New Zealand Journal of Crop and Horticultural Science, 2005, Vol. 33: 223–231
0014–0671/05/3303–0223

Weed control in lentil (*Lens culinaris*) in eastern Turkey

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Abstract This study investigated the effect of 12 herbicide applications and hand weeding (once, twice, and repeated) in comparison with a weedy control on seed and total crop biomass yield of lentil (*Lens culinaris*) in 2000 and 2001 under the dry conditions of Erzurum (29°55′N and 41°16′E at an altitude of 1850 m), Turkey. In both growing seasons, data were collected on the density and dry weight of weed species, density of lentil, seed yield, total crop biomass yield, and harvest index. Weed control applications significantly decreased density and dry weight of weeds and increased total crop biomass and seed yields by 49.2% (linuron plus prometryn) and 74.9% (prometryn plus fluazifop-p-butyl), compared with the unweeded control. Pre-emergence plus post-emergence combinations, however, gave no clear advantages over single applications of linuron, prometryn, and metribuzin. Metribuzin reduced plant density in wetter conditions of the second year. In conclusion, linuron and prometryn alone were effective in controlling weeds on lentils without apparent toxic effects. Hand weeding once was equally effective.

Keywords lentil; herbicides; weed control; yield

H04077; Online publication date 5 July 2005
Received 31 August 2004; accepted 7 February 2005

INTRODUCTION

Lentil (*Lens culinaris* Medik.) is one of the most important pulse crops in Turkey. A nationwide project towards decreasing fallow areas supported lentil-cereal rotation in the 1980s and consequently its acreage and production increased remarkably. Currently, lentil is grown on 517 000 ha in dry areas and its production reached 380 000 t (Anon. 2000). Although lentil acreage and production has increased considerably, its yield has not risen in parallel to its production. Many factors are responsible for yield reduction in Turkey, including poor distribution of rainfall, low soil fertility levels, minimal use of fertilisers, a lack of effective weed control measures, and a lack of basic knowledge of weed management in lentil production (Kantar et al. 1998).

Because of their small stature and lack of a protective canopy to prevent establishment of weeds, lentils are poor competitors and good weed control is essential for successful production (Muehlbauer et al. 1995; Mohamed et al. 1997). Lentil growth rates are slow during early stages of vegetative growth and weeds can quickly overgrow the crop if not adequately controlled. Weeds compete with the crop for nutrients, water, and light, reducing crop yields and grain quality (Turk & Tawaha 2003). Yield losses in lentil of 40–80%, as a result of weeds, have been reported (Saxena & Wassimi 1980; Chaudhary & Singh 1987; Al-Thahabi et al. 1994).

In lentil production in the region weeds are generally controlled by hand. However, hand weeding which is labour-intensive and an expensive operation is impractical in the extensive production areas (Bhan & Kukula 1987; Saxena 1990) and, if delayed, the operation does not prevent the adverse effect of the weeds on crop yield (Mohamed et al. 1997). The use of appropriate herbicides can eliminate this early weed competition and prevent yield losses in lentil production (Muehlbauer et al. 1995). It is therefore necessary that effective herbicides are used to reduce unwanted competition. Linuron, prometryn, and metribuzin are inhibitors of photosynthesis and are generally used at pre-emergence or sometimes at post-emergence (Touloupakis et al. 2005). When these herbicides are used at pre-emergence, they are absorbed through the plant shoots while they are still underground and kill or injure the shoots before they emerge from the soil. Fluazifop-p-butyl and quizalofop-p-ethyl used post-emergence are both grass-specific herbicides that inhibit the synthesis of enzymes required for lipid synthesis. Both inhibit acetyl CoA carboxylase, the enzyme responsible for catalysing an early step in fatty acid synthesis (Ma et al. 2004).

In this study, the efficacy of some herbicide and herbicide combinations were evaluated in comparison with hand weeding in lentil under the ecological conditions of Erzurum, Turkey.

MATERIALS AND METHODS

This study was carried out on the experimental farm of Ataturk University in Erzurum in eastern Anatolia (29°55′N and 41°16′E at an altitude of 1850 m a.s.l.) in 2000 and 2001 using a red-seeded nationally registered lentil cultivar (*Lens culinaris* Medik. Malazgirt-89) with average plant height of 21 cm and 1000-seed weight of 29 g. With an average temperature and total rainfall of 5.7°C and 440 mm (Table 1), plant growth in the region is restricted to the period between May and October. The second year of the experiment received higher and more even distribution of rainfall in the growing months of May, June, and July. The experimental soil was a sandy loam with organic matter content ranging between 1.68% and 1.87%, and lime content between 0.34% and 0.66% (pH 6.36–6.62). Available P_2O_5 content ranged between 87 and 119 kg ha^{-1} and K_2O content between 1422 and 1596 kg ha^{-1}. Seeds were inoculated with a culture in peat obtained from the Soil and Fertilizer Research Institute, Ankara, Turkey and all plots received 60 kg P_2O_5 ha^{-1} in triple superphosphate form (Kantar et al. 1994b).

