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Response of vetch, lentil, chickpea and red pea to pre- or post-emergence applied herbicides

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Abstract

Broad-leaved weeds constitute a serious problem in the production of winter legumes, but few selective herbicides controlling these weeds have been registered in Europe. Four field experiments were conducted in 2009/10 and repeated in 2010/11 in Greece to study the response of common vetch (*Vicia sativa* L.), lentil (*Lens culinaris* Medik.), chickpea (*Cicer arietinum* L.) and red pea (*Lathyrus cicera* L.) to several rates of the herbicides pendimethalin, *S*-metolachlor, *S*-metolachlor plus terbuthylazine and flumioxazin applied pre-emergence, as well as imazamox applied post-emergence. Phytotoxicity, crop height, total weight and seed yield were evaluated during the experiments. The results of this study suggest that common vetch, lentil, chickpea and red pea differed in their responses to the herbicides tested. Pendimethalin at 1.30 kg ha^{-1}, *S*-metolachlor at 0.96 kg ha^{-1} and flumioxazine at 0.11 kg ha^{-1} used as pre-emergence applied herbicides provided the least phytotoxicity to legumes. Pendimethalin at 1.98 kg ha^{-1} and both rates of *S*-metolachlor plus terbuthylazine provided the greatest common lambsquarters (*Chenopodium album* L.) control. Imazamox at 0.03 to 0.04 kg ha^{-1} could also be used as early post-emergence applied herbicide in common vetch and red pea without any significant detrimental effect.

Additional key words: *Cicer arietinum* L.; flumioxazin; imazamox; *Lathyrus cicera* L.; *Lens culinaris* Medik.; phytotoxicity; *Vicia sativa* L.

Introduction

Weeds constitute a serious problem in the production of winter legumes because they can compete for resources like light, nutrients, water and space, directly influencing legumes yield and standability. In some legume crops, which are poor competitors, weed competition can result in deficient establishment (Fraser *et al.*, 2004; Fedoruk *et al.*, 2011). Especially for broad-leaved weeds, their control is a major production problem in winter legumes due to the absence of selective herbicides for these crops (Malik & Waddington, 1989; Fraser *et al.*, 2003).

Herbicides of the chloroacetamides (such as metolachlor), dinitroanilines (such as trifluralin and ethalfluralin) or imidazolinones (such as imazethapyr) have been evaluated for possible use in legumes (Friesen & Wall, 1986; Wilson & Miller, 1991; Wall, 1996; Fraser *et al.*, 2003). However, these herbicides, which are not moreover registered in Europe for legumes, due to the European agri-environmental policy and the reduced interest of the chemical companies for these herbicides, did not control all key weeds or significantly injured legumes.

Flumioxazin is an *N*-phenylphthalimide herbicide, which inhibits protoporphyrinogen oxidase (PPO) in the chlorophyll biosynthetic pathway, registered for use in soybean (*Glycine max* L.) and peanuts (*Arachis hypogaea* L.) (Taylor-Lovell *et al.*, 2001; Senseman, 2007). Also, it has been evaluated for selective weed

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Abbreviations used: AHAS (acetohydroxyacid synthase); ALS (acetolactate synthase); POST (post-emergence); PPO (protoporphyrinogen oxidase); PRE (pre-emergence); WAS (weeks after seeding).

control in chickpea (*Cicer arietinum* L.) and kidney beans (*Phaseolus vulgaris* L.) (Soltani *et al.*, 2005; Taran *et al.*, 2010; García-Garijo *et al.*, 2012). It controls several serious weed species including redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), common purslane (*Portulaca oleracea* L.) and barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] (Wilson *et al.*, 2002). This herbicide could provide an alternative mode of action in legumes production systems to control herbicide resistant and common broadleaf weeds.

Imazamox, a member of the imidazolinone family, inhibits acetolactate synthase or acetohydroxyacid synthase (ALS, AHAS or EC 4.1.3.18), a key enzyme in the biosynthesis of branched-chain amino acids, valine, leucine and isoleucine (Stidham & Singh, 1991). It can be applied in post-emergence in legumes such as alfalfa (*Medicago sativa* L.) and soybean (*Glycine max* L.) for grass and broadleaf weed control (Steele et al., 2002; Wilson &Burgener, 2009). It kills several key weed species of legumes including wild mustard (*Sinapis arvensis* L.), rigid ryegrass (*Lolium rigidum* Gaudin) and redroot pigweed.

Only few selective herbicides are registered in Europe in winter legumes. Nevertheless, some herbicides have been shown to control several weeds that are problematic in these crops (Senseman, 2007). Many Greek legume producers have also expressed interest in using new herbicides (Dr. D. Vlachostergios, pers. comm.), but research reports on selective herbicides for legume crops are relatively limited in the literature. So, more research is needed to identify herbicides with an acceptable margin of crop safety that can be used for weed management in legumes production. Therefore, the objective of this study was to evaluate, under field conditions, the response (phytotoxicity, height, total weight and seed yield) of four winter legumes (common vetch, lentil, chickpea and red pea), widely cultivated in Europe, to different rates of the herbicides pendimethalin, *S*-metolachlor, *S*-metolachlor plus terbuthylazine, flumioxazin and imazamox.

