Weed control in white bean with herbicide-insecticide tankmixes

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Abstract

Six field trials (three to evaluate broadleaved weed control and three to evaluate grass weed control) were conducted from 2006 to 2008 in Ontario, Canada to evaluate the co-application of postemergence herbicides with dimethoate or cyhalothrin-lambda insecticides for control of annual broadleaved and grass weeds in white bean. Bentazon, fomesafen and bentazon plus fomesafen provided 3-62, 73-100 and 68-99% control of redroot pigweed, 34-98, 81-100 and 88-100% control of common ragweed, 78-85, 38-56 and 72-80% control of common lambsquarters, and 81-100, 97-100 and 96-100% control of wild mustard, respectively. Sethoxydim and quizalofop-p-ethyl provided 84-98 and 74-98% control of green foxtail, 91-98 and 91-97% control of giant foxtail, respectively. The addition of dimethoate or cyhalothrin-lambda insecticides to bentazon, fomesafen or bentazon plus fomesafen generally did not have any adverse effect on control, density and biomass of redroot pigweed, common ragweed, common lambsquarters and wild mustard. The addition of dimethoate or cyhalothrin-lambda to sethoxydim or quizalofop-p-ethyl decreased control of green foxtail and giant foxtail as much as 6% under some environments but did not have any significant effect on green foxtail and giant foxtail density and biomass. Injury in white bean was minimal (6% or less) with no adverse effect on yield in both studies. These studies conclude that dimethoate or cyhalothrin-lambda can be tankmixed with bentazon, fomesafen, bentazon plus fomesafen, sethoxydim or quizalofop-p-ethyl when the optimum application timing of theses herbicides and insecticides coincide with no adverse effect on weed control or white bean yield.

Keywords: Biomass, cyhalothrin-lambda, density, dimethoate, white bean, yield.

INTRODUCTION

Dry bean (*Phaseolus vulgaris* L.) is an important crop in southwestern Ontario where 57,000 hectares of dry bean were planted in 2010 with a market value of approximately $100,000,000 (McGee 2011). Dry bean is commonly grown in rotation with other crops such as corn (*Zea mays* L.) and soybean (*Glycine max* L.) as it offers growers a higher net return than traditional field crops, and can break pest cycles where continuous corn or soybean is grown. The quantity and quality of dry bean harvested is dependent on effective and efficient pest management. Growers often use postemergence (POST) herbicides such as bentazon, fomesafen and bentazon plus fomesafen for annual broadleaved weed control and

sethoxydim and quizalofop-p-ethyl for grass weed control in dry bean.

Bentazon is a benzothiadiazole herbicide that controls *Chenopodium album* L. (common lambsquarter), *Amaranthus retroflexus* L. (redroot pigweed), *Ambrosia artemesiifolia* L. (common ragweed), *Abutilon theophrasti* Medic. (velvetleaf), *Sinapis arvensis* L. (wild mustard), *Polygonum persicaria* L. (ladysthumb), *Xanthium strumarium* L. (cocklebur), *Datura stramonium* L. (jimsonweed), *Capsella bursa-pastoris* (L.) Medic (shepherdspurse) and *Stellaria media* (L.) Vill. (common chickweed) including group II and V resistant biotypes (Senseman, 2007; OMAFRA, 2011).

Fomesafen is a diphenyl ether herbicide that controls *Amaranthus retroflexus, Sinapis arvensis*, *Polygonum persicaria*, *Ambrosia artemesiifolia*, *Xanthium strumarium* and *Solanum spp.* (black nightshade) (OMAFRA, 2011; Senseman, 2007). Bentazon in tank mix combination with fomesafen can provide improved control of broadleaved weeds such as *Amaranthus* spp., *Ambrosia* spp., *Solanum* spp. and *Polygonum convolvulus* L. (wild buckwheat) (Senseman, 2007; OMAFRA, 2011).

Sethoxydim and quizalofop-p-ethyl control annual and perennial grass species such as *Setaria viridis* (L.) Beauv. (green foxtail), *Digitaria sanguinalis* (L.) Scop. (large crabgrass), *Echinochloa crusgalli* L. (barnyard grass), *Panicum dichotomiflorum* Michx. (fall panicum), *Panicum miliaceum* L. (proso millet), *Panicum capillare* L. (witchgrass) and *Elytrigia repens* (L.) Nevski (quackgrass) (Senseman, 2007; OMAFRA, 2011).

