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Response of dry bean to pendimethalin applied preplant incorporated or preemergence

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There is little information on the tolerance of dry bean to pendimethalin applied preplant incorporated (PPI) or preemergence (PRE). Five field studies were conducted over a two-year period (2009 and 2010) in major dry bean growing areas in Ontario, Canada to evaluate tolerance of black, cranberry, kidney, and white bean to the pendimethalin applied PPI or PRE at 1080 and 2160 g ai ha^{-1}. There was minimal injury in various market classes of dry bean with pendimethalin applied PPI or PRE at 1080 or 2160 g ai ha^{-1} 1 and 2 weeks after emergence (WAE). However, pendimethalin applied PRE caused slightly greater injury than pendimethalin applied PPI at 4 WAE. Pendimethalin applied PPI or PRE at 1080 or 2160 g ai ha^{-1} had no adverse effect on height of black, cranberry, kidney, and white bean except with pendimethalin at 2160 g ai ha^{-1} which decreased plant height 2% at Exeter and Ridgetown in 2009 and 2010. Pendimethalin applied PPI or PRE at 1080 or 2160 g ai ha^{-1} had no adverse effect on shoot dry weight of black, cranberry, kidney, and white bean. Yield of black, cranberry, kidney, and white bean was not adversely affected with pendimethalin applied PPI or PRE at 1080 or 2160 g ai ha^{-1} but there were differences between seed yield of various market classes of dry bean. Based on these results, there is an adequate margin of crop safety for pendimethalin applied PPI or PRE at the proposed rate of 1080 g ai ha^{-1} in black, cranberry, kidney, and white bean in Ontario.

Key words: Black bean, cranberry bean, kidney bean, navy bean, pendimethalin, *Phaseolus vulgaris* L., white bean.

INTRODUCTION

Dry bean (*Phaseolus vulgaris* L.) is an economically important agricultural crop in Ontario where nearly 77,000 tonnes are produced on approximately 34,000 hectares (Kulasekera, 2012). In 2010, dry bean had a farm-gate value of $90 million, and ranks as the fifth largest field crop grown in Ontario after corn (*Zea mays* L.), soybean (*Glycine max* L.), alfalfa (*Medicago sativa* L.), and wheat (*Triticum aestivum* L.) (Kulasekera, 2012). Major market classes of dry bean grown in Ontario include black, cranberry, kidney, and white (navy) bean. Weed management continues to be one of the major production problems for dry bean growers and is essential to optimize the yield of this non-competitive crop. Weeds left uncontrolled can reduce quality and yield of dry beans and interfere with harvesting efficiency and stain the beans (Bauer et al., 1995; Urwin et al., 1996). More research is needed to identify herbicides that provide consistent annual grass and broadleaved weed control and are safe to use on dry bean.

Pendimethalin is a dinitroaniline selective herbicide that can control smooth crabgrass (*Digitaria ischaemum* (Schreb) Muhl.), barnyardgrass (*Echinochloa crusgalli*

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(L.) Beauv.), fall panicum (*Panicum dichotomiflorum* Michx.), large crabgrass (*Digitaria sanguinalis* (L.) Scop), giant foxtail (*Setaria faberii* Herrm.), green foxtail (*Setaria viridis* (L.) Beauv.), yellow foxtail (*Setaria glauca* (L.) Beauv.), and certain annual broadleaved weeds such as common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.),(Senseman, 2007; OMAFRA, 2009). Pendimethalin is primarily absorbed by the emerging coleoptile of grasses and hypocotyl/epicotyl of broadleaf weeds. Beyond the germination stage pendimethalin is also taken up by the roots where the chemical inhibits cell division and cell elongation. Susceptible plants die shortly after germination or following emergence from the soil (Senseman, 2007).

Dry bean market classes have different geographic origins and thus different gene pools which impacts their tolerance to herbicides. Previously published research indicates that the response to soil applied herbicides varies among market classes of dry beans (Renner and Powell, 1992; Sikkema et al. 2004; Soltani et al., 2003, 2004). There is little information on the response of various market classes of dry beans to PPI and PRE applications of pendimethalin. Pendimethalin will provide dry bean growers with an additional weed management option for the control of annual grasses and small seeded broadleaved weeds such a common lambsquarters, and pigweed species in dry bean.

The objective of this research was to determine the tolerance of black, cranberry, kidney, and white bean to pendimethalin applied PPI or PRE at the rate of 1080 and 2160 g a.i. ha^{-1}, representing the 1X and 2X rate of the manufacturer's recommended rate.

