Weed Technology

cambridge.org/wet

Research Article

Cite this article: Soltani N, Shropshire C, Sikkema PH (2019) Sensitivity of dry bean to herbicides applied preplant for glyphosate-resistant horseweed control in a strip-tillage cropping system. Weed Technol 33:178–184. doi: 10.1017/wet.2018.107

Received: 20 July 2018
Revised: 25 October 2018
Accepted: 22 November 2018

Associate Editor:
Andrew Kniss, University of Wyoming

Nomenclature:
2,4-D ester, chlorimuron-ethyl; cloransulam-methyl; flumetsulam, metribuzin; saflufenacil; horseweed, *Conyza canadensis* L.; dry bean, *Phaseolus vulgaris* L.; soybean, *Glycine max* (L.) Merr.

Key words:
Canada fleabane; kidney bean; small red bean; white bean; biomass; yield

Author for correspondence:
Nader Soltani, Department of Plant Agriculture, University of Guelph Ridgetown Campus, 120 Main Street East, Ridgetown, ON N0P 2C0. (Email: soltanin@uoguelph.ca)

Sensitivity of Dry Bean to Herbicides Applied Preplant for Glyphosate-Resistant Horseweed Control in a Strip-Tillage Cropping System

Nader Soltani[1], Christy Shropshire[2] and Peter H. Sikkema[3]

[1]Adjunct Professor, University of Guelph Ridgetown Campus, Ridgetown, ON, Canada, [2]Research Technician, University of Guelph Ridgetown Campus, Ridgetown, ON, Canada and [3]Professor, University of Guelph Ridgetown Campus, Ridgetown, ON, Canada

Abstract

During 2016 and 2017, four field experiments were conducted at Huron Research Station near Exeter, ON, to evaluate the sensitivity of dry bean grown under a strip-tillage cropping system, to potential herbicides for the control of glyphosate-resistant (GR) horseweed. At 8 wk after emergence (WAE), saflufenacil, metribuzin, saflufenacil + metribuzin, 2,4-D ester, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl caused 13% to 32%, 8% to 52%, 32% to 53%, 5% to 7%, 13% to 21%, 16% to 29%, and 23% to 43% visible injury in dry beans, respectively. Saflufenacil decreased aboveground biomass 65% in kidney bean and 80% in white bean. Metribuzin decreased biomass 82% in kidney bean and 50% in white bean. Saflufenacil + metribuzin decreased biomass 88% in kidney bean, 68% in small red bean, and 80% in white bean. Chlorimuron-ethyl decreased biomass 40% in white bean. There was no decrease in dry bean biomass with the other herbicides evaluated. Metribuzin and saflufenacil + metribuzin reduced kidney bean seed yield 72% and 76%, respectively. Saflufenacil + metribuzin, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl reduced small red bean seed yield 39%, 27%, 30%, and 54%, respectively. Saflufenacil, metribuzin, saflufenacil + metribuzin, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl reduced seed yield of white bean 52%, 32%, 62%, 33%, 42%, and 62%, respectively. There was no decrease in dry bean yield with the other herbicides evaluated. Among herbicides evaluated, 2,4-D ester caused the least crop injury with no effect in dry bean seed yield.

Introduction

Dry bean is a valuable crop grown in certain regions of North America. In 2015, Ontario growers produced dry beans on 53,000 ha, with an annual production of 115,000 Mg, valued at $93 million (Mailvaganam 2018). Dry bean is extremely sensitive to weed interference. In a study completed by the WSSA Weed Loss Committee, the potential yield loss due to weed interference across North America in dry bean was 71% (Soltani et al. 2018). In Ontario, dry bean yield loss due to weed interference was 55%, compared to 49% and 35% in corn and soybean, respectively (Soltani et al. 2018). At this level of weed loss, dry bean growers in Ontario would have lost more than $50 million in 2015 if no weed management practices had been implemented. Growers in Ontario have primarily utilized conventional tillage and, to a much lesser degree, reduced- and no-tillage cropping systems to grow dry bean.

