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Critical period of weed control in winter lentil under non-irrigated conditions in Turkey

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This study was conducted during the growing seasons of 1998 - 1999 and 2003-2004 to determine the critical period of weed control (CPWC) in winter-lentil (cv. Sazak-91). The experiments were laid out in a randomised block design with four replications. The beginning and end of CPWC were based on 5% acceptable yield loss levels which were determined by fitting logistic and Gompertz equations to relative yield data, representing increasing duration of weed-interference and weed-free period, estimated as growing degree days (GDD). The results indicated that CPWC for seed yield was between 237 and 846 GDD in the first year and between 123 and 414 GDD in the second year, while CPWC for biomass was between 216 and 820 GDD in the first year and between 212 and 374 GDD in the second year. Thus weeds should be controlled from the first week after the onset of regrowing stage of the crop in spring up to 7th week for winter-lentil to avoid losses above 5%.

Key words: Lentil, critical period, weed competition, weed interference.

INTRODUCTION

Turkey, one of the three countries in terms of lentil (*Lens culinaris* Medik.) production and sowing area in the world, follows after India and Canada. However, Turkey is the tenth in terms of lentil yield in the world. Lentil is the second leading grain legume crop after chickpea in Turkey. According to the latest statistics from FAO (2006), 440 000 hectares were used for lentil production and 555 000 tonnes of production were obtained in 2005 in Turkey. Lentil is commonly grown as a rotation crop in east and southeast of Turkey. It is an important crop because of its high protein content of seed and straw for human and animal nutrition. Traditionally, lentil is grown in spring in Turkey; however, winter-lentil cultivars are grown in recent years.

Weeds are known to be the most important factor affecting lentil yield. Halila (1995) reported that the average loss in lentil yield caused by weeds was 60% and that, at the highest density of weeds, loss could amount to 100%. Weeds compete with crop for nutrients, soil moisture and sunlight. The extend of weed competition depends upon type of weed species, severity of weed infestation, duration of infestation, climatic conditions which affect weed and crop growth. Reduction in crop yield has a direct correlation with weed competition. Generally an increase in one kilogram of weed growth corresponds to a reduction in one kilogram of crop growth. Weeds remove plant nutrients more efficiently than crops. In a drought situation, they thrive better than crop. When left undisturbed, some weeds can grow faster and taller than crop and inhibit tillering and branching. They can curtail sunlight and adversely affect photosynthesis and plant productivity (Rao, 2000). Therefore, weeds are of crucial importance. The loss caused by weeds in lentil production is considerable for two reasons: first, the lentil has a slow rate of development and, thus, is overwhelmed by weeds in the early stages of its development. Weeds are easily compatible with the lentil and grow without difficulty, because weeds utilize soil moisture and plant nutrients in prevailing environmental conditions efficiently better than crops in their first development stages (Basler, 1981; Bukun and

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Table 1. Some chemical and physical properties of soil.

Years	Texture class	$CaCO_3$(%)	Salt (%)	Org. matter (%)	pH	Total N (%)	Available P (ppm)	Available K (ppm)
1998-99	Loamy	17.5	0.053	1.00	8.1	0.025	4.4	310
2003-04	Loamy	17.7	0.060	1.18	7.9	0.041	4.2	298

Guler, 2005). The second reason for such a loss is that lentil is grown in Turkey in regions which have limited rainfall, and have to share the limited available soil moisture with the weeds. Thus effective weed control will result in higher seed yields of lentil.

Zimdahl (1980) defines the critical period as the last term or point in which weed control could be effectively made without posing a remarkable effect on yield. The critical period of weed control (CPWC) in a particular crop is the minimum period of time during which weeds must be suppressed in order to prevent yield losses (Weaver and Tan, 1983). Swanton and Weise (1991) identified the CPWC as a key component of a successful integrated weed management (IWM) program.

Many studies have been conducted around the world to determine the CPWC in various crops, with a range of environmental conditions (Dawson, 1970; Buchanan et al., 1980; Weaver, 1984; Rogers and Buchanan, 1986; Bryson, 1990; Hall et al., 1992; Van Acker et al., 1993; Bedmar et al., 1999; Halford et al., 2001; Martin et al., 2001; Amador-Ramirez, 2002; Evans et al., 2003; Knezevic et al., 2003; Bukun, 2004; Norsworthy and Oliveira, 2004).

