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Abstract: This study was conducted on the lentil cultivar Malazgirt 89 during 1999 and 2000 to determine the most appropriate method for controlling weeds. In the experiments, hand hoeing, trifluralin, imazethapyr, linuron, prometryn, phenmedipham + desmediphame, trifluralin + hand hoeing and linuron + hand hoeing which should be used as an alternative to hand weeding, were tested. The effects of herbicides on nodulation in lentils were also investigated. *Centaurea depressa* in the first year, and *Ranunculus arvensis* and *Acroptilon repens* in the second year were the dominant weed species encountered in the plots. A combination of linuron + hand hoeing, linuron alone and hand hoeing were the most effective methods for weed control. Trifluralin, imazethapyr and phenmedipham + desmedipham showed phytotoxic effects on lentils. None of the herbicides and methods used in the investigation had any adverse effects on nodulation, and *Rhizobium leguminosarum* inoculation was not found to have any effect on the competitive ability of weeds in lentils.

Key Words: Lentil, weed, herbicides, nodulation, *Rhizobium*

Yazlık Mercimekte Farklı Mücadele Yöntemlerinin Yabancı Otlara, Verime, Verim Unsurlarına ve Nodülasyona Etkisi

Özet: Bu çalışma, mercimekte sorun olan yabancı otlarla en uygun mücadele yöntemini belirlemek amacıyla 1999-2000 yıllarında yürütülmüştür. Denemelerde yazlık özelliğe sahip Malazgirt 89 çeşidi kullanılmıştır. Yabancı otlarla mücadelede, elle yolmaya alternatif olabilecek çapalama, trifluralin, imazethapyr, linuron, prometryn, phenmedipham + desmedipham, trifluralin + çapa, linuron + çapa uygulamaları denenmiş ve uygun yöntem belirlenmeye çalışılmıştır. Ayrıca, kullanılan herbisitlerin mercimekte nodül oluşumu üzerindeki etkileri de araştırılmıştır. Deneme parsellerinde, birinci yıl *Centaurea depressa*, ikinci yıl ise *Ranunculus arvensis* ve *Acroptilon repens* baskın yabancı ot türleri olarak belirlenmişlerdir. Yabancı otlarla mücadelede, yazlık mercimekte linuron'un çapa kombinasyonu, linuron ve çapalama uygulamaları en iyi ot kontrolü ve mercimekte en yüksek verimleri sağlamışlardır. Bu çalışmada, trifluralin, phenmedipham + desmedipham ve imazethapyr'in mercimeğe fitotoksik etkilerinin olduğu gözlenmiştir. Bununla beraber, kullanılan herbisitlerin ve yöntemlerin nodülasyon üzerine herhangi bir olumsuz etkilerinin olmadığı tespit edilmiştir. Ayrıca, *Rhizobium leguminosarum* aşılamanın, mercimekte yabancı ot rekabeti üzerine bir etkisi bulunmamıştır.

Anahtar Sözcükler: Mercimek, yabancı ot, herbisit, nodülasyon, *Rhizobium*

Introduction

Turkey is one of the foremost countries in terms of lentil (*Lens culinaris* Medik.) production and sowing area in the world, and is followed by Canada. However, Turkey is thirteenth in terms of lentil yield. The lentil is the second grain legume crop after the chickpea in Turkey. According to the latest statistics from The Food and Agricultural Organisation of the United Nations,

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380,000 ha were used for lentil production and 380,000 t of production were obtained in Turkey in 2000 (FAO, 2002).

Weeds are known to be the most important factor affecting lentil yield (Tepe, 1998). Halila (1995) reported that the mean loss in lentil yield caused by weeds is 60% and that, at the highest densities of weeds, losses can reach up to 100%. Therefore, controlling weeds must be considered to be of crucial importance. The loss caused by weeds in lentil production is considerable for 2 reasons: first, the lentil has a slow rate of development and thus is overwhelmed by weeds in the early stages of development. Basler (1981) reported that weeds are easily compatible with the lentil and so grow without difficulty. The other reason for such losses is that the lentil is grown in regions with little rainfall and has to share the limited amount of humidity in the soil with weeds.

