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Tolerance of white and adzuki bean to pendimethalin plus reduced doses of imazethapyr

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A total of six field trials were conducted over a three-year period (2009 to 2011) to determine the tolerance of white and adzuki bean to pendimethalin plus reduced doses of imazethapyr applied preplant incorporated (PPI) in Ontario, Canada. There was minimal injury in white and adzuki bean with pendimethalin, imazethapyr and the tankmix of pendimethalin plus imazethapyr applied PPI at Harrow and Ridgetown. In contrast, at Exeter in 2009 and 2010, pendimethalin caused as much as 5 and 8% injury; imazethapyr caused as much as 18 and 5% injury; and the tankmix of pendimethalin plus imazethapyr caused as much as 20 and 14% injury in white and adzuki bean, respectively. Generally, the tank mixture of pendimethalin at 1080 or 2160 g ai ha^{-1} and imazethapyr at 37.5 g ai ha^{-1} had no adverse effect on height, biomass, seed moisture content and yield of white and adzuki bean. In white bean, the tank mixture of pendimethalin at 1080 or 2160 g ai ha^{-1} plus imazethapyr at 75 or 150 g ai ha^{-1} resulted in a decrease in height, biomass, and yield of white bean in some environments. In adzuki bean, the tank mixture of pendimethalin at 1080 g ai ha^{-1} plus imazethapyr at 37.5, 75 or 150 g ai ha^{-1} did not have any adverse effect on height, biomass, seed moisture content or yield. However, when the rate of pendimethalin was increased to 2160 g ai ha^{-1} in a tank mixture with imazethapyr at 37.5, 75 or 150 g ai ha^{-1}, a decrease in adzuki bean height and biomass was observed but there was no effect on seed moisture content or yield. Based on this study, there is an adequate margin of crop safety for pendimethalin at 1080 g ai ha^{-1}, imazethapyr at 37.5 g ai ha^{-1}, and the tankmix of pendimethalin plus imazethapyr at 1080 + 37.5 g ai ha^{-1} applied PPI in white and adzuki bean.

Key words: Imazethapyr, navy bean, pendimethalin, *Phaseolus vulgaris, Vigna angularis*.

INTRODUCTION

Canada is one of the largest dry bean (*Phaseolus vulgaris* L.) producing countries in the world (Breuer, 2002; McGee, 2012). Dry bean is the fifth largest field crop grown in Ontario after corn, soybean, hay and wheat in terms of farm-gate value. White and adzuki beans (*Vigna angularis* L.) are alternative high-value crops that producers can grow in sequence with wheat, corn and soybean.

Adzuki bean (*V. angularis*) is a new market class of dry bean grown in southwestern Ontario for export to Japan where it is used primarily in confectionery products (Lumpkin et al., 1993; Rubatzky and Yamaguchi, 1997; Sacks, 1977). Recent studies have shown that adzuki bean grown in the temperate climates of North America provides the needed quality for the export market to Japan and has resulted in keen interest in adzuki bean

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production in North America (Hang et al., 1993; McGill, 1995; McClary et al., 1989, 1993).

White and adzuki beans are short season crops with short physical stature which are very sensitive to weed interference, especially during the early stages of growth. The quantity and quality of dry bean harvested is dependent on weed management (Chikoye et al., 1995; Malik et al., 1993; Urwin et al., 1996). Efficient weed management programs are an important component of profitable white and adzuki bean production. Currently, there are a limited number of herbicide options available for white and adzuki bean production in Ontario. For example, when this study was initiated, adzuki bean growers had only one herbicide registered for use in Ontario. Lack of registered herbicides result in higher input costs for cultivation and hand hoeing and, white and adzuki bean yield and quality are reduced. Therefore, there is a great need for new herbicide options to keep Ontario white and adzuki bean production competitive in the global market.

