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Weed Management in Kidney Bean with Tank Mixes of S-Metolachlor, Imazethapyr and Linuron

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Abstract

Field studies were conducted in various locations in Ontario during 2011 to 2013 to evaluate s-metolachlor, imazethapyr and linuron applied preemergence (PRE) alone and in tankmix combination for the control of troublesome weeds in kidney bean. S-metolachlor, imazethapyr, linuron, s-metolachlor + imazethapyr, s-metolachlor + linuron and s-metolachlor + imazethapyr + linuron applied PRE at rates evaluated caused 3% or less injury in kidney bean. S-metolachlor provided 87% - 91% control of redroot pigweed, 46% - 55% control of common lambsquarters, and 96% - 97% control of green foxtail. Imazethapyr provided 93% - 96% control of redroot pigweed, 96% - 99% control of lambsquarters and 86% - 93% control of green foxtail. Linuron provided 82% - 98% control of lambsquarters, 82% - 99% control of redroot pigweed and 55% - 85% control of green foxtail. The tank mixes of s-metolachlor plus imazethapyr, s-metolachlor plus linuron, and s-metolachlor plus imazethapyr plus linuron provided 92% - 100% control of lambsquarters, redroot pigweed and green foxtail. Generally, kidney bean yields reflected the level of weed control. Based on these results, tank mixes of s-metolachlor plus imazethapyr, s-metolachlor plus linuron, and s-metolachlor plus imazethapyr plus linuron all provide an adequate margin of crop safety and excellent control of redroot pigweed, common lambsquarters and green foxtail in kidney bean.

Keywords

Biomass, Density, Herbicide Sensitivity, Injury, Kidney Bean, Tolerance, Weed Control, Yield

1. Introduction

Dry bean is an important crop in many countries around the world. Ontario has been one of the leading provinc-

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es in dry bean production in Canada where the crop has been grown since the 1940's [1]. In 2013, dry bean growers planted 36,000 hectares of dry beans and produced 83,000 MT of dry bean with a farm-gate value of approximately $90 million [2]. Dry bean is a warm season crop which is evaluated based on its seed size, shape and colour and is very sensitive to weed interference due to its short physical characteristics [3]-[7]. In Ontario, yield losses of up to 70% have been documented in dry bean when weeds were not controlled [8]. Additionally, If weeds are not adequately controlled in dry bean at harvest time, they can interfere with harvesting efficiency and cause staining of the beans, reducing seed quality and marketability [9]-[12]. There are a limited number of herbicide options that provide broad spectrum weed control in dry bean in Ontario. More research is needed to identify herbicides/tank mixes that have an adequate margin of crop safety and provide consistent broad spectrum control of troublesome weeds in dry bean.

S-metolachlor is a chloroacetanilide herbicide that can control annual grasses such as *Setaria viridis* (L.) Beauv. (green foxtail), *Setaria glauca* (L.) Beauv. (yellow foxtail), *Setaria faberii* Herrm. (giant foxtail), *Digitaria ischaemum* (Schreb) Muhl. (smooth crabgrass), *Digitaria sanguinalis* (L.) Scop. (large crabgrass), *Echinochloa crusgalli* (L.) Beauv. (barnyardgrass), *Panicum dichotomiflorum* Michx. (fall panicum) and *Panicum capillare* L. (witchgrass) [13] [14].

Imazethapyr is an imidiazolinone herbicide that can control annual broadleaf and some annual grass weeds including *Chenopodium album* L. (common lambsquarters), *Abutilon theophrasti* Medic. (velvetleaf), *Ambrosia artemesiifolia* L. (common ragweed), *Amaranthus retroflexus* L. (redroot pigweed), *Sinapis arvensis* L. (wild mustard), *Solanum ptycanthum* Dun. ex DC. pp. (Eastern black nightshade), *Polygonum convolvulus* (wild buckwheat.) and other *Polygonum* spp. [15] [16].

Linuron is a substituted urea herbicide that can control many broadleaf weeds including common lambsquarters, redwood pigweed, common ragweed, velvetleaf, common chickweed [*Stellaria media* (L.) Cyrillo], smartweed (*Polygonum* spp.), prostrate knotweed (*Polygonum arenastrum* L.), wild buckwheat (*Polygonum convovulus* L.), purslane (*Portulaca oleracea* L.), shepherd's purse [*Capsella bursa-pastoris* (L.) Medic.], annual sowthistle (*Sonchus oleraceus* L.), field pennycress (*Thlaspi arvense* L.) and wormseed mustard (*Erysimum cheiranthoides* L.), including acetolactate synthase- and triazine-resistant biotypes [15] [16].