There are several troublesome insect pests that dry bean growers in Ontario have to control for profitable production. These insect pests include potato leafhopper (*Empoasca fabae*), bean leaf beetle (*Certoma trifurcata*), Mexican bean beetle (*Epilachna varivestis*), western bean cutworm (*Striacosta albicosta*) and tarnished plant bug (*Lygus lineolaris*). Growers often use a single or multiple foliar applications of dimethoate (Lagon®) and cyhalothrin-lambda (Matador®) insecticides during the growing season to effectively control troublesome insects in dry bean (OMAFRA, 2009). Optimum application timing of postemergence herbicides and insecticides may coincide, however, currently there are no herbicide plus insecticide tank mix combinations labelled for use in dry bean in Ontario. Co-application of herbicides with an insecticide would allow growers to reduce the number of passes through the field thereby reducing fuel and labor costs, machinery depreciation, soil compaction, as well as mechanical damage to dry bean foliage (Jordan et al., 2003, 2006; Lancaster et al. 2005a, 2005b; Robinson et al. 2006; Grichar and Prostko, 2009 Limited information exists on the effects of tankmixing dimethoate or cyhalothrin-lambda with bentazon, fomesafen, bentazon plus fomesafen, sethoxydim or quizalofop-p-ethyl in white bean production. In addition, information on compatibility of bentazon, fomesafen, bentazon plus fomesafen, sethoxydim or quizalofop-p-ethyl with dimethoate or cyhalothrin-lambda insecticides is very important to dry bean growers since incompatibility in the tank can result in plugged nozzles, equipment damage, crop injury as well as reduction in weed and insect control .Therefore, the objectives of this study were to evaluate the effects of the co-application of dimethoate or cyhalothrin-lambda with bentazon, fomesafen, bentazon plus fomesafen, sethoxydim or quizalofop-p-ethyl for the control of annual broadleaved and grass weeds in white bean.

MATERIALS AND METHODS

Six field trials were conducted over a three-year period (2006 to 2008) at the Huron Research Station near Exeter, ON Canada. The soil type was a Brookston clay loam (Orthic Humic Gleysol, mixed, mesic, and poorly drained) with 34% sand, 36% silt, 30% clay, 3.6% organic matter and pH of 8.0 in 2006; 39% sand, 37% silt, 24% clay, 4.3% organic matter and pH of 7.9 in 2007; and 28% sand, 38% silt, 34% clay, 4.1% organic matter and pH of 7.9 in 2008. Seedbed preparation at all sites consisted of fall moldboard plowing followed by three passes with a field cultivator in the spring.

The experiments (three to evaluate broadleaved weed control and three to evaluate grass weed control) were established adjacent to each other as a completely randomized block with four replications. There were 13 treatments in the broadleaved weed control trials and 10 treatments in the grass weed control trials as listed in Table 1. Plots were 3 m wide and 10 m long and consisted of four rows spaced 0.75 m apart of white ('OAC REX') bean planted 5 cm deep at a rate of 235,000 seed ha^{-1} in late May to early June of each year.

Herbicide and insecticide applications were applied using a CO_2 pressurized backpack sprayer equipped with Hypro ULD120-02 nozzle tips (Hypro, New Brighton, MN, USA) calibrated to deliver 200 L ha^{-1} aqueous solution at 241 kPa. The boom was 1.5 m long with four nozzles spaced 0.5 m apart. Treatments were applied at the 1-3 trifoliate leaf stage. Weed-free treatments were main-

Table 1. Herbicide and insecticide treatment combinations and rates

	Treatment	Rate
		g ai ha^{-1}
Annual broadleaved weed control trials		
1	Weedy check	0
2	Weed free check	0
3	Bentazon	1080
4	Fomesafen[a]	240
5	Bentazon + fomesafen	840 + 140
6	Dimethoate	480
7	Cyhalothrin-lambda	10
8	Bentazon + dimethoate	1080 + 480
9	Bentazon + cyhalothrin-lambda	1080 + 10
10	Fomesafen + dimethoate[a]	240 + 480
11	Fomesafen + cyhalothrin-lambda[a]	240 + 10
12	Bentazon + fomesafen + dimethoate	840 + 140 + 480
13	Bentazon + fomesafen + cyhalothrin-lambda	840 + 140 + 10
Annual grass weed control trials		
1	Weedy check	0
2	Weed-free check	0
3	Sethoxydim[b]	150
4	Quizalofop-p-ethyl[c]	36
5	Dimethoate	480
6	Cyhalothrin-lambda	10
7	Sethoxydim + dimethoate[b]	150 + 480
8	Sethoxydim + cyhalothrin-lambda[b]	150 + 10
9	Quizalofop-p-ethyl + dimethoate[c]	36 + 480
10	Quizalofop-p-ethyl + cyhalothrin-lambda[c]	36 + 10

