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Sensitivity of Adzuki Bean (*Vigna angularis*) to Acifluorfen, Fomesafen, Bentazon, Imazethapyr and Halosulfuron-Methyl Applied Postemergence

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Abstract

New herbicide options are needed for postemergence (POST) broadleaf weed control in adzuki bean. A field study, of five experiments, was conducted over a three-year period (2014, 2015, 2016) in Ontario to evaluate the tolerance of adzuki bean to the POST application of acifluorfen (600 and 1200 g·ai·ha^{-1}), fomesafen (240 and 480 g·ai·ha^{-1}), bentazon (1080 and 2160 g·ai·ha^{-1}), imazethapyr (100 and 200 g·ai·ha^{-1}) and halosulfuron-methyl (75 and 150 g·ai·ha^{-1}). Acifluorfen and fomesafen applied POST caused as much as 12% visible injury at the 1X rate and 20% visible injury at the 2X rate but had no adverse effect on adzuki bean population, shoot dry weight, height, maturity or yield. Bentazon caused as much as 23% visible injury at 1080 g·ai·ha^{-1} and 28% visible injury at 2160 g·ai·ha^{-1} but caused no adverse effect on adzuki bean population, shoot dry weight, height, maturity or yield at either rate, except at 2160 g·ai·ha^{-1} which reduced shoot dry weight 20% and height 12%. Imazethapyr caused as much as 22% visible injury at 100 g·ai·ha^{-1} and 34% visible injury at 200 g·ai·ha^{-1} but caused no adverse effect on adzuki bean population, shoot dry weight, height, maturity or yield at either rate except at 200 g·ai·ha^{-1} which delayed maturity slightly. Halosulfuron-methyl caused as much as 65% visible injury and reduced shoot dry weight, height and yield 64%, 41%, and 28%, respectively. This research concludes that acfluorfen, fomesafen, bentazon, imazethapyr and halosulfuron at the rates evaluated can cause the significant injury in adzuki bean.

Keywords

Acifluorfen, Bentazon, Biomass, Fomesafen, Imazethapyr, Halosulfuron-Methyl, Injury, *Vigna angularis,* Yield

1. Introduction

Adzuki bean [*Vigna angularis* (Willd.) Ohwi & Ohashi] is a niche market class of bean that is popular with growers in south-western Ontario [1] [2]. Most of the adzuki bean produced in Ontario is exported to Asia, in particular to Japan, where demand has been increasing steadily over the last few years [1] [2]. Adzuki bean is a small, red, oval-shaped, sweet bean with a nutty taste, used mainly in sweet desserts in the orient [3]. Adzuki bean is a legume crop with an indeterminate growth habit and has similar characteristics as edible dry bean (*Phaseolus vulgaris* L.) growing to heights of 40 - 60 cm and maturing in 110 - 220 days [4]. Adzuki beans have slow early growth and consequently do not compete well with weeds which can cause substantial seed yield losses if not adequately controlled [4]. Currently, few herbicide options are available for weed management in adzuki bean. New herbicide options must be found for the control of broadleaf weeds in adzuki bean.

Acifluorfen {5-[2-Chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid} is a diphenyl ether herbicide that controls broadleaf weeds such as cocklebur (*Xanthium strumarium* L.), jimsonweed (*Datura stramonium* L.), ladystumb (*Polygonum persicaria* L.), wild mustard (*Sinapis arvensis* L.), redroot pigweed (*Amaranthus retroflexus* L.), common ragweed (*Ambrosia artemesiifolia* L.) and eastern black nightshade (*Solanum* spp.) [5]. Acifluorfen is a postemergence (POST), contact herbicide that has very little to no residual activity [5].

Fomesafen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-N-(methylsulfonyl)-2-nitrobenzamide} is another POST applied diphenyl ether herbicide with similar weed control spectrum as acifluorfen that is commonly used for broadleaf weed control in dry beans. Unlike acifluorfen, fomesafen has some residual activity in the soil which can help with season long control of some annual broadleaf weeds [5]. Persistence in the soil is, in part, dependent on soil properties and environmental conditions [5] [6].