Pendimethalin is a dinitroaniline selective herbicide that provides control of annual grasses such as *Echinochloa crusgalli* (L.) Beauv. (barnyardgrass), *Digitaria ischaemum* (Schreb) Muhl. (smooth crabgrass.), *Digitaria sanguinalis* (L.) Scop. (large crabgrass), *Panicum dichotomiflorum* Michx. (fall panicum), *Setaria faberi* Herrm. (giant foxtail), *Setaria viridis* (green foxtail), *Setaria glauca* (L.) Beauv. (yellow foxtail), and certain annual broadleaved weed such as *Chenopodium album* L. (common lambsquarter L.) and *Amaranthus retroflexus* L. (redroot pigweed) including acetolactate synthase and triazine-resistant biotypes (OMAFRA, 2011; Senseman, 2007). Pendimethalin is primarily absorbed by the emerging coleoptile of grasses and hypocotyl/epicotyl of broadleaved 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).

Imazethapyr is an imidiazolinone herbicide that controls annual broadleaved and grass weeds including *Abutilon theophrasti* Medic. (velvetleaf), *Amaranthus retroflexus* L., *Chenopodium album* L., *Sinapis arvensis* L. (wild mustard), *Ambrosia artemisiifolia* L. (common ragweed), *Polygonum convolvulus* L. (wild buckwheat.) and *Solanum ptycanthum* L. (Eastern black nightshade) (Arnold et al., 1993; Bauer et al., 1995; OMAFRA, 2011; Senseman, 2007; Wilson and Miller, 1991). However, imazethapyr, under some environmental conditions, has a narrow margin of crop safety in dry bean and may cause unacceptable crop injury in some market classes of dry bean at higher doses (Arnold et al., 1993; Bauer et al., 1995; Blackshaw and Saindon, 1996; Renner and Powell, 1992; Wilson and Miller, 1991).

There is little information on tolerance of white and adzuki bean to pendimethalin plus reduced doses of imazethapyr applied preplant incorporated (PPI) under Ontario environmental conditions. The tankmix of pendimethalin plus reduced doses of imazethapyr has the potential to reduce crop injury and provide broad spectrum control of troublesome weeds in white and adzuki bean. The objective of this study was to determine the tolerance of white and adzuki beans to pendimethalin, imazethapyr and the tankmix of pendimethalin plus imazethapyr applied PPI.

MATERIALS AND METHODS

Six field studies were conducted over a three-year period (2009 to 2011) in the major dry bean growing areas in Ontario, Canada. Locations included the University of Guelph, Huron Research Station, Exeter, ON (2009 to 2011), Agriculture and Agri-Food Canada, Greenhouse and Processing Crops Research Centre, Harrow, ON (2010), and University of Guelph, Ridgetown Campus, Ridgetown, ON (2010 and 2011). 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 autumn moldboard plowing followed by two passes with an S-tine cultivator with rolling basket harrows in the spring prior to herbicide application.

The experiment was arranged in a randomized block design with treatments replicated four times. Treatments are listed in Table 1. Each plot was 3.0 m (four rows) wide and 8 m long at Harrow and Ridgetown and 10 m long at Exeter and consisted of two rows of 'ERIMO' adzuki bean and two rows of 'T9905' white bean spaced 0.75 m apart. Adzuki and white bean were seeded at approximately 250,000 seeds ha^{-1} in late May to early June of each year.

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. Preplant incorporated herbicides were applied 1 to 2 days before planting and were immediately incorporated into the soil with two passes (in opposite directions) of an S-tine cultivator with rolling basket harrows. All plots were maintained weed free during the growing season by hand hoeing as required.

Adzuki and white bean 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 weight and the biomass 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 control plots of each cultivar had turned from green to a golden colour. Yields were adjusted to 18% moisture content for white bean and 13% moisture content for adzuki bean.

All data were subjected to analysis of variance (ANOVA) using SAS (2009). Variance analyses combined over years and locations were performed using the *Proc Mixed* procedure of SAS. Herbicide treatment was considered a fixed effect, while environment (year), environment by treatment interaction, and replicate nested within environment were considered random effects. Significance of the fixed effects was tested using F-tests and random effects were

Table 1. Percent visual injury observed in white and adzuki beans at Exeter (2009-2011), Harrow (2010) and Ridgetown (2010-2011) at 1, 2, and 4 weeks after emergence (WAE). Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05.