Thus control of weeds will pave the way for higher lentil production if the means and modes of the application are well established. In addition to all these traits, the lentil, a legume crop, fixes the atmospheric nitrogen in root-nodules by the *Rhizobium* bacteria. The amount of nitrogen released into the soil through the symbiotic cycle is 84 kg ha^{-1} per annum (Şehirali, 1988). Sprout et al. (1992) reported that higher rates of some herbicides could impair plant growth, resulting in reduced nodulation. The most effective method of controlling weeds has been reported to be hand weeding; however, this method is only used on small farms operated on a family basis. This method is not economical on large farms (Eyüpoğlu et al., 1995). The use of effective herbicides or a number of different integrated control methods could be more economical than hand hoeing. In accordance with this premise, this study examines alternative methods to hand weeding to determine an appropriate method, and investigates the effects of herbicides used on nodulation in lentil production.

Materials and Methods

Trials were conducted in fields belonging to the Agriculture Occupational High School in Van. The lentil (*Lens culinaris* Medik.) cultivar Malazgirt 89, known to be well adapted to the region, was used in the study (Günel et al., 1994).

In the trials, the inoculation material produced from the mixture of nodule-forming strains in lentil by the bacteria strains, *Rhizobium leguminosarum*, resembling pith culture, was used. This material was provided by the Soil and Fertilizer Research Institute of Ankara.

Some local climatologic data for 1999-2000 are presented in Table 1. The soils of the trial area were loamy, with alkali reaction (pH 8.1), low in organic matter and available nitrogen and moderate in available phosphorus.

In both years of the study, the amount of precipitation was below the long-term average and there was an increase in the average temperature. In addition, the amount of precipitation in the second year of the trial was lower than that in the first year.

The herbicides used in the study are presented in Table 2. The rates and times of application of herbicides

Table 1. Some climatologic data pertaining to the region in which the study was conducted (TSMS, 2001).

Month	Precipitation (mm)			Average temperature (ºC)		
	1999	2000	LTA*	1999	2000	LTA*
April	49,2	36,5	51,7	8,4	9,5	8,1
May	41,8	23,9	50,5	14,9	14,3	13,2
June	7,4	3,3	17,8	20,0	19,5	18,2
Total	98,4	63,7	120,0			
Annual total	322,8	234,9	393,8			
Annual average				10,7	10,3	9,3

*LTA: Long-term average (1979-2000)

Table 2. Active ingredients (a.i), application rates, application times and trade names of herbicides.

Active ingredient (a.i)	Application rate	Application time	Trade name
Trifluralin	1 kg a.i. ha^{-1}	Pre-plant incorporation	Treflan, 480 g l^{-1}, DowElanco
Imazethapyr	0.05 kg a.i. ha^{-1}	Pre-plant incorporation	Pursuit, 100 g l^{-1}, Cyanamid
Linuron	0.9 kg a.i. ha^{-1}	Pre-emergence	Afalon Dispersion, 450 g l^{-1}, AgrEvo
Prometryn	1.5 kg a.i. ha^{-1}	Pre-emergence	Gesagard, 500 g l^{-1}, Novartis
Phenmedipham + desmedipham	0.49 kg a.i. ha^{-1}	Post-emergence	Betanal Compact, 129 + 34 g l^{-1}, AgrEvo

are as found in the guidebook of the Ministry of Agriculture and Rural Affairs (TKB, 1995) and Thomson (1997).

Various cultural and chemical control methods were compared to determine the most appropriate method for controlling weeds. For this purpose the following treatments were applied; weed-free control (hand weeding), hand hoeing once, pre-plant incorporation of trifluralin, pre-plant incorporation of imazethapyr, pre-emergence application of linuron, pre-emergence application of prometryn, post-emergence application of phenmedipham + desmedipham, pre-plant incorporation of trifluralin + hand hoeing, pre-emergence application of linuron + hand hoeing, weedy control (inoculated), weedy control (uninoculated).

