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The critical period of weed control in rain-red lentil (*Lens culinaris* Medik.) in Lorestan Province

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ABSTRACT

The critical period of weeds refers to the stage of the plant's growth cycle during which weeds must be controlled to avoid crop damage. Understanding the critical period of weed control is beneficial for both biological and economic reasons when making weed control decisions and scheduling. Field experiments were conducted in 2018 in Khorramabad, Iran to determine the critical period of weed control (CPWC) in rain-fed lentil. The treatments were divided into two series: weed interference with the crop from emergence to 10, 20, 30, 40, 50, or 70 days after emergence with a control treatment (weed infested), and weed-free treatments up to the aforementioned stages. The logistic and Gamprtz nonlinear models were used to determine the start and end of the critical period of weed control, respectively. *Galium tricornutum*, *Turgenia latifolia*, *Cerastium dichotomum*, and *Lathyrus aphaca* were the most significant weed species in the experiment due to their greater biomass and size. The results indicated that weed control and interference treatments significantly increased lentil yield. Grain yields were 471 and 187 kg ha^{-1} for weed-free and interference-control treatments, respectively. Thus, when compared to weed-free control, weed interference reduced grain yield by 60%. The critical period of weed control began and ended 43 and 26 days after emergence, respectively, based on acceptable yield reductions of 5% and 10%.

Highlights

- Knowing the critical period of weed control is beneficial for both biological and economic reasons.
- In 2018, field trials in Khorramabad, Iran, determined the weed control critical period in rain-fed lentil.
- *Galium tricornutum, Turgenia latifolia, Cerastium dichotomum, and Lathyrus aphaca* had the highest biomass and size in the experiment.
- Weed control was critical 43 and 26 days after emergence, based on acceptable yield reductions of 5% and 10%.

1. Introduction

Lentil (*Lens culinaris* Medik.) is one of the world's oldest domesticated plants (Sarker and Erskine, 2006). Lentil is an important cool-season grain legume crop, mainly grown in South and West Asia. This plant has 23% of the cultivated area among legumes in Iran. Due to its ability to fix nitrogen, this plant causes soil fertility and, in rotation with some crops, especially cereals such as wheat and barley, will improve and maintain yield (Hoseyni et al., 2011). Over the past 30 years, many agronomic improvements to lentil have been made, such as improved disease resistance, height, lodging tolerance, and yield potential (Elkoca et al., 2005; Sarker and Erskine, 2006). However, weed control is a major concern and one of the greatest limiting factors in lentil production (Erman et al., 2004). Weeds compete with the crop for nutrients, soil moisture, light and space and may also harbour insects, pests and pathogens that can affect the lentil crop (Brand et al., 2007). Weed competition has resulted in lentil yield losses of 14–100% (Elkoca et al., 2004), and can also cause problems for mechanical harvest (Brand et al., 2007). Additionally, several important weeds in lentil, such as *Lathyrus aphaca* L., *Vicia sativa* L., and *Vicia hirsuta* L. Gray, produce seeds similar in shape and size to that of lentil, and separation from the crop is difficult, resulting in lower quality and value of the harvested crop (Brand et al., 2007). Lentil is a poor competitor with weeds due to its short stature, slow canopy closure, and slow rate of development, especially early in the growing season (Blackshaw et al., 2002;

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Elkoca et al., 2004). As a result, lentils are ranked as the least competitive crop grown in western Iran.

The critical period of weed control (CPWC) defines the period in a crop life cycle in which weeds must be controlled to prevent yield losses and is a useful tool to determine the optimal timing of weed control (Knezevic et al., 2002). The CPWC has been determined in many crops and has helped producers identify the optimal weed control timing and method. Comprehension of the CPWC will increase the understanding of lentil-weed competition and will enable lentil producers to optimize weed control timing to maximize yield. The CPWC was first documented by Nieto et al. (1968). Since its inception, the CPWC has been determined for many crops, including maize (*Zea mays* L.) (Nieto et al., 1968; Dong and Albay, 2004; Williams, 2006), soybean (Knezevic et al., 2003), canola (Martin et al., 2001), chickpea (*Cicer arietinum* L.) (Mohammadi et al., 2005), lentil (*Lens culinaris* Medik.) (Mohamed et al., 1997; Taherabadi et al., 2016), dry bean (*Phaseolus vulgaris* L.) (Ahmadi et al., 2004), and potato (*Solanum tuberosum* L.) (Ahmandvand et al., 2009). The goal of this study was to determine the critical period for lentil weed control as well as to investigate the response of this crop to weed competition in the Lorestan province climatic conditions. CPWC comprehension provides insights into the required weed control timing and guidance on how long weed control remains to prevent weed diminished yields.

