Determination of The Critical Period of Weed Control in Fall-grown Safflower (*Carthamus tinctorius*)

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(Received 6 March 2006; returned 16 May 2006; accepted 26 August 2006)

ABSTRACT

To determine the critical period of weed control in safflower (*Carthamus tinctorius*), two field studies were conducted in 2002 at the Bajgah and Kooshkak Experimental Stations, College of Agriculture, Shiraz University. Each experiment consisted of two series of treatments. In the first series, weeds were kept in place until crop emergence, leaf formation, stem elongation, lateral stem emergence, head emergence, flowering and ripening, and were then removed and the crop kept weed-free for the rest of the season. In the second series, crops were kept weed-free until the above growth stages after which weeds were allowed to grow in the plots for the rest of the season. The beginning of the critical period was defined as the crop stage in which weed interference reduced crop yield by 10%. Similarly, the end of the critical period was defined as the crop stage in which the crop had to be weed free to prevent more than 10% yield loss. The Weibull and MMF models were used to determine the critical period. The critical period of weed control occurred between safflower early stem elongation and flowering stages (144-220 days after planting, DAP) at the Bajgah site and between early stem elongation and

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early head emergence stages (135-184 DAP) at Kooshkak. The onset of interference seems to be less variable than its conclusion, indicating that early weed control is necessary to prevent yield loss. Also, with increase in as the weed interference period increased so yield components (number of heads per plant and number of seeds per head) decreased significantly.

Key words: Safflower, weed competion, weed interference, critical period.

چکیده

به منظور تعیین دوره بحرانی علف‌های هـرز در گلرنـگ، دوآزمـایش صـحرایی در ایسـتگاه تحقیقـاتی دانشـکده کشاورزی دانشگاه شیراز در دو منطقه باجگاه و کوشکک انجام شد. تیمارهای آزمایشی شامل حفـظ و یـا حـذف علف‌های هرز تا مدت زمانی مشخص پس از کاشت گیاه زراعی بود. شروع دوره بحرانی کنترل علف‌های هـرز بـه صورت مرحله‌ای از رشد گیاه زراعی که رقابت علف هرز منجر به کاهش ۱۰ درصد عملکرد گردیـد، تعریـف شـد. همچنین انتهای دوره بحرانی به صورت مرحله‌ای از رشد گیاه زراعی تعریـف شـد کـه در آن بـرای جلـوگیری از کاهش عملکرد تا سطح ۱۰ درصد، مزرعه باید عاری از علف هرز نگهداری شود. دوره بحرانی کنترل علف‌های‌هرز برای باجگاه بین مراحل ابتدای ساقه رفتن تا گلدهی (۱۴۴ تا ۲۲۰روز پس از کاشـت) و بـرای منطقـه کوشـکک بین مراحل ابتدای ساقه رفتن تا ابتدای ظهور جوانه گل(۱۳۵ تا روز پس از کاشت۱۸۴) بود. نتایج نشان داد کـه شروع دوره بحرانی، در قیاس با انتهای آن، تغییرات کمتری دارد که تأیید کننده این موضوع است کـه مهـار زود هنگام علف‌های هرز در گلرنگ امری ضروری است. همچنین با افزایش طول دوره تداخل علف‌های هـرز، اجـزای عملکرد (تعداد قوزه در بوته و تعداد دانه در قوزه) بطور معنی داری کاهش یافت.

واژه‌های کلیدی: گلرنگ، رقابت علف هرز، تداخل علف هرز، دوره بحرانی.

INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is a deep-rooted, drought-tolerant crop that is well adapted to the semi arid regions (Blackshaw *et al*., 1990a). New cultivars and improved production practices make safflower a viable alternative crop in such regions. It is grown primarily as an oil seed crop or as birdseed in many areas. It provides good economic returns and helps to break disease and pest cycles associated with continuous cereal production (Blackshaw, 1993). Safflower is a poor competitor with weeds and, so, requires intensive weed control for optimum yield (Blackshaw *et al*., 1990b; Blackshaw *et al*., 1992; Blackshaw, 1993). Safflower seedlings grow slowly, remaining in the rosette stage for 3-4 weeks after emergence. During this period, safflower may be dominated by weeds (Blackshaw *et al*., 1990b; Muendel *et al*., 1992).