Critical period studies have been conducted on limited number of legume crops. Field studies were conducted to determine the critical period of weed control in soybean in Ontario, and it has been found that the critical weed-free period was relatively short and consistent across locations and years. A period of weed control, lasting up to the fourth node growth stage approximately 30 days after emergence (DAE), was adequate to prevent yield loss of more than 2.5% (Van Acker et al., 1993). Ngouajio et al. (1997) in a 3 year study in Cameroon found that the critical period to prevent more than 10% yield loss was 3-4 trifoliate leaves, and this level could be obtained by one weeding in common bean. In another study, the critical period of weed interference in one variety of chickpea was determined in field experiments in Iran. Results of these experiments indicated that chickpea must be kept weed-free between the five-leaf and full flowering stages (24 and 48 DAE) and from the four-leaf to beginning of flowering stages (17 and 49 DAE) at the two sites, respectively, in order to prevent more than 10% seed yield loss (Mohammadi et al., 2005). Singh et al. (1996) determined that critical period of weed interference varied from 7.7 to 9.3 weeks for seed yield and from 6.5 to 9.9 weeks for straw yield, after crop emergence in lentil in Jordan. Mohamed et al. (1997) reported that this period was between 2 and 4 weeks after sowing, but between 4 and 6 weeks after sowing in a cooler location with a longer growing season which suggests that the critical period might vary with the environmental conditions, level of weed infestations, composition of weed population and soil moisture, and fertility level. Several factors, including the climate, have made such results inappropriate for other regions of the world (Norsworthy and Oliveira, 2004) because many weed species which were studied are might not common for Turkey.

This research was aimed to determine the effects of the timing of weed removal and duration of weed interference on winter-lentil yield in Turkey, since this kind of information is lacking. This information could help lentil producers improve the efficacy of their current weed management systems and reduce yield loss, resulting from weed competition. Also it will assist to determine the appropriate time of herbicide application and the other control methods in integrated weed management (IWM) systems.

MATERIALS AND METHODS

Experimental details

The effects of duration of weed-free and weed-interference period on above-ground biomass, and seed yield of lentil were studied in Van (33°28'N, 43°21'E, 1725 m elevation), eastern Turkey. The experiments were carried out on winter-lentil cv. Sazak 91 in 1998 - 1999 and 2003 - 2004. Soil samples from two years were analysed and physical and chemical properties of soil are presented in Table 1. The soils of the trial areas were loamy texture, high $CaCO_3$ content, low salt content and slightly alkali. The organic matter and nitrogen contents of soil were extremely low while available K content was enough and available P content was low. Some local climatologic data for years of experiments are presented in Table 2. In 1998 - 1999 and 2003 - 2004 precipitation throughout the growing season (from October to June) was 251.8 and 331.3 mm respectively, and the long-term average for the same period was 364.0 mm for winter-lentil. The average temperature for two years was higher than the long-term average. Also precipitation in the first year of the trial was less compared with the second year.

The experimental design was a randomised complete block with four replications. Plot size was 2.5 x 4 m. Seeds were inoculated with a mixture of nodule-forming strains of *Rhizobium leguminosarum,* specific to lentil provided by the Soil and Fertilizer Research Institute of Ankara, Turkey. The soil was deeply ploughed after cereal harvest and left until disc-harrowing and rotary-harrowing in autumn when seeds were sown. Fertilizer was applied at a rate of 140 kg DAP (diammonium phosphate) ha^{-1}, at sowing. Lentil was hand-drilled in rows 30 cm apart on a flat plot at a seed rate of 160

Table 2. Some climatological data belong to years of experiment.