Included non-ionic surfactant (0.25% v/v).
[b] Included Merge (1 L ha^{-1}).
[c] Included Sure-mix (0.5% v/v).

tained with hand hoeing and cultivation during the season as required.

Visible crop injury was evaluated 1 and 4 weeks after herbicide treatment (WAT) and percent weed control was evaluated change to evaluated 4 and 8 WAT on a scale of 0 to 100% (0% = no injury/no control and 100% = plant death/complete weed control). Weed density and biomass (shoot dry weight) from weed populations naturally occurring in each plot was determined at 8 WAT by cutting the plants at the soil surface from two 0.5-m^{-2} quadrats (total of 1 m^{-2}). Weeds were separated by species, combined from the two quadrats in each plot, counted (weed density), and dried at 60 ^{o}C to a constant moisture and the dry weight was recorded. At physiological maturity (when 90% of pods in the untreated plots of each cultivar had turned from green to a golden colour), dry bean was harvested from the two middle rows of each plot using a small-plot combine. Yields were adjusted to 18% seed moisture content.

All data were subjected to analysis of variance (ANOVA). Data were analyzed using the PROC MIXED procedure of Statistical Analysis Systems (SAS, 2008).

Table 2. Contrasts planned for treatment comparisons

Contrast label	Contrast description	Treatments
Annual broadleaved weed control trials		
B vs B+D	bentazon vs bentazon + dimethoate	3 vs 8
B vs B+C	bentazon vs bentazon + cyhalothrin-lambda	3 vs 9
F vs F+D	fomesafen vs fomesafen + dimethoate	4 vs 10
F vs F+C	fomesafen vs fomesafen + cyhalothrin-lambda	4 vs 11
BF vs BF+D	bentazon + fomesafen vs bentazon + fomesafen + dimethoate	5 vs 12
BF vs BF+C	bentazon + fomesafen vs bentazon + fomesafen + cyhalothrin-lambda	5 vs 13
Annual grass weed control trials		
S vs S+D	sethoxydim vs sethoxydim + dimethoate	3 vs 7
S vs S+C	sethoxydim vs sethoxydim + cyhalothrin-lambda	3 vs 8
Q vs Q+D	quizalofop-p-ethyl vs quizalofop-p-ethyl + dimethoate	4 vs 9
Q vs Q+C	quizalofop-p-ethyl vs quizalofop-p-ethyl + cyhalothrin-lambda	4 vs 10

Variances were partitioned into the fixed effects of herbicide/insecticide treatment and the random effects of environment, replication (within environment) and the interactions with fixed effects. Significance of fixed effects was tested using F-tests and random effects were tested using a Z-test of the variance estimate. The assumptions of the variance analyses (random, homogeneous, normal distribution of error) were confirmed using residual plots and the Shapiro-Wilk statistic. To meet the assumptions of the variance analysis, percent control, density and biomass were subjected to log transformation or square root transformation if needed. Data were compared on the transformed scale and were converted back to the original scale for presentation of results. Yield data did not require any transformation. Treatments were compared using planned contrasts (Table 2). The Type I error was set at $P<0.05$ for all statistical comparisons.

RESULTS AND DISCUSSION

Data were pooled and averaged over environments when the environment by treatment interaction was not significant. There were no visible incompatibility problems in respect to the spray solution or application with the various herbicide plus insecticide tank mix combinations evaluated in this study.