The investigation was carried out in 1999 and 2000 in a completely randomized block design with 4 replications. The plot size was 20 m^2 (4 m x 5 m) according to the criteria proposed by the European and Mediterranean Plant Protection Organization (EPPO, 1986). Sowing was carried out manually in rows 30 cm apart. Plots were not irrigated because the lentil is grown in dry conditions. Seeds were sown on 8 April in both years. Diammoniumphosphate fertilizer was uniformly applied at 140 kg ha^{-1}in the trial area. Before the sowing process, except for the uninoculated weedy control, all of the trial plots were inoculated with *R. leguminosarum* bacteria. The seeding rate was 80 kg ha^{-1} (Şehirali, 1988). Control by hand weeding was carried out twice when the weed density was high, in the pre- and post-flowering stages (flowering period: 15-24 May). Hand hoeing was performed on 1-2 May in both years. Herbicide treatments were applied with a hand-held boom with flat-fan nozzles (Teejet TIM 03-F 80 and 06-F 110 TIMSAN, Turkey) that delivered 140 l ha^{-1} on post-emergence and 200 l ha^{-1} on pre-plant and pre-emergence applications at 200 kPa. In the period when weeds were heavy, and their identification was much easier, they were counted in all of the plots on 13-14 May in both years. Three samples representative of each plot were taken and an average of each plot was calculated; for this purpose, a quadrate of 1 m^2 was used.

In the investigation, yield components were classified as biological yield, grain yield, harvest index, number of plants per square meter, 1000-seed weight, plant height, nodule number and dry weight of root. At flowering, 10 plants were sampled at random from each plot and the number of nodules and root dry weight determined. At maturity another 10 plants were sampled from each plot and plant height was measured and the average calculated. The crop was harvested manually on 14-15 July when the crop was mature. At harvest, 2 outer rows for each plot and 50 cm from each end of the plots were left as borders and the middle 4 m of the central rows were harvested: grain yield and straw yield were measured. Seeds and straw samples were collected from each plot, dried and then ground. In addition to these criteria, the percentage of weed-covered area was determined using the method proposed by Uygur (1985).

Although the data concerning weeds were obtained successfully, the data concerning seed yield and yield components could not be obtained due to severe damage caused by birds during the harvesting period in 1999, for which reason statistical analyses related to yield and its components were made on 2000 annual basis.

Statistical analyses

The effect of treatments on weeds and differences among treatments were analyzed using analysis of variance procedures for a completely randomized design with the SAS (1996) statistical package. When the F-value of the ANOVA was significant at the $P < 0.05$ level of probability, means were separated using Duncan's multiple comparison tests (Cochran and Cox, 1957).

Results and Discussion

The densities and general coverage areas of weed species in the experimental plots in 1999 and 2000 are presented in Table 3. In the first year *Centaurea depressa* was the most dominant species of the weed population in the plots. However, in the second year *Ranunculus arvensis* and *Acroptilon repens* were the most dominant weed species encountered. Weed species, their densities and general coverage areas showed significant differences in both years.

In the control of dominant weed species encountered in the plots, the best results, approximating to weed-free control, were obtained from phenmedipham + desmedipham, linuron + hand hoeing, hand hoeing once and linuron in *C. depressa* in 1999; and from linuron + hand hoeing, imazethapyr, phenmedipham + desmedipham, linuron, trifluralin + hand hoeing and hand hoeing once in *R. arvensis* and linuron in *A. repens* in 2000 (Table 4).

The difference between the years with regard to weed density was statistically significant. This density was generally higher in 2000 than in 1999. The differences between the control methods in terms of weed density were also statistically significant (Table 5). The most effective results in reducing weed density in 1999 were obtained with hand hoeing, linuron + hand hoeing and trifluralin + hand hoeing. Similarly, the most effective results in 2000 were obtained with linuron + hand hoeing, trifluralin + hand hoeing, linuron and hand hoeing.

