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Tolerance of Dry Beans to Pyraflufen-Ethyl/2,4-D Ester

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Abstract

Five field experiments were conducted in Ontario to determine the tolerance of dry beans to pyraflufen-ethyl (6.7 and 13.4 g ai ha^{-1}), 2,4-D ester (520.3 and 1040.6 g ai ha^{-1}) and pyraflufen-ethyl/2,4-D ester (527 and 1054 g ai ha^{-1}) applied preplant. Pyraflufen-ethyl at 6.7 and 13.4 g ai ha^{-1} caused < 2% injury in azuki, kidney, small red, and white bean. 2,4-D ester at 520.3 and 1040.6 g ai ha^{-1} caused up to 4 and 6% injury in azuki bean; up to 5 and 12% injury in kidney bean; up to 7 and 12% injury in small red bean; and up to 5 and 8% injury in white bean, respectively. Pyraflufen-ethyl/2,4-D ester at 527 and 1054 g ai ha^{-1} caused up to 4 and 6% injury in azuki bean; 5 and 11% injury in kidney bean; 7 and 13% injury in small red bean; and 5 and 10% injury in white bean, respectively. Pyraflufen-ethyl (6.7 and 13.4 g ai ha^{-1}), 2,4-D ester (520.3 and 1040.6 g ai ha^{-1}) or their combination applied preplant caused no adverse effect on dry bean stand, aboveground dry biomass, height, seed moisture content, or yield except for 2,4-D (2X rate) and pyraflufen-ethyl/2,4-D ester (2X rate) which reduced dry bean aboveground biomass as much as 32% and plant height up to 28%. This study concludes that pyraflufen-ethyl (6.7 g ai ha^{-1}), 2,4-D ester (520.3 g ai ha^{-1}), and pyraflufen-ethyl/2,4-D ester (527 g ai ha^{-1}) applied preplant is safe to use for weed management in azuki, kidney, small red, and white bean. However, care must be taken to avoid spray overlaps with 2,4-D ester and pyraflufen-ethyl/2,4-D ester to avoid unacceptable dry bean injury.

Keywords: aboveground biomass, stand, dry bean height, density, yield, herbicide sensitivity

1. Introduction

Dry bean is a valuable crop grown in Ontario. In 2020, dry bean producers seeded nearly 69,000 ha and harvested 384,000 tonnes of dry beans valued at approximately CAD$120 million (OMAFRA, 2021). Market classes of dry beans grown in Ontario include azuki, black, cranberry, kidney, otebo, small red, and white beans. Dry beans are susceptible to yield loss from weed interference as they are short in stature with slow early growth. A meta-analysis completed by the Weed Science Society of America estimated that 71% of dry bean yield would be lost in North America if weeds are not controlled (Soltani et al., 2018). Weed control in dry beans in Ontario has become a more challenging issue with the evolution of herbicide-resistant weeds; in particular glyphosate-resistant (GR) Canada fleabane (*Erigeron canadensis* L.). GR Canada fleabane was first confirmed in Ontario from seeds collected in 2010. GR Canada fleabane has now been confirmed in 30 counties across southern Ontario in a geographic area that extends from the western to the eastern regions of the province; the geographic area affected continues to increase (Byker et al., 2013a). A recent study estimated that uncontrolled GR Canada fleabane interference in dry beans causes a 65% yield loss and a potential monetary loss of CAD$3.2 million in Ontario (Soltani et al., 2022).

GR Canada fleabane is a highly competitive winter/summer annual weed that does not have a dormancy requirement which allows for immediate germination and emergence of seedlings in the same growing season following seed release from the mother plant (Buhler & Owen, 1997). The variable emergence and establishment characteristics of Canada fleabane and the subsequent variation in height and plant development at preplant herbicide application timing in the spring make control challenging (Buhler and Owen, 1997; Weaver, 2001). Early-season GR Canada fleabane control is critical to minimize dry bean yield loss from early-season weed interference. GR Canada fleabane must be controlled prior to dry bean seeding with preplant (PP) herbicides that have burndown plus residual activity because the registered postemergence (POST) herbicides in dry beans in Ontario do not provide acceptable control of Canada fleabane (Bruce & Kells, 1990; Budd et al., 2016, 2017;

Davis & Johnson, 2008; Ford et al., 2014; Mahoney et al., 2016). There are no PP herbicides registered for the control of GR Canada fleabane in dry beans in Ontario. More research is needed to find new herbicide options for GR Canada fleabane control in dry bean.