Annual Broadleaved Weed Control Trials

White bean injury

Bentazon, fomesafen and bentazon plus fomesafen caused 0-2.9% injury in white bean at 1 WAT (Table 3). The addition of dimethoate insecticide to bentazon or bentazon plus fomesafen resulted in increased injury of 6.3 and 5.2%, respectively (Table 3). However, the addition of cyhalothrin-lambda insecticide to bentazon, fomesafen or bentazon plus fomesafen did not cause an increase in injury in white bean. Crop injury was zero for all treatments at 4 WAT and not analyzed. In other studies, VanGessel et al. (2000) reported 3 to 20% visual injury to dry bean with bentazon applied POST. However, other studies have shown less than 3% injury in black bean and less than 2% injury in cranberry bean with bentazon applied POST at 1080 g ha^{-1} (Soltani et al. 2005). Minimal visual injury was also reported with fomesafen applied POST in tank mix with other herbicides (Soltani et al. 2005).

Weed control efficacy

Bentazon, fomesafen and bentazon plus fomesafen provided 3-62, 73-100 and 68-99% control of redroot

Table 3. Contrasts comparing white bean injury 1 WAT for herbicide and insecticide treatment combinations at Exeter, ON.[a]

Treatment comparison	2006	2007&2008
	%	
B vs B+D	2.7 vs 2.0	2.2 vs 8.5*
B vs B+C	2.7 vs 2.2	2.2 vs 3.5
F vs F+D	0 vs 0.8	0.2 vs 0.2
F vs F+C	0 vs 0.8	0.2 vs 0
BF vs BF+D	1.8 vs 2.2	2.9 vs 8.1*
BF vs BF+C	1.8 vs 0.5	2.9 vs 1.9

* Denotes significance at P<0.05.
Abbreviations: B, bentazon; C, cyhalothrin-lambda; D, dimethoate; F, fomesafen; WAT, weeks after treatment.

pigweed in dry bean, respectively (Table 4). The addition of dimethoate or cyhalothrin-lambda insecticides to bentazon, fomesafen or bentazon plus fomesafen did not have any effect on control of redroot pigweed except for bentazon plus dimethoate and bentazon plus cyhalothrin-lambda which increased control of redroot pigweed 37% and 27% compared to bentazon alone at 4 WAT in 2008, respectively (Table 4). This increase in pigweed control with the addition of an insecticide to bentazon was not observed in the studies completed in 2006 and 2007 and was not observed in all three years at 8 WAT. The addition of dimethoate or cyhalothrin-lambda insecticides to bentazon, fomesafen or bentazon plus fomesafen did not have any effect on density and biomass of redroot pigweed (Table 4).

Bentazon, fomesafen and bentazon plus fomesafen provided 34-98, 81-100 and 88-100% control of common ragweed in dry bean, respectively (Table 5). The addition of dimethoate or cyhalothrin-lambda insecticides to bentazon, fomesafen or bentazon plus fomesafen did not have any effect on the control of common ragweed except for bentazon plus dimethoate which increased control 28% in 2006 and 2007 and bentazon plus cyhalothrin-lambda which increased control 2% in 2008 compared to bentazon alone at 8 WAT (Table 5). The addition of dimethoate or cyhalothrin-lambda insecticides to bentazon, fomesafen or bentazon plus fomesafen did not have any effect on density and biomass of common ragweed (Table 5).

Bentazon, fomesafen and bentazon plus fomesafen provided 78-85, 38-56 and 72-80% control of common lambsquarters in dry bean, respectively (Table 6). The addition of dimethoate or cyhalothrin-lambda insecticides to bentazon, fomesafen or bentazon plus fomesafen did not have any effect on common lambsquarters control at 4 and 8 WAT, density and biomass (Table 6).

Bentazon, fomesafen and bentazon plus fomesafen provided 81-100, 97-100 and 96-100% control of wild mustard in dry bean, respectively (Table 7). The addition of dimethoate or cyhalothrin-lambda insecticides to bentazon, fomesafen or bentazon plus fomesafen did not have any effect on wild mustard control at 4 and 8 WAT, density and biomass (Table 7).

Weed control results correspond well with those of Burnside et al. (1998) who found improved broadleaved weed control in kidney bean with bentazon POST. Wall (1995) found good control of common lambsquarters with bentazon alone in navy bean. Wilson (2005) also reported improved control of redroot pigweed and common lambsquarters when a tank mixture of bentazon plus fomesafen POST was applied in dry bean. Fomesafen has been reported to control 90% or more of redroot pigweed in mung bean (Balyan and Malik 1989). Fomesafen and fomesafen plus bentazon have been reported to provide good control of common lambsquarters in snap bean (Bailey et al., 2003).