Month	Precipitation (mm)			Average temperature (°C)		
	1998-99	2003-04	LTA*	1998-99	2003-04	LTA*
October	0.3	23.6	45.2	11.9	13.0	10.6
November	14.9	59.6	47.9	8.8	4.5	4.4
December	59.3	14.9	37.3	3.0	0.2	-0.8
January	8.1	25.0	35.4	0.3	-0.9	-3.6
February	24.9	39.6	32.5	0.4	-0.6	-3.2
March	45.9	69.9	45.7	2.6	3.7	0.9
April	49.2	26.9	56.6	8.4	6.9	7.4
May	41.8	68.7	45.0	14.9	12.4	13.0
June	7.4	3.1	18.5	20.0	18.5	18.0
July	-	2.0	5.2	22.8	21.4	22.2
August	2.2	-	3.4	23.8	22.2	21.8
September	17.2	-	13.0	17.5	18.0	17.2
Total	271.2	333.3	385.7			
Average				11.2	9.9	9.0

*LTA = Long-term average (1949-2004) (TSMS, 2005).

kg ha^{-1} on 26 October 1998 and 25 October 2003. The experiment was carried out as rainfed. Sazak 91 emerged 10 - 12 days after sowing (DAS) and was covered by snow in late November and started to regrow in mid-April in the both years. No agronomic interventions were made during this period.

Two sets of weed interference treatments were started after the onset of regrowing stage of the crop in spring for winter-lentil. In order to evaluate the beginning of CPWC, weeds were allowed to compete with winter-lentil at weekly interval for 1 to 10 weeks after crop regrowing (WAR). To determine the end of critical period, plots were kept weed-free at weekly interval for 1 to 10 WAR with periodic hand hoeing.

Weed and crop measurements

Natural occurring weed populations were used in all trials. Weeds were counted at full emergence. Three square meter samples were randomly collected from each plot. Total weed densities and major species for each trial were determined. Weed removal within and between crop rows was carried out manually. Crop variables included biomass and seed yield. At maturity 3 m length of the six central rows of each plot was harvested (26 June 1999 and 26 June 2004) by hand.

Meteorological data

The meteorological data were collected from Van State Directorate of Meteorology as daily maximum (T_{max}, °C) and daily minimum (T_{min}, °C) temperatures.

Statistical analysis

Actual yield and relative yield were subjected to analysis of variance using PROC MIXED function of Statistical Analysis System (SAS, 1999), to evaluate the effect of the length of the weed-free period and increasing duration of weed interference on relative lentil yields (Evans et al., 2003; Knezevic et al., 2002; Norsworthy and Oliveira, 2004). Relative yield of each treatment was calculated in percent of the corresponding weed-free yield. The significance of the interaction between year and treatment combinations was evaluated at the 5% level of probability.

A three-parameter logistic equation proposed by Hall et al. (1992) and modified by Knezevic et al. (2003), was used to describe the effect of increasing duration of weed interference on relative yield and to determine the onset of critical period. The equation had the following form:

$$RY = \left[\frac{1}{\exp(C*(T-D))+F} + \frac{F-1}{F}\right]*100 \quad [1]$$

where, RY is the relative yield (% of season-long weed-free yield), T is the duration of weed interference measured from the time of regrowing stage in days for winter-lentil, D is the point of inflection in GDD, C and F are constants.

The Gompertz model has been shown to provide a good fit to yield under increasing length of the weed-free period (Hall et al., 1992; Knezevic et al., 2002). The model has the following form:

$$RY=A*\exp(-B*\exp(-K*T)) \quad [2]$$

Where, RY is the relative yield (% of season-long weed-free yield), A is the yield asymptote, B and K are constants, and T is the length of the weed-free period after crop sowing in growing degree days (GDD). At both trials, GDD were accumulated from the date of sowing (time zero) using a base temperature (T_b) of 5°C (Pikul et al., 2004)

$$GDD = [(T_{max} + T_{min})/2 - T_b] \quad [3]$$

Where T_{max} is daily maximum air temperature (°C) and T_{min} is daily minimum air temperature (°C).

Determination of the CPWC in this study was on the basis of an acceptable yield loss level (AYL) of 5%, because the 5% yield loss level is generally accepted for most crops in Turkey (Dogan et al., 2006).

Table 3. Major species and average density (plants m^{-2}) of weeds present at the experimental plots (weedy control).