The differences between the years and among the control methods applied in terms of coverage area were statistically significant. Values with regard to general coverage area were also generally higher in 2000 than in 1999. The best results approximating to weed-free control with regard to general coverage area were obtained with hand hoeing, linuron + hand hoeing, phenmedipham + desmedipham, linuron and trifluralin +

Table 3. Weed species in experimental spring lentil plots in 1999 and 2000.

Species	1999		2000	
	Density (plant m^{-2})	General cover area (%)	Density (plant m^{-2})	General cover area (%)
Centaurea depressa Bieb.	12.50	10.00	-	-
Acroptilon repens (L.) DC.	5.50	3.85	10.50	7.35
Hordeum vulgare L.	2.50	1.00	3.00	1.20
Convolvulus arvensis L.	1.00	0.50	1.00	0.50
Tragopogon sp.	1.00	0.40	-	-
Geranium tuberosum L.	1.00	0.10	-	-
Adonis aestivalis L.	0.50	0.20	1.25	0.50
Echinophora orientalis Hedge et Lamond	0.25	0.20	-	-
Turgenia latifolia (L.) Hoffm.	0.25	0.20	5.75	4.60
Circium arvense (L.) Scop.	0.25	0.15	0.25	0.15
Ranunculus arvensis L.	-	-	12.25	3.68
Aegilops spp.	-	-	2.75	1.65
Cynodon dactylon (L.) Pers.	-	-	1.25	0.25
Boreava orientalis Jaub. & Spach.	-	-	1.00	1.00
Cephalaria syriaca (L.) Schrad.	-	-	1.00	0.90
Falcaria vulgaris Bernh.	-	-	0.75	0.38
Lallemantia peltata (L.) Fisch. et Mey.	-	-	0.75	0.30
Polygonum aviculare L.	-	-	0.75	0.15
Centaurea balsamita Lam.	-	-	0.25	0.23
Fumaria officinalis L.	-	-	0.25	0.05
Galium tricornutum Dandy	-	-	0.25	0.05
Total	24.75	16.60	43.00	22.94

Table 4. Effect of weed control treatments on the dominant weeds in the experimental spring lentil plots in 1999 and 2000.

Treatments	1999	2000	
	Centaurea depressa (plant m^{-2})	*Ranunculus arvensis* (plant m^{-2})	*Acroptilon repens* (plant m^{-2})
Weedy control (uninoculated)	12.25 a	12.25 a	10.50 ab
Trifluralin	12.00 a	11.50 a	12.75 a
Imazethapyr	9.25 ab	0.50 b	13.50 a
Weedy control (inoculated)	5.75 bc	10.25 a	8.25 ab
Prometryn	5.75 bc	9.00 a	9.00 ab
Trifluralin + hand hoeing	5.00 cd	1.00 b	14.00 a
Linuron	2.75 cde	1.00 b	4.75 bc
Hand hoeing once	2.25 cde	1.75 b	13.75 a
Linuron + hand hoeing	1.00 de	0 b	14.25 a
Phenmedipham + desmedipham	0 e	1.00 b	10.50 ab
Weed-free control (hand weeding)	0 e	0 b	0 c

* Values in a column with different letters are significantly different from each other (Duncan's multiple range tests, < 0.05)

Table 5. Effect of weed control treatments on weeds in the spring lentil.