2. Materials and Methods

2.1 Materials

Field experiment was conducted during the 2018 growing season at the Agricultural Research Station of Lorestan University, Iran (46.21°E, 32.3°N, altitude), 1100 m above sea level with a yearly average precipitation and temperature of 461 mm and 18.2 °C respectively. The experiment was carried out on a soil characterized as clay loam. The physicochemical properties of soil are presented in Table 1.

Table 1. Physicochemical properties of the soil at surface and surface depth

Parameters	Values	
	0-15 cm	**15-30 cm**
Clay (%)	35	35
Silt (%)	40	40
Sand (%)	25	25
texture	Clay loam	Clay loam
Organic C (%)	0.7	0.65
pH	7.8	7.8
EC (ds/m)	2.03	2.03
Available N (%)	0.09	0.07
Available P_2O_5 (ppm)	6.8	6.0
Available K (ppm)	278	278

2.2. Experimental layout

The experimental design was a randomized complete block with four replications and 10 treatments. The treatments included two series: weed interference with the crop from emergence to 10, 20, 30, 40, 50, or ~70 days after emergence with control treatment (weed infested), and the second series included weed-free treatments up to the above stages. Planting operations, including plowing with reversible plowing, disc cutting to crumble, and leveling the land with a trowel, were carried out in early October. Each block consisted of 10 plots. Each plot consisted of ten planting rows, each five meters long. Seeds were planted in rows by hand. Lentil (Gachsaran variety) was sown at a density of 80 seeds per m^2 by hand on February 20, 2018.The distance between planting rows was 20 cm, and the distance between plants on each planting row was 2-cm. Cultivation was carried out in early January. In order to measure the number and dry weight of weeds for interference treatments. Weed sampling was performed in the first series of treatments at the end of the growth period and in the second series at the end of the interference period using a frame (11 m^2) with two replications in each plot. The weeds were dried at 70 °C in an oven and then weighed. Harvesting was done on June 10, 2018 by removing marginal effects. In order to estimate the yield by removing the marginal effects, an area of 6 square meters was harvested from each plot, and its grain yield was calculated based on 14% seed moisture.

2.3. Statistical analysis

ANOVA was used to analyze the data, and the treatment means were separated using the least significant difference test at P<0.05. Non-linear regression analysis was done to estimate the CPWC. To determine the beginning of CPWC, the logistic equation was fitted to relative yield (% of season-long weed-free period) with the increasing duration of weed interference, whereas to determine the end of CPWC, the modified Gompertz equation was fitted to relative yield with an increasing length of weed-free period (Knezevic et al., 2002).

Gamprtz equation the general form (A):

$$y = A.\exp^{(\beta \exp(-kt))} \tag{1}$$

Where y = relative yield, A = Asymptotic percent yield, b and k are Constant coefficient equation, and t is days after crop emergence in weed- free treatments.

Logistic equation the general form (B):

$$Y = \left[\left(\frac{1}{D \exp^{k(t-x)} + F} \right) + \frac{(F-1)}{F} \right] \times 100 \qquad (2)$$

In this equation, Y= Yield (% of control without competition), K, D, and F are Constant coefficient equations, t is days after emergence, and x is the per day milestone curve. (Knezevic et al., 2003).

Finally, using these two curves for two cases of allowable yield reduction of 5 and 10%, the critical period of weed control was estimated. For statistical analysis of data, MSTAT-C software for drawing graphs in Excel and Sigmaplot software were used.

3. Results and Discussion

3.1. Mean weed species density

A comparison of the mean densities of 42 common weed species at the lentil field level is shown in Table 2. The average weed density of *galium tricornutum* in lentil field was 16.6 plants m^{-2}, and it was clearly different from other weeds. The mean densities of *Turgenia latifolia*, *Cerastium dichotomum*, and *Lathyrus aphaca* were 5.4, 4, and 3.76 plants m^{-2}, respectively.