In recent years, some growers have been implementing a strip-tillage cropping system instead of reduced- and no-tillage cropping systems out of concerns for the adverse effects of conventional-tillage cropping systems on soil structure, soil health, water infiltration, and wind and water erosion (Deibert 1995). Strip-tillage allows dry bean growers to remove in-row crop residues without disturbing the soil in other areas of the field, while helping to maintain some beneficial effects of a no-tillage cropping system, such as building soil structure and soil health as well as addressing environmental and regulatory concerns (Bottenberg et al. 1999). Removing in-row residues will also provide some of the beneficial effects of a conventional-tillage cropping system such as soil warming and drying, as well as the ability to place fertilizers within the row area if needed (Godsey et al. 2018; Licht and Al-Kaisi 2005).

Glyphosate-resistant (GR) weeds such as horseweed are spreading rapidly throughout Ontario (Budd 2016; Byker et al. 2013). GR horseweed has been confirmed in 30 counties across Ontario (Budd et al. 2016). GR horseweed is a much greater concern in no-, reduced-, and strip-tillage than in conventional-tillage cropping systems. Currently, there are no strategies to control GR horseweed in dry bean production. Growers need efficacious, cost-effective weed management options for GR horseweed control in dry bean in strip-tillage and no-tillage production systems.

Currently, saflufenacil, metribuzin, saflufenacil + metribuzin, 2,4-D ester, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl applied preplant are being utilized to control GR horseweed in soybean in Ontario (Budd et al. 2016; Byker et al. 2013; Soltani et al. 2017). Currently, these herbicides are not registered for use in dry bean crops. Few studies have collectively compared the sensitivity of dry beans to commonly used herbicides for the control of GR horseweed prior to seeding.

The objective of this study was to determine the response of kidney, small red, and white bean to saflufenacil, metribuzin, saflufenacil + metribuzin, 2,4-D ester, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl applied approximately 1 wk prior to seeding.

Materials and Methods

During 2016 and 2017, four field trials (two in each year) were established at the University of Guelph Huron Research Station, Exeter, ON (43.19° N, 81.30° E). The seedbed was established using a four-row Orthman 1tRIPr (Orthman Mfg., 75765 Road 435, Lexington, NE, USA) strip-tillage implement. During the fall prior to trial establishment, the strip-tillage implement was used to make tilled strips into which the bean rows were then planted the following spring. The strip-tiller used a heavy coulter and a set of trash management disks to cut and clear the strip of crop and weed residue. Behind the disks was an adjustable shank that lifted and broke the soil in a narrow band. The shank was run approximately 18 cm deep and lifted and fractured the soil, causing it to move up and out. Behind the shank, coulters on each side of the strip were installed on an angle that moved the soil back onto the strip and left approximately a 20-cm strip that was loose with a slight berm. Behind the coulters was a basket harrow that firmed the strip lightly, leaving the soil in the strip slightly higher than the undisturbed soil around it.

The trial was established in a split-plot design with four replications. The main factor was herbicide treatment, and the split-plot factor was dry bean market class. Treatments included an untreated control, saflufenacil (50 g ai ha^{-1}), metribuzin (800 g ai ha^{-1}), saflufenacil + metribuzin (50 + 800 g ai ha^{-1}), 2,4-D ester (1,064 g ai ha^{-1}), flumetsulam (140 g ai ha^{-1}), cloransulam-methyl (70 g ai ha^{-1}), and chlorimuron-ethyl (18 g ai ha^{-1}). The herbicide rates represented twice the recommended rate for GR horseweed control in soybean to simulate a spray overlap in the field. Within each plot were three rows of dry bean (one row of each market class) spaced 0.75 m apart in rows that were 10 m long. Kidney, small red, and white beans were planted 5 cm deep at a rate of approximately 190,000, 220,000, and 250,000 seeds ha^{-1}, respectively.

A CO_2-pressurized backpack sprayer calibrated to deliver 200 L ha^{-1} at 240 kPa was used to apply the herbicides 7 d before seeding. The boom was 1.5 m long with four ultra-low drift ULD120-02 nozzles (VeeJet® Ultra low-drift 12002 nozzles, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189-7900) spaced 0.5 m apart. All plots were maintained weed-free with hand weeding during the growing season.