Treatments	1999		2000	
	Weed density (plant m^{-2})	General coverage area (%)	Weed density (plant m^{-2})	General coverage area (%)
Weedy control (uninoculated)	24.75 a	16.60 a	43.00 a	22.94 a
Trifluralin	22.50 ab	14.08 ab	43.00 a	24.05 a
Weedy control (inoculated)	20.25 abc	11.45 abcd	33.50 abc	17.43 abcd
Imazethapyr	18.50 abcd	11.58 abc	37.75 ab	20.65 abc
Prometryn	18.00 abcd	10.63 abcd	40.00 a	21.50 ab
Phenmedipham + desmedipham	17.50 abcd	9.23 bcd	32.25 abcd	21.15 abc
Linuron	16.50 abcd	9.45 bcd	21.00 cd	12.83 cd
Trifluralin + hand hoeing	15.25 bcd	9.65 bcd	21.00 cd	13.18 bcd
Linuron + hand hoeing	11.50 cd	6.95 cd	18.00 d	12.10 d
Hand hoeing	9.75 d	5.30 de	25.00 bcd	15.78 abcd
Weed-free control (hand weeding)	0 e	0 e	0 e	0 e

*Values in a column with different letters are significantly different from each other (Duncan's multiple range tests,< 0.05)

hand hoeing in 1999. Similarly, the best results with weed-free control in 2000 were obtained with linuron + hand hoeing, linuron and trifluralin + hand hoeing (Table 5). These results indicated that hand hoeing and its combinations with herbicides controlled weeds effectively and produced grain yield in spring lentil production. A higher yield of lentil as a result of weed control through hoeing over the weedy control could have resulted from the availability of more space, nutrients and water due to removal of weeds. In a study conducted by Sekhon et al. (1986) hand hoeing twice proved to be as effective as herbicides in the controlling of weeds in lentils and

increasing yield. Meanwhile, in the inoculated plots inoculation had no effect on the competitiveness of the lentil with weeds (Table 5).

Statistically significant differences were found in terms of biological yield, grain yield and harvest index, depending on different treatments. The values closely approximated the weed-free control with respect to biological and grain yield for linuron + hand hoeing, linuron alone and hand hoeing applications. The best results in terms of harvest index were obtained with hand hoeing and its combined treatments with trifluralin + hand hoeing, linuron + hand hoeing, linuron and prometryn (Table 6).

The differences among the results obtained from the methods of weed control related to plant number per square meter, 1000-seed weight and root dry weight were statistically significant, although differences related to plant height and nodule number were not statistically significant. The values related to plant number per square meter and approximating to those of the weed-free controls were obtained with linuron + hand hoeing, weedy control (inoculated), hand hoeing, weedy control (uninoculated), linuron and phenmedipham + desmedipham (Table 7).

The values related to 1000-seed weight and approximating to the weed-free control were obtained with trifluralin and phenmedipham + desmedipham. The values related to the dry weight of root and approximating to the weed-free control were obtained with linuron, linuron + hand hoeing, weedy control (uninoculated), hand hoeing and weedy control (inoculated) (Table 7).

In the observations made in these trials herbicides such as trifluralin, imazethapyr and phenmedipham + desmedipham showed phytotoxic effects on lentils. Trifluralin has a negative effect on lentil emergence. Imazethapyr stunted seedlings, thickening and shortening the roots, caused foliar chlorosis and some leaf burn, delayed flowering and led to a decrease in yield. Phenmedipham + desmedipham caused burn in the sub-leaves of the plant. Basler (1981) reported that trifluralin was more phytotoxic to lentils in dry years. Similarly, Wall (1994) reported that trifluralin diminished germination ability, which led to a decrease in grain yield; Abdou and Ashour (1990) also reported that trifluralin and prometryn thickened the roots, stunted the plant and impaired its ability to germinate. In some other studies the phytotoxic effect of prometryn has been cited (Uzun, 1988, 1992). Wall (1995, 1996) reported that imazethapyr severely decreased lentil yields, also drawing attention to similar effects of imazamethabenz.

When inoculation and uninoculation were compared, yield and its components were not affected by inoculation. No methods or herbicides were found to have

Table 6. Effect of weed control treatments on biological yield, grain yield and harvest index in spring lentil.