MATERIALS AND METHODS

Study establishment

Five field studies were conducted over a two-year period (2009 and 2010) in major dry bean growing areas in Ontario, Canada. Locations included the University of Guelph, Huron Research Station, Exeter, ON (2009 and 2010), Agriculture and Agri-Food Canada, Greenhouse and Processing Crops Research Centre, Harrow, ON (2010), and University of Guelph, Ridgetown Campus, Ridgetown, ON (2009 and 2010). The soil type at Exeter was a Brookston clay loam soil, at Harrow was a Fox sandy loam soil, and at Ridgetown was a Brookston loam soil. Seedbed preparation at all sites consisted of fall moldboard plowing followed by two passes with a field cultivator in the spring.

Experiments were arranged in a completely randomized block design in a three way factorial arrangement with four replications. Factor 1 was market classes of dry bean (black, cranberry, kidney, white), Factor 2 was rate of pendimethalin (0, 1080 and 2160 g a.i. ha^{-1}), and Factor 3 was application timing (PPI or PRE). A non-treated check was included in each trial representing the zero dose. Plots were 3 m wide (4 rows spaced 0.75 m apart) and 10 m long at Exeter and 3 m wide and 8 m long at Harrow and Ridgetown. Within each plot there was one row of black ('Black Velvet'), cranberry ('Etna'), kidney ('Red Hawk'), and white ('T9905') bean planted to a depth of 5 cm in late May to early June of each year at a rate of 175,000, 230,000, 230,000, and 175,000 seeds ha^{-1}, respectively.

The PPI application of pendimethalin was made to the soil surface one day before planting and was immediately incorporated into the soil to a depth of 5 cm with two passes (in opposite directions) of an S-tine cultivator with rolling basket harrows. The PRE application was made to the soil surface one day after planting. Herbicide treatments were applied using 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. Plots were maintained weed free by cultivation and hand hoeing as required to eliminate the confounding effect of weed interference.

Data collection

Crop injury was evaluated visually 1, 2 and 4 weeks after emergence (WAE) using a scale of 0 to 100% where a rating of 0 was defined as no visible plant injury and a rating of 100 was defined as plant death. Ten plants per plot were randomly selected and the height from the soil surface to the highest growing point was measured 4 WAE. At 6 WAE, a 1 m section of row for each cultivar was hand harvested at the ground level, oven dried at 60°C to a constant moisture and the dry weight was recorded. Yields were measured at crop maturity by combining the remaining 9 m from each plot at Exeter and 7 m from each plot at Harrow and Ridgetown. Crops were considered physically mature when 90% of pods in the untreated plots of each cultivar had turned from green to a golden colour. All yields were adjusted to 18% moisture.

Statistical analysis

All data were subjected to analysis of variance (ANOVA) using SAS statistical software (Statistical Analysis Systems, version 9.2, Box 8000, SAS Institute Inc., Cary, NC 27512). Variance analyses combined over years and locations were performed using the *Proc Mixed* procedure of SAS. Variances were partitioned into the random effects of location, year, and year by location, block within year by location, and their interactions with fixed effects, and into the fixed effects of market class, herbicide rate, and application timing. Significance of random effects were tested using a Z-test of the variance estimate and fixed effects were tested using F-tests. Error assumptions of the variance analyses (random, homogeneous, normal distribution of error) were confirmed using residual plots and the Shapiro-Wilk normality test. To meet assumptions of the normality, injury at 1 and 4 WAE were arcsine square-root transformed, injury at 2 WAE was square-root transformed and seed moisture content was log-transformed.Means were compared using Fisher's protected LSD. The Type I error was set at 0.05 for all statistical comparisons.

RESULTS AND DISCUSSION

Analysis of variance indicated that environment by bean type by application timing by pendimethalin rate interactions were not significant for injury, therefore the five data sets were combined for analysis. Environment by bean type by application timing by pendimethalin rate interactions were significant for shoot dry weight and height (Exeter and Ridgetown could be combined, Harrow alone), and seed moisture and yield (Exeter combined, Ridgetown 2009 alone, Ridgetown 2010 alone, Harrow alone). Dry bean market class was significant for injury 2 WAE, height (Harrow), seed moisture content (Ridgetown, Harrow), yield (all). Pendimethalin rate was significant for height (Exeter and Ridgetown), seed moisture content (Exeter), yield (Ridgetown). Application timing was significant for injury at 4 WAE.