Visible injury was evaluated 1, 2, 4, and 8 wk after crop emergence (WAE) using a scale of 0 to 100%, with 0 indicating no visible dry bean injury and 100% indicating total dry bean plant death. At 3 WAE, dry bean plant stand (counts at 1 m row^{-1}) and dry bean biomass (g plant^{-1}) were determined. At 6 WAE, dry bean height was assessed by measuring the height of 10 randomly selected plants for each market class of dry bean in each plot. Different market classes of dry beans were harvested at their respected maturity stage using a small-plot combine. Final yields were adjusted to 18% moisture content.

The GLIMMIX procedure in SAS (Ver. 9.4, SAS Institute Inc., Cary, NC) was used for data analysis along with the Laplace estimation method (SAS Institute Inc. 2016). The experimental design was used to construct an initial model, which was then refined by comparing the most plausible random variable combinations. The final model was selected based on the best-fit statistics and studentized residual plots, and contained the fixed effects of HERB, TYPE, as well as their interaction. Random effects consisted of environment (location–year combinations), environment by HERB by TYPE interaction, and HERB by replication within environment interaction. The significance of fixed and random effects was tested using the F-test and likelihood ratio tests, respectively. For each parameter, different distributions were assessed on the model scale, and once the best distribution was confirmed, least square means (LSMEANS) were calculated on the data scale using the inverse link function. Tukey's adjustment was applied to pairwise comparisons to determine differences among treatment means at a significance level of 0.05. The Poisson distribution and log link best described percent visible injury; each data point had a value of one added prior to analysis, because positive integer values are required for this distribution and the final LSMEANS were adjusted by subtracting one. A negative binomial distribution (log link) was used for dry bean biomass per meter of row, and a gamma distribution (log link) was used for dry bean biomass per plant and percent moisture at harvest. Plant stand, average plant height, and dry bean yield were analyzed using a Gaussian distribution and the default identity link. Differences for main effects (HERB and TYPE) were determined if the HERB by TYPE interaction was negligible; when the interaction was non-negligible, only differences among simple effects were determined (Stroup 2012). For percent visible dry bean injury, the untreated control was assigned a value of zero and was thus excluded from the analysis because it had zero variance. However, the LSMEANS output provides a comparison of each treatment least square mean with the value zero. This information was used to identify differences between the treatments included in the analysis and the excluded control treatment.

Results and Discussion

Main Effect of Herbicide

At 1 WAE, visible injury to dry bean from saflufenacil was 18%, from metribuzin 5%, saflufenacil + metribuzin 22%, 2,4-D ester 12%, flumetsulam 6%, cloransulam-methyl 7%, and chlorimuron-ethyl 10% (Table 1). Reductions in dry bean biomass per plant were 42% for saflufenacil, 58% for metribuzin, 58% for saflufenacil + metribuzin, 33% for flumetsulam, 33% for cloransulam-methyl, and 42% for chlorimuron-ethyl. There was no decrease in dry bean biomass treated with 2,4-D ester 1 wk prior to seeding (Table 1). At harvest time, dry bean seed moisture content was 3%, 3.8%, and 3.2% greater than the untreated control with saflufenacil, saflufenacil + metribuzin, and chlorimuron-ethyl, respectively. There was no delay in maturity with other herbicide treatments (Table 1).

Visible Injury

Injury symptoms seen with herbicides evaluated included delayed emergence, reduced stand, decreased growth, necrosis, and chlorosis of dry beans. At 2 WAE, injury from saflufenacil, metribuzin, saflufenacil + metribuzin, 2,4-D ester, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl ranged from 7% to

https://doi.org/10.1017/wet.2018.107 Published online by Cambridge University Press

Table 1. Significance of main effects and interaction for visible injury, stand count, aboveground biomass (dry weight) per meter of row and per plant, plant height, moisture, and yield of three dry bean market classes treated with various preplant herbicides in a strip-tillage system at Exeter, ON, from 2016 to 2017.[a,b]