Bentazon {3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-doxide} is a herbicide from benzothiadiazole chemical class that is mainly taken up in plants through foliage with no residual activity. Broadleaf weeds controlled by bentazon include common lambsquarters, purslane (*Portulaca oleracea* L.), wild radish (*Raphanus raphanistrum* L.), flower-an-hour (*Hibiscus trionum* L.), jimsonweed, velvetleaf (*Abutilon theophrasti* Medic.), wild mustard, cocklebur, stinkweed (*Thlaspi arvense* L.), shepherdspurse (*Capsella bursa-pastoris* (L.) Medic) and common chickweed (*Stellaria media* (L.) Vill.) including group 2 and 5 resistant biotypes [5] [6].

Imazethapyr {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1h-imidazol-2-yl]-5-ethyl-3-pyridinecarboxylic acid} is an imidazolinone herbicide that can be applied preplant (PP), preplant incorporated (PPI), preemergence (PRE) or POST with full season residual activity. Imazethapyr is absorbed through roots and shoots and is translocated in both the xylem and phloem. Imazethapyr has activity on annual grass and broadleaf weeds including barnyardgrass (*Echinochloa crusgalli* (L.) Beauv.), common lambsquarters, redroot pigweed, ladystumb, smartweed, wild mustard, velvetleaf, ragweed species, eastern black nightshade (*Solanum ptycanthum* Dun. *ex* DC. pp.), yellow nutsedge (*Cyperus esculentus* L.), and foxtails (*Setaria* species) [5] [6] including group 5 resistant biotypes. Imazethapyr is very persistent in the soil, with persistence dependent on soil properties and environmental conditions [5] [6].

Halosulfuron-methyl {3-Chloro-5-[[[[(4,6-dimethoxy-2-pyrimidinyl)amino] carbonyl]amino]sulfonyl]-1-methyl-1*H*-pyrazole-4-carboxylic acid} is a sulfonylurea herbicide that can be applied PP, PPI, PRE and POST and can provide season long control of common ragweed, yellow nutsedge, common chickweed, cocklebur, redroot pigweed, smartweed, velvetleaf, horsetail (*Equisetum* spp.), shepherdspurse, jimsonweed and common lambsquarters including group 5 resistant biotypes [5].

Acifluorfen (600 and 1200 g·ai·ha^{-1}), fomesafen (240 and 480 g·ai·ha^{-1}), bentazon (1080 and 2160 g·ai·ha^{-1}), imazethapyr (100 and 200 g·ai·ha^{-1}) and halosulfuron-methyl (75 and 150 g·ai·ha^{-1}) have been successfully used by *Phaseolus vulgaris* bean growers to control broadleaf weeds in Ontario. However, tolerance of adzuki been to these herbicides needs to be established under Ontario environmental conditions.

The purpose of this research was to ascertain the tolerance of adzuki bean to acifluorfen (600 and 1200 g·ai·ha^{-1}), fomesafen (240 and 480 g·ai·ha^{-1}), bentazon (1080 and 2160 g·ai·ha^{-1}), imazethapyr (100 and 200 g·ai·ha^{-1}) and halosulfuron-methyl (75 and 150 g·ai·ha^{-1}) applied POST under Ontario environmental conditions.

2. Materials and Methods

Five field experiments were conducted in southwestern Ontario over a three-year period (1 in 2014, 2 in 2015 and 2 in 2016). Locations included the University of Guelph, Huron Research Station, Exeter, ON (2014, 2015 and 2016) and University of Guelph, Ridgetown Campus, Ridgetown, ON (2015 and 2016). The soil at the Exeter location was a Brookston clay loam and at Ridgetown was a Brookston loam soil. Seedbed preparation included moldboard plowing in the fall followed by two passes with a field cultivator with rolling basket harrows in the spring prior to seeding adzuki bean.