Pyraflufen-ethyl/2,4-D (BlackHawk®) is a new preformulated mixture herbicide that is currently registered for broadleaf weed control in soybean applied PP (Anonymous, 2019). Pyraflufen-ethyl is a contact herbicide that inhibits the protoporphyrinogen IX oxidase (PPO) enzyme (Anonymous, 2019). Pyraflufen-ethyl can control troublesome weeds including *Amaranthus* spp., *Ambrosia* sp., *Erigeron Canadensis*, *Capsella bursa-pastoris*, *Chenopodium album*, *Consolida regalis*, *Datura stramonium*, *Galeopsis* sp., *Lamium* sp., *Mercurialis annua*, *Polygonum* sp., *Portulaca oleracea*, *Sinapis arvensis*, *Solanum nigrum*, and *Thlaspi arvense* (Anonymous, 2019). Pyraflufen-ethyl has favorable environmental safety as it is active against resilient troublesome weeds at relatively low doses (Anonymous, 2019). 2,4-D, is a phenoxy carboxylic acid herbicide that can control a wide spectrum of annual, biennial, and perennial broadleaf weed species (OMAFRA, 2022; Shaner, 2014). 2,4-D is an auxinic herbicide that in susceptible plants upregulates silent DNA resulting in plant death (Shaner, 2014). 2,4-D is often mixed with other herbicides to improve weed control efficacy and control of a wider spectrum of weed species (Soltani et al., 2019).

Earlier studies have shown that 2,4-D ester provides variable control of GR Canada fleabane. In earlier studies, Eubank et al. (2008) reported 95-99% control of GR Canada fleabane with 2,4-D ester in soybean. Kruger et al. (2010) reported 90-97% control of Canada fleabane with 2,4-D ester in soybean. However, in Ontario, GR Canada fleabane control was more variable (53 to 92%) with 2,4-D ester applied PP to soybean (Byker et al., 2013b; Soltani et al., 2020b). There is a limited amount of published research on GR Canada fleabane control with pyraflufen-ethyl/2,4-D. An earlier study reported that pyraflufen-ethyl/2,4-D can control GR Canada fleabane 85% and provide similar density and biomass reduction of GR Canada fleabane as the weed-free control in soybean (Soltani et al., 2020a). Soybean yield was also comparable to the weed-free control (Soltani et al., 2020a). In contrast, Dilliott et al. (2022) reported 52% GR Canada fleabane control with pyraflufen-ethyl/2,4-D applied preplant in soybean. The addition of metribuzin or saflufenacil to pyraflufen-ethyl/2,4-D applied PP improved GR Canada fleabane control to 89% and 99%, respectively (Dilliott et al., 2022).

Preliminary studies have shown that there is potential for using 2,4-D ester, and pyraflufen-ethyl/2,4-D ester applied preplant in dry beans (Soltani et al., 2022). There is little information on the sensitivity of azuki, kidney, small red, and white beans to pyraflufen-ethyl, 2,4-D ester, and pyraflufen-ethyl/2,4-D ester applied preplant. If tolerance is satisfactory, pyraflufen-ethyl/2,4-D ester applied preplant can provide a new tool for the control of troublesome weeds such as GR Canada fleabane prior to seeding dry beans.

The objective of this research was to determine the tolerance of azuki, kidney, small red, and white beans to pyraflufen-ethyl (6.7 and 13.4 g ai ha^{-1}), 2,4-D ester (520.3 and 1040.6 g ai ha^{-1}) and pyraflufen-ethyl/2,4-D ester (527 and 1054 g ai ha^{-1}) applied preplant. The herbicide rates represent the currently registered rate (1X rate) in soybean and twice that rate (2X rate) to simulate a spray overlap in the field.