The occurrence of herbicides in ground water and the emergence of sustainable agriculture concepts have stimulated efforts to reduce herbicide use in agriculture (Burnside *et al*., 1998). While the critical period of weed control can help to determine the appropriate time of herbicide applications and weed population impact on the crop, it also has an important role in the development of alternative weed management strategies (Woolley *et al*., 1993). Hall *et al*. (1992), described the critical period of weed control as representing the time interval between two separate components. The first component is the maximum length of time that weeds emerging with a crop can remain before they reduce crop yield. This is the period when tillage or post-emergence herbicide application must be used in order to prevent weed derived crop yield loss (Weaver & Tan 1987; Woolley *et al*., 1993; Burnside *et al*., 1998). The second component is the length of time a crop must be kept weed free after planting so that weeds emerging later do not reduce yield. This component represents the minimum period for which a residual pre-plant incorporated or pre-emergence herbicide must remain effective (Woolley *et al*., 1993). The time interval between the two components is the critical period of weed control (Singh *et al*., 1996; Ghosheh *et al*., 1996; Burnside *et al*., 1998). Weed control after the critical period is not necessary for optimum crop yield and should be evaluated only in terms of harvest efficiency (Swanton *et al*., 1999).

The critical period of weed control has been determined for many crops. In soybean [*Glycine max* (L.) Merrill, it occurred between 9 to 38 days after planting (van Acker *et al*., 1993while for Hemp sesbania [*Sesbania exaltata*(Rof) Cory.] control in cotton (*Gossypium hirsutum* L.) it is less than 65 days after planting (Bryson, 1990). For dry bean (*Phaseolus vulgaris* L.), this period was 20 to 35 or 42 days after planting (Burnside *et al*., 1998). The beginning of the critical period of weed control in maize (*Zea mays* L.) varied from the 3 to 14-leaf stage of corn development (Hall *et al*., 1992). However, the end of the critical period was less variable and ended on average at the 14-leaf stage (Hall *et al*., 1992). Depending on the weed density, the beginning of the critical period of quackgrass [*Elytrigia repense* (L.) Desv.ex] interference in potato (*Solanum tuberosum* L.) ranged from prior to emergence to 15 days after planting and ended between 23 and 68 days after planting (Baziramakenga & Leroux, 1994). There is no puplished information on weed interference and the critical period in fall-grown safflower.

Knowledge of the critical period of weed control and the potential weed impacts on crop morphology provides useful information upon which future weed control recommendations can be based. Obviously, different locations, with different soil and agroclimatic conditions, and with different weed floras and densities would have different critical weed control periods in safflower.

The objective of this study was to determine the critical period of weed control in safflower. To ensure that the results could be applied to safflower growing areas throughout the Fars province, it was conducted at two well separated locations.

MATERIALS AND METHODS

Experimental site: Field studies were conducted in 2002 at the research station of the College of Agriculture of Shiraz University in Bajgah (1810 msl, longitude 52°, 46′, latitude 29°, 50′) and Kooshkak (1650 msl, longitude 52°, 36′, latitude 30°, 7′).

The meteorological data for these locations during the safflower growing season are shown in Table 1. In Bajgah, the soil was a sandy loam (pH of 8; 2% organic matter) of the fine, mixed, mesic, calcixerollic xerochrepts soil series. In Kooshkak, the soil was a silty loam (pH of 7.3; 1.6% organic matter) of the calcixerollic xerochrepts soil series. At both locations maize had been grown in the experimental fields in the previous season. The fields were moldboard plowed and seedbeds prepared by two passes with a tandem disk. Safflower cv. Zarghan (a native, winter late-ripening cultivar with a rosette growth period) was sown in early November in 0.60 m rows at about 170,000 plants ha^{-1}. Plot size was 2.5×4 m, and consisted of 4 rows including one buffer row at either side of the plot. Urea (200 kg ha^{-1}) was broadcasted at three growth stages (split-applications at sowing, stem elongation and head emergence stages) and phosphate fertilizer (200 kg ha^{-1}) prior to planting.