Treatment	Dose (g ai ha^{-1})	White bean Injury						Adzuki bean Injury					
		1 WAE	2 WAE			4 WAE		1 WAE	2 WAE			4 WAE	
		Pooled	Exeter		Pooled	Exeter	Pooled	Exeter		Pooled	Exeter	Pooled	Exeter	Pooled
			2009	2010		pooled		2009	2010		2009/10		pooled	
Pendimethalin	1080	0^{a}	0^{e}	0^{b}	0^{a}	0^{e}	0^{a}	2de	0^{c}	0^{a}	1^{d}	0^{a}	0^{e}	0^{a}
Pendimethalin	2160	0^{a}	5de	1^{b}	0^{a}	2de	0^{a}	6^{bc}	10^{b}	0^{a}	8^{abc}	0^{a}	7^{abc}	0^{a}
Imazethapyr	37.5	0^{a}	0^{e}	0^{b}	0^{a}	0^{e}	0^{a}	0^{e}	0^{c}	0^{a}	0^{d}	0^{a}	1^{e}	0^{a}
Imazethapyr	75	0^{a}	8^{cd}	2^{b}	0^{a}	8^{b}	0^{a}	2de	0^{c}	0^{a}	0^{d}	0^{a}	1^{e}	0^{a}
Imazethapyr	150	0^{a}	16^{ab}	6^{a}	0^{a}	18^{a}	0^{a}	1^{e}	0^{c}	1^{a}	5^{abcd}	0^{a}	4^{bcd}	0^{a}
Pendimethalin + imazethapyr	1080 + 37.5	0^{a}	4de	1^{b}	0^{a}	2de	0^{a}	4^{cd}	0^{c}	1^{a}	2^{cd}	0^{a}	0^{e}	0^{a}
Pendimethalin + imazethapyr	1080 + 75	0^{a}	7^{cd}	1^{b}	0^{a}	7^{bc}	0^{a}	4^{cd}	0^{c}	0^{a}	4^{bcd}	0^{a}	4^{bcd}	0^{a}
Pendimethalin + imazethapyr	1080 + 150	0^{a}	20^{a}	6^{a}	0^{a}	19^{a}	0^{a}	6^{bc}	1^{c}	1^{a}	5^{abcd}	0^{a}	7^{abc}	0^{a}
Pendimethalin + imazethapyr	2160 + 37.5	0^{a}	7^{cd}	1^{b}	0^{a}	3^{cde}	0^{a}	7^{ab}	13^{ab}	0^{a}	9^{ab}	0^{a}	7^{abc}	0^{a}
Pendimethalin + imazethapyr	2160 + 75	0^{a}	11^{bc}	2^{b}	0^{a}	7^{bc}	0^{a}	7^{ab}	10^{b}	0^{a}	11^{a}	0^{a}	6^{abc}	0^{a}
Pendimethalin + imazethapyr	2160 + 150	1^{a}	19^{a}	7^{a}	0^{a}	17^{a}	0^{a}	9^{a}	14^{a}	1^{a}	13^{a}	1^{a}	9^{a}	0^{a}

tested using a Z-test of the variance estimate. Environments were combined for a given variable if the environment by treatment interaction was not significant. The UNIVARIATE procedure was used to test data for normality and homogeneity of variance. Any treatment assigned a value of zero was excluded from the analysis. To satisfy the assumptions of the variance analyses, data were arcsine square root transformed or log transformed as needed. Treatment comparisons were made using Fisher's Protected LSD at a level of P<0.05. Data compared on the transformed scale were converted back to the original scale for presentation of results.

RESULTS AND DISCUSSION

Crop Injury

There was minimal injury in white bean with pendimethalin, imazethapyr and pendimethalin plus imazethapyr applied PPI at 1, 2 and 4 WAE at Harrow or Ridgetown (Table 1). However at Exeter, pendimethalin, imazethapyr and the tankmix of imazethapyr plus pendimethalin applied PPI caused as much as 5, 16 and 20% injury at 2 WAE and 2, 18 and 19% injury at 4 WAE in white bean, respectively (Table 1). In other studies, imazethapyr alone or in combination with other herbicides caused as much as 20% injury in white bean and other market classes of dry bean (Blackshaw and Saindon, 1996; Renner and Powell, 1992).