White bean yield

The addition of dimethoate or cyhalothrin-lambda insecticides to bentazon, fomesafen or bentazon plus fomesafen did not have any effect on yield of dry bean except for fomesafen plus dimethoate and fomesafen

Table 4. Contrasts comparing redroot pigweed control 4 and 8 WAT, density and dry weight for herbicide and insecticide treatment combinations at Exeter, ON.[a]

	4 WAT		8 WAT			
Treatment comparison	**2006&2007**	**2008**	**2006&2007**	**2008**	**Density[b]**	**Dry weight[b]**
	%				# m^{-2}	g m^{-2}
B vs B+D	59 vs 53	3 vs 40*	62 vs 57	32 vs 45	5.4 vs 4.7	17.6 vs 27.9
B vs B+C	59 vs 76	3 vs 30*	62 vs 70	32 vs 42	5.4 vs 3.1	17.6 vs 6.4
F vs F+D	81 vs 81	97 vs 93	73 vs 76	100 vs 98	1.1 vs 1.2	1.3 vs 1.6
F vs F+C	81 vs 74	97 vs 99	73 vs 65	100 vs 100	1.1 vs 0.7	1.3 vs 1.2
BF vs BF+D	71 vs 60	94 vs 94	68 vs 60	99 vs 96	2.4 vs 2.2	4.7 vs 6.4
BF vs BF+C	71 vs 69	94 vs 98	68 vs 60	99 vs 99	2.4 vs 2.2	4.7 vs 3.8

* Denotes significance at P<0.05.
Abbreviations: B, bentazon; C, cyhalothrin-lambda; D, dimethoate; F, fomesafen; WAT, weeks after treatment.
[b] Data were averaged for 2006-2008 (environment by treatment interaction was not significant)

Table 5. Contrasts comparing common ragweed control 4 and 8 WAT, density and dry weight for herbicide and insecticide treatment combinations at Exeter, ON. [a]

		8 WAT			
Treatment comparison	**4 WAT[b]**	**2006&2007**	**2008**	**Density[b]**	**Dry weight[b]**
	%			# m^{-2}	g m^{-2}
B vs B+D	77 vs 86	34 vs 62*	98 vs 99	0.4 vs 0.6	1.3 vs 0.7
B vs B+C	77 vs 91	34 vs 48	98 vs 100*	0.4 vs 0.3	1.3 vs 0.6
F vs F+D	91 vs 96	81 vs 91	100 vs 100	0.2 vs 0.2	0.6 vs 0.3
F vs F+C	91 vs 97	81 vs 88	100 vs 100	0.2 vs 0.2	0.6 vs 0.2
BF vs BF+D	93 vs 89	88 vs 80	100 vs 100	0.3 vs 0.5	1.0 vs 1.3
BF vs BF+C	93 vs 93	88 vs 88	100 vs 100	0.3 vs 0.1	1.0 vs 0.2

* Denotes significance at P<0.05.
Abbreviations: B, bentazon; C, cyhalothrin-lambda; D, dimethoate; F, fomesafen; WAT, weeks after treatment.
[b] Data were averaged for 2006-2008 (environment by treatment interaction was not significant).

Table 6. Contrasts comparing common lamb'squarters control 4 and 8 WAT, density and dry weight for herbicide and insecticide treatment combinations at Exeter, ON.[a,b]

Treatment comparison	4 WAT	8 WAT`	Density	Dry weight
	%		# m^{-2}	g m^{-2}
B vs B+D	85 vs 84	78 vs 77	5.4 vs 4.1	9.1 vs 5.5
B vs B+C	85 vs 92	78 vs 81	5.4 vs 1.9	9.1 vs 3.8
F vs F+D	56 vs 66	38 vs 46	12.1 vs 9.7	78.5 vs 58.1
F vs F+C	56 vs 63	38 vs 45	12.1 vs 6.4	78.5 vs 28.4
BF vs BF+D	80 vs 79	72 vs 69	6.6 vs 5.7	13.8 vs 20.3
BF vs BF+C	80 vs 80	72 vs 69	6.6 vs 4.7	13.8 vs 7.7

* Denotes significance at P<0.05.
Abbreviations: B, bentazon; C, cyhalothrin-lambda; D, dimethoate; F, fomesafen; WAT, weeks after treatment.
[b] Data were averaged for 2006-2008 (environment by treatment interaction was not significant).