In the experiment, 16 treatments (Table 2) were investigated in three randomised complete blocks. Sowing was done by hand after mixing seeds with 15% glucose solution and bacterial culture in plots having six rows of 5 m length with 20 cm inter-row spacing so as to give 350 seeds m^{-2} (Anon. 1995) on 26 April 2000 and 26 April 2001. Herbicides were applied with a hand-pressurised knapsack sprayer fitted with a single flat-fan nozzle at 300 litre ha^{-1} application volume. Pre-emergence herbicides were applied on 27 April 2000 and 28 April 2001, and post-emergence herbicides were applied at the recommended doses (Table 2) on 13 June 2000 and 14 June 2001, at 2 weeks before the flowering stage of lentil. No rain was recorded 2 days before or after the herbicide application. No irrigation or other chemical application was done during the plant growth, until harvest. The first hand weeding was applied when lentil reached 10–12 cm length on 30 May 2000 and 30 May 2001. The second hand weeding was done at the flowering stage on 26 June 2000 and 26 June 2001. In the weeded control, from emergence to harvest, weeds were removed by hand every week without using any mechanical equipment to avoid damage to lentil roots.

Data on weed species in each plot were collected at the flowering stage of lentil. Two quadrates (0.25 m^2) were randomly placed in each plot and weeds were cut from ground level totally of 0.5 m^2 area. Weeds were taken to the laboratory for separation and dried in an oven at 65°C for 24 h for dry weight determinations. The weed control efficiency (WCE) was calculated using the following formula, as reported by Tawaha et al. (2002):

WCE ((Dry matter or density of weeds in unweeded plot – Dry matter or density of weeds in treatment) /Dry matter or density of weeds in unweeded plot) × 100

At the harvest stage, lentil density was determined and plots were harvested by hand excluding one row

Table 1 Climatic data on the experimental site.

Climatic factors	Years	Months: May	Jun	Jul	Total/average: Growth season	Annual
Total rainfall (mm)	2000	42.0	9.7	4.0	55.7	305.2
	2001	63.2	14.6	36.9	114.7	355.2
	1929–98	73.6	51.1	29.0	153.7	440.0
Average air temp. (°C)	2000	9.8	15.5	22.3	15.9	5.4
	2001	9.8	14.4	19.5	14.6	6.3
	1929–98	10.7	15.0	19.2	15.0	5.7

from each side and 50 cm from both ends giving an harvest area of 3.2 m^2 on 26 July 2000 and 28 July 2001. Plants were dried for 2–3 days for yield and harvest index measurements.

The data were subjected to analysis of variance using MSTATC Statistical Package. WCE values were subjected to arcsine transformation to obtain normal distribution before running analysis of variance. Since there were no significant year by treatment interactions, the individual weed species control data were combined over years in Table 3. Mean values were separated according to LSD test at $P = 0.01$.

RESULTS

As an average of both years, *Amaranthus retroflexus* L. (64.8%), *Chenopodium album* L. (24.7%), *Polygonum* spp. (3.0%), and *Convolvulus arvensis* L. (2.7%) were the most dominant broad-leaved weed species in the unweeded control (Table 3). *Polygonum* spp. present in the experiment included species of *P. convolvulus* L., *P. aviculare* L., *P. bellardii* All., *P. cognatum* Meissn., and *P. pulchellum* Loiss. at the rates of 37%, 32%, 11%, 11%, and 9% respectively. *Avena fatua* L. and *Hordeum vulgare* L. were the only two grasses present in the trial. Other species which were comparatively less dense in the plots included *Amaranthus graecizans* L., *Cirsium arvense* (L.) Scop., *Crambe orientalis* L., *Fumaria officinalis* L., *Hyoscyamus niger* L., *Lactuca serriola* L., *Malva neglecta* Wallr., *Sideritis montana* L., and *Tragopogon dubius* Scop. (Table 3).