Main effects[c]	Rate	Visible injury 1 WAE	2 WAE	4 WAE	8 WAE	Stand	Biomass		Height	Moisture	Yield
	g ai ha^{-1}	——%——				No. plants m^{-1}	g m^{-1}	g plant^{-1}	cm	%	Mg ha^{-1}
Dry bean market class		**	**	**	**	**	**	**	**	**	**
Kidney		9 a	14	21	21	9	7	0.9 a	34	19.5 b	0.71
Small red		9 a	13	16	16	14	12	0.9 a	37	16.5 a	1.61
White		15 b	20	26	25	14	6	0.5 b	28	18.3 b	1.10
Herbicide treatment[d]		**	**	**	**	**	**	**	**	**	**
Untreated control		0 a	0	0	0	15	17	1.2 a	41	16.5 a	1.65
Saflufenacil[e]	50	18 de	20	23	19	9	5	0.7 bc	35	19.5 bcd	1.09
Metribuzin	800	5 b	18	28	20	10	5	0.5 c	32	17.7 abcd	1.12
Saflufenacil + metribuzin[e]	50 + 800	22 e	34	50	44	7	3	0.5 c	28	20.3 d	0.73
2,4-D ester	1,064	12 cde	12	8	7	14	11	0.9 ab	39	16.7 ab	1.52
Flumetsulam	140	6 b	9	14	18	16	12	0.8 b	33	16.9 abc	1.19
Cloransulam-methyl	70	7 bc	11	20	21	15	12	0.8 b	31	17.5 abcd	1.06
Chlorimuron-ethyl	18	10 bcd	17	28	33	14	9	0.7 bc	27	19.7 cd	0.75
Interaction											
M × H		NS	**	**	**	*	*	NS	**	NS	**

[a]Abbreviations: H, herbicide treatment; NS, not significant at P = 0.05 level; M, dry bean market class; WAE, wk after crop emergence.
[b]Means followed by the same letter within a column are not significantly different according to a Tukey-Kramer multiple range test at P < 0.05. Means for a main effect were separated only if the interaction involving the main effect was negligible.
[c]Significance at P < 0.05 and P < 0.01 levels denoted by * and **, respectively.
[d]All herbicide treatments were tank mixed with glyphosate (1,800 g ae ha^{-1}).
[e]Included Merge (1.0 L ha^{-1}).

Table 2. Visible injury 2 WAE for three dry bean market classes treated with various preplant herbicides in a strip-tillage system at Exeter, ON, from 2016 to 2017.[a,b]

Herbicide treatment	Rate	Dry bean injury Kidney	Small red	White
	g ai ha^{-1}	——%——		
Untreated control		0 a	0 a	0 a
Saflufenacil[c]	50	13 bcZ	16 bcZ	40 cY
Metribuzin	800	28 cdY	13 bcZ	17 bYZ
Saflufenacil + metribuzin[c]	50 + 800	31 d	27 c	46 c
2,4-D ester	1,064	12 b	12 b	11 b
Flumetsulam	140	7 b	8 b	12 b
Cloransulam-methyl	70	9 b	9 b	16 b
Chlorimuron-ethyl	18	13 bc	15 bc	23 bc

[a]Abbreviations: WAE, wk after crop emergence application.
[b]Means followed by the same letter within a column (a–c) or row (Y–Z) are not significantly different according to a Tukey-Kramer multiple-range test at P < 0.05. Rows without an uppercase letter have no cultivar differences.
[c]Included Merge (1.0 L ha^{-1}).

https://doi.org/10.1017/wet.2018.107 Published online by Cambridge University Press

Table 3. Visible injury 4 WAE for three dry bean market classes treated with various preplant herbicides in a strip-tillage system at Exeter, ON, from 2016 to 2017.[a,b]

Herbicide treatment	Rate	Dry bean injury		
		Kidney	Small red	White
	g ai ha^{-1}	———	%	———
Untreated control		0 a	0 a	0 a
Saflufenacil[c]	50	15 bcZ	15 bcZ	45 cdY
Metribuzin	800	62 e	12 bcZ	26 cdY
Saflufenacil + metribuzin[c]	50 + 800	56 de	37 d	57 d
2,4-D ester	1,064	8 b	7 b	7 b
Flumetsulam	140	10 bc	13 bc	19 bc
Cloransulam-methyl	70	17 bc	14 bc	28 cd
Chlorimuron-ethyl	18	23 cd	26 cd	34 cd

[a]Abbreviations: WAE, wk after crop emergence application.
[b]Means followed by the same letter within a column (a–e) or row (X–Z) are not significantly different according to a Tukey-Kramer multiple-range test at $P < 0.05$. Rows without an uppercase letter have no cultivar differences.
[c]Included Merge (1.0 L ha^{-1}).