2. Materials and Methods

Five field experiments were conducted at the Huron Research Station near Exeter, Ontario in 2018, 2019 (A & B), 2020, and 2021. The soil was a Brookston clay loam (Orthic Humic Gleysol, mixed, mesic, and poorly drained). The experiment was set up as a split-plot design established as a randomized complete block design with four replications. The main plot was herbicide treatment and the subplots were dry bean market class. Treatments included a weed-free control and pyraflufen-ethyl (6.7 g ai ha^{-1}), pyraflufen-ethyl (13.4 g ai ha^{-1}), 2,4-D ester (520.3 g ai ha^{-1}), 2,4-D ester (1040.6 g ai ha^{-1}), pyraflufen-ethyl/2,4-D ester (527 g ai ha^{-1}), and pyraflufen-ethyl/2,4-D ester (1054 g ai ha^{-1}).

The main plots were 6.0 m wide (8 rows spaced 0.75 m apart, 2 rows for each dry bean market class) and 10.0 m long and consisted of two rows of azuki (‘Erimo’); kidney (‘Red Hawk’); small red (‘Merlot’) and white (‘T9905’) beans. Azuki, kidney, small red, and white beans were seeded 3-4 cm deep in late May to early June at the rate of approximately 280, 190, 210, and 250 thousand seed ha^{-1}, respectively. The entire experimental area was maintained weed-free throughout the entire growing season.

Herbicide treatments were sprayed up to one-day preplant (not incorporated) with a CO_2-pressurized backpack sprayer calibrated to deliver 200 L ha^{-1} at 240 kPa. The boom was 2.5 m long with six ultra-low drift nozzles (ULD120-02, Hypro, New Brighton, MN) spaced 50 cm apart producing a spray width of 3.0 m.

Crop injury was evaluated 1, 2, 4, and 8 weeks after dry bean emergence (WAE) based on a rating of 0-100% (0 = no injury; 100 = total necrosis). At 3 WAE, relative plant stand (percent of the control), and shoot dry biomass was determined from a 1-meter row of each market class. The number of plants in a 1-meter row of each market class was counted, cut at the soil surface, placed in a paper bag and dried at 60 °C to constant moisture and then weighed. Average plant height was determined at 6 WAE (from 10 randomly selected plants per subplot). A small plot combine was used to harvest dry beans based on maturity. Azuki bean yield was adjusted to 13% seed moisture content. Kidney, small red, and white bean yields were adjusted to 18% seed moisture content.

The GLIMMIX procedure in SAS (Ver. 9.4, SAS Institute Inc., Cary, NC) was used for data analysis. Significance was set at a level of 0.05. Variances were partitioned into the random effects of locations, years, and years by locations, blocks within years by locations, and their interactions with fixed effects, and into the fixed effects of herbicide treatment, market class (Cultivar), and herbicide by market class. Studentized residual plots, Chi-square/df ratio, normal probability plot and Shapiro-Wilk statistic were used to assess how well the assumptions of analysis were met for potential distributions. A Gaussian distribution was used for plant stand, biomass per meter of row, average height, and crop yield. Dry bean injury was arcsine square-root transformed and biomass per plant was square-root transformed prior to analysis with a Gaussian distribution. Dry bean moisture at harvest was analyzed using a lognormal distribution. Pairwise comparisons among least-square means were carried out using the Tukey-Kramer adjustment. Any means transformed prior to analysis were back-transformed for presentation. If treatment was assigned a fixed value of 0 and had zero variance, it was excluded from the analysis; means could still be compared to the value zero using the p-value associated with each treatment in the LSMEANS output.

3. Results and Discussion

There was a significant HERB × RATE interaction at 1, 2, 4, and 8 WAE for visible crop injury. There was no HERB × RATE interaction for dry bean stand, shoot biomass (dry weight) per m of row, shoot biomass (dry weight) per plant, height, seed moisture content, and yield (Table 1).