Experiment design: The experimental design was a randomized complete block with 16 treatments and three replications. The treatments were weed removal at different safflower growth stages. To represent increasing duration of weed interference, weeds were allowed to interfere with safflower from emergence until safflower reached 1) emergence, 2) leaf rosette formation , 3) stem elongation, 4) lateral stem emergence, 5) head emergence, 6) flowering and 7) ripening. At these stages weeds were removed and plots were then maintained weed-free for the remainder of the season. In another set of treatments, designed to represent increasing duration of weed control, some plots were maintained weed-free until safflower reached the above mentioned stages, after which weeds were allowed to grow for the remainder of the season. In addition, each trial had season-long weed-infested and weed-free checks. Table 2 shows the developmental stages based on days after planting and growing degree day (GDD) for each location. In all cases, weeds were controlled by hand weeding.

Table 1. Meteorological data of the experimental locations during 2001-2002

Location	Temperature (˚C)			Relative Humidity (%)	Precipitation (mm)
	Maximum	Minimum	Mean		
Bajgah	20.9	4.4	11.0	47.3	602
Kooshkak	24.0	7.1	15.4	48.3	554

Table 2. Growth stages of safflower based on days after planting(DAP) and growing degree days(GDD)

Location		**Safflower growth stages**							
		Emergence	Leaf formation	Stem elongation	Lateral stem emergence	Head emergence	Flowering	Ripening	Season-long
Bajgah	**DAP**	31	110	168	183	210	219	253	263
	GDD	121	275	661	833	1212	1375	1995	2197
Kooshkak	**DAP**	24	115	158	175	198	210	241	251
	GDD	97	431	750	951	1304	1522	2109	2337

Weed and crop measurements: At each time of weeding and before crop harvest, above-ground weed biomass was harvested in all treatments and in the unweeded control. Weeds were separated by species, counted and their dry weights measured (Table 3). The leaf areas of four individual safflower plants in all treatments were measured at four sampling times (stem elongation, lateral stem emergence, flowering and early ripening stages) with a leaf area meter (DIAS II model, ΔT-devices, England). To measure yield and yield components, safflower plants were hand harvested from the central 2 m of the two middle rows in each plot (equivalent to an area 2̣1.2m) on 16 August (295 days after planting) and 27 July (276 days after planting) at Bajgah and Kooshkak, respectively. The dominant weeds observed at Bajgah were wild garlic (*Allium vineale* L.), field bindweed (*Convolvulus arvensis* L.) and common lambsquarters (*Chenopodium album* L.) . Wild mustard (*Sinapis arvensis* L.), field bindweed (*Convolvulus arvensis* L.) and common lambsquarters (*Chenopodium album* L.) dominated at Kooshkak.

Statistical analysis- All data were subjected to analysis of variance (ANOVA) and main effects and interactions were tested for significance. Because the ANOVA indicated significant treatment by location interactions, the data were analyzed separately for each location. Means were compared using the Duncan Mutiple Range Test (DMRT). Grain yield data were subjected to non-linear regression analysis. By comparing different equations with the standard errors (*se*) and regression coefficients the Weibull model (Ratkowfky, 1983) provided the best fit for the maximum weed-infested treatments.

$Y= a-b\exp(-cT^{d})$ (Weibull model)

Y= grain yield (percent of season-long weed free)

T= time (days after safflower planting)

a, b, c and d= constants.

The relationship between grain yield and weed-free periods was best described by the MMF (Marcel Mercer Flodin) model.

$Y= (ab + (cT^{d}))/(b +T^{d})$ (MMF model)

Y= grain yield (percent of season-long weed-free)

T= time (days after safflower planting)

a, b, c and d= constants.

Table 3. Dominant weed biomass in safflower plots in different treatments.

