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Full Length Research Paper

Weed control in dry bean with Pendimethalin plus reduced rates of Imazethapyr

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Abstract

A total of six field trials were conducted over a three-year period (2008 to 2010) to evaluate various preplant incorporated (PPI) herbicides in white bean in Ontario, Canada. There was minimal visible injury or effect on seed moisture content of white bean with the herbicides evaluated. The control of AMARE, AMBEL, CHEAL, and ECHCG were as much as 76, 62, 45, and 58% with pendimethalin; 98, 78, 81, and 74% with imazethapyr at 15 g ai ha-^{1}; 99, 90, 94, and 90% with imazethapyr at 30 g ai ha-^{1}; 99, 97, 90, and 91% with imazethapyr at 45 g ai ha-^{1}; 100, 90, 99, and 95% with imazethapyr at 60 g ai ha-^{1}; 99, 99, 99, and 96% with imazethapyr at 75 g ai ha-^{1}; 99, 92, 83, and 84% with pendimethalin plus imazethapyr at 1080+15 g ai ha-^{1}; 100, 100, 97, 97% with pendimethalin plus imazethapyr at 1080+30 g ai ha-^{1}; 100, 98, 96, and 94% with pendimethalin plus imazethapyr at 1080+45 g ai ha-^{1}; 100, 98, 99, and 98% with pendimethalin plus imazethapyr at 1080+60 g ai ha-^{1}; 100, 99, 98, and 98% with pendimethalin plus imazethapyr at 1080+75 g ai ha-^{1}; 100, 97, 99, and 99% with trifluralin plus imazethapyr at 600+45 g ai ha-^{1}; 100, 100, 100, and 99% with EPTC plus imazethapyr at 3400+45 g ai ha-^{1}; and 99, 99, 99, and 99% with s-metolachlor plus trifluralin plus imazethapyr at 525+300+37.5 g ai ha-^{1}, respectively. Above ground weed biomass reduction was similar to weed control. Weed interference reduced white bean yield 6-82% with pendimethalin, imazethapyr, pendimethalin plus imazethapyr (15 g ai ha-^{1}), trifluralin plus imazethapyr, EPTC plus imazethapyr, and s-metolachlor plus trifluralin plus imazethapyr. In contrast, there was no yield loss in white bean due to weed interference with pendimethalin at 1080 g ai ha-^{1} plus imazethapyr at 30, 45, 60, or 75 g ai ha-^{1}. Therefore, pendimethalin at 1080 g ai ha-^{1} plus imazethapyr at 30, 45, 60, or 75 g ai ha-^{1} applied PPI has the potential for broad spectrum weed control in white bean in Ontario.

Keywords: Dimethenamid, EPTC, imazethapyr, navy bean, pendimethalin, s-metolachlor, trifluralin.

INTRODUCTION

Dry bean (*Phaseolus vulgaris* L.) is the fifth largest field crop grown in Ontario after corn, soybean, hay, and wheat in terms of farm-gate value. Major market classes of dry bean grown in Ontario include black, cranberry, kidney, and white (navy) bean. White bean is of economic importance to agriculture in Ontario where nearly 82,600 MT is produced on 34,000 hectares with a farm-gate value of $55 million (Breuer, 2002; McGee, 2012). White bean being a short season crop with short physical stature is 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). Major weeds in white bean production in Ontario include common lamb's-quarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), velvetleaf (*Abutilon theophrasti* Medic), wild mustard (*Sinapis arvensis* L.), common ragweed (*Ambrosia artemisiifolia* L.), *Solanum* spp. (annual nightshades), and green foxtail (*Setaria viridis* (L.) Beauv.) (OMAFRA, 2011). More research is needed to identify broad spectrum herbicides that can effectively control grass and broadleaf weeds in white bean production.

Pendimethalin is a dinitroaniline selective herbicide that provides control of annual grasses such as

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barnyardgrass (*Echinochloa crusgalli* (L.) Beauv.), smooth crabgrass (*Digitaria ischaemum* (Schreb) Muhl.), large crabgrass (*Digitaria sanguinalis* (L.) Scop), fall panicum (*Panicum dichotomiflorum* Michx., giant foxtail (*Setaria faberii Herrm.*), S. *viridis*, yellow foxtail (*Setaria glauca* (L.) Beauv.), and certain annual broadleaf weed such as C. *album* and A. *retroflexus* including acetolactate synthase and triazine-resistant biotypes (OMAFRA, 2011; Senseman, 2007).

