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Responses of Dry Bean to 2,4-D Ester Applied Preplant and Preemergence

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Abstract

Six field studies were completed in Ontario (during 2016 to 2018) to assess the tolerance of adzuki, kidney, small red and navy bean to 2,4-D ester at 528 or 1056 g·ai·ha^{-1} applied 14, 7 and 1 day before seeding (PP) and 3 days after seeding (PRE). 2,4-D applied PP or PRE caused as much as 4%, 6%, 7% and 8% injury in adzuki, kidney, small red and navy (white) bean, respectively. There was an increase in bean injury as the preplant interval decreased. At 1 WAE, 2,4-D applied at 1056 g·ai·ha^{-1} 14, 7 and 1 day PP and 3 days after seeding caused up to 6%, 10%, 18% and 5% visible bean injury, respectively. The level of injury decreased over time with minimal bean injury (0 to 3%) at 8 WAE. Bean stand counts were similar to the non-treated control with 2,4-D applied at various timings except at 1 day PP when 2,4-D at the 2X rate decreased bean stand 13%. There was up to 23% and 43% decrease in bean dry weight with 2,4-D applied PP at 528 and 1056 g·ai·ha^{-1} 7 and 1 day PP, respectively. Bean height (6 WAE) was not affected by 2,4-D applied at various timings except at 1 day PP when 2,4-D (1056 g·ai·ha^{-1}) decreased bean height 10%. Additionally, there was no effect of 2,4-D treatments on bean maturity or yield. Based on these results, the safest times to apply 2,4-D are 14 days before seeding or PRE. Injury was higher when 2,4-D was applied 7 and 1 day PP. Injury was lower in adzuki bean compared to kidney, small red or navy bean.

Keywords

Bean Stand, Crop Injury, Dry Bean Biomass, Plant Height, Plant Sensitivity, Yield

1. Introduction

Dry bean (*Phaseolus vulgaris* L.) is a short season crop that was first cultivated by aboriginal peoples in South America [1]. Dry bean production has expanded to most subtropical and temperate regions of the world over the years [1]. The top dry bean producers (mostly for domestic use) in the world include Brazil, India, China and Myanmar [1]. The top dry bean exporting countries include Myanmar, China, Canada, the United States and Argentina, exporting as much as 2.6 to 3.5 million tonnes of dry bean annually [1]. In Canada, dry edible bean is primarily grown in Ontario, Manitoba, and Alberta. Growers in these provinces harvest approximately 220,000 MT of dry bean grown on 110,000 ha, mostly for export to other countries [2].

Weed management continues to be a challenging component of dry bean production in Ontario. Agri-chemical companies have preferred to invest their resources for the development of herbicide options for large acreage crops such as corn and soybean rather than for low acreage crops such as dry bean. The Weed Science Society of America (WSSA) reported that dry bean yield was reduced 71% compared to 50% in corn and 52% in soybean due to weed interference [3] [4] [5]. Dry bean growers need new weed management options that are safe, efficacious, environmentally acceptable, increase seed yield and increase the net return to farmers.

In the past, Ontario dry bean growers have primarily used conventional tillage to produce dry bean. Recently some growers are changing their cropping system to no-, reduced- and strip-till practices [6]. In strip-tillage, only the in-row area is tilled and the rest of the area is not tilled. This practice provides the positive benefits of conventional-tillage such as soil warming/drying and fertilizer side-dressing while providing the added benefits of no-tillage practices including improving soil structure, soil microbial biodiversity, and water drainage as well as reducing soil losses due to wind and water erosion [7] [8] [9].

There has been a rapid spread of glyphosate-resistant (GR) Canada fleabane [*Conyza canadensis* (L.) Cronq.] in Ontario in recent years [10]. GR Canada fleabane has been found in many dry bean growing areas of southwestern Ontario. GR Canada fleabane is a greater problem in crops grown in fields with no- , reduced- , and strip-tillage practices in comparison to conventionally tilled fields. This increases the complexity of weed management in reduced- or strip-till dry beans with GR Canada fleabane since it is no longer controlled with tillage. At present, there is no herbicide option for control of GR Canada fleabane in dry beans in fields with no- , reduced- , and strip-tillage. In order to help dry bean producers adapt to strip-tillage and other conservation-tillage practices, reliable and cost-effective weed management options for the control of troublesome weeds including GR Canada fleabane needs to be developed.