Table 7. Contrasts comparing wild mustard control 4 and 8 WAT, density and dry weight for herbicide and insecticide treatment combinations at Exeter, ON.[a]

	4 WAT				
Treatment comparison	2006&2007	2008	8 WAT[b]	Density[b]	Dry weight[b]
	%			# m^{-2}	g m^{-2}
B vs B+D	81 vs 74	85 vs 87	100 vs 99	0.4 vs 0.6	0.5 vs 0.4
B vs B+C	81 vs 80	85 vs 84	100 vs 97	0.4 vs 1.0	0.5 vs 0.9
F vs F+D	97 vs 92	100 vs 100	100 vs 100	0 vs 0	0 vs 0
F vs F+C	97 vs 99	100 vs 100	100 vs 100	0 vs 0	0 vs 0
BF vs BF+D	96 vs 94	99 vs 100	100 vs 100	0 vs 0	0 vs 0
BF vs BF+C	96 vs 91	99 vs 100	100 vs 100	0 vs 0.1	0 vs 0.6

* Denotes significance at P<0.05.
Abbreviations: B, bentazon; C, cyhalothrin-lambda; D, dimethoate; F, fomesafen; WAT, weeks after treatment.
[b] Data were averaged for 2006-2008 (environment by treatment interaction was not significant).

cyhalothrin-lambda which increased yield compared to fomesafen alone in 2008 (Table 8). In other studies, herbicides such as bentazon, fomesafen and bentazon plus fomesafen caused no adverse effect on yield of dry bean (VanGessel et al., 2000; Sikkema et al. 2004; Soltani et al., 2005; Soltani and Sikkema 2005). Blackshaw et al. (2000) also reported no yield reduction in dry bean with the POST application of bentazon. However, Wall (1995) found up to 21% yield reduction in white navy bean with bentazon applied POST.

Annual Grass Weed Control Trials

White bean injury

Sethoxydim or quizalofop-p-ethyl caused 0 to 5% injury in white bean at 1 WAT (data not shown). Crop injury was zero for all treatments at 4 WAT and not analyzed. Also, the addition of dimethoate or cyhalothrin-lambda insecticides to sethoxydim and quizalofop-p-ethyl did not increase injury in white bean (data not shown). Results

Table 8. Contrasts comparing white bean yield for herbicide and insecticide treatment combinations at Exeter, ON.

Treatment comparison	2006&2007	2008
	MT ha^{-1}	
B vs B+D	1.48 vs 1.33	3.08 vs 3.15
B vs B+C	1.48 vs 1.51	3.08 vs 3.29
F vs F+D	1.33 vs 1.46	2.60 vs 3.16*
F vs F+C	1.33 vs 1.44	2.60 vs 3.31*
BF vs BF+D	1.45 vs 1.46	3.06 vs 3.23
BF vs BF+C	1.45 vs 1.37	3.06 vs 3.34

* Denotes significance at P<0.05.
Abbreviations: B, bentazon; C, cyhalothrin-lambda; D, dimethoate; F, fomesafen; WAT, weeks after treatment.

Table 9. Contrasts comparing green foxtail control 4 and 8 WAT, density and dry weight for herbicide and insecticide treatment combinations at Exeter, ON.[a]

	4 WAT		8 WAT			
Treatment comparison	2006&2008	2007	2006&2008	2007	Density[b]	Dry weight[b]
	%				# m^{-2}	g m^{-2}
S vs S+D	97 vs 97	85 vs 86	98 vs 98	84 vs 89	3.0 vs 2.0	2.4 vs 2.4
S vs S+C	97 vs 95	85 vs 80*	98 vs 97	84 vs 80	3.0 vs 2.4	2.4 vs 3.7
Q vs Q+D	96 vs 96	75 vs 69*	98 vs 97	74 vs 68*	3.7 vs 4.1	5.1 vs 6.5
Q vs Q+C	96 vs 96	75 vs 75	98 vs 98	74 vs 79	3.7 vs 3.1	5.1 vs 3.7

* Denotes significance at P<0.05.
Abbreviations: C, cyhalothrin-lambda; D, dimethoate; Q, quizalofop-p-ethyl; S, sethoxydim; WAT, weeks after treatment.
[b] Data were averaged for 2006-2008 (environment by treatment interaction was not significant).

are similar to other studies that have shown sethoxydim and quizalofop-p-ethyl cause no reduction in biomass of dry bean (VanGessel et al., 2000; Sikkema et al. 2004; Soltani et al., 2005). However, Burnside et al. (1994) has reported as much as 11% of dry bean injury when sethoxydim was applied POST in combination with imazethapyr or acifluorfen and bentazon.