Table 1. Response of four dry bean market classes to pyraflufen-ethyl, 2,4-D ester, and pyraflufena-ethyl/2,4-D ester from five trials conducted near Exeter, ON (2018-2021). Parameters evaluated were crop injury, stand count, above-ground biomass (dry weight) per m^{-1} row^{-1} and per plant, height, seed moisture content, and yield. Means for the main effect were separated only if the interaction involving the main effect was negligible[a,b]

Main effects	Rate	Visible Crop Injury[c] (%)				Stand	Biomass		Height	Moisture	Yield
	(g ai ha^{-1})	1 WAE	2 WAE	4 WAE	8 WAE	(# m^{-1})	(g m^{-1})	(g $plant^{-1}$)	(cm)	(%)	(t ha^{-1})
Dry bean market class											
Azuki		2.9	3.1	2.2	0.6	15 a	8.5 c	0.54 d	33 c	14.6 a	1.40 c
Kidney		4.7	4.5	3.2	1.1	10 b	15.7 ab	1.56 a	42 ab	17.1 b	1.56 c
Small Red		4.7	5.5	3.9	0.7	15 a	16.8 a	1.10 b	44 a	18.0 c	2.45 a
White		3.5	4.1	2.8	0.8	15 a	15.0 b	0.98 c	41 b	19.6 d	2.09 b
BEAN P-value		<0.0001	<0.0001	<0.0001	0.0074	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Herbicide treatment[d]											
Non-treated control		0	0	0	0	14.0 ab	16.4 a	1.17 a	41	17.3	1.93
Pyraflufen-ethyl[a]	6.7	0.4	0.4	0.1	0.0	13.8 ab	15.7 a	1.14 a	40	17.4	1.87
Pyraflufen-ethyl[e]	13.4	1.1	1.5	0.6	0.3	13.4 ab	15.1 a	1.09 a	41	17.2	1.90
2,4-D ester	520.3	4.5	4.9	3.2	0.7	13.6 ab	14.1 a	1.04 a	40	17.6	1.89
2,4-D ester	1040.6	8.9	8.7	7.8	2.5	13.5 ab	11.1 b	0.84 b	38	17.6	1.73
Pyraflufen-ethyl/2,4-D ester	527	4.4	5.0	3.4	0.6	14.1 a	14.2 a	0.98 ab	40	17.5	1.94
Pyraflufen-ethyl/2,4-D ester	1054	9.1	9.4	7.9	2.1	12.5 b	11.2 b	0.87 b	39	17.6	1.86
HERB P-value		<0.0001	<0.0001	<0.0001	<0.0001	0.0466	<0.0001	<0.0001	0.1814	0.8771	0.5325
Interaction											
HERB × RATE P-value		0.0001	<0.0001	0.0009	0.0034	0.4243	0.6273	0.8073	0.9814	0.9947	1.000

Note. [a] Abbreviations: BEAN, dry bean market class; HERB, herbicide treatment; 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] Non-treated control excluded from analysis due to zero variance; comparison of herbicide treatments with the value zero obtained using LSMEANS table from the GLIMMIX procedure.

[d] All treatments included glyphosate (900 g ai ha^{-1}).

[e] Included Carrier surfactant (0.25% v/v).

At 1 WAE, pyraflufen-ethyl at 6.7 and 13.4 g ai ha^{-1} caused ≤ 1.3% dry bean injury; there was no difference in injury level among dry bean market classes (Table 2). 2,4-D ester at 520.3 and 1040.6 g ai ha^{-1} caused visible injury of 4 and 6% in azuki bean, 5 and 12% in kidney bean, 6 and 11% in small red bean, and 4 and 8% in white bean, respectively (Table 2). Pyraflufen-ethyl/2,4-D ester at 527 and 1054 g ai ha^{-1} caused visible injury of 3 and 6% in azuki bean, 5 and 11% in kidney bean, 6 and 12% in small red bean, and 4 and 8% in white bean, respectively (Table 2). Dry bean injury with 2,4-D and pyraflufen-ethyl/2,4-D ester was consistently numerically less in azuki bean than other market classes of dry bean evaluated although differences were not always statistically significant.