S-metolachlor provides only partial control of some small-seeded broadleaved weeds such as common lambsquarters, redroot pigweed, and nightshades. Imazethapyr can cause significant dry bean injury under some environmental conditions and provides marginal control of common ragweed and common lambsquarters. Linuron does not adequately control troublesome grass weed species in Ontario. Tank mixing s-metolachlor, imazethapyr and linuron have the potential to provide one pass preemergence broad spectrum weed control in dry bean production.

To our knowledge, there has been no study that has compared the effect of tank mixing of s-metolachlor, imazethapyr and linuron applied PRE in kidney bean production. The objective of this study was to evaluate if a one pass preemergence weed control program with tank mixes of s-metolachlor, imazethapyr and linuron would provide full season control of troublesome annual grass and broadleaf weeds with an acceptable margin of crop safety in kidney bean under Ontario environmental conditions.

2. Materials and Methods

Field studies were conducted in 2011 to 2013 at the Huron Research Station, Exeter, Ontario and in 2012 at the Greenhouse and Processing Crops Research Centre, Agriculture and Agri-Food Canada, Harrow, Ontario. The soils ranged from Fox sandy loam to Brookston clay loam. Seedbed preparation at all sites consisted of fall moldboard plowing followed by two passes with a field cultivator in the spring.

The experiments were established as a completely randomized block with four replications. Treatments included a weedy and weed free control, s-metolachlor (1050 g a.i. ha^{-1}), imazethapyr (45 g a.i. ha^{-1}), linuron (1125 g a.i. ha^{-1}), linuron (2250 g a.i. ha^{-1}), s-metolachlor + imazethapyr (1050 + 45 g a.i. ha^{-1}), s-metolachlor + linuron (1050 + 1125 g a.i. ha^{-1}), s-metolachlor + linuron (1050 + 2250 g a.i. ha^{-1}), s-metolachlor + imazethapyr + linuron (1050 + 45+ 1125 g a.i. ha^{-1}) and s-metolachlor + imazethapyr + linuron (1050 + 45 + 2250 g a.i. ha^{-1}).

Plots were 3 m wide (4 rows spaced 0.75 m apart) and 10 m long at Exeter and 8 m long at Harrow. Within each plot there were four rows of 'Red Hawk' kidney bean. Beans were planted in late May to early June of each year.

Herbicide applications were made with a CO_2-pressurized backpack sprayer calibrated to deliver 200 L·ha^{-1} of spray solution at a pressure of 240 kPa using ultra low drift nozzles (ULD120-02, Hypro, New Brighton, MN). Treatments were applied one day after seeding and were left undisturbed on the surface of soil. Wee-free plots were maintained weed-free during the season with hand hoeing and cultivation as required.

Dry bean injury was visually estimated on a scale of 0 (no injury) to 100% (complete plant death) at 1 and 4 weeks after crop emergence (WAE). Percent weed control was visually assessed 4 and 8 WAE using a scale of 0 to100% where a rating of 0 was defined as no weed control and a rating of 100 was defined as complete control. Weed density and biomass (shoot dry weight) were also evaluated at 8 WAE by counting and cutting plants at the soil surface in two 0.5 m^2 quadrats per plot and separating by species. Plants were dried at 60˚C to constant moisture and then weighed. Dry bean was considered mature when 90% of the pods in the weed-free control had turned from green to a golden colour. Beans were harvested from middle 2 rows of each plot with a small plot combine, weight and seed moisture content were recorded, and yields were adjusted to 18% moisture.

Data were analyzed as an RCBD using PROC MIXED in SAS 9.2. Herbicide treatment was considered a fixed effect, while environment (year-location combinations), the interaction between environment and herbicide treatment, and replicate nested within environment were considered random effects. Significance of the fixed effect was tested using F-test and random effects were tested using a Z-test of the variance estimate. Environments were combined for all variables. The UNIVARIATE procedure was used to test data for normality and homogeneity of variance. For all weed control ratings, the untreated control (assigned a value of zero) was excluded from the analysis. However, all values were compared independently to zero to evaluate treatment differences with the untreated control. To satisfy the assumptions of the variance analyses, injury 1 WAE was square root transformed; injury 4 WAE was log transformed; weed control of AMARE, CHEAL and SETVI at 8 DAE were arcsine square root transformed; AMARE, CHEAL, and SETVI dry weight and density were all log transformed; yield was untransformed. 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.