Imazethapyr is an imidazolinone herbicide that controls several annual grass and broadleaf weeds including *Setaria* spp, E. *crus-galli*, P. *capillare*, Polygonum convolulus L. (wild buckwheat), *Polygonum persicaria* L. (ladysthumb), C. *album*, S. *arvensis, Solanum* spp., A. *retroflexus*, A. *artemisiifolia*, and A. *theophrasti* including triazine-tolerant biotypes (Arnold et al., 1993; Bauer et al., 1995; OMAFRA, 2011; Senseman, 2007; Wilson et al., 1991).

Identification of herbicides that provide consistent effective broad spectrum weed control in white bean is needed for a competitive white bean industry. There is little information on the relative efficacy of pendimethalin plus reduced rates of imazethapyr applied preplant incorporated (PPI) in white bean under Ontario environmental conditions. The objective of this study was to evaluate the efficacy of pendimethalin plus reduced rates of imazethapyr applied PPI in white bean.

MATERIALS AND METHODS

Field trials were conducted at the Agriculture and Agri-Food Canada Research Centre, Harrow, Ontario and the Huron Research Station, Exeter, Ontario in 2008 to 2010. The soil at Harrow was a Fox sandy loam (Brunisolic Gray Brown Luvisol). The soil at Exeter was a Brookston clay loam (Orthic Humic Gleysol, mixed, mesic, and poorly drained). Seedbed preparation at all sites consisted of fall 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 wide and 10 m long and consisted of four rows of ‘T9905’ white bean spaced 0.75 m apart. White bean was planted at a rate of 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 1.5 m long with four ultra-low drift nozzles (ULD120-02, Hypro, New Brighton, MN) spaced 50 cm apart. The surface area sprayed was the center 2.0 m of each plot by 10.0 m in length. There was a 1.0 m unsprayed area between adjacent plots. Preplant incorporated herbicides were applied 1-2 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. Weed-free plots were maintained weed free during the growing season by hand hoeing as required.

White bean injury and weed control were visually estimated on a scale of 0 (no injury/control) to 100% (complete plant death) 1 and 4 weeks after crop emergence (WAE), and 4 and 8 WAE, respectively. Weed shoot dry weight (aboveground biomass) was evaluated 8 WAE by cutting plants at the soil surface from two 0.5 m^2 quadrats per plot and separated by species. Plants were dried at 60 C to constant moisture and then weighed. White bean was considered mature when 90% of the pods in the weed-free check had turned from green to a golden colour. Beans were harvested from each plot with a small plot combine, weight and moisture were recorded, and yields were adjusted to 18% moisture.

Data were analyzed using PROC MIXED in SAS 9.2. 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 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 (weedy check for injury and weed control; weed-free check for injury, weed density and dry weights) was excluded from the analysis. However, all values were compared independently to zero to evaluate treatment differences with the weedy and/or weed-free checks. 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 visible injury in white bean with the herbicides evaluated at 1 and 4 WAE (data not shown). In other studies, white bean and other market classes of dry bean exhibited as much as 20% injury with imazethapyr alone or in combination with other herbicides (Blackshaw and Saindon, 1996; Renner and Powell, 1992).

Weed Control

Dominant weeds in this study as determined by quanti-

Table 1. Visual estimates of percent weed control 4 and 8 WAE with various PPI herbicides in white bean at Harrow and Exeter, ON from 2008 to 2010. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05[a]