Table 2. Visible crop injury of four dry bean market classes 1, 2, 4, and 8 WAE following pyraflufen-ethyl, 2,4-D ester, or pyraflufen-ethyl/2,4-D ester applied preplant from five trials conducted near Exeter, ON (2018-2021)[a,b]

Herbicide treatment[c]	Rate (g ai ha^{-1})	Visible crop injury[d] (%)			
		Azuki	Kidney	Small Red	White
1 WAE					
Non-treated control		0 a	0 a	0 a	0 a
Pyraflufen-ethyl[e]	6.7	0.4 b	0.3 b	0.4 b	0.3 b
Pyraflufen-ethyl[e]	13.4	1.3 b	1.2 b	0.7 b	1.1 b
2,4-D ester	520.3	3.5 c Z	5.4 c YZ	5.5 c Y	3.9 c YZ
2,4-D ester	1040.6	5.8 c Z	11.8 d Y	10.9 d Y	7.7 d Z
Pyraflufen-ethyl/2,4-D ester	527	3.4 c Z	4.6 c YZ	5.5 c Y	4.1 c YZ
Pyraflufen-ethyl/2,4-D ester	1054	5.8 c Z	10.9 d XY	12.0 d X	8.2 d YZ
2 WAE					
Non-treated control		0 a	0 a	0 a	0 a
Pyraflufen-ethyl[e]	6.7	0.7 b Y	0.5 b YZ	0.4 b YZ	0.1 a Z
Pyraflufen-ethyl[e]	13.4	1.7 bc	1.1 b	1.4 b	1.6 b
2,4-D ester	520.3	3.5 cd Z	4.6 c YZ	6.6 c Y	5.2 c YZ
2,4-D ester	1040.6	5.7 d Z	9.9 d XY	11.6 d X	8.2 cd Y
Pyraflufen-ethyl/2,4-D ester	527	3.6 cd Z	5.1 c YZ	6.7 c Y	5.0 c YZ
Pyraflufen-ethyl/2,4-D ester	1054	5.5 d Z	10.7 d Y	12.5 d Y	9.6 d Y
4 WAE					
Non-treated control		0 a	0 a	0 a	0 a
Pyraflufen-ethyl[e]	6.7	0.3 b	0.1 ab	0.1 ab	0.1 ab
Pyraflufen-ethyl[e]	13.4	0.6 bc	0.4 b	0.4 b	0.8 b
2,4-D ester	520.3	2.0 c Z	3.1 c YZ	4.9 c Y	3.2 c YZ
2,4-D ester	1040.6	5.2 d Z	8.6 d Y	10.0 d Y	7.8 d YZ
Pyraflufen-ethyl/2,4-D ester	527	1.9 c Z	3.9 c Y	5.1 c Y	3.0 c YZ
Pyraflufen-ethyl/2,4-D ester	1054	5.6 d Z	9.1 d XY	10.8 d X	6.6 d YZ
8 WAE					
Non-treated control		0 a	0 a	0 a	0 a
Pyraflufen-ethyl[e]	6.7	0 a	0.1 ab	0.1 ab	0 a
Pyraflufen-ethyl[e]	13.4	0.1 ab	0.1 ab	0.3 bc	0.5 b
2,4-D ester	520.3	0.4 bc	0.5 bc	0.7 bcd	1.2 bc
2,4-D ester	1040.6	1.3 bc Z	3.5 d Y	2.3 d YZ	3.1 c Y
Pyraflufen-ethyl/2,4-D ester	527	0.6 bc YZ	1.6 cd Y	0.3 bc Z	0.2 ab Z
Pyraflufen-ethyl/2,4-D ester	1054	2.1 c YZ	3.5 d Y	1.6 cd Z	1.5 bc Z

Note. [a] Abbreviations: WAE, weeks after crop emergence.

[b] Means followed by the same letter within a column (a-d) 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 differences among market classes.