Extensive studies conducted in Ontario have established that PP applications of saflufenacil, metribuzin, 2,4-D ester and their tankmixes are the most efficacious herbicide choices for the control of GR Canada fleabane in soybean [11] [12]. A preliminary study showed that among these herbicides only 2,4-D ester has the potential to be utilized in dry bean in Ontario [13]. Saflufenacil and metribuzin alone and in a tankmix applied 1 week before seeding caused 53%

visible injury, 47% height reduction and 76% yield decrease in dry bean [13].

Growers need further information on the tolerance of commonly grown dry beans market classes to 2,4-D ester sprayed at different application timings before dry bean seeding under strip-tillage practices. At present, 2,4-D ester is not registered for use in dry beans when applied PP or PRE. The availability of 2,4-D ester will provide bean growers with an effective herbicide choice to manage GR Canada fleabane in dry bean. The purpose of this study was to evaluate the sensitivity of adzuki, kidney, small red and navy (white) bean to 2,4-D (528 or 1056 g·ai·ha^{-1}) applied 14, 7 or 1 day before seeding and 3 days after seeding.

2. Material and Methods

Six experiments were conducted at the University of Guelph Research Station near Exeter, ON during 2016, 2017 and 2018 (two in each year). A 4-row Orthman 1tRIPr strip-tiller was used to prepare the seedbed. Tools on the Orthman includes a 60 cm vertical disc that cut residues, followed by trash whippers, then a shank with two discs beside it to hold the soil in the 20 cm strip, followed by a rolling basket that breaks up clumps and creates a berm that warms the soil by catching more sun.

The experiments were established using a split plot design (4 replicates). The whole plot factor consisted of the 2,4-D ester (HERB) while the split plot factor comprised dry bean type (TYPE); trials were established with the whole plot factor in a RCBD design. Treatments consisted of non-treated control and 2,4-D ester at 528 and 1056 g·ai·ha^{-1} sprayed approximately 14, 7 and 1 day before seeding and 3 days after seeding. Plots were 10 m long and included eight rows, spaced 75 cm apart, of dry beans (two rows of adzuki, kidney, small red and navy bean) planted at a rate of 200 to 250 thousand seeds ha^{-1}.

2,4-D ester was sprayed approximately 14, 7 and 1 day before seeding and 3 days after seeding using a CO_2 pressurized backpack sprayer (delivery rate of 200 L·ha^{-1} at a pressure of 240 kPa). The spray boom was 2.5 m long and had 6 ULD 120-02 (Pentair-Hypro, New Brighton, Minnesota) nozzles spaced 0.5 m apart producing a spray with of 3.0 m. All plots were kept free of weeds for the duration of the experiment.

Visible injury on dry bean was assessed 1, 2, 4 and 8 weeks after crop emergence (WAE) using a scale of 0 - 100 (0 = no injury/100 = total bean necrosis). Plant stand (count) and shoot dry weight (g 1 m·row^{-1}/g·plant^{-1}) were ascertained 3 WAE by harvesting a meter row of each market class. The height of 10 randomly selected plants from each bean type was measured 6 WAE. Dry beans were combine harvested based on maturity, moisture and yield were recorded. Adzuki bean yield was adjusted to 13% moisture; all other bean types were adjusted to 18% moisture.

The GLIMMIX procedure in SAS [14] was used to analyze the data. The model included the fixed effects of HERB, TYPE and HERB by TYPE interaction, while random effects included environment, environment by HERB by TYPE interaction, replicate within environment and the HERB by replicate within environment interaction. The best distribution for each parameter was selected based on an assessment of residual plots and fit statistics. The analysis was conducted on the model scale using the distribution chosen for each parameter. Treatment pairwise comparisons were subjected to Tukey's adjustment to determine differences at a significance level of $P < 0.05$. Least square means (LSMEANS) were calculated on the data for presentation using the inverse link function or by back-transforming means if a transformation was applied. The normal distribution (identity link) was used for dry bean plant stand, average plant height and yield; the same distribution with an arcsine square root transformation was used for dry bean injury. The gamma distribution (log link) was used to analyze dry bean biomass per meter of row and biomass per plant, and the lognormal distribution (identity link) was used for dry bean moisture at harvest. Differences among simple effects were determined only if the HERB by TYPE interaction was non-negligible, otherwise, differences for the main effects of HERB and TYPE were ascertained [15]. The non-treated control was assigned a value of zero for dry bean injury, resulting in zero variance, and was thus excluded from the analysis. However, the LSMEANS output could be used to perform comparisons with the value zero and differences identified.