Treatment	Rate	Visible Weed Control							
	g ai ha^{-1}	4 WAE				8 WAE			
		AMARE	AMBEL	CHEAL	ECHCG	AMARE	AMBEL	CHEAL	ECHCG
		%							
Pendimethalin	1080	73b	46h	45c	13d	76d	62c	37g	58d
Imazethapyr	15	98a	56g	81b	0e	43f	78b	50f	74c
Imazethapyr	30	99a	70ef	94a	0e	55e	90a	66e	90ab
Imazethapyr	45	99a	80cd	90ab	13d	62e	97a	78cd	91ab
Imazethapyr	60	100a	83bc	99a	40cd	76d	90a	83abc	95a
Imazethapyr	75	99a	87abc	99a	15d	77d	99a	86ab	96a
Pendimethalin + imazethapyr	1080 + 15	99a	65f	83b	49bc	82c	92a	62e	84bc
Pendimethalin + imazethapyr	1080 + 30	100a	75de	97a	90a	95a	100a	75d	97a
Pendimethalin + imazethapyr	1080 + 45	100a	83bc	96a	53bc	89ab	98a	80bcd	94a
Pendimethalin + imazethapyr	1080 + 60	100a	88ab	99a	78b	95a	98a	86ab	98a
Pendimethalin + imazethapyr	1080 + 75	100a	91a	98a	60b	94a	99a	90a	98a
Trifluralin + imazethapyr	600 + 45	100a	83bc	99a	99a	86bc	97a	83abc	95a
EPTC + imazethapyr	3400 + 45	100a	88ab	100a	99a	87bc	100a	86ab	98a
s-metolachlor + trifluralin + imazethapyr	525 + 300 + 37.5	99a	83bc	99a	99a	87bc	99a	80bcd	96a

[a] Abbreviations: AMARE, redroot pigweed; AMBEL, common ragweed; CHEAL, common lamb's quarters; ECHCG, barnyard grass; WAE, weeks after crop emergence; PPI, preplant incorporated.

fication and qualification of non-treated control plots included A. retroflexus (AMARE), A. artemisiifolia (AMBEL), C. album (CHEAL), and E. crusgalli (ECHCG).

The control of AMARE, AMBEL, CHEAL, and ECHCG ranged 73-76, 46-62, 37-45, and 13-58% with pendimethalin; 43-98, 56-78, 50-81, and 0-74% with imazethapyr at 15 g ai ha-^{1}; 55-99, 70-90, 66-94, and 0-90% with imazethapyr at 30 g ai ha-^{1}; 62-99, 80-97, 78-90, and 13-91% with imazethapyr at 45 g ai ha-^{1}; 76-100, 83-90, 83-99, and 40-95% with imazethapyr at 60 g ai ha-^{1}; 77-99, 87-99, 86-99, and 15-96% with imazethapyr at 75 g ai ha-^{1}; 82-99, 65-92, 62-83, and 49-84% with pendimethalin plus imazethapyr at 1080+15 g ai ha-^{1}; 95-100, 75-100, 75-97, 90-97% with pendimethalin plus imazethapyr at 1080+30 g ai ha-^{1}; 89-100, 83-98, 80-96, and 53-94% with pendimethalin plus imazethapyr at 1080+45 g ai ha-1; 95-100, 88-98, 86-99, and 78-98% with pendimethalin plus imazethapyr at 1080+60 g ai ha-^{1}; 94-100, 91-99, 90-98, and 60-98% with pendimethalin plus imazethapyr at 1080+75 g ai ha-^{1}; 86-100, 83-97, 83-99, and 95-99% with trifluralin plus imazethapyr at 600+45 g ai ha-^{1}; 87-100, 88-100, 86-100, and 98-99% with EPTC plus imazethapyr at 3400+45 g ai ha-^{1}; and 87-99, 83-99, 80-99, and 96-99% with s-metolachlor plus trifluralin plus imazethapyr at 525+300+37.5g ai ha-^{1}, respectively (Tables 1).

In other studies, there was no difference between s-metolachlor and trifluralin applied PPI for the control of AMARE and SETVI (Sikkema et al., 2008). However, trifluralin applied PPI provided better control of CHEAL (83 vs 71%) compared with s-metolachlor (Sikkema et al., 2008). Wall (1995) reported improved control of AMARE and CHEAL when imazethapyr was applied at 50 g ha-^{1} in white bean which is similar to findings by Blackshaw and Esau (1991) in pinto bean. However, Cantwell et al. (1991) found that imazethapyr at 50 g ha-^{1} provided only 30% control of CHEAL in soybean. Arnold et al. (1993) reported excellent control of AMARE and AMBEL with imazethapyr applied PPI at 50 or 70 g ai ha-^{1} in pinto bean. In the same study ECHCG was controlled 58-96% with imazethapyr and the control increased to 98% when imazethapyr