Table 2. Mean density of common weed species in lentil field

Row	Weed species	Average density (m^2)	Row	Weed species	Average density (m^2)
1	*Galium tricornutum*	16.6	22	*Cardaria draba*	0.4
2	*Vicia villosa*	2.8	23	*Goldbachia laevigata*	0.87
3	*Vaccaria grandiflora*	1.9	24	*Fumaria* sp.	0.13
4	*Lathyrus aphaca*	4.7	25	*Cichorium intibus*	0.20
5	*Centaurea depressa*	1.4	26	*Lactuca serriolla*	0.92
6	*Papaver dubium*	3.7	27	*Malabaila* sp.	0.18
7	*Cerastium dichotomum*	4.0	28	*Cirsium arvense*	0.11
8	*Anthemis cotula*	2.4	29	*Achillea millefolium*	0.21
9	*Neslia apiculata*	1.0	30	*Tragopogon graminifolius*	0.45
10	*Scandix pecten-veneris*	2.4	31	*Garhadiolus angulosus*	0.07
11	*Turgenia latifolia*	5.4	32	*Taeniatherum crinitum*	0.53
12	*Conringia orientalis*	0.7	33	*Aegilops cylindrica*	0.15
13	*Carthamus oxyacantha*	0.9	34	*Salvia* spp.	0.18
14	*Avena ludoviciana*	1.0	35	*Alyssum* sp.	0.04
15	*Euphorbia helioscopia*	0.8	36	*Hordeum murinun*	0.04
16	*Sinapis arvensis*	1.4	37	*Sonchus asper*	0.04
17	*Hordeum spontaneume*	0.6	38	*Anagalis arvensis*	0.04
18	*Silene conoidea*	1.0	39	*Aristolochia maurorum*	0.04
19	*Bromus* sp.	2.2	40	*Cephalaria syriaca*	0.04
20	*Convolvulus arvensis*	0.4	41	*Senecio vulgaris*	0.15
21	*Pimpinella* sp.	0.5	42	*Linaria* sp.	0.17

3.2. Critical period of weed control for lentil

The critical period of weed control (CPWC) was realized for lentil by combining the yield responses to the duration of weed interference and the duration of the weed-free period. Also, CPWC was determined based on 5% and 10% acceptable yield loss. The CPWC based on 5% acceptable yield loss began at 11 days after emergence and continued until 54 days after emergence, and the CPWC for 10% acceptable yield loss began 16 days after germination and continued until the 43 DAE (Figure 1). The critical period of weed control in lentils covered a large part of the plant's growing season. The length of the critical period can indicate the weak strength of the lentils in competition with weeds. It was observed that the end of the CPWC often coincided with lentil canopy closure. Therefore, the CPWC for lentil generally begins at 14 days after emergence and ends 56 days after emergence. The defined CPWC encompasses all sites, and weed growth outside of this period should not affect yield. Relatively low, weeds should be removed with herbicide application or hand weeding at least 14 days after the emergence of the crop. The end of the CPWC was observed to often coincide with lentil canopy closure, which likely shaded the soil and restricted subsequent weed cohorts (Norworthy and Oliveira, 2004). In this experiment, CPWC was shown using Gamprtz and logistic curves by drawing a mathematical coordinate system, and there is overlap between the two curves, the critical period of weed control in the levels of 5% and 10% yield reduction, respectively, 2-8 and 2-6 weeks after emergence (Tables 3 and 4).

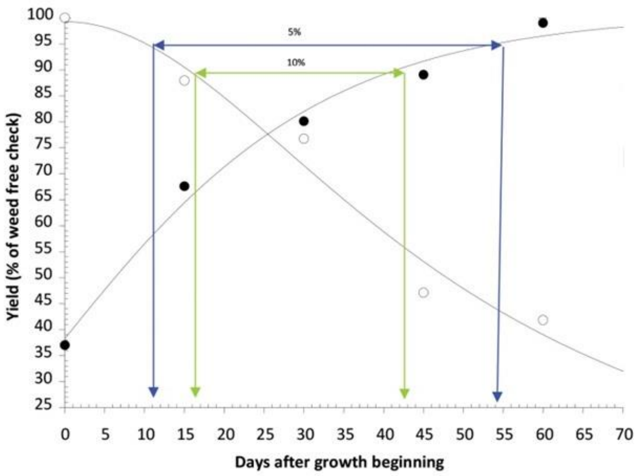
Table 3. Estimated coefficients for the percentage of the control function based Gamprtz days after emergence. Refer to text (Equation A) for model description.