Weed control efficacy

Sethoxydim provided 84-98% and quizalofop-p-ethyl provided 74-98% control of green foxtail in dry bean (Table 9). The addition of dimethoate or cyhalothrin-lambda insecticides to sethoxydim or quizalofop-p-ethyl did not have any adverse effect on control of green foxtail except for sethoxydim plus cyhalothrin-lambda which decreased control 5% compared to sethoxydim alone in 2007 at 4 WAT and quizalofop-p-ethyl plus dimethoate which decreased control 6% compared to quizalofop-p-ethyl alone at 4 and 8 WAT in 2007 (Table 9). The addition of dimethoate or cyhalothrin-lambda insecticides to sethoxydim or quizalofop-p-ethyl did not have any effect on green foxtail density and biomass in dry bean (Table 9).

Sethoxydim provided 91-98% and quizalofop-p-ethyl provided 91-97% control of giant foxtail in dry bean (Table 10). The addition of dimethoate or cyhalothrin-lambda insecticides to sethoxydim or quizalofop-p-ethyl did not have any adverse effect on the control of green foxtail except for sethoxydim plus cyhalothrin-lambda insecticide which decreased giant foxtail control 2% compared to sethoxydim alone and quizalofop-p-ethyl plus dimethoate which decreased giant foxtail control 2% compared to quizalofop-p-ethyl alone at 4 WAT in 2007 (Table 10).

Table 10. Contrasts comparing giant foxtail control 4 and 8 WAT, density and dry weight for herbicide and insecticide treatment combinations at Exeter, ON. [a,b]

Treatment comparison	4 WAT	8 WAT	Density	Dry weight
	%		# m^{-2}	g m^{-2}
S vs S+D	98 vs 97	91 vs 92	0.1 vs 0	0.1 vs 0
S vs S+C	98 vs 96*	91 vs 90	0.1 vs 0	0.1 vs 0
Q vs Q+D	97 vs 95*	91 vs 89	0.1 vs 0	1.5 vs 0
Q vs Q+C	97 vs 97	91 vs 91	0.1 vs 0	1.5 vs 0

* Denotes significance at P<0.05.
Abbreviations: C, cyhalothrin-lambda; D, dimethoate; Q, quizalofop-p-ethyl; S, sethoxydim; WAT, weeks after treatment.
[b] Data were averaged for 2006-2008 (environment by treatment interaction was not significant).

White bean yield

White bean yield was 1.26 MT ha^{-1} for the weedy check, 2.01 MT ha^{-1} for the weed-free check, and ranged from 1.87 to 1.98 MT ha^{-1} for the herbicide and herbicide plus insecticide treatments (data not shown). The addition of cyhalothrin-lambda or dimethoate insecticides to sethoxydim and quizalofop-p-ethyl did not have any effect on yield of white bean under the various environments evaluated (data not shown). In other studies, sethoxydim and quizalofop-p-ethyl caused no adverse effect on yield of dry bean (VanGessel et al., 2000; Sikkema et al. 2004; Soltani et al., 2005; Soltani and Sikkema 2005). Burnside et al. (1994) reported no adverse effect on yield of dry bean when sethoxydim was applied POST in combination with imazethapyr or acifluorfen and bentazon.

CONCLUSIONS

Based on this research, the addition of dimethoate or cyhalothrin-lambda insecticides to bentazon, fomesafen or bentazon plus fomesafen generally did not have any adverse effect on control, density and biomass of broadleaved weeds such as redroot pigweed, common ragweed, common lambsquarters and wild mustard or yield of white bean. The addition of dimethoate or cyhalothrin-lambda to sethoxydim or quizalofop-p-ethyl caused a minimal decrease (6% or less) in control of annual grasses such as green foxtail and giant foxtail with no adverse effect in weed density and biomass or yield of dry bean. These studies conclude that cyhalothrin-lambda or dimethoate can be tankmixed with bentazon, fomesafen, bentazon plus fomesafen, sethoxydim or quizalofop-p-ethyl when the optimum application timing of these herbicides and insecticides coincide.

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