Material and methods

Experimental site

Four field experiments were conducted in 2009/10 (season 1) and were repeated in 2010/11 (season 2) to determine the effects of application rate of pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] (Stomp, Basf Agro Hellas, Athens, Greece), *S*-metolachlor {2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-[(1S)-2-methoxy-1-methylethyl)]acetamide} (Dual Gold, Syngenta Hellas, Anthusa, Greece), *S*-metolachlor plus terbuthylazine [6-chloro-*N*-(1,1-dimethyeethyl)-*N*'-ethyl-1,3,5-triazine-2,4-diamine] (Gardoprim Gold Plus, Syngenta Hellas, Anthusa, Greece), flumioxazin {2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2*H*-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1*H*-isoindole-1,3(2*H*)-dione} (Pledge, Hellafarm, Athens, Greece) and imazamox {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid} (Pulsar, Basf Agro Hellas, Athens, Greece) on common vetch, lentil, chickpea and white pea emergence, growth and yield. Diuron [*N*'-(3,4-dichlorophenyl)-*N*,*N*-dimethyl-urea] was used as chemical control, because was the sole registered for winter legumes herbicide in Greece until 2009. The experiments were established at the Technological Educational Institute Farm of Larissa in central Greece (22° 22" 48' E, 39° 37" 25' N, altitude 81-82 m) on a sandy clay loam (Vertic Chromoxerent) soil with the following physicochemical characteristics: sand 509 g kg^{-1}, silt 200 g kg^{-1}, clay 291 g kg^{-1}, organic C content 6 g kg^{-1}, and pH (1:2 H_2O) 7.5. Mean monthly temperature and rainfall data recorded near the experimental area (200 m far) are shown in Fig. 1.

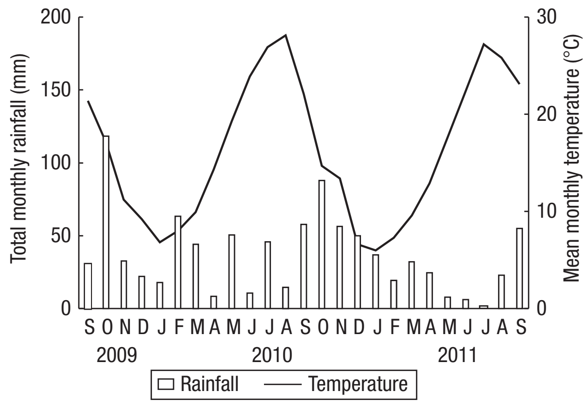

Figure 1. Total monthly rainfall and mean monthly temperature during the experiments.

Treatments and experimental design

Nitrogen and phosphorous at 30 and 60 kg ha^{-1}, respectively, were incorporated before legumes seeding. The four legumes were seeded on 25 December, 2009 (season 1) and on 1 December, 2010 (season 2). Varieties Tempi of common vetch, Samos of lentil, Amorgos of chickpea and Rhodos of red pea were seeded at 180, 100, 160 and 150 kg ha^{-1}, respectively. The seeder (model D8-30 SPECIAL, Amazonen-Werke, Hasbergen-Gaste, Germany) was equipped with 15-cm diam disc openers and adjusted to seed at 2-3 cm depth in 16 cm rows. Legumes were seeded at 4- to 6- cm intervals in rows, reflecting the common practice on Greek legume fields. So, the total seed number per m^2 was about 133, 167, 111 and 133 for common vetch, lentil, chickpea and red pea, respectively. The previous crop was barley harvested in mid-June. Straw bales were removed after harvest and land was ploughed and left undisturbed during summer. The experimental area was cultivated twice (in late October and in mid November) with a harrow disk to prepare the soil for legumes seeding and to incorporate the fertilisers into the soil. Legumes seeds were not inoculated with rhizobia to encourage biological N_2-fixation, because common vetch had been grown in the field recently. The experimental area was naturally infested with wild mustard, common field poppy (*Papaver rhoeas* L.) and common lambsquarters, as confirmed by visual assessments made during the previous growing season.

In each experiment (legume crop), a randomized complete block design was used with four replicates for each herbicide rate and for each control treatment (untreated weedy and untreated weed-free, as well as diuron). Fifty six plots were included in each experiment, with plot size of 2.5 × 4.0 m including 16 rows of crop (Fig. 2). All blocks were separated by 3-m buffer zone. Table 1 shows that all herbicide treatments consisted of two rates of pendimethalin, *S*-metolachlor, *S*-metolachlor plus terbuthylazine or flumioxazin applied in pre-emergence (PRE), as well as three rates of imazamox applied in post-emergence (POST). Diuron was applied PRE at 1.0 kg ha^{-1}. The PRE treatments were applied four days after seeding, while imazamox was applied about 10 weeks after seeding (WAS), when legumes were at the six-to eight-compound leaf growth stage. Also, the two untreated (weedy and weed-free) controls were included to assist in rating injury and yield loss due to herbicide treatments. In the weed-free plots, weeds were twice hand-removed at 4 and 10 WAS. Herbicide applications were made by an air-pressurized hand-field plot sprayer (AZO-Sprayers, Ede, The Netherlands), with a 2.4 m wide boom fitted with six 8002 flat fan nozzles (Teejet Spray System Co., Wheaton, IL, USA), which was calibrated to deliver 300 L ha^{-1} of water at 280 kPa pressure.