A total of 12 herbicide applications and 3 hand weeding treatments (once, twice, and repeated) were tested for control of the above weed species in lentil (Table 2). The existing weed population was significantly affected by applied treatments. All of the herbicide treatments were effective on *Amaranthus retroflexus*, *Chenopodium album*, *Polygonum* spp., *Malva neglecta*, *Hyoscyamus niger*, and *Sideritis montana*, but ineffective on *Convolvulus arvensis* and *Cirsium arvense* when compared with the unweeded control (Table 3). On the other hand, there were no significant differences among the weed control treatments for *Amaranthus graecizans*, *Crambe orientalis*, *Fumaria officinalis*, *Lactuca serriola*, and *Tragopogon dubius*. For weed density, weed control efficiency ranged between 77.8% (linuron plus fluazifop-p-butyl) and 92.3% (metribuzin plus prometryn) in herbicide applications whereas once, twice, and repeated hand weeding provided 90.2%, 89.9%, and 94.1% weed control, respectively (Table 3). All herbicide applications without linuron had weed control efficiency similar to the weeded control.

In both growing seasons, compared with the unweeded control, all weed control methods evaluated caused a marked decrease in weed dry weight (Table 4). However, soil moisture affected the efficiency of the herbicides investigated. Relatively balanced and higher rainfall was received in 2001,

Table 2 Active ingredients, trade name, application doses and periods of herbicides investigated.

Active ingredients (a.i.)/treatments	Trade name	Application rate (kg a.i. ha^{-1})	Application periods
Linuron	Linurex, 450 g a.i. $litre^{-1}$	0.95	Pre-emergence
Prometryn	Gesagard, 500 g a.i. $litre^{-1}$	1.25	Pre-emergence
Metribuzin	Sencor, 700 g a.i. kg^{-1}	0.18	Pre-emergence
Linuron + Prometryn	Linurex + Gesagard	0.95 + 0.5	Pre-emergence + Post-emergence
Prometryn + Prometryn	Gesagard + Gesagard	1.25 + 0.5	Pre-emergence + Post-emergence
Metribuzin + Prometryn	Sencor + Gesagard	0.18 + 0.5	Pre-emergence + Post-emergence
Linuron + Fluazifop-p-butyl	Linurex + Fusilade Super, 125 g a.i. $litre^{-1}$	0.95 + 0.1	Pre-emergence + Post-emergence
Prometryn + Fluazifop-p-butyl	Gesagard + Fusilade Super	1.25 + 0.1	Pre-emergence + Post-emergence
Metribuzin + Fluazifop-p-butyl	Sencor + Fusilade Super	0.18 + 0.1	Pre-emergence + Post-emergence
Linuron + Quizalofop-p-ethyl	Linurex + Targa Super, 50 g a.i. $litre^{-1}$	0.95 + 0.05	Pre-emergence + Post-emergence
Prometryn + Quizalofop-p-ethyl	Gesagard + Targa Super	1.25 + 0.05	Pre-emergence + Post-emergence
Metribuzin + Quizalofop-p-ethyl	Sencor + Targa Super	0.18 + 0.05	Pre-emergence + Post-emergence
Hand weeded once	–	–	One month after emergence
Hand weeded twice	–	–	One and 2 months after emergence
Weeded control	–	–	Repeated after emergence
Unweeded control	–	–	–

Table 3 Density of weed (no. m^{-2}) and the efficacy of different herbicides and weeding by hand on weed species as an average of both years. LSD values in each column are significant at $P < 0.01$. (NS, not significant; WCE, weed control efficiency.)

Treatments	*Amaranthus retroflexus*	*Chenopodium album*	*Convolvulus arvensis*	*Polygonum* spp.	*Cirsium arvense*	*Malva neglecta*	*Tragopogon dubius*
Linuron	17.00	12.34	5.00	3.00	1.84	1.00	0.67
Prometryn	7.50	3.67	5.17	0.00	1.50	0.17	0.17
Metribuzin	5.67	1.67	8.34	0.67	3.00	0.00	0.00
Linuron + Prometryn	14.67	13.00	6.67	0.50	1.34	0.34	0.00
Prometryn + Prometryn	6.34	2.84	6.00	1.34	5.00	0.00	0.34
Metribuzin + Prometryn	3.34	1.17	5.84	1.34	2.67	0.00	0.50
Linuron + Fluazifop-p-butyl	27.67	7.84	5.34	1.34	0.17	0.00	0.67
Prometryn + Fluazifop-p-butyl	6.00	3.67	5.17	0.00	0.34	0.17	0.34
Metribuzin + Fluazifop-p-butyl	4.34	1.00	7.50	3.00	2.17	0.00	0.00
Linuron + Quizalofop-p-ethyl	8.00	8.84	6.00	0.50	3.67	0.50	0.34
Prometryn + Quizalofop-p-ethyl	8.50	5.17	5.14	0.34	1.17	0.17	0.17
Metribuzin + Quizalofop-p-ethyl	4.67	0.67	6.84	2.67	2.17	0.00	0.50
Hand weeded once	12.00	2.84	1.67	0.00	1.84	0.84	0.00
Hand weeded twice	11.00	5.50	1.67	0.17	1.50	0.17	0.00
Weeded control	5.50	3.00	1.34	0.17	1.17	0.17	0.17
Unweeded control	128.84	49.17	5.34	6.00	2.50	2.17	0.17
LSD	7.70	5.16	3.85	1.35	2.35	0.85	NS