There was minimal injury in adzuki bean with pendimethalin, imazethapyr and pendimethalin plus imazethapyr applied PPI at 1, 2 and 4 WAE at Harrow or Ridgetown (Table 1). However at Exeter, pendimethalin, imazethapyr and the tankmix of imazethapyr plus pendimethalin applied PPI caused as much as 10, 2 and 14% injury at 1 WAE; 8, 5 and 13% injury at 2 WAE; and 7, 4 and 9% injury at 4 WAE in adzuki bean, respectively (Table 1). In other studies, trifluralin, another dinitroanaline herbicide caused no visible injury in adzuki, kidney, pinto, otebo and white bean (Arnold et al., 1993; McClary et al., 1993).

Plant height

Plant height is critical to dry bean growers as shorter plants increase bean shatter losses at the cutter bar of
the combine during harvest operations resulting in

Table 2. White bean height, shoot dry weight (biomass), percent seed moisture content and seed yield at Exeter (2009-2011), Harrow (2010) and Ridgetown (2010-2011). Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05.

Treatment	Dose (g ai ha^{-1})	Height (cm)	Biomass (g m row^{-1})	Seed moisture (%)	Yield (MT ha^{-1})		
					Exeter 2009	Exeter 2010	Pooled
Weed-free Control		51.4^{ab}	55.7^{a}	15.9^{d}	3.6^{a}	3.6^{bcd}	2.8^{a}
Pendimethalin	1080	50.7^{ab}	54.7^{ab}	16.2^{bcd}	3.5^{ab}	3.9^{a}	2.8^{a}
Pendimethalin	2160	52.3^{a}	56.2^{a}	16.1^{bcd}	3.5^{ab}	3.8^{ab}	2.9^{a}
Imazethapyr	37.5	51.7^{ab}	52.6^{ab}	16.3^{bcd}	3.4^{abcd}	3.7^{abc}	2.7^{a}
Imazethapyr	75	48.2^{bc}	50.4^{abc}	16.2^{bcd}	3.2^{cde}	3.2^{ef}	2.7^{a}
Imazethapyr	150	45.2^{c}	37.6^{d}	16.9^{a}	2.7^{f}	3.2^{ef}	2.3^{b}
Pendimethalin + imazethapyr	1080 + 37.5	49.8^{ab}	52.3^{abc}	16.5^{ab}	3.3^{bcde}	3.5^{bcd}	2.8^{a}
Pendimethalin + imazethapyr	1080 + 75	48.1^{bc}	43.3^{bcd}	16.0^{cd}	3.2^{cde}	3.4^{de}	2.6^{ab}
Pendimethalin + imazethapyr	1080 + 150	44.8^{c}	40.9^{cd}	16.5^{ab}	2.4^{f}	3.1^{f}	2.5^{ab}
Pendimethalin + imazethapyr	2160 + 37.5	51.5^{ab}	51.9^{abc}	16.1^{bcd}	3.3^{bcde}	3.7^{abc}	2.8^{a}
Pendimethalin + imazethapyr	2160 + 75	45.2^{ab}	45.8^{abcd}	16.5^{ab}	3.0^{e}	3.5^{bcd}	2.8^{a}
Pendimethalin + imazethapyr	2160 + 150	44.8^{c}	38.9^{d}	16.6^{ab}	2.5^{f}	3.0^{f}	2.6a^{b}

lower harvested seed yield. Pendimethalin applied PPI at 1080 or 2160 g ai ha^{-1} had no adverse effect on height of white bean (Table 2). Imazethapyr applied PPI at 37.5 and 75 g ai ha^{-1} had no adverse effect on height of white bean, however, at 150 g ai ha^{-1}, there was decreased plant height (12%) (Table 2). Pendimethalin (1080 or 2160 g ai ha^{-1}) plus imazethapyr (37.5 or 75 g ai ha^{-1}) applied PPI had no adverse effect on height of white bean. However, pendimethalin (1080 or 2160 g ai ha^{-1}) plus imazethapyr at 150 g ai ha^{-1} reduced white bean height (13%) (Table 2).