3. Results and Discussion

3.1. Main Effects of Herbicides

The preplant/preemergence applications of 2,4-D resulted in 4% to 8% injury in dry beans evaluated at 1 WAE (**Table 1**). There was an increase in bean injury as the PP interval decreased. At 1 WAE, 2,4-D applied at 528 g·ai·ha^{-1} 14, 7, and 1 day PP caused 2, 5 and 9% visible bean injury, respectively (**Table 1**). There was also an increase in dry bean injury at the 2X rate. 2,4-D applied at 1056 g·ai·ha^{-1} 14, 7, and 1 day PP caused 6, 10 and 18% visible bean injury, respectively (**Table 1**). 2,4-D applied PRE at 528 and 1056 g·ai·ha^{-1} caused only 3 and 5% injury, respectively. At 8 WAE, 2,4-D applied PP at 528 and 1056 g·ai·ha^{-1} 14, 7, and 1 day PP caused 0 to 3% visible bean injury, respectively (**Table 1**). 2,4-D applied PRE at 528 and 1056 g·ai·ha^{-1} caused 1 and 2% dry bean injury, respectively (**Table 1**).

Bean stand counts did not differ with 2,4-D except at 1 day PP when 2,4-D at the 1056 g·ai·ha^{-1} decreased bean stand 13% (**Table 1**). There was up to 23 and 43% reduction in bean shoot dry weight with 2,4-D applied 7 and 1 day PP at 528 and 1056 g·ai·ha^{-1}, respectively. However, bean dry weight was not reduced with 2,4-D applied 14 day PP or PRE (**Table 1**). Additionally, bean height was not reduced with 2,4-D applied at various timings except at 1 day PP when 2,4-D was sprayed at 1056 g·ai·ha^{-1} which decreased bean height 10%. There was also no effect of 2,4-D on dry bean yield and maturity (**Table 1**).

Dry bean responses are similar to an earlier report [13] in which 2,4-D applied at 1064 g·ai·ha^{-1} 1 week before seeding caused 12, 12, 8 and 7% injury in dry bean at 1, 2, 4 and 8 WAE, respectively. In the same study, 2,4-D applied at 1064

Table 1. Significance of main effects and interaction for percent visible injury, stand count, above ground biomass (dry weight) per m of row and per plant, height, moisture and yield for four dry bean market classes treated with 2,4-D ester at various preplant and preemergence timings at Exeter, ON (2016-2018). Means for a main effect are separated only if the interaction involving the main effect is negligible.[a,b]

Main effects[c]		Visible Injury (%)				Stand	Biomass		Height	Moisture	Yield
		1 WAE	2 WAE	4 WAE	8 WAE	(# m^{-1})	(g·m^{-1}	g·plant^{-1})	(cm)	(%)	(T·ha^{-1})
Dry bean market class		**	**	*	NS	**	**	**	**	**	**
Adzuki		4^{c}	6	3	1	18.9^{a}	6.5^{d}	0.35^{d}	30^{d}	12.7^{d}	1.21^{c}
Kidney		6^{b}	6	2	1	11.1^{d}	14.4^{b}	1.33^{a}	44^{b}	15.7^{b}	1.15^{c}
Small Red Mexican		7^{ab}	6	3	1	14.4^{c}	16.2^{a}	1.13^{b}	46^{a}	14.6^{c}	2.24^{a}
White		8^{a}	7	3	1	15.8^{b}	12.4^{c}	0.81^{c}	38^{c}	16.8^{a}	2.09^{b}
2,4-*D ester timing*	*Rate* (*g·ai·ha*$^{-1}$)	**	**	**	**	**	**	**	**	NS	NS
Non-treated control		0g	0	0	0^{d}	15.8^{a}	13.8^{a}	0.90^{a}	40^{a}	14.6	1.70
14 days PP	528	2f	1	1	0^{d}	15.8^{a}	14.2^{a}	0.92^{a}	41^{a}	14.6	1.76
14 days PP	1056	6^{cd}	5	2	1^{bc}	15.1^{ab}	11.8^{ab}	0.82^{ab}	40^{a}	14.9	1.67
7 days PP	528	5^{d}e	5	1	1^{bc}	15.1^{ab}	12.9^{a}	0.88^{a}	41^{a}	14.7	1.74
7 days PP	1056	10^{b}	8	4	2^{ab}	14.9^{ab}	10.6^{b}	0.74^{b}	39^{ab}	15.1	1.63
1 day PP	528	9^{bc}	8	4	2^{ab}	14.5^{ab}	10.4^{b}	0.74^{b}	39^{ab}	14.9	1.63
1 day PP	1056	18^{a}	14	9	3^{a}	13.7^{b}	7.9^{c}	0.61^{c}	36^{b}	15.5	1.50
PRE	528	3ef	5	2	1^{bc}	15.5^{a}	12.9^{a}	0.87^{a}	40^{a}	14.7	1.71
PRE	1056	5^{d}e	7	4	2^{ab}	15.0^{ab}	12.3^{ab}	0.86^{a}	39^{ab}	14.9	1.71
Interaction											
H × T		NS	*	**	NS	NS	NS	NS	NS	NS	NS

