with what has been reported with other PPO-inhibiting herbicides such as fomesafen, flumioxazin and sulfentrazone that have reduced dry bean height 0% to 47% [12]-[16].

3.5. Yield

Dimethenamid-p at 1X or 2X rate caused no adverse effect on seed yield of black, white, adzuki and kidney bean (**Table 2**). Saflufenacil applied alone or in combination with dimetheanamid-p at 1X rates did not cause any significant seed yield reduction in black or white bean but at 2X rates reduced seed yield 40% - 47% in black bean and 54% - 61% in white bean (**Table 2**). Saflufenacil applied alone or in combination with dimethenamid-p at 1X or 2X rates caused no adverse effect on seed yield of adzuki or kidney bean (**Table 2**).

In other studies saflufenacil applied PRE at 100 and 200 g ai ha^{-1} reduced seed yield 56% to 99% in adzuki, cranberry, lima, snap and white bean [8]. Studies with other PPO inhibitors have shown 47%, 44%, 26% and 52% yield reduction with sulfentrazone in black, cranberry, otebo and white bean, respectively [12]. Flumioxazin reduced seed yield 20% to 30% in black and white bean [14]. However, other PPO inhibitors such as fomesafen have been shown to have little effect on the seed yield of dry bean [13] [16].

4. Conclusions

Based on these results, saflufenacil and dimethenamid-p/saflufenacil applied PRE at the proposed rate of 25 g ai ha^{-1} can be safely used for weed management in adzuki bean. There is also potential for use of saflufenacil and dimethenamid-p/saflufenacil applied PRE at the 25 g ai ha^{-1} in kidney bean. However, saflufenacil and dimethenamid-p/saflufenacil applied PRE at the proposed rates cause substantial injury and a reduction in plant stand, height, shoot dry weight and seed yield in black and white bean. Results showed that black and white bean are the most sensitive to saflufenacil and dimethenamid-p/saflufenacil followed by kidney bean and then adzuki bean.

Dimethenamid-p/saflufenacil with its novel mode of action would be a desirable compliment to the current weed management programs for PRE control of troublesome broadleaf weeds in adzuki bean. More research is needed to evaluate other market classes of dry bean to saflufenacil and dimethenamid-p/saflufenacil.

Acknowledgements

The authors would like to acknowledge Todd Cowan for his expertise and technical assistance in these studies. Funding for this project was provided in part by BASF and the GF2 program of the Agricultural Adaptation Council.

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