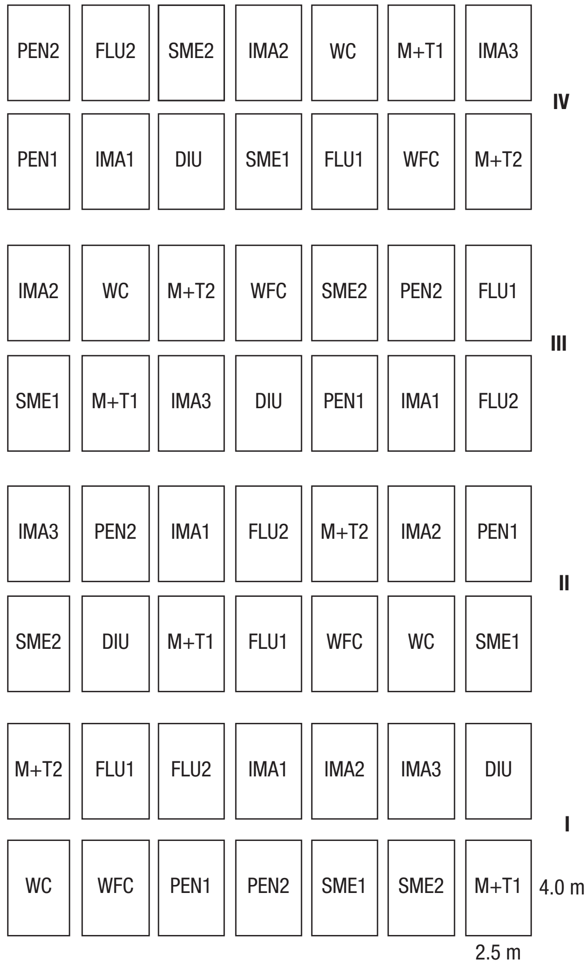

Figure 2. Experimental layout used for each legume crop. DIU: diuron applied PRE at 1.00 kg ai ha^{-1}. FLU1, FLU2: flumioxazin applied PRE at 0.07 and 0.11 kg ai ha^{-1}, respectively. IMA1, IMA2, IMA3: imazamox applied POST at 0.02, 0.03 and 0.04 kg ai ha^{-1}, respectively. M + T1, M + T2: *S*-metolachlor + terbuthylazine applied PRE at 0.94 + 0.56 and 1.25 + 0.75 kg ai ha^{-1}, respectively. PEN1, PEN2: pendimethalin applied PRE at 1.30 and 1.98 kg ai ha^{-1}, respectively. SME1, SME2: S-metolachlor applied PRE at 0.96 and 1.25 kg ai ha^{-1}, respectively. WC: weedy control, WFC: weed-free control.

Data collection

Weed plants present in the center (0.64 m × 4 m) of each plot were counted at 4 and 14 WAS. Legumes plant number was counted at 4 WAS. In addition, legumes injury (plant death and reduced growth) was visually estimated using a scale of 0% (no injury) to

Table 1. Visual injury caused by various herbicide treatments, as well as height, total fresh weight, total dry weight and seed yield of common vetch (*Vicia sativa)* grown in 2009/10 (season 1) and 2010/11 (season 2)

Treatments	Rate	Timing	Visual injury (%)		Height (cm)	Common vetch harvest	
			4 WAS	16 WAS	18 WAS	Dry matter (t ha^{-1})	Seed yield (t ha^{-1})
Season 1							
Weedy control	—	—	0.0	0.0	107	6.92	0.73
Weed-free control	—	—	0.0	0.0	103	7.02	0.79
Pendimethalin	1.30	PRE	0.0	0.0	98	7.02	0.86
Pendimethalin	1.98	PRE	0.0	0.0	96	6.52	0.74
S-metolachlor	0.96	PRE	0.0	0.0	95	6.67	0.99
S-metolachlor	1.25	PRE	0.0	0.0	93	6.42	0.90
S-metolachlor + terbuthylazine	0.94+ 0.56	PRE	0.0	0.0	99	7.87	1.17
S-metolachlor + terbuthylazine	1.25 + 0.75	PRE	0.0	0.0	100	6.62	0.95
Flumioxazin	0.07	PRE	0.0	0.0	96	8.27	0.95
Flumioxazin	0.11	PRE	0.0	0.0	101	9.32	0.85
Diuron	1.00	PRE	0.0	0.0	99	6.92	0.81
Imazamox	0.02	POST	0.0	0.0	94	7.32	0.70
Imazamox	0.03	POST	0.0	5.0	87	8.32	0.93
Imazamox	0.04	POST	0.0	7.5	89	7.32	0.92
Season 2							
Weedy control	—	—	0.0	0.0	105	5.38	1.09
Weed-free control	—	—	0.0	0.0	108	5.63	1.81
Pendimethalin	1.30	PRE	21.3	6.3	99	4.98	1.86
Pendimethalin	1.98	PRE	48.8	21.3	97	5.45	1.91
S-metolachlor	0.96	PRE	15.0	0.0	95	5.00	1.51
S-metolachlor	1.25	PRE	26.3	1.3	93	4.60	1.48
S-metolachlor + terbuthylazine	0.94 + 0.56	PRE	33.8	6.3	96	4.55	1.18
S-metolachlor + terbuthylazine	1.25 + 0.75	PRE	50.0	17.5	102	4.63	1.67
Flumioxazin	0.07	PRE	7.5	4.0	96	4.60	1.18
Flumioxazin	0.11	PRE	10.0	4.0	102	4.73	1.45
Diuron	1.00	PRE	17.5	0.0	99	5.20	1.79
Imazamox	0.02	POST	0.0	1.3	95	5.13	1.56
Imazamox	0.03	POST	0.0	7.5	88	4.68	1.30
Imazamox	0.04	POST	0.0	17.5	89	4.35	1.13
$LSD_{0.05}$			4.2	1.5	8.8	1.50	0.36
CV, %			24.3	20.1	6.4	17.5	20.4