Table 4. Visible injury 8 WAE for three dry bean market classes treated with various preplant herbicides in a strip-tillage system at Exeter, ON, from 2016 to 2017.[a,b]

Herbicide treatment	Rate	Dry bean injury		
		Kidney	Small red	White
	g ai ha^{-1}	———	%	———
Untreated control		0 A	0 a	0 a
Saflufenacil[c]	50	13 BZ	14 cdZ	32 cY
Metribuzin	800	52 CY	8 bcZ	17 bcZ
Saflufenacil + metribuzin[c]	50 + 800	53 C	32 d	45 c
2,4-D ester	1,064	7 B	5 b	6 b
Flumetsulam	140	13 B	18 cd	21 c
Cloransulam-methyl	70	16 B	18 cd	29 c
Chlorimuron-ethyl	18	23 bc	33 d	43 c

[a]Abbreviations: WAE, wk after crop emergence application.
[b]Means followed by the same letter within a column (a–d) or row (Y–Z) are not significantly different according to a Tukey-Kramer multiple-range test at $P < 0.05$. Rows without an uppercase letter have no cultivar differences.
[c]Included Merge (1.0 L ha^{-1}).

46% in the three market classes (Table 2). Visible injury in white bean was greater than kidney or small red bean with saflufenacil. In contrast, metribuzin injury was greater in kidney bean than small red bean. There was no difference in injury with the other herbicides.

At 4 WAE, injury, among the three market classes, from saflufenacil, metribuzin, saflufenacil + metribuzin, 2,4-D ester, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl ranged from 10% to 62% (Table 3). Saflufenacil caused greater injury in white bean than the kidney and small red bean. Metribuzin injury was greatest with kidney bean (62%) compared to white bean and small red bean. There was no difference in injury levels with the other herbicides.

At 8 WAE, dry bean injury with various herbicides persisted (Table 4). As observed at 2 and 4 WAE, 2,4-D ester caused the least visible injury among herbicides at 8 WAE. Dry bean injury with saflufenacil, metribuzin, saflufenacil + metribuzin, 2,4-D ester, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl ranged from 5% to 53% . Similar to 4 WAE, saflufenacil injury was greater in white than kidney and small red bean. In contrast, metribuzin injury was greater in kidney bean than the small red bean and white bean. There was no difference in injury levels with other herbicides.

These results are consistent with other studies in which saflufenacil applied PRE at 50 g ai ha^{-1} caused 20% to 31% visible injury in dry bean (Soltani et al. 2014). Flumetsulam applied PPI at 140 g ai ha^{-1} caused 13% visible injury in pinto and small red

https://doi.org/10.1017/wet.2018.107 Published online by Cambridge University Press

Table 5. Plant stand 3 WAE for three dry bean market classes treated with various preplant herbicides in a strip-tillage system at Exeter, ON, from 2016 to 2017.[a,b]

Herbicide treatment	Rate	Dry bean injury		
		Kidney	Small red	White
	g ai ha^{-1}	——No. plants m^{-1}——		
Untreated control		12 a	16 a	18 a
Saflufenacil[c]	50	8 ab	11 ab	7 b
Metribuzin	800	5 b	12 ab	11 b
Saflufenacil + metribuzin[c]	50 + 800	4 b	10 b	7 b
2,4-D ester	1,064	8 ab	15 ab	17 a
Flumetsulam	140	12 a	16 a	19 a
Cloransulam-methyl	70	11 a	16 a	18 a
Chlorimuron-ethyl	18	12 a	14 ab	17 a

[a]Abbreviations: WAE, wk after crop emergence application.
[b]Means followed by the same letter within a column (a–b) are not significantly different according to a Tukey-Kramer multiple-range test at $P < 0.05$. Rows without an uppercase letter have no cultivar differences.
[c]Included Merge (1.0 L ha^{-1}).