3. Results and Discussion

There was no significant interaction between environments and treatments, therefore all data were pooled and averaged over environments.

3.1. Crop Injury and Yield

S-metolachlor, imazethapyr, linuron, s-metolachlor + imazethapyr, s-metolachlor + linuron and s-metolachlor + imazethapyr + linuron applied PRE at rates evaluated caused minimal (3% or less) visible injury in kidney bean at 1 and 4 WAE (**Table 1**). These results are similar to other studies that have shown less than 4% injury in kidney bean with linuron applied applied PRE at 1125 and 2250 g a.i. ha^{-1} [17]. Similarly, imazethapyr and s-metolachlor applied alone or in combination with other herbicides have been shown to cause minimal injury in dry bean with soil applied PRE herbicides including imazethapyr and s-metolachlor [3] [6] [18]-[21]. However, in contrast, other studies have shown as much as 12% injury in cranberry and kidney beans with linuron applied PRE [22] and 20% injury in dry bean with imazethapyr and s-metolachlor applied PRE alone or in combination with other herbicides [18] [23].

S-metolachlor, imazethapyr, linuron, s-metolachlor + imazethapyr, s-metolachlor + linuron and s-metolachlor + imazethapyr + linuron applied PRE at rates evaluated increased kidney bean yield compared to the weedy control (**Table 1**). S-metolachlor, imazethapyr, linuron (low rate) and s-metolachlor + imazethapyr decreased kidney bean yield 41, 29%, 35% and 24% respectively compared to the weed free control treatment (**Table 1**). However, linuron (high rate), s-metolachlor + linuron and s-metolachlor + imazethapyr + linuron applied PRE treatments provided comparable yield to the weed free control treatment (**Table 1**).

In other studies, linuron applied PRE at 1125 and 2250 g a.i. ha^{-1} did not have any adverse effect on the yield of cranberry and kidney bean [22]. In another study, linuron applied PRE at various doses did not cause any adverse effect on the yield of cranberry, kidney and white beans but yield of black bean was reduced 16% compared to the non-treated control at 2500 g·ha^{-1} [17]. Other studies have also shown that imazethapyr and s-metolachlor applied alone or in combination with other herbicides cause no reduction in yield of dry bean [3] [6] [18]-[21]. In contrast, some studies have shown as much as 25% yield reduction in dry bean with imazethapyr and s-metolachlor applied PRE alone or in combination with other herbicides [18] [23].

Table 1. Visual estimates of percent injury 1 and 4 WAE as well as yield with different rates of s-metolachlor, imazethapyr and linuron alone and in combination on kidney bean at Exeter, ON (2011-2013) and Harrow, ON (2012). 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	Injury 1 WAE	Injury 4WAE	Yield	
	g a.i. ha^{-1}	%		MT ha^{-1}	
Weedy Control		0	0	0.7	f
Weed Free		0	0	1.7	a
S-metolachlor	1050	0	0	1.0	e
Imazethapyr	45	0	1	1.2	c-e
Linuron	1125	0	0	1.1	de
Linuron	2250	0	0	1.4	a-d
S-metolachlor + Imazethapyr	1050 + 45	0	1	1.3	b-e
S-metolachlor + Linuron	1050 + 1125	0	0	1.6	ab
S-metolachlor + Linuron	1050 + 2250	2	2	1.6	ab
S-metolachlor + Imazethapyr + Linuron	1050 + 45 + 1125	0	1	1.5	a-c
S-metolachlor + Imazethapyr + Linuron	1050 + 45 + 2250	3	2	1.4	a-d

[a]Abbreviations: WAE, week after crop emergence.

3.2. Weed Control

The dominant weed species in this study included redroot pigweed (AMARE), common lambsquarters (CHEAL) and green foxtail (SETVI).

S-metolachlor, imazethapyr, linuron, s-metolachlor + imazethapyr, s-metolachlor + linuron and s-metolachlor + imazethapyr + linuron applied PRE at rates evaluated provided 87% - 100% and 82% - 100% control of AMARE at 4 and 8 WAE, respectively (**Table 2**). Generally all herbicide treatments decreased AMARE density and biomass compared to the weedy control (**Table 2**). There was no difference in density or biomass of AMARE among herbicide treatments or with weed free treatment (**Table 2**). Results are similar to other studies where imazethapyr at 15 to 75 ha^{-1} combined with dimethenamid (1000 $g \cdot ha^{-1}$) controlled AMARE 86% - 100% [23]. In other studies with cranberry bean AMARE was controlled 100% with imazethapyr plus trifluralin and 90 -100% with linuron applied PRE at 1000 and 1500 $g \cdot ha^{-1}$ [22].