**Avena fatua* and *Hordeum vulgare*.
†Transformed values.

Table 4 Effect of herbicide applications and hand weeding treatments on the dry weight of weeds and lentil (*Lens culinaris*) density. LSD values in each column are significant at $P < 0.01$. (NS, not significant; WCE, weed control efficiency.)

	Weed dry weight (g m^{-2})				Lentil density (no. m^{-2})		
Treatments	2000	2001	Average	WCE (%)	2000	2001	Average
Linuron	32.1	14.7	23.4	76.7 (0.87)*	205.0	281.7	243.3
Prometryn	39.9	7.0	23.5	76.6 (0.87)	203.3	250.0	226.7
Metribuzin	28.3	8.3	18.3	81.8 (0.96)	200.0	145.0	172.5
Linuron + Prometryn	32.8	1.5	17.1	83.0 (0.98)	206.7	278.3	242.5
Prometryn + Prometryn	23.1	6.3	14.7	85.4 (1.02)	211.7	253.3	232.5
Metribuzin + Prometryn	12.8	11.0	11.9	88.2 (1.08)	226.7	156.7	191.7
Linuron + Fluazifop-p-butyl	42.0	3.7	22.9	77.2 (0.88)	203.3	255.0	229.2
Prometryn + Fluazifop-p-butyl	35.4	3.3	19.4	80.7 (0.94)	216.7	255.0	235.8
Metribuzin + Fluazifop-p-butyl	38.8	11.9	25.3	74.8 (0.85)	213.3	145.0	179.2
Linuron + Quizalofop-p-ethyl	52.1	0.8	26.4	73.7 (0.83)	205.0	260.0	232.5
Prometryn + Quizalofop-p-ethyl	41.4	3.7	22.6	77.5 (0.89)	205.0	270.0	237.5
Metribuzin + Quizalofop-p-ethyl	30.6	1.7	16.2	83.9 (1.00)	215.0	170.7	192.9
Hand weeded once	5.3	1.1	3.2	96.8 (1.32)	215.0	281.7	248.3
Hand weeded twice	4.4	0.9	2.6	97.4 (1.34)	208.3	268.3	238.3
Weeded control	5.6	0.7	3.2	96.8 (1.32)	200.0	255.0	227.5
Unweeded control	108.6	92.3	100.5	–	218.3	268.3	243.3
LSD Treatment	47.3	23.2	25.7	0.25*	NS	74.7	40.2
LSD Year × Treatment	NS				56.9		

*Transformed values.

Hyoscyamus niger	*Crambe orientalis*	*Sideritis montana*	*Amaranthus graecizans*	*Fumaria officinalis*	*Lactuca serriola*	Gramineae*	Total density	WCE (%)
0.17	0.00	0.17	0.17	0.00	0.00	0.17	41.53	79.1 (0.91)†
0.00	0.17	0.00	0.00	0.00	0.00	0.00	18.35	90.8 (1.14)
0.00	0.00	0.00	0.00	0.00	0.00	0.17	19.52	90.2 (1.12)
0.00	0.34	0.00	0.00	0.00	0.00	0.67	37.53	81.1 (0.95)
0.17	0.34	0.00	0.00	0.00	0.00	0.17	22.54	88.7 (1.09)
0.00	0.00	0.00	0.00	0.00	0.00	0.50	15.36	92.3 (1.18)
0.34	0.00	0.17	0.00	0.34	0.00	0.34	44.22	77.8 (0.89)
0.00	0.00	0.00	0.00	0.00	0.17	1.50	17.36	91.3 (1.15)
0.00	0.17	0.00	0.17	0.00	0.00	0.50	18.85	90.5 (1.13)
0.17	0.00	0.00	0.00	0.17	0.00	0.17	28.36	85.7 (1.03)
0.00	0.84	0.00	0.00	0.00	0.00	0.84	22.34	88.8 (1.09)
0.00	0.00	0.00	0.00	0.00	0.00	0.17	17.69	91.1 (1.15)
0.00	0.00	0.00	0.34	0.00	0.00	0.00	19.53	90.2 (1.12)
0.00	0.00	0.00	0.17	0.00	0.00	0.00	20.18	89.9 (1.12)
0.00	0.00	0.00	0.17	0.00	0.00	0.00	11.69	94.1 (1.23)
1.00	0.17	0.67	0.17	0.17	0.17	2.34	198.88	–
0.45	NS	0.27	NS	NS	NS	1.04	20.05	0.14†