Table 6. Crop biomass 3 WAE for three dry bean market classes treated with various preplant herbicides in a strip-tillage system at Exeter, ON, from 2016 to 2017.[a,b]

Herbicide treatment	Rate	Dry bean injury		
		Kidney	Small red	White
	g ai ha^{-1}	——g m^{-1}——		
Untreated control		17 a	19 a	10 a
Saflufenacil[c]	50	6 bc	10 ab	2 c
Metribuzin	800	3 cd	10 ab	5 bc
Saflufenacil + metribuzin[c]	50 + 800	2 d	6 b	2 c
2,4-D ester	1,064	8 ab	14 ab	11 ab
Flumetsulam	140	13 ab	14 ab	10 ab
Cloransulam-methyl	70	11 ab	14 ab	10 ab
Chlorimuron-ethyl	18	11 ab	11 ab	6 bc

[a]Abbreviations: WAE, wk after crop emergence application.
[b]Means followed by the same letter within a column (a–d) are not significantly different according to a Tukey-Kramer multiple-range test at $P < 0.05$. Rows without an uppercase letter have no cultivar differences.
[c]Included Merge (1.0 L ha^{-1}).

bean in one study (Soltani et al. 2008). In contrast, flumetsulam applied PRE at 140 g ai ha^{-1} in another study caused minimal visible injury in pinto and small red bean (Sikkema et al. 2008). Cloransulam-methyl applied PRE at 70 g ai ha^{-1} has been shown to cause 9% to 13% visible injury in dry bean (Soltani et al. 2010).

Plant Stand

At 3 WAE, saflufenacil decreased white bean stand 61%, metribuzin decreased kidney bean stand 58% and white bean stand 39%, and saflufenacil + metribuzin decreased kidney, small red, and white bean stand 67%, 38%, and 61%, respectively (Table 5). Dry bean stand count was not adversely affected with other herbicides evaluated. These results are consistent with other studies in which saflufenacil applied PRE at 50 g ai ha^{-1} reduced plant stand 23% to 67% in dry bean (Soltani et al. 2014).

Biomass

Saflufenacil decreased kidney bean biomass 65% and that of white bean 80% (Table 6). Metribuzin decreased kidney bean biomass 82% and that of white bean 50%. Saflufenacil + metribuzin decreased kidney bean biomass 88%, 68% in small red bean, and 80% in white bean. Chlorimuron-ethyl decreased white bean biomass 40%. There were no differences in dry bean biomass with

https://doi.org/10.1017/wet.2018.107 Published online by Cambridge University Press

Table 7. Average height 6 WAE for three dry bean market classes treated with various preplant herbicides in a strip-tillage system at Exeter, ON, from 2016 to 2017.[a,b]

Herbicide treatment	Rate	Dry bean injury		
		Kidney	Small red	White
	g ai ha^{-1}	----------cm----------		
Untreated control		42 a	44 a	38 a
Saflufenacil[c]	50	38 ab	41 ab	26 bcd
Metribuzin	800	23 c	41 ab	31 abc
Saflufenacil + metribuzin[c]	50 + 800	23 c	35 bc	25 cd
2,4-D ester	1,064	40 ab	41 ab	35 ab
Flumetsulam	140	38 ab	34 bc	28 bcd
Cloransulam-methyl	70	34 ab	34 bc	24 cd
Chlorimuron-ethyl	18	32 b	28 c	20 d

[a]Abbreviations: WAE, wk after crop emergence application.
[b]Means followed by the same letter within a column (a–d) are not significantly different according to a Tukey-Kramer multiple-range test at $P < 0.05$. Rows without an uppercase letter have no cultivar differences.
[c]Included Merge (1.0 L ha^{-1}).