S-metolachlor provided 46% - 55% control of CHEAL (**Table 3**). Imazethapyr, linuron, s-metolachlor + imazethapyr, s-metolachlor + linuron and s-metolachlor + imazethapyr + linuron applied PRE at rates evaluated provided 96% - 100% and 82% - 100% control of CHEAL at 4 and 8 WAE, respectively (**Table 3**). All herbicide treatments except s-metolachlor treatment decreased CHEAL density and biomass compared to the weedy control (**Table 3**). There was no difference in density or biomass of CHEAL among herbicide treatments or with weed free treatment except for s-metolachlor and imazethapyr applied alone which increased CHEAL density and s-metolachlor alone which increased CHEAL biomass compared to other herbicide treatments or weed free treatment (**Table 3**). Results are similar to other studies in which imazethapyr at 15 to 75 $g \cdot ha^{-1}$ plus trifluralin at 600 $g \cdot ha^{-1}$ controlled CHEAL 83% - 100% [22]. In another study imazethapyr (46 $g \cdot ha^{-1}$) combined with dimethenamid (1000 $g \cdot ha^{-1}$) controlled CHEAL as much as 95% [23]. Linuron applied PRE has also been shown to control CHEAL 11% - 100% at 1000 and 1500 $g \cdot ha^{-1}$ and 66% - 100% at the 2000 and 2500 $g \cdot ha^{-1}$ [22].

Linuron applied PRE at rates evaluated provided 55% - 85% control of SETVI (**Table 4**). S-metolachlor, imazethapyr, s-metolachlor + imazethapyr, s-metolachlor + linuron and s-metolachlor + imazethapyr + linuron applied PRE at rates evaluated provided 93% - 100% and 86% - 100% control of SETVI at 4 and 8 WAE, respectively (**Table 4**). All herbicide treatments except linuron treatments decreased SETVI density and biomass com-

Table 2. Visual estimates of percent AMARE weed control 4 and 8 WAE as well as weed density and dry weight at 8 WAE with different rates of s-metolachlor, imazethapyr and linuron alone and in combination on kidney bean at Exeter, ON (2011-2013) and Harrow, ON (2012). 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	Weed Control 4 WAE		Weed Control 8 WAE		Density		Dry Weight	
	g a.i. ha^{-1}	%		%		plant #		grams	
Weedy Control		0		0	d	2.0	b	5.7	b
Weed Free		100		100	a	0.0	a	0.0	a
S-metolachlor	1050	87		91	bc	0.3	a	1.5	ab
Imazethapyr	45	93		96	a - c	0.0	a	0.0	a
Linuron	1125	92		82	c	0.3	a	0.3	a
Linuron	2250	98		90	bc	0.0	a	0.0	a
S-metolachlor + Imazethapyr	1050 + 45	98		99	ab	0.2	a	0.7	a
S-metolachlor + Linuron	1050 + 1125	99		96	a - c	0.0	a	0.0	a
S-metolachlor + Linuron	1050 + 2250	100		98	ab	0.0	a	0.0	a
S-metolachlor + Imazethapyr + Linuron	1050 + 45 + 1125	100		99	ab	0.0	a	0.0	a
S-metolachlor + Imazethapyr + Linuron	1050 + 45 + 2250	100		100	a	0.0	a	0.0	a

[a]Abbreviations: AMARE, redroot pigweed; WAE, week after crop emergence.