Note: Means for a main effect are separated only if the interaction involving the main effect is negligible. [a]Abbreviations: H, 2,4-D ester treatment; NS, not significant at P = 0.05 level; PP, preplant; PRE, preemergence; T, dry bean market class; WAE, weeks 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. [c]Significance at P < 0.05 and P < 0.01 levels denoted by * and **, respectively.

g·ai·ha^{-1} 1 week before seeding did not cause any reduction in plant stand, shoot dry weight, height, maturity and yield of kidney, small red and navy bean [13]. In contrast, PP herbicides such as chlorimuron, cloransulam, flumetsulam, metribuzin and saflufenacil when applied 1 week PP caused 8 to 52% visible injury, 20 to 47% height reduction and 27 to 76% yield reduction in kidney, small red and navy bean [13].

3.2. Simple Effects

There was a significant 2,4-D by timing interaction for visible injury (**Table 1**) at 2 and 4 WAE so the simple effects are presented. At 2 WAE, 2,4-D at 528 g·ai·ha^{-1} 14, 7 and 1 day PP, and PRE caused 1, 5, 7, and 5% visible injury in adzuki bean; 1, 4, 8 and 4% visible injury in kidney bean; 1, 4, 10 and 4% visible injury in small red bean; and 2, 5, 10 and 6% visible injury in navy bean, respectively (**Table 2**). Visible injury generally increased with 2,4-D at the 2X

Table 2. Percent visible injury 2 and 4 WAE for four dry bean market classes after treatment with 2,4-D ester at various preplant and preemergence timings at Exeter, ON (2016-2018).[a]

2,4-D ester timing	Rate (g·ai·ha^{-1})	Dry bean injury (%)							
		Adzuki		Kidney		SRM		White	
Variable									
Injury 2 *WAE*									
Non-treated control		0^{d}		0^{d}		0e		0f	
14 days PP	528	1^{c}		1^{c}		1^{d}		2e	
14 days PP	1056	6^{b}		5^{b}		5^{c}		6^{cd}	
7 days PP	528	5^{b}		4^{b}		4^{c}		5e	
7 days PP	1056	7^{ab}		7^{b}		8^{bc}		9^{bc}	
1 day PP	528	7^{ab}		8^{b}		10^{b}		10^{b}	
1 day PP	1056	10^{a}	Y	16^{a}	Z	16^{b}	Z	16^{a}	Z
PRE	528	5^{b}		4^{b}		4^{c}		6^{cd}	
PRE	1056	9^{ab}		6^{b}		6^{bc}		8^{bcd}	
Injury 4 *WAE*									
Non-treated control		0^{d}		0^{d}		0^{d}		0e	
14 days PP	528	1^{c}		1^{c}		1^{c}		1^{d}	
14 days PP	1056	3^{ab}		1^{c}		2^{bc}		2^{cd}	
7 days PP	528	2^{bc}		1^{c}		1^{c}		2^{cd}	
7 days PP	1056	3^{ab}		4^{b}		3^{b}		4^{bc}	
1 day PP	528	4^{ab}		4^{b}		5^{b}		5^{ab}	
1 day PP	1056	6^{a}	Y	11^{a}	Z	9^{a}	Z	10^{a}	Z
PRE	528	3^{ab}		2^{bc}		1^{c}		2^{cd}	
PRE	1056	4^{ab}		3^{b}		3^{b}		4^{bc}	