Coefficient	A	B	K	R	R^2
Estimated value	100	5.2076	0.0415	0.9383	0.8804

Table 4. Estimated coefficients of the logistic function for the yield reduction compared to control on days after emergence. Refer to text (Equation B) for model description.

Coefficient	F	K	D	R	R^2	X
Estimated value	0.0307	0.0977	1.9262	0.9810	0.9625	26.86

The duration of the weed-free period had a significant effect on lentil yield (Table 5). Lentil yield increased with an extended weed-free period (Figure 1). The yield of weedy and weed -free treatments ranged from 187 to 471 $kgha^{-1}$ at Khorramabad in 2017. The Gompertz equation (Table 1) adequately described the relationship between lentil yield and increasing weed-free periods.



Increasing duration of weed interference (○) and fitted curves as calculated by the logistic equation; increasing weed-free period (●) and fitted curves as calculated by the Gompertz equation. Horizontal lines indicate the 5% and 10% acceptable yield loss levels used to determine the CPWC, whereas vertical lines indicate the beginning and end of CPWC. Parameters for fitted curves given in Table 1and 2.

Figure 1. Effect of weed interference on total yield of lentil.

Table 5. Number of weeds (plant m^{-2}) in Lentil's farm divided by species during weed Interference

Interference Period	*Galium tricornutum*	*Turgenia latifolia*	*Cerastium dichotomum*	*Lathyrus aphaca*
10 DAE	13d	1.1d	1.1d	0d
20 DAE	31.1c	2.2c	2.2d	4.4b
30 DAE	48.9b	5.5b	5.6bc	5.6bc
40 DAE	50b	6.7ab	15.6b	17.1b
50 DAE	80a	7.8ab	24.5a	22.2b
Whole season weed- interference	87.8a	12.2a	30a	34.5a

Means with the same letter are not significantly different based on LSD test (p≤0.05).

3.4. Duration of weed interference:

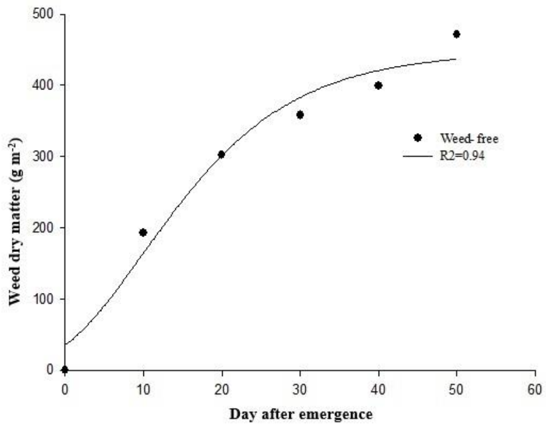
3.4.1. Weed dry matter

There was a significant weed dry matter response to increasing durations of weed interference. Weed dry matter measured at the time of weed control increased as the duration of weed interference increased (Figure 2). There was little weed dry matter when weed removal took place at 10, 20, and 30 days after the growth of lentils. Weed dry matter began to increase when weed control was delayed until 50 or 60 days after the growth of lentils. Presumably, weed growth and dry matter accumulation plateaued after the WI_4 stage since both the crop and weeds were nearing the reproductive stages where vegetative growth would have slowed. Therefore, the effect of weed control timing on weed dry matter accumulation is constant along with the relative rate of dry matter accumulation. Mohammadi et al. (2005) also stated that reducing the length of the weed control period in chickpeas led to an increase in weed dry weight.