There was no adverse effect on adzuki bean height with pendimethalin, imazethapyr, and pendimethalin plus imazethapyr applied PPI at doses evaluated except for pendimethalin (2160 g ai ha^{-1}) plus imazethapyr at 150 g ai ha^{-1} which decreased adzuki bean height 8% (Table 3). Other studies have shown no significant height reduction in dry bean with trifluralin in adzuki and otebo bean (McClary et al., 1993; Soltani et al., 2006; Sikkema et al., 2006). However, soil applied herbicides such as *S*-metolachlor and imazethapyr have been shown to cause differential height reduction among market classes of dry bean (Soltani et al., 2003; Sikkema et al., 2004).

Shoot dry weight (biomass)

Pendimethalin applied PPI at 1080 or 2160 g ai ha^{-1} had no adverse effect on biomass of white bean (Table 2). Imazethapyr applied PPI at 37.5 and 75 g ai ha^{-1} had no adverse effect on biomass of white bean, however, at 150 g ai ha^{-1}, there was decreased biomass (32%) (Table 2). Pendimethalin (1080 g ai ha^{-1}) plus imazethapyr at 37.5 g ai ha^{-1} applied PPI had no adverse effect on white bean biomass. However, pendimethalin (1080 g ai ha^{-1}) plus imazethapyr at 75 and 150 g ai ha^{-1} reduced white bean biomass (22 and 27%), respectively (Table 2). Pendimethalin (2160 g ai ha^{-1}) plus imazethapyr at 37.5 and 75 g ai ha^{-1} applied PPI had no adverse effect on white bean biomass. However, pendimethalin (2160 g ai ha^{-1}) plus imazethapyr at 150 g ai ha^{-1} reduced white bean biomass (30%) (Table 2).

There was no adverse effect on adzuki bean biomass with pendimethalin, imazethapyr, and the tankmixes of pendimethalin plus imazethapyr applied PPI at doses evaluated except for pendimethalin (2160 g ai ha^{-1}) plus imazethapyr applied at 37.5 or 150 g ai ha^{-1} which decreased

Table 3. Adzuki bean height, shoot dry weight (biomass), percent seed moisture content and seed yield at Exeter (2009-2011), Harrow (2010) and Ridgetown (2010-2011). Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05.

Treatment	Dose (g ai ha^{-1})	Height (cm)	Biomass (g m row^{-1})	Seed Moisture (%)	Yield (MT ha^{-1})
Weed-free control		42.6^{ab}	27.1^{a}	13.0^{ab}	1.9^{bc}
Pendimethalin	1080	42.9^{a}	24.8^{ab}	12.9^{b}	2.0^{ab}
Pendimethalin	2160	41.0^{abc}	20.3^{abc}	13.1^{ab}	1.8^{c}
Imazethapyr	37.5	42.4^{abc}	23.2^{ab}	13.0^{ab}	2.0^{ab}
Imazethapyr	75	40.9^{abc}	23.6^{ab}	13.0^{ab}	2.0^{ab}
Imazethapyr	150	39.7^{bc}	22.0^{ab}	13.0^{ab}	2.0^{ab}
Pendimethalin + imazethapyr	1080 + 37.5	42.4^{abc}	23.1^{ab}	13.0^{ab}	2.0^{ab}
Pendimethalin + imazethapyr	1080 + 75	42.1^{abc}	24.2^{ab}	13.0^{ab}	2.1^{a}
Pendimethalin + imazethapyr	1080 + 150	40.4^{abc}	20.3^{abc}	13.2^{a}	2.0^{ab}
Pendimethalin + imazethapyr	2160 + 37.5	40.4^{abc}	17.1^{bc}	13.2^{a}	1.9^{bc}
Pendimethalin + imazethapyr	2160 + 75	40.9^{abc}	19.5^{abc}	13.1^{ab}	2.0^{ab}
Pendimethalin + imazethapyr	2160 + 150	39.3^{c}	14.9^{c}	13.1^{ab}	1.9^{bc}