and as an average of herbicide applications, herbicidal effectiveness was greater (93.3%) compared with dry conditions experienced in 2000 (68.6%). Total weed dry weight mass was 100.5 g m^{-2} in the control plots with no herbicide spraying or hand weeding compared with 20.1 g m^{-2} on average in plants sprayed with herbicide (Table 4). Thus, herbicidal control of weeds was 80.0% on average. For dry weed mass, weed control efficiency showed insignificant differences (from 76.6% to 88.2%) among the herbicide applications. Once, twice, and repeated hand weeding, providing 96.8%, 97.4%, and 96.8% weed dry weight control respectively compared with the unweeded control, were more effective than the herbicide applications (Table 4). However, hand weeding once was almost as effective in controlling weeds as twice and repeated hand weeding.

As an average of both years, weed control treatments significantly affected lentil density, seed yield, total crop biomass yield, and harvest index (Tables 4 and 5). Variation occurred, however, between years. Relatively low rainfall in May–July of the first growing season (Table 1) reduced all the above parameters compared with the second growing season. Except for seed yield, year × treatment interaction was significant.

In the first growing season of the experiment, lentil density, ranging between 200.0 and 226.7 number m^{-2} depending on the treatments, was not affected by weed control applications. However, metribuzin had a toxic effect in relatively wet conditions of the second growing season. Therefore, metribuzin and metribuzin plus post-emergence applications significantly reduced lentil density between 33.1% (metribuzin plus quizalofop-p-ethyl) and 43.1% (metribuzin and metribuzin plus fluazifop-p-butyl) compared with the weeded control (Table 4).

All herbicide and hand weeding treatments significantly increased seed and total crop biomass yields compared with the unweeded control. As an average of both years, the highest (906 kg ha^{-1}) and the lowest seed yields (463 kg ha^{-1}) were obtained from the weeded and the unweeded control, respectively (Table 5). Seed yield increases in herbicide applications ranged between 49.2% (linuron plus prometryn) and 74.9% (prometryn plus fluazifop-p-butyl) over the unweeded control. However, pre-emergence plus post-emergence combinations gave no significant yield increases compared with single applications of linuron, prometryn, and metribuzin. Hand weeding once gave seed yield similar to chemical applications, hand weeding twice, and weeded

Table 5 Effect of herbicide applications and hand weeding treatments on seed yield, total crop biomass yield, and harvest index of lentil (*Lens culinaris*). LSD values in each column are significant at $P < 0.01$. (NS, not significant; WCE, weed control efficiency.)

Treatments	Seed yield (kg ha^{-1})			Total crop biomass yield (kg ha^{-1})			Harvest index		
	2000	2001	Average	2000	2001	Average	2000	2001	Average
Linuron	538	932	735	1704	3113	2409	31.6	29.9	30.3
Prometryn	604	949	777	2004	2921	2463	30.1	32.5	31.3
Metribuzin	648	890	769	1902	2379	2141	34.1	37.4	35.8
Linuron + Prometryn	561	821	691	1899	2671	2285	29.5	30.7	30.1
Prometryn + Prometryn	587	878	733	1794	2705	2250	32.7	32.5	32.6
Metribuzin + Prometryn	625	911	768	2096	2417	2257	29.8	37.7	33.8
Linuron + Fluazifop-p-butyl	557	914	736	1660	2925	2293	33.6	31.2	32.4
Prometryn + Fluazifop-p-butyl	728	892	810	2077	2713	2395	35.1	32.9	34.0
Metribuzin + Fluazifop-p-butyl	759	725	742	2532	2025	2279	30.0	35.8	32.9
Linuron + Quizalofop-p-ethyl	568	992	780	1926	2963	2445	29.5	33.5	31.5
Prometryn + Quizalofop-p-ethyl	553	903	728	1814	2942	2378	30.5	30.7	30.6
Metribuzin + Quizalofop-p-ethyl	570	871	721	2003	2430	2217	28.5	35.8	32.2
Hand weeded once	690	920	805	2254	2855	2555	30.6	32.2	31.4
Hand weeded twice	723	993	858	1998	2954	2476	36.2	33.6	34.9
Weeded control	748	1063	906	2200	3067	2634	34.0	34.7	34.4
Unweeded control	404	522	463	1255	1971	1613	32.2	26.5	29.4
LSD Treatment	196	218	171	609	676	459	NS	6.3	4.3
LSD Year × Treatment	NS			649			6.0		