Crop injury

Visible injury symptoms caused by pendimethalin in dry bean included delayed emergence, hypocotyl swelling, brittle stem at the soil line, and growth reduction. There was minimal injury in various market classes of dry bean with pendimethalin applied PPI or PRE at 1080 or 2160 g ai ha^{-1} 1 and 2 WAE (Table 1). However, pendimethalin applied PRE caused greater injury than pendimethalin applied PPI at 4 WAE (Table 1). Results in this study are similar to other studies that have shown little or no visible injury in adzuki, kidney, pinto, otebo, and white bean with other dinitroanaline herbicides such as trifluralin (Arnold et al., 1993; McClary et al., 1989; Soltani et al., 2005b, 2010; Sikkema et al., 2006). Visible injury was higher in white bean than cranberry and kidney bean at 2 WAE (Table 1). This is similar to other studies that have shown differential sensitivity of various market classes of dry beans to other soil applied herbicides (Wilson and Miller, 1991; Bauer et al., 1995). Higher sensitivity in black and white bean market classes compared to cranberry and kidney bean market classes were reported in response to soil applied herbicides such as *S*-metolachlor, imazethapyr, flumioxazin and pyroxasulfone (Soltani et al., 2003, 2004, 2005a; Sikkema et al., 2004, 2007). Market classes of dry beans originate from different geographic regions and have different genetics which can affect their sensitivity to herbicides (Singh et al., 1991a, b, c).

Plant height

Plant height is important in dry bean production as shorter plants can have greater shatter losses at the cutter bar of the combine during harvest operations resulting in lower harvested yield. Pendimethalin applied PPI or PRE at 1080 or 2160 g ai ha^{-1} had no adverse effect on height of black, cranberry, kidney, and white bean except with pendimethalin at 2160 g ai ha^{-1} which decreased plant height 2% at Exeter and Ridgetown in 2009 and 2010 (Table 1). There were differences between heights of various market classes of dry bean at Harrow (Table 1). Cranberry bean had lower height than kidney bean which had lower height than white bean which had lower height than black bean at Harrow (2010). Other studies have shown no significant height reduction in dry bean with other dinitroanaline herbicides such as trifluralin in adzuki and otebo bean (McClary et al., 1989; Soltani et al., 2005b; Sikkema et al., 2006). However, in other studies, soil applied herbicides such as *S*-metolachlor, imazethapyr, flumioxazin and pyroxasulfone caused differential height reduction among market classes of dry bean (Soltani et al., 2003, 2004, 2005a; Sikkema et al., 2004, 2007).

Shoot dry weight

Pendimethalin applied PPI or PRE at 1080 or 2160 g ai ha^{-1} had no adverse effect on shoot dry weight of black, cranberry, kidney, and white bean in comparison to the untreated control (Table 1). In other studies root and shoot dry weight was not adversely affected with trifluralin, another dinitroanaline herbicide, in adzuki and otebo bean (McClary et al., 1989; Soltani et al., 2005b; Sikkema et al., 2006).

Seed moisture content

Seed moisture content at harvest is important in dry bean production. Dry bean should have a seed moisture content of about 18% at harvest. Low seed moisture can result in mechanical injury (split seed coats) while high seed moisture content can increase respiration and promote growth of seed embryos, bacteria and fungi. Pendimethalin applied PPI at 1080 or 2160 g ai ha^{-1} had no effect on seed moisture content except at Exeter (2009 and 2010) where seed moisture content was slightly higher with the application of pendiemethalin (Table 1). At Ridgetown (2010) with pendimethalin applied at 1080 g ai ha^{-1} the seed moisture content was slightly lower with the PRE compared to the PPI application timing (Table 2). Interestingly the seed moisture content was slightly lower with pendimethalin applied PPI at 2160 g ai ha^{-1} and pendimethalin applied PRE at 1080 g ai ha^{-1} compared to the untreated control (Table 2).

Seed yield

Yield of black, cranberry, kidney, and white bean was not adversely affected by pendimethalin application timing (PPI or PRE) but there were differences in yield among

Table 1. Significance of main effects and interactions for percent visual injury, dry weight, height, moisture and yield of four dry bean cultivars.