Species	Average Density (plants m^{-2})	
	1998-99	2003-04
Acroptilon repens (L.) DC.	3	4
Adonis aestivalis L.	5	5
Aegilops cylindrica Host.	5	2
Alyssum desertorum Stapf.	-	2
Anchusa arvensis (L.) Bieb.	3	-
Anchusa azurea Miller.	5	1
Boreava orientalis Jaub. & Spach.	-	1
Centaurea balsamita Lam.	10	-
Centaurea depressa Bieb.	-	15
Cephalaria syriaca (L.) Schrad.	8	1
Ceratocephalus testiculatus (Cran.) Roth.	6	7
Cichorium inthybus L.	-	1
Convolvulus arvensis L.	11	2
Cynodon dactylon (L.) Pers.	5	3
Descurainia sophia (L.) Webb. ex Prant.	-	3
Echinophora orientalis Hedge & Lamond	-	1
Euphorbia heteradena Jaub et Spach.	1	1
Galium tricornutum Dandy	4	2
Geranium tuberosum L.	-	1
Gypsophila bicolor (Freyn & Sint.) Grossh.	-	1
Hypecoum pendulum L.	2	15
Lallemantia peltata (L.) Fisch. et Mey.	3	-
Lamium amplexicaule L.	3	-
Lathyrus sp.	10	-
Neslia paniculata (L.) Desv.	2	4
Papaver sp.	1	2
Ranunculus arvensis L.	12	-
Roemaria hybrida (L.) DC.	-	2
Turgenia latifolia (L.) Hoffm.	6	2
Vicia sp.	-	1
Viola occulta Lehm.	2	-
Total	107	79

RESULTS

Weed and crop measurements

The weed community was composed of 21 species in 1998 - 1999 and 24 species in 2003-2004. Overall weed density ranged from 107 plants m^{-2} in 1998 - 1999 and up to 79 plants m^{-2} in 2003 - 2004. Major weed species for the first year were *Ranunculus arvensis* L., *Convolvulus arvensis* L., *Centaurea balsamita* Lam. and*Lathyrus* sp. and for the second year *Centaurea depressa* Bieb. and *Hypecoum pendulum* L. (Table 3).

Biomass of winter-lentil on the weed-free plots ranged from 1313 kg ha^{-1} in 1998 - 1999 to 3572 kg ha^{-1} in 2003 - 2004; however, seed yield ranged from 420 kg ha^{-1} in 1998 - 1999 to 1308 kg ha^{-1} in 2003 - 2004 (Table 4).

Critical periods of weed control (CPWC)

Relative data were not pooled across years because significant interaction between years and the treatment levels were observed. Therefore, parameters for logistic and Gompertz equations were obtained for each year and differences between the onset and end of CPWC were tested by year (Table 5). Predicted and observed relative yields, as affected by duration of the weed, interfered or weed-free period are shown in Figures 1 and 2.

The beginnings of CPWC at 5% AYL were 216 GDD in

Table 4. Crop responses to different periods of weed-free (WF) and weed-interference (WI) treatments for two years in winter-lentil (values in parentheses indicate standard errors of means).

Treatments	Biomass (kg ha^{-1})		Seed yield (kg ha^{-1})	
	1998-99	2003-04	1998-99	2003-04
WF 1 WAR	741 (76)	3125 (126)	149 (23)	1059 (42)
WF 2 WAR	867 (114)	3129 (177)	206 (44)	1065 (63)
WF 3 WAR	858 (115)	3152 (119)	241 (32)	1104 (44)
WF 4 WAR	826 (123)	3230 (226)	247 (50)	1165 (76)
WF 5 WAR	1005 (127)	3292 (123)	261 (33)	1187 (40)
WF 6 WAR	1042 (165)	3423 (159)	289 (41)	1226 (54)
WF 7 WAR	1042 (87)	3478 (135)	314 (32)	1248 (35)
WF 8 WAR	1080 (67)	3492 (64)	329 (46)	1253 (28)
WF 9 WAR	1246 (280)	3557 (110)	387 (88)	1293 (35)
WF 10 WAR (WFC)	1313 (201)	3572 (112)	420 (80)	1308 (41)
WI 1 WAR	1551 (168)	3492 (159)	530 (47)	1242 (61)
WI 2 WAR	1236 (153)	3438 (35)	421 (50)	1210 (4)
WI 3 WAR	1134 (416)	3409 (171)	409 (163)	1185 (58)
WI 4 WAR	978 (195)	3362 (237)	333 (73)	1145 (72)
WI 5 WAR	727 (86)	3101 (92)	219 (31)	1051 (34)
WI 6 WAR	716 (215)	3008 (147)	206 (68)	1015 (46)
WI 7 WAR	558 (108)	2812 (95)	174 (31)	948 (30)
WI 8 WAR	413 (104)	2570 (196)	80 (26)	859 (69)
WI 9 WAR	411 (56)	2332 (81)	65 (12)	770 (23)
WI 10 WAR (WC)	386 (25)	2242 (271)	60 (7)	732 (87)

WC, weedy control; WFC, weed-free control.