adzuki biomass (37 and 45%, respectively) (Table 3). In other studies, 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 with the untreated control (Soltani et al., 2012). Other studies have also shown that root and shoot dry weight was not adversely affected by trifluralin, another dinitroanaline herbicide, in adzuki and otebo bean (McClary et al., 1993; Soltani et al., 2006; 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 spoilage due to bacterial and fungal diseases, staining, and increase drying costs and dockage at the point of sale, increase respiration and promote growth of seed embryos, bacteria and fungi. Pendimethalin applied PPI at 1080 or 2160 g ai ha^{-1} had no adverse effect on seed moisture content of white bean (Table 2). Imazethapyr applied PPI at 37.5 and 75 g ai ha^{-1} had no adverse effect on seed moisture content of white bean, however, at 150 g ai ha^{-1}, seed moisture content was increased (1%) (Table 2). Pendimethalin (1080 g ai ha^{-1}) plus imazethapyr at 75 g ai ha^{-1} had no adverse effect on white bean seed moisture content. However, pendimethalin (1080 g ai ha^{-1}) plus imazethapyr at 37.5 or 150 g ai ha^{-1} increased white bean seed moisture content (0.6%), and pendimethalin (2160 g ai ha^{-1}) plus imazethapyr at 75 or 150 g ai ha^{-1} increased white bean seed moisture content (0.6 and 0.7%), respectively (Table 2). There was no effect on adzuki bean seed moisture content with pendimethalin, imazethapyr, and the tankmix of pendimethalin plus imazethapyr applied PPI at doses evaluated (Table 3).

Seed yield

When data were pooled over environments for Harrow, Ridgetown and Exeter in 2011, there was no adverse effect on seed yield of white bean with pendimethalin, imazethapyr, and the tankmix of pendimethalin plus imazethapyr applied PPI except for imazethapyr at 150 g ai ha^{-1} which decreased seed yield (18%) (Table 2). At Exeter in 2009 and 2010, there was no negative effect of pendimethalin on white bean seed yield (Table 2). There was also no negative effect of imazethapyr at 37.5 g ai ha^{-1} on yield but as the dose of imazethapyr was increased to 75 and 150 g ai ha^{-1}, seed yield was reduced as much as 11 and 25%, respectively (Table 2). Pendimethalin (1080 g ai ha^{-1}) plus imazethapyr at 37.5 to 150 g ai ha^{-1} reduced white bean seed yield (8 to 33%) (Table 2). Pendimethalin (2160 g ai ha^{-1}) plus imazethapyr at 37.5 to 150 g ai ha^{-1} reduced seed yield (8 to 31%) (Table 2). There was no adverse effect on adzuki bean seed yield with pendimethalin, imazethapyr, and the tankmix of pendimethalin plus imazethapyr applied PPI at doses evaluated (Table 3).

In other studies, yield was reduced as much as 49% in some market classes of dry bean when imazethapyr was applied at 50 to 150 g ai ha^{-1} (Arnold et al., 1993; Bauer et al., 1995; Blackshaw and Saindon, 1996; Urwin et al., 1996; Wilson and Miller, 1991). Arnold et al. (1993) and Powell et al. (2004) found no yield reduction with other

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., 2006, 2010; Sikkema et al., 2006). Soltani et al. (2007) found no adverse effect on the yield of white bean when imazethapyr was applied at 15 to 75 g ha^{-1} or combined with dimethenamid at 1000 g ai ha^{-1}. Other studies have shown no adverse effect of combining a soil-applied grass herbicide with imazethapyr (Arnold et al., 1993; Urwin et al., 1996).

Conclusion

There was minimal injury with no adverse effect on height, biomass, seed maturity, and yield of white and adzuki bean with pendimethalin applied PPI under most environments evaluated. There was also no negative effect of imazethapyr at 37.5 g ai ha^{-1} on injury, height, biomass, seed moisture content, and yield of white and adzuki bean but as the dose of imazethapyr was increased to 75 and 150 g ai ha^{-1}, there was potential for injury, delay in maturity and reduction in height, biomass, and seed yield of white bean although adzuki bean was not generally affected. The tankmix of pendimethalin plus imazethapyr applied PPI generally provided an adequate margin of crop safety at the lowest dose but had potential to cause significant crop injury at high doses in white and adzuki bean. Based on this study, there is an adequate margin of crop safety for using pendimethalin at 1080 g ai ha^{-1}, imazethapyr at 37.5 g ai ha^{-1}, and pendimethalin plus imazethapyr at 1080 + 37.5 g ai ha^{-1} applied PPI in white and adzuki bean.

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