The field experiments were arranged in a randomized block design with treatments replicated four times. Treatments consisted of a non-treated control, acifluorfen at 600 and 1200 g·ai·ha^{-1}, fomesafen at 240 and 480 g·ai·ha^{-1} (plus a nonionic surfactant at 0.25 v/v), bentazon at 1080 and 2160 g·ai·ha^{-1}, imazethapyr at 100 and 200 g·ai·ha^{-1} (plus a nonionic surfactant at 0.25 v/v and 2 L.ha^{-1} of 28% urea ammonium nitrate) and halosulfuron-methyl at 75 and 150 g·ai·ha^{-1} (plus a nonionic surfactant at 0.25 v/v) representing once and twice the maximum labelled use dose in dry bean or soybean in Ontario. Each plot was 1.5 m wide and consisted of two rows of "Erimo" adzuki bean, spaced 0.75 m apart in rows that were 10 m long at Exeter and 8 m long at Ridgetown. Adzuki bean was seeded in early June at a rate of 175,000 seeds ha^{-1}.

Herbicide treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 200 $L.ha^{-1}$ at 240 kPa. The boom was 1.0 m long with three ultra-low drift nozzles (ULD120-02, Hypro, New Brighton, MN) spaced 50 cm apart. All plots including the non-treated control were maintained weed free by inter-row cultivation and hand hoeing as required to eliminate the confounding effect of weed interference. Herbicides were applied 20 to 26 days after seeding when the adzuki bean was in the 1 - 2 trifoliate leaf stage.

Adzuki bean injury was visually estimated on a scale of 0 (no injury) to 100% (complete plant death) at 1, 2 and 4 weeks after herbicide application (WAA). Plant stand (population) and shoot dry weight were determined 3 WAA by counting the number of bean plants in 1 m of row, cutting them at the soil surface and drying at 60˚C to a constant moisture and then the weight was recorded. Average plant height was determined 6 WAA by measuring the height of 10 randomly selected plants per plot and recording the average. Adzuki bean was harvested at maturity with a small plot combine, weight and moisture were recorded and yields were adjusted to 14% moisture.

Data were analyzed as an RCBD using PROC MIXED in SAS 9.4 [7]. Herbicide treatment was considered a fixed effect, while environment (year-location combinations), the interaction between environment and herbicide treatment, and replicate nested within environment were considered random effects. Significance of the fixed effect was tested using a F-test 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. The untreated control was excluded from the analysis for crop injury data; however, the means were compared independently to zero to evaluate which treatments differed from the untreated control. Plant stand, shoot dry weight, height and yield were converted to a percent of the untreated control for analysis. Shoot dry weight and seed moisture content were log transformed to satisfy the variance analysis assumptions. Treatment comparisons were made using Fisher's Protected LSD at $P < 0.05$. Data compared on the transformed scale were back transformed for presentation.

3. Results and Discussion

Statistical analysis of the data on visible adzuki bean injury, plant population, shoot dry weight, plant height, seed moisture content (maturity) and seed yield showed that the random effects of location, year, year by location and interactions with treatments was not significant. Therefore, data were pooled and averaged over years and locations (**Table 1**).

3.1. Acifluorfen

Acifluorfen, applied POST, caused 12%, 12% and 5% visible injury at 600 $g{\cdot}ai{\cdot}ha^{-1}$ and 20%, 20% and 12% visible injury at 1200 $g{\cdot}ai{\cdot}ha^{-1}$ evaluated 1, 2 and 4 WAA, respectively (**Table 1**). There was no effect of acifluorfen, applied POST at 600 and 1200 $g{\cdot}ai{\cdot}ha^{-1}$, on adzuki bean population, shoot dry weight, height, maturity

Table 1. Percent visible adzuki bean injury 1, 2 and 4 WAA, plant stand, dry weight, height, seed moisture content (maturity) at harvest and yield (as percent of untreated control) for adzuki bean treated with various POST herbicides at Exeter and Ridgetown, ON from 2014 to 2016. Means followed by a different letter within a column are significantly different according to Fisher's Protected LSD at P < 0.05.[a]