Table 5. Parameter estimates and standard errors for the relative biomass and seed yield (%) using the logistic (eqn. 1) and Gompertz (eqn. 2) models belong to 1998-99 and 2003-04 winter-lentil experiments (values in parentheses are standard errors of parameters).

Logistic model			Gompertz model		
Parameters	1998-99	2003-04	Parameters	1998-99	2003-04
Biomass					
C	0.01 (0.002)	0.01 (0.0009)	*A*	438.2 (0.005)	103.8 (2.23)
D	389.9 (16.54)	316.0 (15.15)	*B*	2.2 (0.05)	0.3 (0.02)
F	1.5 (0.06)	2.5 (0.13)	*K*	0.0004 (0.0004)	0.003 (0.0008)
Seed yield					
C	0.01 (0.003)	0.008 (0.0008)	*A*	145.1 (0.02)	101.3 (1.14)
D	450.8 (29.66)	289.7 (17.18)	*B*	1.8 (0.11)	0.5 (0.05)
F	1.2 (0.08)	2.1 (0.11)	*K*	0.002 (0.0002)	0.005 (0.0007)

the first year and 212 GDD in the second year in terms of biomass; 237 GDD in the first year and 123 GDD in the second year in terms of seed yield in winter-lentil, which correspond to 1 - 2 weeks from the onset of regrowing of the crop in spring. The end of CPWC were 820 GDD in the first year and 374 GDD in the second year in terms of biomass; 846 GDD in the first year and 414 GDD in the second year in terms of seed yield (Figures 1 and 2). These correspond to 7-9 WAR in spring.