WAS: weeks after seeding. PRE: pre-emergence. POST: post-emergence.

100% (complete plant death) at 4, 12 and 16 WAS. The final height of the four crops was assessed at 18 WAS. During the first two weeks of June each year, when legumes were at the physiological maturity stage, plants located in the four centre rows of each plot (0.64 m × 4 m) were harvested by hand. Then, total fresh and dry weights, as well as the seed yield of each legume were recorded. For dry weight determination, plant fractions (1 kg) were air-dried in the shade for 3 days and oven-dried at 65°C for 24 h to a constant weight.

Statistical analysis

For each legume crop separately, plant number, % injury, total fresh and dry weights, as well as seed yield data were subjected to a combined over-season ANOVA. The MSTAT program (MSTAT-C, 1988) was used to analyze variances. Fisher's Protected LSD and Tukey's Honestly Significant Difference test procedures were used to detect and separate mean treatment differences at $p = 0.05$.

Results

Weeds presence

In all experimental plots, weeds emerged at very low densities. The weed species with the greatest density, especially in lentil and chickpea, was common lambsquarters emerged in late winter. Wild mustard and common field poppy emerged at very low densities (1- to 2- plants m^{-2}) (data not shown). All herbicide treatments significantly reduced common lamsquarters density, as compared with the untreated weedy control (Fig. 3). Pendimethalin at 1.98 kg ha^{-1} and both rates of *S*-metolachlor plus terbuthylazine provided the greatest common lambsquarters control. Pendimethalin at 1.30 kg ha^{-1}, both rates of metolachlor and flumioxazin, imazamox at 0.03 and 0.04 kg^{-1} and diuron slightly provided a lower weed control. However, imazamox at 0.02 kg ha^{-1} achieved partial common lambsquarters control.

Crops response

For the four legumes, crop injury and their yield components were affected by growing season ($p < 0.001$), herbicide treatments ($p < 0.001$) and growing season × herbicide treatments interaction ($p < 0.001$). So, for each crop separately, the growing season × herbicide treatments interaction means are presented in Tables 1, 2, 3 and 4.

Common vetch

In season 1, the PRE-applied herbicides had not any phytotoxic effect on common vetch. However, imazamox treatments caused slight crop injury which ranged from 5.0 to 16.3% at 12 WAS, without plant number reduction (data not shown). Visible injury caused by imazamox was present as signs of stem and leaf chlorosis (especially in the apex), as well as standing. These phytotoxicity symptoms decreased with time due to plant regrowth, so that at 16 WAS phytotoxicity ranged only from 0.0 to 7.5% (Table 1). Higher herbicide effects in season 2 were observed, in particular, for the greater rates of pendimethalin and *S*-metolachlor plus terbuthylazine (48.8-50%) at 4 WAS. At 16 WAS, crop injury caused by the greater rates of pendimethalin, *S*-metolachlor plus terbuthyazine and imazamox was lower, ranging from 17.5 to 21.3%. The other herbicide treatments caused crop injury which ranged from 0.0 to 7.5%.