[c] Non-treated control excluded from analysis due to zero variance; comparison of herbicide treatments with the value zero obtained using LSMEANS table from the GLIMMIX procedure.

[d] All treatments included glyphosate (900 g ae ha^{-1}).

[e] Included Carrier surfactant (0.25% v/v).

At 2 WAE, pyraflufen-ethyl at 13.2 g ai ha^{-1} caused up to 0.7 and 1.7% dry bean injury, respectively; there was no difference in injury among dry bean market classes (Table 2). 2,4-D ester at 520.3 and 1040.6 g ai ha^{-1} caused visible injury of 4 and 6% in azuki bean; 5 and 10% in kidney bean; 7 and 12% in small red bean; and 5 and 8% in white bean, respectively (Table 2). Pyraflufen-ethyl/2,4-D ester at 527 and 1054 g ai ha^{-1} caused visible injury of 4 and 6% in azuki bean; 5 and 11% in kidney bean; 7 and 13% in small red bean; and 5 and 10% in white bean, respectively (Table 2). Similar to injury 1 WAE, dry bean injury with 2,4-D and pyraflufen-ethyl/2,4-D ester was consistently numerically less in azuki bean than other market classes of dry bean evaluated; however, differences were not always statistically significant.

At 4 WAE, pyraflufen-ethyl at 13.4 g ai ha^{-1} caused up to 0.8% dry bean injury; the response of the dry bean market classes was similar (Table 2). 2,4-D ester at 520.3 and 1040.6 g ai ha^{-1} caused visible injury of 2 and 5% in azuki bean; 3 and 9% in kidney bean; 5 and 10% in small red bean; and 3 and 8% in white bean, respectively (Table 2). Pyraflufen-ethyl/2,4-D ester at 527 and 1054 g ai ha^{-1} caused visible injury of 2 and 6% in azuki bean; 4 and 9% in kidney bean; 5 and 11% in small red bean; and 3 and 7% in white bean, respectively (Table 2). Similar to injury 1 and 2 WAE, dry bean injury with 2,4-D and pyraflufen-ethyl/2,4-D ester was consistently numerically less in azuki bean than in other dry bean market classes although differences were not always statistically significant.

Crop injury decreased over time. At 8 WAE, pyraflufen-ethyl at 6.7 and 13.4 g ai ha^{-1} caused < 0.5% injury in azuki, kidney, small red, and white beans (Table 2). 2,4-D ester at 1040.6 g ai ha^{-1} caused 1% injury in azuki bean, 4% injury in kidney bean, 2% injury in small red bean, and 3% injury in white bean (Table 2). Pyraflufen-ethyl/2,4-D ester at g ai ha^{-1} caused 2% injury in azuki bean, 4% injury in kidney bean, 2% injury in small red bean, and 2% injury in white bean (Table 2). Results are consistent with another study in which 2,4-D ester applied at 528 and 1056 g ai ha^{-1} caused up to 7% and 12% dry bean injury, respectively at 2 WAE (Soltani et al., 2019a). In another study, 2,4-D ester applied at 528 g ai ha^{-1} 14, 7, and 1 day PP, and PRE caused 1, 2, 4, and 3% injury in azuki 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 white bean at 4 WAE (Soltani et al., 2019b). Similar to the current study, injury with 2,4-D ester was generally greater in kidney, small red, and white bean than azuki bean (Soltani et al., 2019a, 2019b). Other studies have also shown no significant injury with 2,4-D ester applied PP alone or premixed with pyraflufen-ethyl in soybean (Soltani et al., 2020a). Dilliot et al. (2022) also found no/minimal soybean injury with pyraflufen/2,4-D ester applied PP.