		Injury (%)			Stand	Dry weight	Height	Seed	Yield
Treatment	Rate	1 WAA	2 WAA	4 WAA	(plants m^{-1})	($g \cdot m^{-1} \cdot row^{-1}$)	(cm)	Moisture	($t \cdot ha^{-1}$)
	$g \cdot ai \cdot ha^{-1}$					%			
Untreated check		0a	0a	0a	100	100a	100a	14.0a	100ab
Acifluorfen	600	12abc	12ab	5a	106	115a	96ab	13.9a	104a
	1200	20cd	20bc	12ab	102	103a	93ab	14.1a	102ab
Fomesafen[b]	240	9ab	8a	4a	92	116a	99a	14.1a	104a
	480	18bcd	17ab	10a	96	106a	96ab	14.2ab	100ab
Bentazon	1080	19cd	23bc	20bc	101	94ab	91ab	14.4ab	98ab
	2160	25de	28cd	28c	96	80b	88b	14.5ab	98ab
Imazethapyr[bc]	100	22de	21bc	15ab	101	100a	93ab	14.4ab	99ab
	200	31e	34d	27c	99	98ab	90ab	14.9b	105a
Halosulfuron[b]	75	46f	58e	52d	97	53c	69c	16.0c	81bc
	150	52f	65e	64e	106	36c	59d	16.2c	72c

[a]Plant stand, dry weights, height and yield analyzed as a percent of the untreated check. Abbreviations: POST, postemergence; WAA, weeks after herbicide application. [b]Included non-ionic surfactant at 0.25% v/v. [c]Included 28% UAN at 2 L ha^{-1}.

or seed yield (Table 1). Results are similar to those reported by Stewart *et al.* [8] who found up to 7% visible injury in adzuki bean with no adverse effect on plant height or seed yield when treated with acifluorfen applied POST at 600 or 1200 $g \cdot ai \cdot ha^{-1}$.

3.2. Fomesafen

Fomesafen, applied POST, caused 9%, 8% and 4% visible injury at 240 $g \cdot ai \cdot ha^{-1}$ and 18%, 17% and 10% visible injury at 480 $g \cdot ai \cdot ha^{-1}$ evaluated 1, 2 and 4 WAA, respectively (Table 1). Fomesafen, applied POST at 240 and 480 $g \cdot ai \cdot ha^{-1}$, caused no adverse effect on adzuki bean population, shoot dry weight, height, maturity or seed yield (Table 1). The results from this study are similar to Powell *et al.* [9] who found 14% to 28% injury in adzuki bean with no adverse effect on final seed yield and Stewart *et al.* [8] who found 8% visible injury in adzuki bean with no adverse effect on plant height or seed yield of adzuki bean with fomesafen applied POST at 240 or 480 $g \cdot ai \cdot ha^{-1}$. In studies with *Phaseolus vulgaris* such as black and cranberry bean, injury was minimal and transient with fomesafen applied POST at 240 or 480 $g \cdot ai \cdot ha^{-1}$ alone or tankmixed with other herbicides [10].

3.3. Bentazon

Bentazon, applied POST, caused 19%, 23% and 20% visible injury at 1080 $g \cdot ai \cdot ha^{-1}$ and 25%, 28% and 28% visible injury at 2160 $g \cdot ai \cdot ha^{-1}$ evaluated 1, 2 and 4 WAA, respectively (Table 1). Bentazon, applied POST at 2160 $g \cdot ai \cdot ha^{-1}$, did not adversely affect adzuki bean shoot dry weight and height, but at 2160 $g \cdot ai \cdot ha^{-1}$, it reduced shoot dry weight 20% and height 12% compared to the untreated control (Table 1). Adzuki bean population, seed moisture content and seed yield were not adversely affected by either rate of bentazon (Table 1). In other studies, bentazon caused higher injury in adzuki bean. Stewart *et al.* [8] found that bentazon applied POST at 1080 or 2160 $g \cdot ai \cdot ha^{-1}$ caused as much as 66% visible injury and reduced biomass 90%; height 27% and seed yield 57% in adzuki bean. Effect of bentazon on *Phaseolus vulgaris* species has been variable. VanGessel *et al.* [11] found that bentazon applied POST caused as much as 20% visible injury in dry bean but Soltani *et al.* [10] found less than 3% injury in dry bean. Also, Wall [12] found 21% seed yield reductions in dry bean but Blackshaw *et al.* [13] and Burnside *et al.* [14] found no seed yield reduction with bentazon applied POST in dry bean.