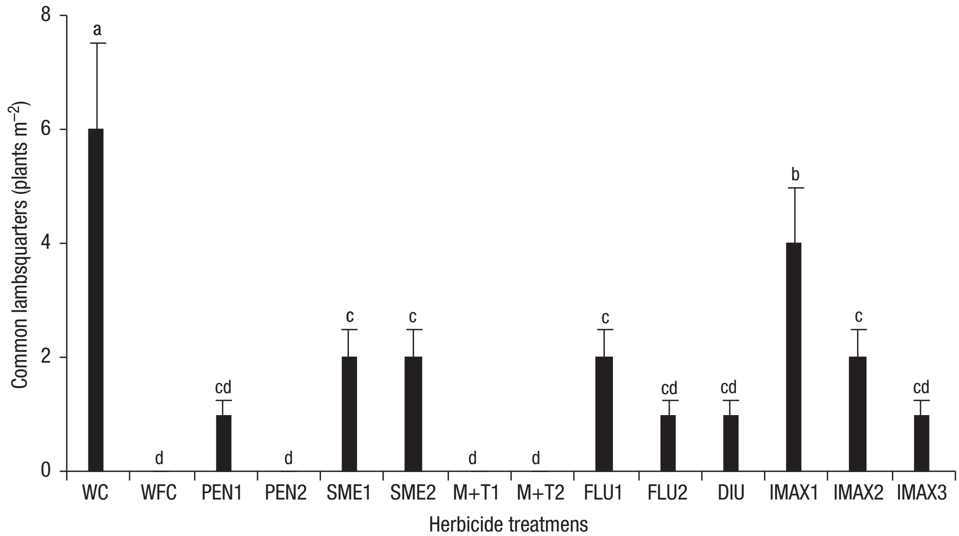

Figure 3. Common lambsquarters plant density, at 14 weeks after seeding, as affected by various herbicide treatments. Weed density values are averaged across two growing seasons (2009/10 and 2010/11) and two crops (lentil and chickpea). Means with different letter indicate significant difference according to Tukey's Honestly Significant Difference test at $p = 0.05$. Vertical lines indicate standard errors. WC: weedy control. WFC: weed-free control. PEN1, PEN2: pendimethalin applied PRE at 1.30 and 1.98 kg ai ha^{-1} respectively. SME1, SME2: S-metolachlor applied PRE at 0.96 and 1.25 kg ai ha^{-1}, respectively. M + T1, M + T2: *S*-metolachlor + terbuthylazine applied PRE at 0.94 + 0.56 and 1.25 + 0.75 kg ai ha^{-1}, respectively. FLU1, FLU2: flumioxazin applied PRE at 0.07 and 0.11 kg ai ha^{-1}, respectively. DIU: diuron applied PRE at 1.00 kg ai ha^{-1}. IMA1, IMA2, IMA3: imazamox applied POST at 0.02, 0.03 and 0.04 kg ai ha^{-1}, respectively.

Table 2. Visual injury caused by various herbicide treatments, as well as height, total fresh weight, total dry weight and seed yield of lentil (*Lens culinaris*) grown in 2009/10 (season 1) and 2010/11 (season 2)

Treatments	Rate	Timing	Visual injury (%)		Height (cm)	Common vetch harvest	
			4 WAS	16 WAS	18 WAS	Dry matter (t ha^{-1})	Seed yield (t ha^{-1})
Season 1							
Weedy control	—	—	0.0	0.0	41.8	4.37	0.69
Weed-free control	—	—	0.0	0.0	43.3	4.62	0.71
Pendimethalin	1.30	PRE	0.0	0.0	40.0	5.12	0.85
Pendimethalin	1.98	PRE	0.0	0.0	40.8	5.07	1.00
S-metolachlor	0.96	PRE	0.0	0.0	42.3	4.87	1.04
S-metolachlor	1.25	PRE	0.0	0.0	42.0	4.57	1.06
S-metolachlor + terbuthylazine	0.94 + 0.56	PRE	0.0	0.0	40.0	4.97	0.92
S-metolachlor + terbuthylazine	1.25 + 0.75	PRE	0.0	0.0	38.3	4.52	0.98
Flumioxazin	0.07	PRE	0.0	0.0	40.5	5.02	1.00
Flumioxazin	0.11	PRE	0.0	0.0	44.0	5.64	0.98
Diuron	1.00	PRE	0.0	0.0	39.0	4.02	0.82
Imazamox	0.02	POST	0.0	3.5	36.8	4.37	0.89
Imazamox	0.03	POST	0.0	7.3	35.0	5.02	0.96
Imazamox	0.04	POST	0.0	17.5	37.3	4.62	0.91
Season 2							
Weedy control	—	—	0.0	0.0	43.5	4.58	1.58
Weed-free control	—	—	0.0	0.0	43.3	4.55	1.60
Pendimethalin	1.30	PRE	27.5	6.0	40.3	4.68	1.79
Pendimethalin	1.98	PRE	46.3	11.3	41.5	4.48	1.77
S-metolachlor	0.96	PRE	6.0	2.5	43.0	5.05	1.93
S-metolachlor	1.25	PRE	15.0	3.8	43.0	4.88	1.57
S-metolachlor + terbuthylazine	0.94 + 0.56	PRE	31.3	18.8	40.0	4.65	1.90
S-metolachlor + terbuthylazine	1.25 + 0.75	PRE	38.8	20.0	37.8	2.75	1.06
Flumioxazin	0.07	PRE	10.0	5.0	43.8	4.68	1.76
Flumioxazin	0.11	PRE	20.0	5.5	45.5	4.15	1.80
Diuron	1.00	PRE	23.8	5.5	39.3	4.15	1.63
Imazamox	0.02	POST	0.0	6.3	36.8	4.73	1.59
Imazamox	0.03	POST	0.0	17.5	31.8	3.20	0.95
Imazamox	0.04	POST	0.0	28.8	34.3	2.83	0.73
$LSD_{0.05}$		4.1	2.7	4.5	4.1	0.73	0.28
CV, %			22.9	23.8	8.0	11.7	16.2

WAS: weeks after seeding. PRE: pre-emergence. POST: post-emergence.

In both growing seasons, common vetch height was slightly decreased (14 to 16% as compared with the weed-free control) by the two greater rates of imazamox (Table 1). The other herbicide treatments did not significantly affect common vetch height.