control (Table 5). Total crop biomass yield was also highest in the weeded control (2634 kg ha^{-1}) and lowest in the unweeded control (1613 kg ha^{-1}) as an average of both years. In the herbicide applications, as an average of years, total crop biomass yields ranged between 2141 (metribuzin) and 2463 kg ha^{-1} (prometryn). Except for metribuzine, all herbicide applications gave total crop biomass yields similar to the weeded control (Table 5). However, the effects of metribuzin alone and metribuzin plus post-emergence applications on total crop biomass yield significantly changed between years. Although all herbicide applications with metribuzin significantly increased total crop biomass yields compared with the unweeded control in the first year, these applications gave total crop biomass yields similar to the unweeded control depending on the toxic effect of metribuzin in the relatively wet conditions of the second year.

As an average of years, the effect of weed control treatments on harvest index was significant. The unweeded control had the lowest harvest index (29.3%). Metribuzin alone (35.7%), hand weeding twice (34.9%), weeded control (34.4%), prometryn plus fluazifop-p-butyl (33.9%), and metribuzin plus prometryn (33.8%) gave significantly higher harvest index values than the unweeded control (Table 5). But the effect of treatments on harvest index significantly changed between years. In the second year of the experiment, metribuzin alone and metribuzin plus post-emergence treatments had the highest harvest index values whereas there were no significant differences among the weed control treatments in the first year.

DISCUSSION

Two years of trials showed that all of the herbicide applications and hand weeding (once, twice, and repeated) considerably decreased density and dry weight of weeds in lentil compared with the unweeded control. All herbicide applications having metribuzin were the most effective on *Amaranthus retroflexus* and *Chenopodium album* whereas the other chemical applications significantly reduced the density of these weed species compared with the unweeded control. Linuron, metribuzin plus fluazifop-p-butyl, and metribuzin plus quizalofop-p-ethyl were less effective than the other herbicide treatments in controlling of *Polygonum* spp. (Table 3). *Malva neglecta*, *Hyoscyamus niger*, and *Sideritis montana* were effectively controlled by all of the chemical applications falling into the statistically same group as the weeded control.

The efficacy of herbicides tested was rated in comparison with the control as <40% weak, 40–70% medium, 70–90% good, >90% excellent (Salonen & Ervio 1988). Thus, for weed density and dry weed mass, weed control efficiency was good or excellent in all of the herbicide applications, as an average of both years (Tables 3 and 4). These results are in agreement with those of the other researchers (Hernado et al. 1987; Boerboom & Young 1995; Muehlbauer et al. 1995; Yasin et al. 1995; Mohamed et al. 1997) who reported that density of weeds were significantly reduced (>90%) by metribuzin, prometryn, and linuron applications in lentil. Hand weeding once, on the other hand, was almost as effective in controlling weeds as herbicide applications, twice and repeated hand weeding. Other researchers also reported that hand weeding once controlled weeds effectively in lentil (Basler 1981; Haddad 1983; Singh et al. 1992).

Pre-emergence applications of herbicides require adequate rainfall to distribute the herbicide into the zone where weed seeds germinate and thus, dry conditions reduce the effectiveness of soil-active herbicides and weed control may be poor (Muehlbauer et al. 1995; Kantar et al. 1999). In our experiment, all herbicidal weed control treatments markedly reduced weed dry weight as compared with the unweeded control in both years (Table 4). But soil moisture also affected efficiency of the herbicides investigated. Relatively balanced and higher rainfall received in 2001 (Table 1), as an average of herbicide applications, resulted in greater (93.3%) herbicidal effectiveness compared with dry conditions experienced in 2000 (68.6%) (Table 4). However, under wet conditions and on soils with minimal organic matter, metribuzin may leach deeper into the profile and cause crop injury (Muehlbauer et al. 1995; Yasin et al. 1995). In our trial, treatments with metribuzin also had a toxic effect in relatively wet conditions of the second year on the experimental soils containing low organic matter content (1.68–1.87%) and significantly reduced lentil density (Table 4).

Weed control treatments significantly affected seed and total crop biomass yields. However, variation occurred between years. As an average of the weed control treatments, seed and total crop biomass yields were lower in the first growing season (Table 5). This could be attributed to the deficiency of rainfall. The 2000 growing season was warmer and drier than 2001 with a seasonal precipitation total of 55.7 and 114.7 mm, in the first and second growing seasons, respectively (Table 1).