Treatment	Weed biomass ($g\ m^{-2}$) in Bajgah				Weed biomass ($g\ m^{-2}$) in Kooshkak			
	Allium vineale	*Convolvulus arvensis*	*Chenopodium album*	Total	*Sinapis arvensis*	*Convolvulus arvensis*	*Chenopodium album*	Total
Weed free, up to:								
Emergence	1	0	0	0	10	0	0	10
Leaf formation	12	0	0	12	34	0	0	34
Stem elongation	57	6	0	67	58	48	0	104
Lateral stem emergence	68	13	11	92	47	55	17	119
Head emergence	56	18	17	91	29	29	43	101
Flowering	53	22	24	99	25	53	36	112
Ripening	47	34	40	121	29	46	54	129
Weed infested, up to:								
Emergence	58	15	9	82	33	49	44	126
Leaf formation	50	11	3	64	30	43	41	114
Stem elongation	69	9	5	83	21	42	42	105
Lateral stem emergence	65	49	6	111	17	35	52	104
Head emergence	21	73	18	112	11	31	30	72
Flowering	11	21	17	49	0	38	39	77
Ripening	8	11	11	30	0	36	48	84

RESULTS AND DISCUSSION

Critical period of weed control: Regression analysis has been suggested to be a more appropriate and useful method than mean comparison tests for determining the critical period of weed control (Cousens, 1988). Cousens (1988) suggested the use of the Gompertz equation to describe the relationship between the lengths of the weed control period and yield. Hall *et al*. (1992) also suggested Logistic equations to represent the influence of increasing duration of weed interference on yield. In this study, the Weibull and MMF equations (Ratkowfky, 1983) showed a better fit to the data (lower standard error (*se)* and higher regression coefficient (*r)* than the Gompertz and Logistic equations, respectively (Table 4).

The beginning of the critical period (based on 10% yield loss) was similar at both locations and was at the early stem elongation stage (144 and 135 days after planting in Bajgah and Kooshkak, respectively) (Fig. 1). However, the end of the critical period varied between locations. At Bajgah, the end of the critical period was at the flowering stage (220 days after planting), but in Kooshkak, it was before the head emergence stage (184 days after planting).

The crop development stage at which weed interference occurs is an important factor in determining potential yield losses. Expressing data as days after planting, could indicate more variation between locations and years due to different planting dates and different environments (Hall *et al*., 1992). Effects of weed competition on absolute yield of safflower are shown in Table 5.

Weed density has an important effect on critical period (Bridges & Chandler 1987; Weaver *et al*., 1992; Baziramakenga & Leroux 1994). Differences in the period before the critical period ended in Bajgah and Kooshkak were possibly associated with the different weed species and weed densities in these locations. Thus, weed density was greater at Bajgah, than at Kooshkak (Table 2) and the critical period was longer. Baziramaknga and Leroux (1994) showed that, in potatoes, as weed density increased the critical period of weed control began earlier and ended later. Weed density showed a more pronounced effect on the weed-free period in comparison with the weed-infested period.