DISCUSSION

The composition and densities of weed species showed

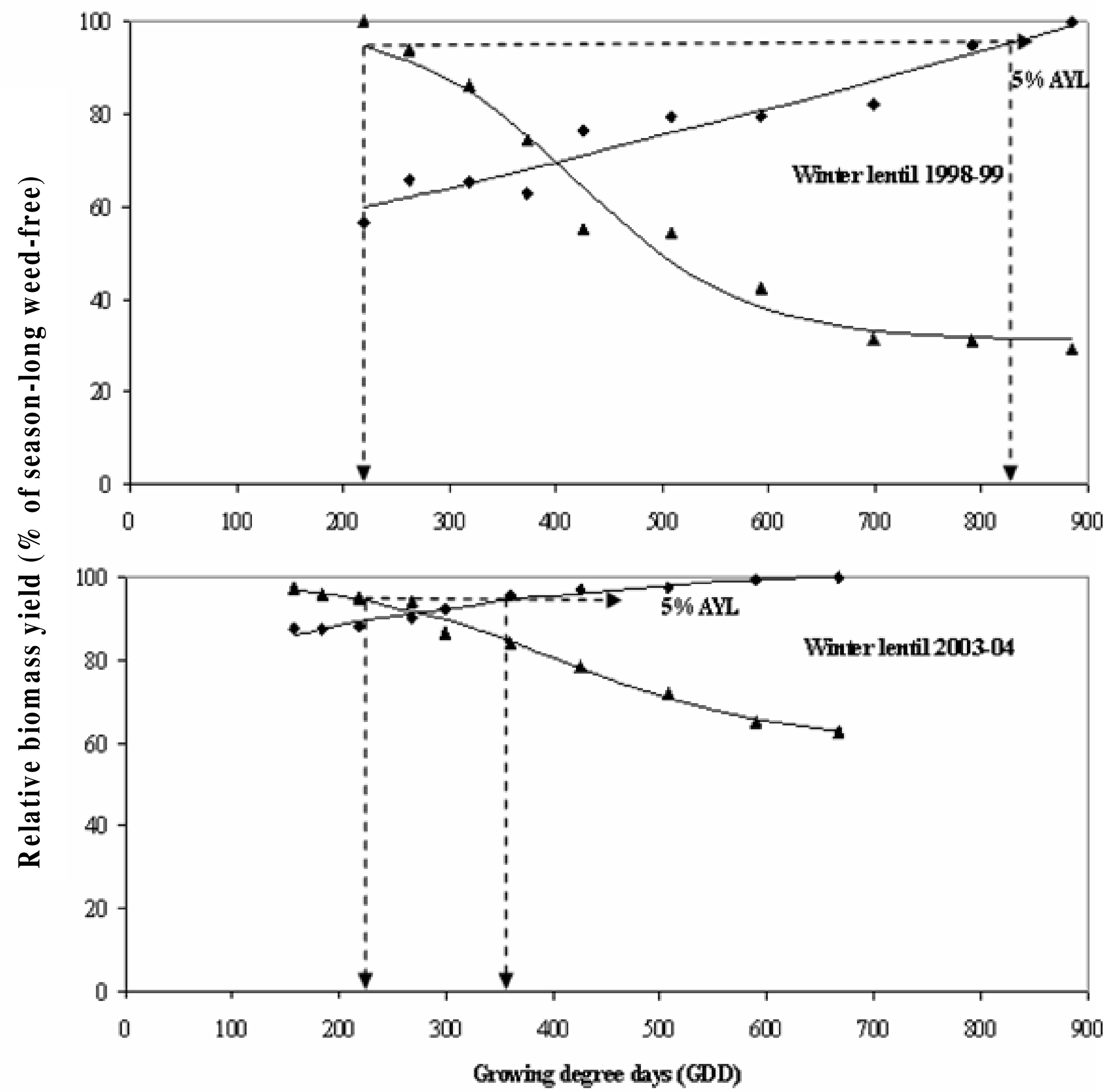

Figure 1. Effect of weed interference on biomass of winter lentil in 1998-99 and 2003 - 2004. Symbols represent observed data; solid lines represent fitted curves (that is, logistic equation for increasing duration of weed interference (▲); Gompertz equation for increasing weed-free period (♦)); horizontal dashed lines indicate the 5% acceptable yield loss level used to determine the CPWC, whereas vertical dashed lines indicate the beginning and end of CPWC. Estimated parameters for fitted curves are given in Table 4.

significant differences between years (Table 3). Differences between years in weed composition and density can be attributed to management practices in previous crops and climatologic conditions.

The results of the experiments showed that both biomass and seed yield decreased with increasing duration of weed presence in lentil. This yield reduction resulted from the competition with major weed species which were found in experimental plots. Lentil has a slow rate of development and is quickly overwhelmed by weeds in the early stages of development (Erman et al., 2004; Tepe et al., 2005); thus, weeds are not affected by lentil and grow quite easily (Basler, 1981). Therefore, in this study the beginning of CPWC started at the earlier stages (1 - 2 weeks) of the development and continued up to 8^{th} week in lentil during its maturity stage. This finding was in conformity with that reported by Mohamed et al. (1997) who found that the period of weed competition, the crop can tolerate, appeared to be the first 2 weeks after sowing in lentil. However, the CPWC for lentil was found to be between 4 - 8 weeks after sowing in India, and between 7-13 weeks after sowing in Medi-