As an average of both years, all herbicide and hand weeding treatments significantly increased seed and total crop biomass yields compared with the unweeded control. However, pre-emergence plus post-emergence combinations did not enhance weed control (Tables 3 and 4) and gave no significant seed and total crop biomass yield increases compared with single applications of linuron, prometryn, and metribuzin (Table 5) probably owing to the high levels of broad-leaved weed species in the experimental fields (Table 3). Fluazifop-p-butyl and quizalofop-p-ethyl used post-emergence to control grass weed in broad-leaved crops have no effect on broad-leaved weed species (Balyan et al. 1999; Siddique & Loss 1999; Luo & Matsumoto 2002) and, therefore, they do not increase seed yield in fields where broad-leaved weed species are dominant (Kantar et al. 1999). Conversely, hand weeding once gave seed and total crop biomass yields similar to chemical applications, hand weeding twice, and weeded control (Table 5). In other studies, hand weeding once which controlled weeds effectively and produced grain yield almost equal to herbicide applications was also found to be sufficient for lentil (Basler 1981; Haddad 1983; Singh et al. 1992).

Decreases in lentil density and total crop biomass yield depending on the toxic effect of metribuzin in the wet conditions of the second year were compensated with increases in harvest index. Therefore, reductions of lentil density did not have any negative effect on seed yields in the treatments having metribuzin, except for metribuzin plus fluazifop-p-butyl giving seed yield similar to the unweeded control in the second year of experiment (Table 5). These results are in agreement with the results reported previously by Kantar et al. (1994a), who reported that higher harvest index compensated yield disadvantages at lower plant densities in lentil.

In other studies, the highest seed and total crop biomass yields were obtained from weeded control in lentil, but herbicide applications and hand weeding also considerably increased seed and total crop biomass yields compared with the unweeded control (Chaudhary & Singh 1987; Mishra et al. 1996). In India, seed yield was decreased by 66.5% as a result of uncontrolled weeds, however metribuzin application gave a seed yield similar to weed-free conditions (Singh & Singh 1985). Pre-emergence prometryn and hand weeding twice gave the best weed control results and the highest seed yields in Egypt (Rizk et al. 1986; Saleeb & Al-Assily 2001). In Spain, prometryn provided the best control of 65% of the major weed species in lentil and gave the highest grain yield (1333 kg ha^{-1}) which was 457 kg more than the unweeded control (Hernado et al. 1987). In Sudan's irrigated conditions, seed yield was 1400 kg ha^{-1} in weedy control but increased to 2400 kg ha^{-1} when prometryn plus pendimethalin was applied (Mohamed et al. 1997).

In conclusion, 2 years of trials showed that herbicide applications considerably increased lentil yields compared with the unweeded control under Erzurum's dry conditions. However, pre-emergence plus post-emergence combinations gave no significant yield increases compared with the single applications of linuron, prometryn, and metribuzin. On the other hand, metribuzin which controlled weeds effectively had a toxic effect and significantly reduced lentil density in relatively wet conditions of the second year. As a result of these findings, it was concluded that linuron and prometryn alone, which considerably increased seed yield compared with the unweeded control and had no toxic effect, were appropriate for weed control in lentil. Furthermore, hand weeding once may equally be effective in controlling weeds subject to economical availability of labour.

REFERENCES

Al-Thahabi SA, Yassin JZ, Abu-Irmaileh BE, Saxena MC 1994. Effect of weed removal on productivity of chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris* Med.) in Mediterranean environment. Journal of Agronomy and Crop Science 172: 333–341.

Anonymous 1995. Annual activity reports. Eastern Anatolia Agricultural Research Institute, Erzurum. (In Turkish.)

Anonymous 2000. Agricultural structure and production. State Statistics Institute, Ankara. (In Turkish.)

Balyan RS, Pahwa SK, Dhankar RS, Malik RK 1999. Efficacy of linuron and fluazifop-p-butyl against weeds in soybean (*Glycine max*). Indian Journal of Weed Science 31: 229–233.

Basler F 1981. Weeds and their control. In: Webb C, Hawtin G ed. Lentils. London, Commonwealth Agricultural Bureaux. Pp. 143–153.

Bhan VM, Kukula S 1987. Weed and their control in chickpea (*Cicer arietinum* L.). In: Saxena MC, Singh KB ed. The chickpea. Wallingford, Oxon, CAB International. Pp. 319–328.

Boerboom CM, Young FL 1995. Effect of postplant tillage and crop density on broadleaf weed control in dry pea (*Pisum sativum*) and lentil (*Lens culinaris*). Weed Technology 9: 99–106.

Chaudhary M, Singh TP 1987. Studies on weed control in lentil. Indian Journal of Agronomy 32: 295–297.

Haddad N 1983. Effect of date of planting and plant population on yield and other agronomic characters of lentils (*Lens culinaris* Med.). Dirasat 5: 153–167.