3.5. Duration of the weed-free period

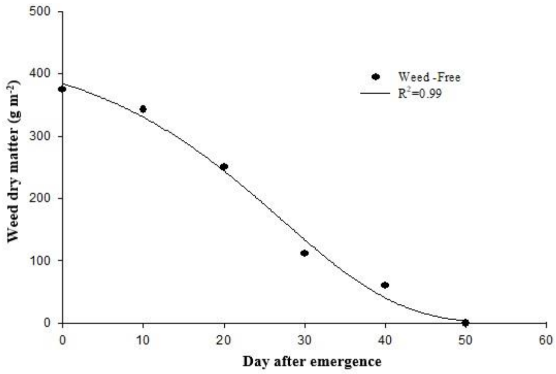
3.5.1. Weed dry matter

Weed dry matter decreased significantly as the duration of the weed-free period increased (Figure 3). Overall, weed dry matter at harvest was greatest when weeds emerged early in lentil development. For example, weeds emerging at the one node stage (10 DAE) produced biomass comparable to that of weeds that emerged at the same time as the crop (i.e., zero node). There was a near linear decrease in weed dry matter beginning at the two -node stage (15 DAE) and continuing until 50 or 60 days after emergenc. The Gompertz regression described the effect of the duration of the weed-free period on weed dry matter, and a common value for the rate of weed dry matter accumulation (*K*) was significant (Table1). There was a drastic decrease in weed biomass when the weed-free period lasted until 50 days after emergenc (Figure 3). The decrease in weed dry matter was nearly linear after the one node stage until 50 or 60 days after emergence for lentil cultivars for Gachsaran in Khorramabad in 2017 and 2018 as well as in western Canada (Fedoruk et al., 2011).



Points represent observed mean values whereas the lines represent the fitted curves of the three-parameter logistic equation.

Figure 2. Weed dry matter response to increasing duration of weed interference.



The points represent the observed values whereas the lines represent the fitted curves for the modified tree parameter Gompertz equation.

Figure 3. Weed dry matter response to the duration of the weed-free period.

3.6. Lentil yield

Lentil is a vulnerable crop to weed competition because of its short stature, slow establishment, and limited vegetative growth (Mousavi and Ahmadi, 2008). Lentil yield responses to increasing durations of weed interference were significant. Based on the results of this study, it can be concluded that lentil variety Gachsaran is able to function without any reduction one week after planting with a mixture of annual weed competition. With a delay in weed removal, lentil yield decreased (Table 5). According to this table, long-term interaction of weeds with lentils significantly reduced grain yield, so that in the treatment of complete weed interference, plant grain yield was reduced by 60. 29% compared to the complete control treatment. The findings of this study were consistent with the results of the experiment of Taherabadi et al. (2016). There were no weed-related performance losses in WI_1, WI_2 or WI_3; all three weed removal times were comparable to weed-free treatment. Delayed weed removal past the WI_3 stage (i.e., 30 days of weed infestation) generally results in a reduced lentil yield in comparison to the weed-free treatment. When weed removal was delayed until the WI_4 stage, there was a linear decrease in yield until the WI_T stage, when the yield reached a minimum and was comparable to season -long weed growth (i.e., until Physiological maturity). Lentil yield response to the duration of weed interference was adequately described by the four -parameter logistic equation (Equation B; Table 6).

Table 6. Mean yield of lentil at different treatments of weed interference and weeding

Treatments	Yield (kg ha^{-1})	Treatments	Yield (kg ha^{-1})
WF_1 (10DAE)	193e	WI_1 (10DAE)	423b
WF_2 (20DAE)	302d	WI_2 (20DAE)	393bc
WF_3 (30DAE)	358c	WI_3 (30DAE)	343c
WF_4 (40DAE)	399bc	WI_4 (40DAE)	211e
WFT (weed free total)	471a	WIT (weed interference total)	187e

4. Conclusion

Following the emergence of lentil under Khorramabad climatic conditions, the results showed that the critical periods for weed control in lentil were 43 and 26 days after emergence, respectively, based on a 5 percent and 10 percent acceptable yield reduction. Increased weed interference duration resulted in a decrease in lentil (*Lens culinaris* Medik.) yield and biomass, whereas increasing the control period resulted in an increase in both yield and biomass of lentil. In order to avoid lentil yield losses of more than 5 and 10 percent during the critical period, weed control must be implemented during this time period.

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