3.4. Imazethapyr

Imazethapyr, applied POST, caused 22%, 21% and 15% visible injury at 100 $g \cdot ai \cdot ha^{-1}$ and 31%, 34% and 27% visible injury at 200 $g \cdot ai \cdot ha^{-1}$ evaluated 1, 2 and 4 WAA, respectively (Table 1). Imazethapyr applied POST at 100 and 200 $g \cdot ai \cdot ha^{-1}$ had no adverse effect on adzuki bean population, shoot dry weight, height, seed moisture content or seed yield except for seed moisture content which was increased 0.9% at 200 $g \cdot ai \cdot ha^{-1}$ compared to the untreated control indicating that adzuki bean injury from imazethapyr delayed maturity (Table 1). Results are similar to those found by Stewart *et al.* [8] who reported as much as 23% visible injury in adzuki bean with no adverse effect on plant height or seed yield of adzuki bean with imazethapyr applied POST at 100 or 200 $g \cdot ai \cdot ha^{-1}$. However, Powell *et al.* [9] found 4% injury in adzuki bean with no adverse effect on final seed yield with imazethapyr.

3.5. Halosulfuron-Methyl

Halosulfuron-methyl, applied POST, caused 46%, 58% and 52% visible injury at 75 $g \cdot ai \cdot ha^{-1}$ and 52%, 65% and 64% visible injury at 150 $g \cdot ai \cdot ha^{-1}$ evaluated 1, 2 and 4 WAA, respectively (Table 1). Halosulfuron-methyl, applied POST at 75 $g \cdot ai \cdot ha^{-1}$, reduced adzuki bean shoot dry weight and height 47 and 31, respectively (Table 1). Halosulfuron-methyl, applied POST at 150 $g \cdot ai \cdot ha^{-1}$, reduced adzuki bean shoot dry weight, height and seed yield 64%, 41% and 28% compared to the untreated control, respectively (Table 1). Halosulfuron-methyl, applied POST at 75 $g \cdot ai \cdot ha^{-1}$ and 150 $g \cdot ai \cdot ha^{-1}$, resulted in an increase in seed moisture content at harvest of 2.0% and 2.2%, respectively, indicating that adzuki bean injury due to halosulfuron-methyl delayed maturity. Results are similar to Stewart *et al.* [9] which found as much as 86% visible injury, 93% biomass reduction, 53% height reduction and 75% seed yield reduction in adzuki bean with halosulfuron-methyl applied POST at 35 or 70 $g \cdot ai \cdot ha^{-1}$. Other studies with halosulfuron-methyl applied POST in *Phaseolus vulgaris* have found up to 50% injury in white bean [12] but no adverse effect on seed yield of black, cranberry, kidney, otebo, pinto and small red Mexican beans [15].

4. Conclusion

Results from this research show that acifluorfen (600 and 1200 g·ai·ha^{-1}), fomesafen (240 and 480 g·ai·ha^{-1}), bentazon (1080 and 2160 g·ai·ha^{-1}), imazethapyr (100 and 200 g·ai·ha^{-1}) and halosulfuron (75 and 150 g·ai·ha^{-1}) applied POST cause the significant injury in adzuki bean. Injury with acifluorfen and fomesafen was not as severe and persistent as bentazon, imazethapyr or halosulfuron-methyl. Further studies are needed to determine if lower rates of these herbicides will result in less visible injury but still provide the effective control of annual broadleaf weeds in adzuki bean under Ontario environmental conditions.