Hernado J, Portillo R, Garcia-Orbegozo E, Fuertes T 1987. Weed surveys and control studies on lentil in central Spain. Lens Newsletter 14: 12–15.

Kantar F, Caglar O, Akten S 1994a. Lentil (*Lens culinaris* Medik.) yields in Erzurum in relation to sowing density. Ataturk University Journal of Agriculture Faculty 25: 390–397.

Kantar F, Demirci E, Agsakalli A 1998. Problems of grain legumes in Eastern Anatolia. Eastern Anatolia Agriculture Congress, 14–18 September 1998, Erzurum, Turkey. Pp. 490–498. (In Turkish with English abstract.)

Kantar F, Elkoca E, Zengin H 1999. Chemical and agronomical weed control in chickpea (*Cicer arietinum* L. cv. Aziziye-94). Turkish Journal of Agriculture and Forestry 23: 631–635.

Kantar F, Kiziloglu T, Caglar O, Akten S 1994b. Lentil yield in relation to *Rhizobium leguminosarum* inoculation in Eastern Anatolia. Lens Newsletter 21: 36–40.

Luo X, Matsumoto H 2002. Susceptibility of a broad-leaved weed, *Acanthospermum hispidum*, to the grass herbicide fluazifop-butyl. Weed Biology and Management 2: 98–103.

Ma J, Lin F, Zhang R, Yu W, Lu N 2004. Differential sensitivity of two green algae, *Scenedesmus quadricauda* and *Chlorella vulgaris*, to 14 pesticide adjuvants. Ecotoxicology and Environmental Safety 58: 61–67.

Mishra JS, Singh VP, Bhan VM 1996. Response of lentil to date of sowing and weed control in Jabalpur, India. Lens Newsletter 23: 18–23.

Mohamed ES, Nourai AH, Mohamed GE, Mohamed MI, Saxena MC 1997. Weeds and weed management in irrigated lentil in Northern Sudan. Weed Research 37: 211–218.

Muehlbauer FJ, Kaiser WJ, Clement SL, Summerfield RJ 1995. Production and breeding of lentil. Advances in Agronomy 54: 283–332.

Rizk TY, Ashoub MA, Mostafa MT, Hassan MWA 1986. Lentils productivity as affected by seeding rates and some herbicides. Annals of Agricultural Science, Ain Shams University 31: 1143–1157.

Saleeb SR, Al-Assily KA 2001. Effect of irrigation regime and some weed control treatments on lentil yield and associated weeds. Annals of Agricultural Science (Cairo) 46: 605–617.

Salonen J, Ervio LR 1988. Efficacy of chemical weed control in spring cereals in Finland. Weed Research 28: 231–235.

Saxena MC 1990. Problem and potential of chickpea production in the nineties. In: Chickpea in the nineties. Proceedings of the Second International Workshop on Chickpea Improvement, 4–8 December 1989, ICRISAT Center, Patancheru, India. Pp. 13–28.

Saxena MC, Wassimi N 1980. Crop weed competition studies in lentils. Lens Newsletter 7: 55–57.

Siddique KHM, Loss SP 1999. Studies on sowing depth for chickpea (*Cicer arietinum* L.), faba bean (*Vicia faba* L.) and lentil (*Lens culinaris* Medik.) in a Mediterranean-type environment of south-western Australia. Journal of Agronomy and Crop Science 182: 105–112.

Singh G, Singh D. 1985. Effect of herbicides on weed control in lentil (*Lens esculenta*). In: Abstracts of Papers, Annual Conference of Indian Society of Weed Science. Pp. 59–60.

Singh S, Sinha KK, Mishra SS, Pandey IS, Sinha SS 1992. Effect of inoculation, nitrogen and weed management on lentil (*Lens culinaris*). Indian Journal of Agronomy 37: 115–118.

Tawaha AM, Turk MA, Maghaireh GA 2002. Response of barley to herbicide versus mechanical weed control under semi-arid conditions. Journal of Agronomy and Crop Science 188: 106–112.

Touloupakis E, Giannoudi L, Piletsky SA, Guzzella L, Pozzoni F, Giardi MT 2005. A multi-biosensor based on immobilized photosystem II on screen-printed electrodes for the detection of herbicides in river water. Biosensors and Bioelectronics 20: 1984–1992.

Turk MA, Tawaha AM 2003. Weed control in cereals in Jordan. Crop Protection 22: 239–246.

Yasin JZ, Althahabi S, Abuirmaileh BE, Saxena MC, Haddad NI 1995. Chemical weed control in chickpea and lentil. International Journal of Pest Management 41: 60–65.