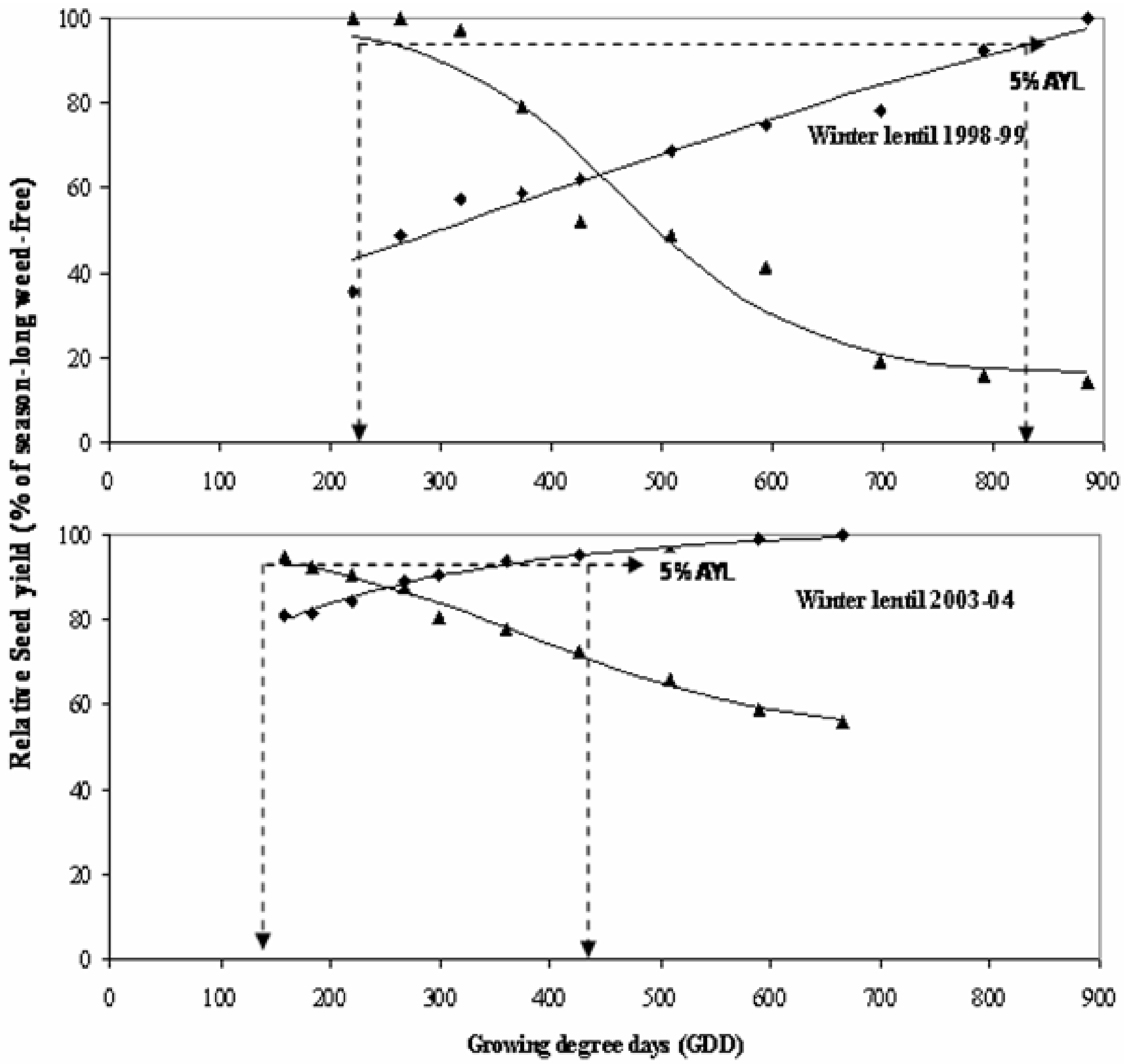

Figure 2. Effect of weed interference on seed yield of winter lentil in 1998-99 and 2003-2004. Symbols represent observed data; solid lines represent fitted curves (that is, logistic equation for increasing duration of weed interference (▲); Gompertz equation for increasing weed-free period (♦)); horizontal dashed lines indicate the %5 acceptable yield loss level used to determine the CPWC, whereas vertical dashed lines indicate the beginning and end of CPWC. Estimated parameters for fitted curves are given in Table 4.

terranean region (Ahlawat et al., 1979; Saxena and Wassimi, 1980; Al-Thahabi et al., 1994). The differences between the above conclusions could be attributed mainly to different weed densities and species, as well as to the environmental factors.

The results of this study indicated that biomass and seed yields were higher in the second year than the first year. The lower temperature and higher precipitation in the second year, compared to the first year, promoted vegetative and reproductive growth. Furthermore, in the period between October and June, which is the growth period of winter-lentil, rainfall was 251.8 mm in 1998-99 whereas rainfall was 331.3 mm in 2003 - 2004 (Table 2). Singh et al. (1996) reported that weeds cause severe reduction in the yield of lentils in rain fed farming systems in the Mediterranean region.

The development of any Integrated Weed Management System (IWM) requires the knowledge of weed behaviour in the agro ecosystem, including possible effects on crop yields. The approach of the CPWC is part of that knowledge which would allow the development of strategies for IWM (Amador-Ramirez, 2002). The practical implication of this study is that weeds must be controlled starting from the first WAR in spring up to 7th week for winter-lentil.

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