Note: Means followed by the same letter within a column (a-f) or row (Y-Z) for each variable are not significantly different according to a Tukey-Kramer multiple range test at $P < 0.05$. Rows without an uppercase letter have no differences among market classes. [a]Abbreviations: PP, preplant; PRE, preemergence; SRM, Small Red Mexican; WAE, weeks after crop emergence.

rate. 2,4-D applied at 1056 g·ai·ha^{-1} 14, 7 and 1 day PP, and PRE caused 6, 7, 10 and 9% visible injury in adzuki bean; 5, 7, 16, and 6% visible injury in kidney bean; 5, 8, 16, and 6% visible injury in small red bean; and 6, 9, 16, and 8% visible injury in navy bean, respectively. The injury did not differ among the market classes evaluated with the exception with 2,4-D applied at 1056 g·ai·ha^{-1} 1 day PP there was lower adzuki bean injury in comparison to kidney, small red or navy bean. Adzuki bean (*Vigna angularis* L.) is from a different genus than common bean (*Phaseolus* spp.) and has been shown to respond differently to many herbicides compared to *Phaseolus* species [16] [17] [18]. There was a consistent trend to increased dry bean injury among all four dry bean market classes and the preplant interval was decreased from 14 to 7 to 1 day preplant, although not all differences were statistically significant. Very interestingly, 2,4-D applied PRE caused less dry bean injury than when applied 1 day PP. In most cases 2,4-D applied 7 days PP and PRE caused similar dry bean injury.

Similarly at 4 WAE, 2,4-D at 528 $g \cdot ai \cdot ha^{-1}$ 14, 7 and 1 day PP, and PRE caused 1, 2, 4, and 3% injury in adzuki bean; 1, 1, 4 and 2% injury in kidney bean; 1, 1, 5 and 1% injury in small red bean; and 1, 2, 5 and 2% injury in navy bean, respectively (**Table 2**). 2,4-D at the rate of 1056 $g \cdot ai \cdot ha^{-1}$ applied 14, 7 and 1 day PP, and PRE caused 3, 3, 6 and 4% injury in adzuki bean; 1, 4, 11 and 3% injury in kidney bean; 2, 3, 9 and 3% injury in small red bean; and 2, 4, 10 and 4% injury in navy bean, respectively (**Table 2**). Similar to 2 WAE, the adzuki bean visible injury was lower than other bean types evaluated with 2,4-D at 1056 $g \cdot ai \cdot ha^{-1}$ applied 1 day PP. Similar to 2 WAE, there was also a consistent tendency to increased dry bean injury among all four dry bean market classes as the preplant interval was decreased from 14 to 7 to 1 day preplant. Generally, 2,4-D applied PRE caused less dry bean injury than when applied 1 day PP. 2,4-D applied 7 days PP and PRE caused similar dry bean injury.

These results are consistent to an earlier study in which 2,4-D (1064 $g \cdot ai \cdot ha^{-1}$) when applied 1 week before seeding caused 12, 12 and 1% injury 2 WAE and 8, 7 and 7% injury 4 WAE on kidney, small red and navy bean, respectively [13]. However, 2,4-D applied at a lower rate (528 $g \cdot ai \cdot ha^{-1}$) 1 week before seeding caused only 5% to 7% injury on kidney, small red and navy bean in the same study [13].

4. Conclusion

In conclusion, based on visible bean injury, at 1 WAE, the safest times to apply 2,4-D ester are 14 days PP or PRE. Injury is generally higher with 7 and 1 day PP and at the 2X rates. At 2 and 4 WAE, 1 day PP application of 2,4-D ester is generally the most injurious treatment to bean types evaluated. The level of injury decreases over time. At 8 WAE, 2,4-D applied PP at 528 and 1056 $g \cdot ai \cdot ha^{-1}$ 14, 7, and 1 day PP and PRE caused 0% to 3% visible bean injury in dry bean, respectively. At 3 WAE, bean stand was reduced the most with 2,4-D ester applied 1 day PP. At 3 WAE, bean biomass was reduced the most with 2,4-D ester applied 7 or 1 day PP. At 6 WAE, height of dry bean was reduced the most when applied 1 day PP. There was also no effect of 2,4-D ester applied at various timings on adzuki, kidney, small red and navy bean maturity, and yield. Results also indicated that the safest times to apply 2,4-D ester are 14 days PP or PRE. Adzuki bean is more tolerant to 2,4-D ester than kidney, small red, and navy bean.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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