Main effects[b]	Injury			Dry weight		Height		Moisture				Yield			
	1 WAE	2 WAE	4 WAE	E1-4	E5	E1-4	E5	E1	E3	E2,4	E5	E1	E3	E2,4	E5
	%			g		cm		%				MT ha^{-1}			
Application timing	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Untreated	0	0	0^{b}	67	64	56	61	15.2	17.6	16.0	4.8	2.8	2.4	2.9	1.7
Preplant incorporated	0	0.3	0.2^{b}	69	64	56	61	15.1	17.6	16.3	5.0	2.9	2.6	2.8	1.7
Preemergence	0.2	2.9	1.2^{a}	69	68	55	62	15.1	17.3	16.8	4.8	2.9	2.7	2.8	1.8
SE	0.1	0.2	0.2	1	2	1	1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Dry bean market class	NS	*	NS	NS	NS	NS	**	**	**	NS	**	**	**	*	**
Black	0.1	1.4^{ab}	0.5	69	68	58	71^{a}	14.9^{b}	17.6^{bc}	16.8	4.0	3.5^{b}	2.6^{b}	3.2^{ab}	2.1^{b}
Cranberry	0.1	0.9^{b}	0.3	72	67	54	54^{d}	14.9^{b}	17.5^{b}	16.8	4.6	2.0^{c}	2.2^{c}	2.2^{c}	1.5^{c}
Kidney	0.1	1.2^{b}	0.4	70	69	56	59^{c}	14.5^{a}	16.3^{a}	16.1	5.5	2.0^{c}	2.5^{bc}	2.3^{bc}	1.2^{d}
White	0.1	2.3^{a}	1.1	67	59	55	62^{b}	16.1^{c}	18.2^{c}	16.6	5.8	4.1^{a}	3.3^{a}	3.7^{a}	2.3^{a}
SE	0.1	0.2	0.2	1	2	1	1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Pendimethalin rate (g ai/ha)	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS	**	*	NS	NS
0	0	0	0	67	64	56^{a}	61	15.2	17.6	16.0^{a}	4.8	2.8	2.4^{b}	2.9	1.7
1080	0.1	0.9	0.3	72	68	56^{a}	62	15.1	17.3	16.9^{b}	5.0	3.0	2.8^{a}	2.8	1.8
2160	0.1	2.0	0.9	68	66	55^{b}	61	15.1	17.3	16.8^{b}	4.9	2.9	2.7^{a}	2.8	1.8
SE	0.1	0.2	0.2	1	2	1	1	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1
Interactions															
T x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
T x R	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	*	NS	NS	NS
C x R	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS	NS	NS	NS
T x R x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1] Abbreviations: WAE, weeks after emergence; E1, Ridgetown 2009; E2, Exeter 2009; E3, Ridgetown 2010; E4, Exeter 2010; E5, Harrow; T, application timing; C, dry bean market class; R, pendimethalin rate; NS, not significant at P=0.05 level. [b]Significance at P<0.05 and P<0.01 levels denoted by * and **, respectively. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05. Means for a main effect were separated only if there were no significant interactions involving that main effect.[a]

the various market classes of dry bean (Table 1). Generally, black and white bean had higher seed yield than cranberry and kidney bean although results were not always statistically significant (Table 1). In 2009 at Ridgetown, pendimethalin applied PPI at 2160 g ai ha^{-1} increased seed yield 7% compared to the untreated control and pendimethalin applied PRE at 1080 g ai ha^{-1} increased seed yield 10% compared to the untreated control or pendimethalin applied PRE at 2160 g ai ha^{-1} (Table 3). Results of this study are similar to those found by Arnold et al. (1993) and

Table 2. Seed moisture and yield of dry bean at two application timings as a function of pendimethalin rate.

Pendimethalin rate (g ai ha^{-1}) by variable	Application timing		
	Preplant incorporated	Preemergence	SE
Moisture (E3)	%		
0	17.6^{abZ}	17.6^{aZ}	0.3
1080	18.0^{aY}	16.7^{bZ}	0.2
2160	17.0^{bZ}	17.5^{aZ}	0.2
SE	0.2	0.2	
Yield (E1)	MTha^{-1}		
0	2.8^{bZ}	2.8^{bZ}	0.2
1080	2.9^{abZ}	3.1^{aZ}	0.2
2160	3.0^{aZ}	2.8^{bY}	0.2
SE	0.1	0.1	

[1]E1, Ridgetown 2009; E3, Ridgetown 2010. Means followed by the same letter within a column or row for each section are not significantly different according to Fisher's Protected LSD at $P<0.05^{a}$.

Table 3. Moisture for four dry bean cultivars as a function of pendimethalin rate at Harrow in 2010.

Pendimethalin rate (g ai ha^{-1})	Dry bean market class				
	Black	Cranberry	Kidney	White	SE
			%		
0	4.1^{aZ}	4.0^{bZ}	5.4^{aY}	5.9^{aY}	0.2
1080	4.1^{aZ}	4.9^{aY}	5.4^{aX}	5.7^{aX}	0.1
2160	3.8^{aZ}	4.8^{aY}	5.5^{aX}	5.8^{aX}	0.1
SE	0.1	0.1	0.1	0.1	

Means followed by the same letter within a column or row for each section are not significantly different according to Fisher's Protected LSD at P<0.05.

Powell et al. (2004) which showed no yield reduction with dinitroanaline herbicides such as trifluralin in pinto and adzuki bean. Other studies have also shown no adverse effects on seed yield with trifluralin in adzuki, kidney, otebo, and white bean (Soltani et al., 2005b, 2010; Sikkema et al., 2006).

Conclusion

Based on this study pendimethalin applied PPI or PRE at the proposed rate of 1080 g ai ha^{-1} has an adequate margin of crop safety for used in black, cranberry, kidney, and white bean under Ontario environmental conditions. Availability of pendimethalin would provide Ontario dry bean producers with a new herbicide for the control of annual grasses and small seeded broadleaved weeds. Using pendimethalin in a diversified, integrated weed management program could also help reduce the selection intensity for herbicide resistant weeds.

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