Table 2. Aboveground dry biomass of weeds at 8 WAE treated with various PPI herbicides in white bean at Harrow and Exeter, ON from 2008 to 2010. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05[a]

Treatment	Rate g ai ha^{-1}	Aboveground Dry Biomass			
		AMARE	AMBEL	CHEAL	ECHCG
		gm^2			
Untreated Control		26a	1448a	461a	2814a
Pendimethalin	1080	30a	1849a	59c	32d
Imazethapyr	15	4c	230b	111b	573b
Imazethapyr	30	0c	163b	29c	122c
Imazethapyr	45	1c	2c	6d	51d
Imazethapyr	60	2c	13c	30c	34d
Imazethapyr	75	0c	10c	5d	78cd
Pendimethalin + imazethapyr	1080 + 15	12b	281b	34c	123b
Pendimethalin + imazethapyr	1080 + 30	2c	6c	2d	8d
Pendimethalin + imazethapyr	1080 + 45	0c	2c	3d	105c
Pendimethalin + imazethapyr	1080 + 60	0c	0c	2d	206c
Pendimethalin + imazethapyr	1080 + 75	1c	0c	2d	24d
Trifluralin + imazethapyr	600 + 45	1c	4c	6d	71cd
EPTC + imazethapyr	3400 + 45	0c	0c	1d	14d
S-metolachlor + trifluralin + imazethapyr	525 + 300 + 37.5	2c	0c	8d	57d

[a] Abbreviations: AMARE, redroot pigweed; AMBEL, common ragweed; CHEAL, common lamb's quarters; ECHCG, barnyard grass; WAE, weeks after crop emergence; PPI, preplant incorporated

was tankmixed with EPTC, metolachlor, pendimethalin, or trifluralin (Arnold et al., 1993).

Above ground Dry Biomass

Pendimethalin applied PPI at 1080 g ai ha^{-1} did not reduce biomass of AMARE and AMBEL but reduced biomass of CHEAL 87% and ECHCG 99% compared to the untreated control (Tables 2).

Imazethapyr applied PPI at15 to 75 g ai ha^{-1} reduced AMARE 85-100%, AMBEL 84-100%, CHEAL 76-99%, and ECHCG 80-99% compared to the untreated control.

Pendimethalin (1080 g ai ha^{-1}) plus imazethapyr applied PPI at 15 to 75 g ai ha-1 reduced AMARE 54-100%, AMBEL 81-100 %, CHEAL 93-100%, and ECHCG 96-100% compared to the untreated control.

Trifluralin plus imazethapyr applied PPI at 600+45 g ai ha^{-1} reduced AMARE 96%, AMBEL 100 %, CHEAL 99%, and ECHCG 97% compared to untreated control.

EPTC plus imazethapyr applied PPI at 3400+45 g ai ha^{-1} reduced biomass of AMARE, AMBEL, CHEAL, and ECHCG 100% compared to the untreated control.

S-metolachlor plus trifluralin plus imazethapyr applied PPI at 525+300+37.5 g ai ha^{-1} reduced AMARE 92%, AMBEL 100 %, CHEAL 98%, and ECHCG 98% compared to the untreated control.

White Bean Yield and Seed Moisture Content

There was no effect on seed moisture content (maturity) of white bean with the herbicide treatments evaluated (Tables 3).

Weed interference in white bean with pendimethalin applied PPI at 1080 g ai ha^{-1} reduced yield of the white bean 35-46% compared to the weed-free control (Tables 3).

Weed interference in white bean with imazethapyr applied at15 to 75 g ai ha^{-1} reduced yield of the white bean 6-82% compared to the weed-free control (Tables 3).

Weed control with pendimethalin (1080 g ai ha^{-1}) plus imazethapyr applied PPI at 15 to 75 g ai ha^{-1} resulted in white bean yield that was equivalent to the weed-free control at all environments except at Exeter in 2009 and Harrow in 2010 where yield was decreased as much as 32% with pendimethalin (1080 g ai ha^{-1}) plus imazethapyr (15 g ai ha^{-1}) (Tables 3).

Weed control with trifluralin plus imazethapyr applied PPI at 600+45 g ai ha^{-1} resulted in white bean yields that were equivalent to the weed-free control at all environments except at Exeter in 2008/2010 where yield was decreased as much as 32% (Tables 3).