At harvest, common vetch total fresh (data not shown) and dry weights were not significantly affected by the herbicide treatments (Table 1). Weedy and weed-free treatments did not differ according to total fresh or dry weight. In season 1, seed yield did not differ among treatments. However, in season 2, common vetch seed yield in weedy treatment was slightly lower than that in weed-free and pendimethalin treatments. Generally, common vetch seed yield was greater in season 2 than in season 1.

Lentil

In season 1, the PRE herbicide treatments had not any phytotoxic effect on lentil (Table 2). On the contrary, imazamox treatments caused crop injury which

Table 3. Visual injury caused by various herbicide treatments, as well as height, total fresh weight, total dry weight and seed yield of chickpea (*Cicer arietinum*) grown in 2009/10 (season 1) and 2010/11 (season 2)

Treatments	Rate	Timing	Visual injury (%)		Height (cm)	Common vetch harvest	
			4 WAS	16 WAS	18 WAS	Dry matter ($t\ ha^{-1}$)	Seed yield ($t\ ha^{-1}$)
Season 1							
Weedy control	—	—	0.0	0.0	51.0	4.02	1.09
Weed-free control	—	—	0.0	0.0	52.8	5.77	2.30
Pendimethalin	1.30	PRE	0.0	0.0	54.8	7.32	2.74
Pendimethalin	1.98	PRE	0.0	0.0	52.0	6.02	2.15
S-metolachlor	0.96	PRE	0.0	0.0	51.8	6.67	2.39
S-metolachlor	1.25	PRE	0.0	0.0	52.8	6.77	2.35
S-metolachlor + terbuthylazine	0.94 + 0.56	PRE	0.0	0.0	55.0	5.42	2.02
S-metolachlor + terbuthylazine	1.25 + 0.75	PRE	0.0	0.0	53.5	6.97	2.60
Flumioxazin	0.07	PRE	0.0	0.0	52.3	5.57	2.06
Flumioxazin	0.11	PRE	0.0	0.0	51.5	6.22	1.97
Diuron	1.00	PRE	0.0	0.0	49.5	6.92	2.62
Imazamox	0.02	POST	0.0	3.3	45.8	5.57	1.58
Imazamox	0.03	POST	0.0	6.0	42.5	5.67	1.69
Imazamox	0.04	POST	0.0	13.8	41.0	5.02	1.23
Season 2							
Weedy control	—	—	0.0	0.0	52.5	3.83	1.24
Weed-free control	—	—	0.0	0.0	54.0	4.20	1.70
Pendimethalin	1.30	PRE	22.5	15.0	52.8	4.33	1.98
Pendimethalin	1.98	PRE	41.3	17.5	52.3	4.89	2.26
S-metolachlor	0.96	PRE	17.5	4.3	52.5	4.30	1.78
S-metolachlor	1.25	PRE	22.5	6.8	53.8	4.28	1.66
S-metolachlor + terbuthylazine	0.94 + 0.56	PRE	27.5	8.0	56.0	4.28	1.70
S-metolachlor + terbuthylazine	1.25 + 0.75	PRE	37.5	18.8	52.5	4.43	2.03
Flumioxazin	0.07	PRE	21.3	6.0	52.5	4.28	2.20
Flumioxazin	0.11	PRE	30.0	7.5	52.0	4.25	1.82
Diuron	1.00	PRE	26.3	6.5	50.8	4.28	2.24
Imazamox	0.02	POST	0.0	11.3	47.5	2.55	0.84
Imazamox	0.03	POST	0.0	28.8	43.5	2.15	0.73
Imazamox	0.04	POST	0.0	43.8	41.5	1.48	0.63
$LSD_{0.05}$			4.4	3.4	5.7	1.05	0.49
CV, %			24.4	24.2	8.0	15.3	19.3

WAS: weeks after seeding. PRE: pre-emergence. POST: post-emergence.

ranged from 7.5 to 31.3% at 12 WAS without plant number reduction (data not shown). Similarly to common vetch, visible injury caused by imazamox was present as signs of stem and leaf chlorosis, as well as standing, but the phytotoxicity symptoms decreased with time due to plant regrowth, so that at 16 WAS phytotoxicity ranged only from 3.5 to 17.5% (Table 2). In season 2, all herbicide treatments caused significant injury to lentil plants. In particular, the greater rate of flumioxazin, both rates of pendimethalin and *S*-metolachlor plus terbuthylazine, as well as diuron caused the greatest lentil injury which ranged from 20.0 to 46.3% at 4 WAS. At 16 WAS, crop injury caused by the greater rates of pendimethalin and *S*-metolachlor plus terbuthylazine was lower, 11.3 and 20.0%, respectively. The other herbicide PRE treatments caused crop injury which ranged from 2.5 to 18.8%. Imazamox caused significant lentil injury which ranged from 6.3 to 28.8% at 16 WAS.