Table 3. Visual estimates of percent CHEAL weed control 4 and 8 WAE as well as weed density and dry weight at 8 WAE with different rates of s-metolachlor, imazethapyr and linuron alone and in combination on kidney bean at Exeter, ON (2011-2013) and Harrow, ON (2012). 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	Weed Control 4 WAE		Weed Control 8 WAE		Density		Dry Weight	
	g a.i. ha^{-1}	%		%		plant #		grams	
Weedy Control		0	c	0	d	7.4	d	23.8	b
Weed Free		100	a	100	a	0.0	a	0.0	a
S-metolachlor	1050	55	b	46	c	3.5	cd	23.5	b
Imazethapyr	45	96	a	99	a	1.3	bc	1.2	a
Linuron	1125	96	a	82	b	0.8	ab	1.2	a
Linuron	2250	99	a	95	ab	0.2	ab	0.4	a
S-metolachlor + Imazethapyr	1050 + 45	98	a	100	a	0.3	ab	0.7	a
S-metolachlor + Linuron	1050 + 1125	98	a	92	ab	0.8	ab	1.5	a
S-metolachlor + Linuron	1050 + 2250	99	a	97	ab	0.0	a	0.0	a
S-metolachlor + Imazethapyr + Linuron	1050 + 45 + 1125	100	a	99	a	0.0	a	0.0	a
S-metolachlor + Imazethapyr + Linuron	1050 + 45 + 2250	100	a	100	a	0.0	a	0.0	a

[a]Abbreviations: CHEAL, common lambsquarters; WAE, week after crop emergence.

Table 4. Visual estimates of percent SETVI weed control 4 and 8 WAE as well as weed density and dry weight at 8 WAE with different rates of s-metolachlor, imazethapyr and linuron alone and in combination on kidney bean at Exeter, ON (2011-2013) and Harrow, ON (2012). 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	Weed Control							
		4 WAE		8 WAE		Density		Dry Weight	
	g a.i. ha^{-1}	%				plant #		grams	
Weedy Control		0	e	0	e	29.3	c	87.2	b
Weed Free		100	a	100	a	0.0	a	0.0	a
S-metolachlor	1050	97	ab	96	ab	0.8	a	0.4	a
Imazethapyr	45	93	bc	86	bc	6.8	bc	2.9	a
Linuron	1125	73	d	55	d	11.1	bc	26.6	b
Linuron	2250	85	cd	73	c	2.0	ab	3.2	a
S-metolachlor + Imazethapyr	1050 + 45	100	a	99	a	0.5	a	0.2	a
S-metolachlor + Linuron	1050 + 1125	99	a	99	a	0.5	a	0.7	a
S-metolachlor + Linuron	1050 + 2250	99	a	98	a	0.3	a	0.8	a
S-metolachlor + Imazethapyr + Linuron	1050 + 45 + 1125	100	a	100	a	0.1	a	0.0	a
S-metolachlor + Imazethapyr + Linuron	1050 + 45 + 2250	100	a	100	a	0.0	a	0.0	a

[a]Abbreviations: SETVI, green foxtail; WAE, week after crop emergence.

pared to the weedy control (**Table 4**). There was no difference in density or biomass of SETVI among herbicide treatments or with weed free treatment except for linuron which increased SETVI density and biomass compared to other herbicide treatments or weed free treatment (**Table 4**). Results are similar to other studies in which imazethapyr plus trifluralin and the sequential application of imazethapyr plus trifluralin PPI followed by linuron PRE at various doses controlled SETVI 97% - 100% in cranberry bean [22]. In other studies, imazethapyr (15 g·ha^{-1}) plus trifluralin (600 g·ha^{-1}) controlled SETVI greater than 98% and imazethapyr plus dimethenamid (18 g·ha^{-1} + 1000 g·ha^{-1}) controlled SETVI 95% in dry bean [23].

4. Conclusion

Based on this research, s-metolachlor, imazethapyr, linuron, s-metolachlor + imazethapyr, s-metolachlor + linuron and s-metolachlor + imazethapyr + linuron applied PRE at rates evaluated had an adequate margin of crop safety for use in kidney bean. S-metolachlor provided excellent full season control of redroot pigweed and green foxtail and poor control of lambsquarters. Imazethapyr provided excellent control of lambsquarters, redroot pigweed and poor control of green foxtail. Linuron at 1125 g a.i. ha^{-1} provided excellent control of lambsquarters and redroot pigweed and poor control of green foxtail. Increasing the rate of linuron to 2250 g a.i. ha^{-1} resulted in excellent control of lambsquarters and redroot pigweed and good control of green foxtail. The tank mixes of s-metolachlor plus imazethapyr, s-metolachlor plus linuron and s-metolachlor plus imazethapyr plus linuron all provided excellent control of lambsquarters, redroot pigweed and green foxtail. Generally, kidney bean yields reflected the level of weed control. Based on these results, tank mixes of s-metolachlor plus imazethapyr, s-metolachlor plus linuron and s-metolachlor plus imazethapyr plus linuron all had an adequate margin of crop safety and provided excellent control of annual broadleaf and grass species in kidney bean production in Ontario.

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