Weed control with EPTC plus imazethapyr applied PPI at 3400+45 g ai ha^{-1} resulted in white bean yields that were equivalent to the weed-free control at all environments except at Exeter in 2008/2010 where yield was decreased as much as 24% (Tables 3).

Weed control with S-metolachlor plus trifluralin plus imazethapyr applied PPI at 525+300+37.5 g ai ha^{-1} resulted in white bean yields that were equivalent to the weed-free control at all environments except at Exeter in

Table 3. Yield and seed moisture content at harvest of white bean treated with various PPI herbicides in white bean at Harrow and Exeter, ON from 2008 to 2010. Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD at P<0.05[a]

Treatment	Rate g ai ha^{-1}	Yield Environment			Moisture pooled
		Harrow 2008/2009	Harrow 2010/ Exeter 2009	Exeter 2008/2010	
		MT ha^{-1}			%
Untreated Control		0.1e	0.7e	1.5b	14.6a
Weed-free Control		1.7a	2.8a	3.4a	12.8a
Pendimethalin	1080	1.1bc	1.5bcde	2.0b	14.6a
Imazethapyr	15	0.3de	1.3de	2.9a	14.6a
Imazethapyr	30	0.6cde	1.4cde	2.9a	14.3a
Imazethapyr	45	0.7cde	1.9bcd	3.2a	14.3a
Imazethapyr	60	0.9cd	1.8bcd	3.0a	14.5a
Imazethapyr	75	0.8cd	1.9abcd	3.0a	14.0a
Pendimethalin + imazethapyr	1080 + 15	1.6a	1.9bcd	3.0a	14.4a
Pendimethalin + imazethapyr	1080 + 30	1.9a	2.2abcd	3.0a	14.4a
Pendimethalin + imazethapyr	1080 + 45	1.7a	2.3abc	3.1a	14.5a
Pendimethalin + imazethapyr	1080 + 60	2.0a	2.1abcd	3.0a	14.4a
Pendimethalin + imazethapyr	1080 + 75	1.8a	2.5ab	2.9a	14.6a
Trifluralin + imazethapyr	600 + 45	1.6a	2.1abcd	2.3b	14.3a
EPTC + imazethapyr	3400 + 45	1.7a	2.4abc	2.6b	14.1a
S-metolachlor + trifluralin + imazethapyr	525 + 300 + 37.5	1.7a	2.2abcd	2.4b	13.9a

2008/2010 where yield was decreased as much as 29% (Tables 3).

In other studies, inadequate control of broadleaf weeds such as AMARE and CHEAL has resulted in yield losses of 40-71% in white bean (Blackshaw and Saindon, 1996; Wall, 1995). Blackshaw and Esau (1991) reported 71-85% yield losses in pinto bean when AMARE and CHEAL were left uncontrolled. In other studies, there was 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} (Soltani et al., 2007). However, yield was significantly higher in kidney bean when imazethapyr was applied at 15 g ai ha-^{1} in combination with dimethenamid at 1000 g ha-^{1} compared to imazethapy at 15 g ai ha-^{1} (Soltani et al., 2007). Other studies have shown no adverse effect of combining a soil-applied grass herbicide with imazethapyr (Arnold et al., 1993; Urwin et al., 1996). However, 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; Soltani et al., 2004a, 2004b, 2006; Urwin et al., 1996; Wilson and Miller, 1991).

CONCLUSION

Based on this study weed interference with pendimethalin (1080 g ai ha-^{1}), imazethapyr (15, 30, 45, 60, or 75 g ai ha-^{1}), pendimethalin plus imazethapyr at 1080+15 g ai ha-^{1}, trifluralin plus imazethapyr at 600+45 g ai ha-^{1}, EPTC plus imazethapyr at 3400+45 g ai ha-^{1}, and s-metolachlor plus trifluralin plus imazethapyr at 525+300+37.5 g ai ha-^{1} applied PPI has the potential to cause significant yield reduction in white bean under some Ontario environmental conditions. However, pendimethalin at 1080 g ai ha-^{1} plus imazethapyr at 30, 45, 60, or 75 g ai ha-^{1} applied PPI has the potential for broad spectrum weed control with no yield reduction in white bean.

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