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References

[1] Hensall District Co-Operative (2009) Coloured Beans Seed. www.hdc.on.ca/food/seed/coloured.php

[2] Statistic Canada (2016) Estimated Areas, Yield, Production and Average Farm Price of Principal Field Crops, in Metric Units Annual.

[3] Lumpkin, T.A., Konovsky, J.C., Larson, K.J. and McClary, D.C. (1993) Potential New Specialty Crops from Asia: Azuki Bean, Edamame Soybean, and Astragalus. In: Janick, J. and Simon, J.E., Eds., *New Crops*, Wiley, New York, 45-51.

[4] Hardman, L.L., Oplinger, E.S., Doll, J.D. and Combs, S.M. (1989) Adzuki Bean. University of Minnesota Extension Service, St. Paul, MN. http://corn.agronomy.wisc.edu/Crops/AdzukiBean.aspx

[5] Ontario Ministry of Agriculture and Food (2016) Guide to Weed Control. Publication 75. Toronto, ON. Canada. 447 p.

[6] Shaner, D.L. (2014) Herbicide Handbook. 10th Edition, Champaign, Champaign, Illinois.

[7] Statistical Analysis Systems, SAS (2013) The SAS System for Windows, Release 9.4. Statistical Analysis Systems Institute, Cary, NC, 556 p.

[8] Stewart, C.L., Nurse, R.E., Gillard, C.L. and Sikkema, P.H. (2010) Tolerance of Adzuki Bean (*Vigna angularis*) to Preplant-Incorporated, Pre-Emergence and Post-Emergence Herbicides in Ontario, Canada. *Weed Biology and Management*, **10**, 40-47. https://doi.org/10.1111/j.1445-6664.2010.00365.x

[9] Powell, G., Sprague, C. and Renner, K.A. (2004) Adzuki Bean: Weed Control and Production Issues. *Proceedings of North Central Weed Science Society*, CD-ROM #32.

[10] Soltani, N., Bowley, S. and Sikkema, P.H. (2005) Responses of Black and Cranberry Beans (*Phaseolus vulgaris*) to Postemergence Herbicides. *Crop Protection*, **24**, 15-21.

[11] VanGessel, J.M., Monks, W.D. and Quintin, R.J. (2000) Herbicides for Potential Use

in Lima Bean (*Phaseolus lunatus*) Production. *Weed Technology*, **14**, 279-286. https://doi.org/10.1614/0890-037X(2000)014[0279:HFPUIL]2.0.CO;2

[12] Wall, D.A. (1995) Bentazon Tank-Mixtures for Improved Redwood Pigweed (*Amaranthus retroflexus*) and Common Lambsquarters (*Chenopodium album*) Control in Navy Beans (*Phaseolus vulgaris*). *Weed Technology*, **9**, 610-616.

[13] Blackshaw, R.E., Molnar, J.L., Muendel, H.H., Saindon, G. and Li, X. (2000) Integration of Cropping Practices and Herbicides Improves Weed Management in Dry Bean (*Phaseolus vulgaris*). *Weed Technology*, **14**, 327-336. https://doi.org/10.1614/0890-037X(2000)014[0327:IOCPAH]2.0.CO;2

[14] Burnside, O.C., Ahrens, W.H., Holder, B.J., Wiens, M.J., Johnson, M.M. and Ristau, E.A. (1994) Efficacy and Economics of Various Mechanical plus Chemical Weed Control Systems in Dry Beans (*Phaseolus vulgaris*). *Weed Technology*, **8**, 238-244.

[15] Soltani, N., Shropshire, C. and Sikkema, P.H. (2012) Response of Dry Bean to Halosulfuron Applied Postemergence. *Canadian Journal of Plant Science*, **92**, 723-728. https://doi.org/10.4141/cjps2011-220