At 3 WAE, pyraflufen-ethyl (6.7 and 13.4 g ai ha^{-1}), 2,4-D ester (520.3 and 1040.6 g ai ha^{-1}) and pyraflufen-ethyl/2,4-D ester (527 and 1054 g ai ha^{-1}) applied preplant caused no decrease in dry bean stand (Table 1). Pyraflufen-ethyl/2,4-D ester at 1054 g ai ha^{-1} reduced dry bean stand 11% compared to pyraflufen-ethyl/2,4-D ester at 527 g ai ha^{-1}. In other studies, plant stand of azuki, kidney, small red, and white bean was not adversely affected with 2,4-D ester applied one day PP at 528 g ai ha^{-1}, but was decreased as much as 13% with 2,4-D ester applied one day PP at 1056 g ai ha^{-1} (Soltani et al., 2019b).

At 3 WAE, 2,4-D (2X rate) and pyraflufen-ethyl/2,4-D ester (2X rate) reduced dry bean aboveground biomass/metre of row by 32% (Table 1). However, other treatments evaluated had no adverse effect on dry bean aboveground biomass/metre of row. Similarly, 2,4-D (2X rate) and pyraflufen-ethyl/2,4-D ester (2X rate) reduced dry bean aboveground biomass $plant^{-1}$ by 28 and 26%, respectively but other treatments evaluated had no adverse effect on dry bean aboveground biomass $plant^{-1}$ (Table 1). In other studies, aboveground biomass per meter row of azuki, kidney, small red, and white bean was reduced by 25 and 43% with 2,4-D ester applied one day PP at 528 and 1056 g ai ha^{-1}, respectively (Soltani et al., 2019b).

At 6 WAE, pyraflufen-ethyl (6.7 and 13.4 g ai ha^{-1}), 2,4-D ester (520.3 and 1040.6 g ai ha^{-1}) and pyraflufen-ethyl/2,4-D ester (527 and 1054 g ai ha^{-1}) applied preplant caused no adverse effect on the height of azuki, kidney, small red, and white bean (Table 1). In other studies, dry bean height was not adversely affected with 2,4-D ester applied one day PP at 528 g ai ha^{-1} but was decreased by 10% with 2,4-D ester applied one day PP at the 1056 g ai ha^{-1} (Soltani et al., 2019b).

At maturity, pyraflufen-ethyl (6.71 and 13.42 g ai ha^{-1}), 2,4-D ester (520.3 and 1040.6 g ai ha^{-1}) and pyraflufen-ethyl/2,4-D ester (527 and 1054 g ai ha^{-1}) applied preplant did not affect dry bean maturity as measured by seed moisture content or yield (Table 1). Results are similar to other studies in which seed yield of azuki, kidney, small red, and white bean was not adversely affected with 2,4-D ester applied one-day preplant at 528 or 1056 g ai ha^{-1} (Soltani et al., 2019b). In another study, there was also no significant adverse effect on seed yield with 2,4-D ester applied PP alone or premixed with pyraflufen-ethyl in soybean (Soltani et al., 2020a).

4. Conclusions

This study concludes that pyraflufen-ethyl (6.7 and 13.4 g ai ha^{-1}) applied preplant causes minimal injury in azuki, kidney, small red, and white bean with no adverse effect on dry bean stand, aboveground dry biomass, height, maturity, or yield. Herbicide treatments that include 2,4-D ester and pyraflufen-ethyl/2,4-D ester at twice the manufacturer's recommended rate in soybean can cause significant dry bean injury and a decrease in dry bean aboveground biomass. There was no adverse effect of the herbicides evaluated on dry bean stand, height, maturity, or yield. Generally, dry bean injury from the herbicide treatments evaluated was greater in *Phaseolus vulgaris* species than *Vigna angularis* species, however, differences were not always statistically significant. Dry bean injury decreased over time. Based on these results, there is potential for use of pyraflufen-ethyl, 2,4-D ester, and pyraflufen-ethyl/2,4-D applied PP in azuki, kidney, small red, and white beans. However, care must be taken to avoid spray overlaps with 2,4-D ester and pyraflufen-ethyl/2,4-D ester as there is potential for unacceptable crop injury. Further studies are needed to determine the preplant application timing that minimizes injury to dry bean injury with 2,4-D ester and pyraflufen-ethyl/2,4-D ester applied preplant.

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