Treatments	Biological yield (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index (%)
Linuron + hand hoeing	1002.91 a	201.18 a	20.58 b
Linuron	963.85 a	187.84 ab	19.49 bc
Weed-free control (hand weeding)	806.23 b	163.11 b	20.34 b
Hand hoeing	748.45 bc	121.56 c	15.79 cd
Weedy control (inoculated)	647.05 c	68.70 de	10.51 ef
Weedy control (uninoculated)	462.40 d	38.48 ef	8.27 f
Phenmedipham + desmedipham	397.51 d	35.07 f	8.34 f
Trifluralin + hand hoeing	358.57 d	101.00 cd	27.80 a
Prometryn	358.28 d	69.80 de	19.16 bc
Imazethapyr	161.72 e	21.32 f	12.89 de
Trifluralin	136.24 e	11.73 f	8.23 f

* Values in a column with different letters are significantly different from each other (Duncan's multiple range tests, < 0.05)

Table 7. Effect of weed control treatments on spring lentil yield components.

Treatments	Plant number m^{-2}	1000-seed weight (g)	Plant height (cm)	Dry weight of root (g $plant^{-1}$)	Nodule number $plant^{-1}$
Linuron + hand hoeing	254.50 a	30.54 b	16.03 ns	0.050 ab	4.25 ns
Linuron	180.50 abc	30.38 b	16.38	0.059 a	7.18
Weed-free control (hand weeding)	196.75 abc	31.19 ab	14.98	0.046 abc	6.30
Hand hoeing	205.00 abc	30.95 b	15.90	0.046 abc	8.98
Weedy control (inoculated)	217.25 ab	29.34 bc	16.23	0.045 abc	4.18
Weedy control (uninoculated)	184.50 abc	30.21 b	16.80	0.049 ab	4.45
Phenmedipham + desmedipham	175.50 abcd	31.47 ab	14.80	0.037 bc	3.40
Trifluralin + hand hoeing	129.25 bcd	30.03 b	15.98	0.040 bc	6.20
Prometryn	161.75 bcd	29.19 bc	15.88	0.040 bc	4.35
Imazethapyr	123.50 cd	25.71 c	15.60	0.036 bc	3.53
Trifluralin	91.25 d	34.84 a	13.33	0.030 c	4.03

*Values in a column with different letters are significantly different from each other (Duncan's multiple range tests, < 0.05)
ns: not significant

any negative effect on nodulation during the trials. In a study carried out by Sekhon et al. (1986) in India herbicides such as terbutryne and methabenzthiazuron and hand hoeing twice were observed to effectively control weeds and to show no negative effect on nitrogen fixation and nodulation. In Turkey, Çetinsoy (1998) found that prometryn, methabenzthiazuron and metribuzin increased lentil yield, exerted no negative effects on nodulation, and were comparable to weed-free controlled plots. Sandhu et al. (1991) reported that oxyfluorfen, linuron, metribuzin and oxadiazon had some effect on nodule number, nodule dry weight and nitrogenase activity, although terbutryn and methabenzthiazuron did not. They reported that hand hoeing positively affected nodulation in the plant. Sprout et al. (1992) reported that increased doses of metribuzin could negatively affect plant growth and, associated with this, the nodulation process. Pahwa and Prakash (1992), in a study conducted on the chickpea, found that lower doses of fluchloralin, metribuzin and pendimethalin had no negative effects on nodulation, but, taking into account plant growth, pendimethalin was found to be a more reliable herbicide.

Conclusions

In this study, linuron + hand hoeing, linuron alone and hand hoeing were found to give the best yields in terms of controlling weeds in the spring lentil. Therefore, it was concluded that it could be recommended for the control of weeds in spring lentil production.

In these trials, trifluralin, phenmedipham + desmedipham and imazethapyr caused phytotoxic effects on the lentil. However, the herbicides used and the methods conducted in the trials were found to have no negative effects on nodulation. Similarly, inoculation with *Rhizobium* bacteria was not found to have any effects on the lentils competitiveness against weeds.

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