In season 1, lentil height was not significantly decreased by the herbicide treatments. However, in season 2, imazamox rates of 0.03 and 0.04 kg ha^{-1}

Table 4. Visual injury caused by various herbicide treatments, as well as height, total fresh weight, total dry weight and seed yield of red pea (*Lathyrus cicera*) grown in 2009/10 (season 1) and 2010/11 (season 2)

Treatments	Rate	Timing	Visual injury (%)		Height (cm)	Common vetch harvest	
			4 WAS	16 WAS	18 WAS	Dry matter (t ha^{-1})	Seed yield (t ha^{-1})
Season 1							
Weedy control	—	—	0.0	0.0	77.3	9.39	3.19
Weed-free control	—	—	0.0	0.0	87.0	9.87	4.40
Pendimethalin	1.30	PRE	0.0	0.0	77.3	8.87	3.42
Pendimethalin	1.98	PRE	0.0	0.0	71.5	9.37	3.70
S-metolachlor	0.96	PRE	0.0	0.0	79.0	9.42	4.53
S-metolachlor	1.25	PRE	0.0	0.0	77.0	8.72	3.58
S-metolachlor + terbuthylazine	0.94 + 0.56	PRE	0.0	0.0	75.8	9.22	3.67
S-metolachlor + terbuthylazine	1.25 + 0.75	PRE	0.0	0.0	78.5	9.32	3.99
Flumioxazin	0.07	PRE	0.0	0.0	71.8	9.07	3.19
Flumioxazin	0.11	PRE	0.0	0.0	74.3	9.82	3.87
Diuron	1.00	PRE	0.0	0.0	71.8	8.07	2.68
Imazamox	0.02	POST	0.0	0.0	85.8	9.12	3.86
Imazamox	0.03	POST	0.0	0.0	80.8	9.52	3.37
Imazamox	0.04	POST	0.0	0.0	81.0	8.97	3.50
Season 2							
Weedy control	—	—	0.0	0.0	78.5	6.08	1.75
Weed-free control	—	—	0.0	0.0	87.5	6.45	3.02
Pendimethalin	1.30	PRE	27.5	15.0	79.0	5.00	2.38
Pendimethalin	1.98	PRE	40.0	28.8	72.5	5.83	2.89
S-metolachlor	0.96	PRE	22.5	0.0	80.0	5.95	2.84
S-metolachlor	1.25	PRE	28.8	8.8	77.5	5.48	2.59
S-metolachlor + terbuthylazine	0.94 + 0.56	PRE	33.8	25.0	75.0	3.60	1.78
S-metolachlor + terbuthylazine	1.25 + 0.75	PRE	60.0	42.5	51.0	2.73	1.27
Flumioxazin	0.07	PRE	17.5	7.5	72.0	5.80	2.83
Flumioxazin	0.11	PRE	23.8	8.0	64.0	4.48	2.40
Diuron	1.00	PRE	28.8	12.5	61.0	4.28	1.57
Imazamox	0.02	POST	0.0	0.0	86.5	5.83	2.56
Imazamox	0.03	POST	0.0	0.0	82.5	6.38	2.76
Imazamox	0.04	POST	0.0	0.0	82.5	5.75	2.64
$LSD_{0.05}$			4.9	3.2	6.3	1.24	0.67
CV, %			24.3	23.6	6.0	12.2	15.9

WAS: weeks after seeding. PRE: pre-emergence. POST: post-emergence.

caused 21 to 27% lentil height reduction (Table 2). The other herbicide treatments did not significantly affect lentil height.

At harvest in season 1, lentil total fresh and dry weights were not significantly affected by the herbicide treatments (Table 2). Weedy and weed-free treatments again did not differ, according to total fresh or dry weight. However, in season 2, total fresh and dry weights of lentil treated with the greater rates of *S*-metolachlor plus terbuthylazine or imazamox were significantly decreased as compared with weights achieved by the other treatments. In season 1, seed yield did not differ among treatments. However, in season 2, lentil seed yield in imazamox treatments of 0.03 and 0.04 kg ha^{-1} was lower by 41 to 55% than that in weed-free treatment. Lentil seed yield was greater in season 2 than in season 1.

Chickpea

In season 1, the PRE-applied herbicides had not any phytotoxic effect on chickpea (Table 3). On the contrary, imazamox treatments caused crop injury which ranged from 7.5 to 35.0% at 12 WAS without plant number reduction (data not shown). Visible injury caused by imazamox was present as signs of stem and leaf chlorosis, as well as standing, but the phytotoxicity symptoms decreased with time due to plant regrowth, so that at 16 WAS phytotoxicity ranged only from 3.3 to 13.8% (Table 2). In season 2, all herbicide treatments caused significant injury to chickpea plants. In particular, the greater rates of pendimethalin, *S*-metolachlor, *S*-metolachlor plus terbuthylazine and flumioxazin, as well as diuron caused the greatest chickpea injury which ranged from 22.5 to 41.3% at 4 WAS. At 16 WAS, crop injury caused by the greater rates of pendimethalin and *S*-metolachlor plus terbuthylazine was lower, 17.5 and 18.8%, respectively. The other herbicide PRE treatments caused crop injury which ranged from 6.0 to 15.0%. Imazamox caused significant chickpea injury that increased with time. In particular, crop injury caused by imazamox ranged from 10.0 to 38.8% at 14 WAS and from 11.3 to 43.8% at 16 WAS.

In both growing seasons, imazamox rates of 0.03 and 0.04 kg ha^{-1} caused 19 to 23% chickpea height reduction (Table 3). The other herbicide treatments did not significantly affect chickpea height. Also, chickpea height was similar to both weedy and weed-free controls.