Table 8. Yield of three dry bean market classes treated with various preplant herbicides in a strip-tillage system at Exeter, ON, from 2016 to 2017.[a,b]

Herbicide treatment	Rate	Dry bean injury		
		Kidney	Small red	White
	g ai ha^{-1}	----------Mg ha^{-1}----------		
Untreated control		1.13 a	2.08 a	1.73 a
Saflufenacil[c]	50	0.72 ab	1.72 abcd	0.83 cd
Metribuzin	800	0.32 b	1.87 abc	1.17 bc
Saflufenacil + metribuzin[c]	50 + 800	0.27 b	1.26 de	0.66 d
2,4-D ester	1,064	0.98 a	1.97 ab	1.63 ab
Flumetsulam	140	0.88 a	1.52 bcd	1.16 bc
Cloransulam-methyl	70	0.73 ab	1.46 cd	1.00 cd
Chlorimuron-ethyl	18	0.64 ab	0.96 e	0.65 d

[a]Abbreviations: WAE, wk after crop emergence application.
[b]Means followed by the same letter within a column (a–e) are not significantly different according to a Tukey-Kramer multiple-range test at $P < 0.05$. Rows without an uppercase letter have no cultivar differences.
[c]Included Merge (1.0 L ha^{-1}).

other herbicides. Results are consistent with other studies that have shown similar biomass reduction in dry bean with saflufenacil (Soltani et al. 2014), flumetsulam (Soltani et al. 2008), cloransulam-methyl (Soltani et al. 2004, 2010), and chlorimuron-ethyl (Sikkema et al. 2004).

Height

The impact on dry bean height 6 WAE depended on herbicide and dry bean market class. Metribuzin, saflufenacil + metribuzin, and chlorimuron-ethyl reduced kidney bean height 45%, 45%, and 24%, respectively (Table 7). Saflufenacil + metribuzin, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl reduced small red bean height 20%, 23%, 23%, and 36%, respectively. Saflufenacil, saflufenacil + metribuzin, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl reduced white bean height 32%, 34%, 26%, 37%, and 47%, respectively. 2,4-D ester was the only herbicide that consistently had no effect on height. Similar plant height reduction has been reported in dry bean with saflufenacil (Soltani et al. 2014), flumetsulam (Soltani et al. 2008), cloransulam-methyl (Soltani et al. 2004, 2010), and chlorimuron-ethyl (Sikkema et al. 2004).

Seed Yield

Seed yield of the three dry bean market classes treated with various preplant herbicides in a strip-tillage system was variable depending on herbicide evaluated (Table 8). Metribuzin and saflufenacil + metribuzin reduced kidney bean seed yield 72% and 76%, respectively. Saflufenacil + metribuzin, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl reduced small red bean seed yield 39%, 27%, 30%, and 54%, respectively. Saflufenacil, metribuzin, saflufenacil + metribuzin, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl reduced white bean seed yield 52%, 32%, 62%, 33%, 42%, and 62%, respectively. 2,4-D ester consistently had no significant effect on the seed yield of kidney, small red, and white bean. In other studies, saflufenacil applied PRE at 50 g ai ha^{-1} reduced seed yield 40%, 54%, and 22% in black, white, and kidney bean, respectively (Soltani et al. 2014). Flumetsulam applied PPI or PRE at 140 g ai ha^{-1} did not reduce seed yield in pinto and small red bean (Sikkema et al. 2008; Soltani et al. 2008). Seed yield reductions in this study with cloransulam-methyl are similar to those seen in other studies in which cloransulam-methyl applied PRE at 70 g ha^{-1} decreased seed yield of cranberry, black, and white bean 43% to 54% (Soltani et al. 2004, 2010).

In conclusion, the potential herbicides for GR horseweed control including saflufenacil, metribuzin, saflufenacil + metribuzin, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl applied 1 wk prior to seeding can significantly injure dry bean. Saflufenacil generally caused greater visible injury in white bean than the kidney and small red dry bean market classes. However, metribuzin generally caused more visible injury in kidney bean compared to the small red and white bean. This study demonstrates that saflufenacil, metribuzin, saflufenacil + metribuzin, flumetsulam, cloransulam-methyl, and chlorimuron-ethyl when applied 1 wk prior to seeding do not have an adequate margin of crop safety for use in dry bean under a strip-tillage cropping system for the control of GR horseweed. Among the herbicides evaluated, 2,4-D ester caused the least crop injury with no effect in dry bean seed yield. Further research is needed to determine the sensitivity of dry beans to 2,4-D applied at various rates and application intervals prior to dry bean seeding for the control of GR horseweed under strip-tillage production systems in Ontario.