At harvest in season 1, chickpea total fresh and dry weights were not significantly affected by the herbicide treatments (Table 3). Fresh and dry weights in weedy treatment were slightly lower than those in weed-free treatment. In season 2, total fresh and dry weights of chickpea treated with imazamox were significantly decreased compared to other treatments. In both growing seasons, chickpea seed yield was significantly reduced by imazamox ranging from 27 to 47% and 51 to 63%, in season 1 and season 2, respectively.

Red pea

In season 1, all herbicide treatments had not any phytotoxic effect on red pea (Table 4). However, in season 2, all PRE herbicide treatments caused significant injury to red pea plants. In particular, the greatest crop injury (from 28.8 to 60.0% at 4 WAS) was caused by the higher rates of pendimethalin, *S*-metolachlor and *S*-metolachlor plus terbuthylazine. However, crop injury decreased with time and at 16 WAS was 28.8, 8.8 and 42.5%, respectively. The other herbicide PRE treatments caused crop injury which ranged from 0.0 to 25.0%. Imazamox treatments did not affect red pea growth.

In season 1, red pea height was not affected by herbicide treatments (Table 4). However, in season 2, the higher rates of S-metolachlor plus terbuthylazine and flumiozaxin, as well as diuron caused height reduction of red pea, which ranged from 27 to 42%, as compared with the weed-free control.

At harvest in season 1, red pea total fresh and dry weights were not significantly affected by the herbicide treatments (Table 4). Weedy and weed-free treatments did not differ according to total fresh or dry weight. However, in season 2, red pea total fresh and dry weights were significantly reduced by *S*-metolachlor plus terbuthylazine and diuron treatments. In season 1, red pea seed yield was not affected by herbicide treatments, while seed yield in weedy treatment was slightly lower than that in weed-free treatment. In season 2, *S*-metolachlor plus terbuthylazine and diuron treatments caused the greatest red pea seed yield reduction which ranged from 42 to 58%, as compared with that in weed-free control.

Discussion

Weeds presence

In all experimental plots, weeds emerged at very low densities, maybe due to the late soil cultivation which had as result the control of annual winter weeds emerged until early November. The greatest rate of pendimethalin provided excellent common lambsquarters control, while *S*-metolachlor achieved lower control of this weed. Similarly, Chomas & Kells (2004) found that pendimethalin provided greater (98%) and more consistent control of common lambsquarters in maize (*Zea mays* L.) than metolachlor (66%). Soltani *et al.* (2007) also found poor control of common lambsquarters by the chloroacetamide dimethenamid applied in kidney beans, while Kantar *et al.* (1999) reported satisfactory control of this weed by the urea linuron or by the imidazolinone imazethapyr applied in pre-emergence in chickpea.

Crops response

In season 1, PRE herbicide treatments had not any phytotoxic effect on legumes. Friesen & Wall (1986) reported that lentil was tolerant to preplant soil incorporated metolachlor. However, significant plant injury was caused by the PRE-applied herbicides in season 2, maybe due to increased soil humidity during herbicide application and the increased rainfall during December and January after herbicide application (Fig. 1), resulting in reduced herbicide adsorption by soil colloids and increased herbicide leaching to crop root system depth (Monaco *et al.*, 2002). This crop injury was reduced with time. Wall (1996) found that lentil tolerance to PRE-applied imazethapyr differed among years and crop injury tented to decrease between 2 and 4 weeks after treatment. According to the same researcher, the greater herbicide uptake by crop under conditions of increased and excessive soil moisture, as well as the higher precipitation for the week following herbicide application may account for the observed greater lentil injury.

The POST-applied recommended rate (0.04 kg ha^{-1}) of imazamox caused significant legumes injury, especially to lentil and chickpea, visible as signs of stem and leaf chlorosis, as well as standing, but the phytotoxicity symptoms decreased with time due to plant regrowth. Similar phytotoxicity symptoms have been reported in lentil to imazethapyr (Wall, 1996). According to Bukun *et al.* (2012), the increased lentil susceptibility to imazamox, as compared with the other legumes, could be attributed to the combined effects of increased herbicide absorption and reduced metabolism. Chickpea injury caused by imazamox is in agreement with other studies reporting chickpea tolerance to imazamox and imazethapyr (Taran *et al.*, 2010).

Generally, common vetch and lentil seed yields were greater in season 2 than in season 1, maybe due to greater rainfall recorded in April (period of legumes anthesis and fruit development) the second season (Fig. 1). For all legumes, weedy and weed-free treatments did not differ in most cases in terms of fresh or dry weight, due to low weed densities.

The results of this study suggest that common vetch, lentil, chickpea and red pea differ in their responses to herbicides tested. Pendimethalin at 1.30 kg ha^{-1}, *S*-metolachlor at 0.96 kg ha^{-1} and flumioxazin at 0.11 kg ha^{-1} in pre-emergence caused the least phytotoxicity to common vetch, lentil, chickpea or red pea. Also, imazamox at 0.03 to 0.04 kg ha^{-1} in post-emergence was slightly phytotoxic to common vetch or red pea. These treatments could be a chemical option to control serious weeds in legumes, without any yield lost.

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