Acknowledgments. No conflicts of interest have been declared. This research was funded by the Ontario Bean Growers (OBG).

References

Bottenberg H, Masiunas J, Eastman C (1999) Strip tillage reduces yield loss of snapbean planted in rye mulch. Hort Technol 9:235–240

Budd CM (2016) Improving the Consistency of Glyphosate-resistant Canada fleabane (*Conyza canadensis*) Control with Saflufenacil: Distribution and Control in Soybean (*Glycine max*). M.Sc. thesis. Guelph, ON: University of Guelph. 51 p

Budd CM, Soltani N, Robinson DE, Hooker DC, Miller RT, Sikkema PH (2016) Control of glyphosate resistant Canada fleabane with saflufenacil plus tankmix partners in soybean. Can J Plant Sci 96:989–994

Byker HP, Soltani N, Robinson DE, Tardif FJ, Lawton MB, Sikkema PH (2013) Control of glyphosate-resistant Canada fleabane [*Conyza canadensis* (L.) Cronq.] with preplant herbicide tankmixes in soybean [*Glycine max*. (L). Merr.]. Can J Plant Sci 93:659–667

Deibert EJ (1995) Dry bean production with various tillage and residue management systems. Soil Tillage Res 36:97–109

Godsey C, Kochenower R, Taylor R (2018) Strip-till considerations in Oklahoma. Oklahoma Cooperative Extension Service, 4 p. http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-5035/PSS-2134web.pdf. Accessed: June 28, 2018

Licht MA, Al-Kaisi M (2005) Strip-tillage effect on seedbed soil temperature and other soil physical properties. Soil Tillage Res 80:233–249

Mailvaganam S (2018) Area, Yield, Production and Farm Value of Specified Field Crops, Ontario, 2012–2017 (Imperial and Metric Units). http://www.omafra.gov.on.ca/english/stats/crops/estimate_new.htm#metric. Accessed: June 22, 2018

SAS Institute Inc. (2016) Base SAS® 9.4 Procedures Guide: Statistical Procedures. 5th ed. Cary, NC: SAS Institute Inc.

Sikkema PH, Soltani N, Shropshire C, Cowan T (2004) Tolerance of white beans to postemergence broadleaf herbicides. Weed Technol 18:893–901

Sikkema PH, Robinson DE, Nurse RE, Soltani N (2008) PRE-emergence herbicides for potential use in pinto and small red Mexican bean (*Phaseolus vulgaris*) production. Crop Prot 27:124–129

Soltani N, Shropshire C, Cowan T, Sikkema PH (2004) White bean sensitivity to preemergence herbicides. Weed Technol 18:675–679

Soltani N, Nurse RE, Robinson DE, Sikkema PH (2008) Response of pinto and small red Mexican beans (*Phaseolus vulgaris* L.) to pre-plant incorporated herbicides. Weed Bio Manag 8:25–30

Soltani N, Shropshire C, Sikkema PH (2010) Tolerance of black, cranberry, kidney, and white bean to cloransulam-methyl. Weed Biol Manag 10:33–39

Soltani N, Shropshire C, Sikkema PH (2014) Sensitivity of dry bean to dimethenamid-p, saflufenacil and dimethenamid-p/saflufenacil. Am J Plant Sci 5:3288–3294

Soltani N, Brown LR, Sikkema PH (2017) Control of glyphosate-resistant Canada fleabane in soybean with preplant herbicides. Can J Plant Sci 97:408–410

Soltani N, Dille JA, Gulden R, Sprague C, Zollinger R, Morishita DW, Lawrence NC, Sbatella GM, Kniss AR, Jha P, Sikkema PH (2018) Potential yield loss in dry bean crops due to weeds in the United States and Canada. Weed Technol 32:342–346

Stroup WW (2012) Generalized Linear Mixed Models: Modern Concepts, Methods and Applications. Boca Raton, FL: CRC Press, Taylor & Francis Group