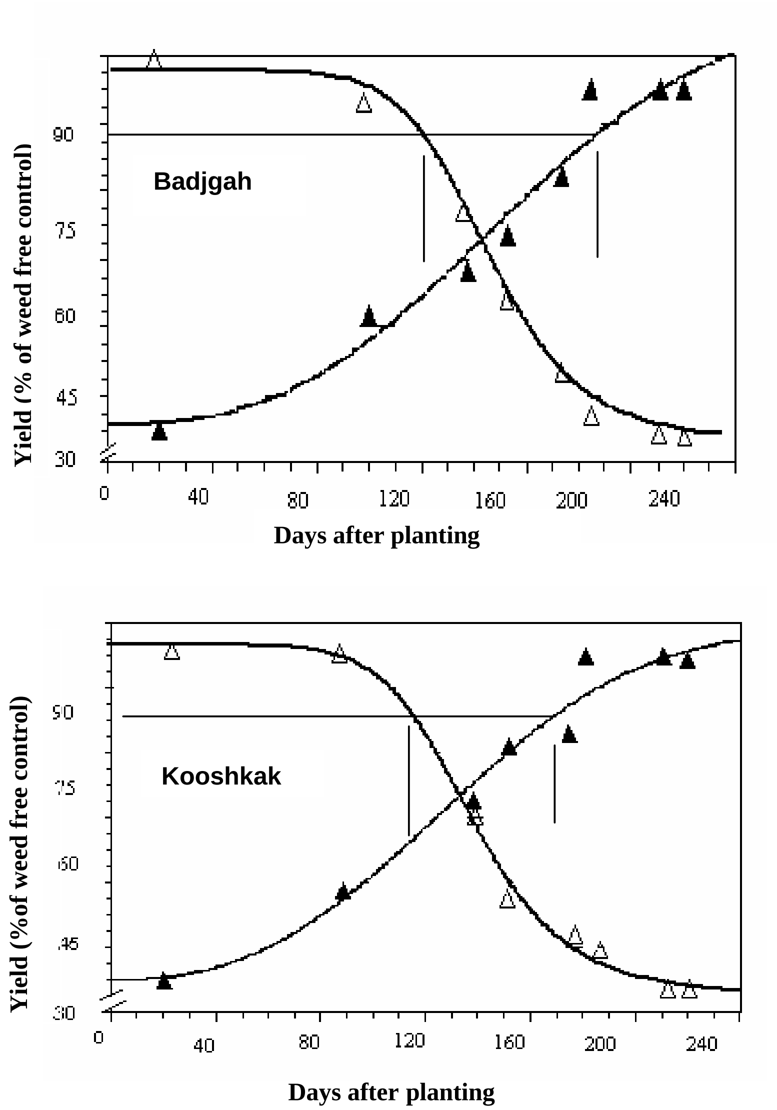

Figure 1.The critical period of weed control (weed-free ▲ and weed-infested Δ) in safflower in Bajgah and Kooshkak. Predicted yield values for weed-free duration were obtained from the equation $Y = 1.113 - 0.665 * \exp(-1.986 * T^{-2.756})$ for Bajgah and $Y = 1.114 - 0.734 * \exp(-2.812 * T^{2.74})$ for Kooshkak. Predicted yield values for weed-infested duration were obtained from $Y = \frac{0.348 * 25.34 + 0.934 * T^{-8.322}}{25.34 * T^{-8.322}}$ for Bajgah and $Y = \frac{0.349 * 42.67 + 1.072 * T^{-8.182}}{42.67 * T^{-8.182}}$ for Kooshkak.

Table 4. Comparison of standard error (SE) and regression coefficient (R) for Weibull, MMF, Logistic and Gompertz equations

Location	Weibull		Gompertz		MMF		Logistic	
	SE	R	SE	R	SE	R	SE	R
Bajgah	0.03426	0.9897	0.06941	0.9554	0.01606	0.9986	0.13946	0.96348
Kooshkak	0.04625	0.98639	0.05795	0.9605	0.02689	0.9975	0.13243	0.92368

Table 5. Effects of weed-free and weed-infested periods on safflower yield.

Safflower growth stages	Yield kg ha^{-1}			
	Bajgah		Kooshkak	
	Weed free	Weed infested	Weed free	Weed infested
Emergence	1533 e*	3359 a	1423 d	3962 a
Leaf formation	1792 de	3139 a	2104 c	3902 a
Stem elongation	2239 cd	2608 ab	2802 b	2620 b
Lateral stem emergence	2675 bc	2207 bc	3030 b	1998 bc
Head emergence	2963 abc	2009 bcd	3355 ab	1739 cd
Flowering	3256 ab	1788 cd	3917 a	1700 cd
Ripening	3240 ab	1592 cd	3932 a	1454 cd
Control	3500 a	1314 d	3913 a	1272 d

*Means in each column followed by same letter are not significantly different at the 5% level (DuncanMean Range test).

The differences between locations may result from climatological and environmental conditions. For example, the higher mean temperature at Kooshkak caused a higher safflower growth rate which resulted in greater crop competitive ability and reduction in the length of critical period. Weed density and composition are important factors that affect the critical period. At Bajgah, higher weed biomass resulted in increased weed competition and, thus, increased the length of the critical period. Safflower, a winter crop, and its associated weeds in a temperate climate (such as ours) grow slowly during fall and winter. Therefore, weed density had little effecton the onset of competition. However, at the end of the competition period, which coincided with the period of active growth of weed and crop, weed density was more important.

Yield components: The number of heads per plant significantly increased with increasing length of weed-free period and decreased with increasing length of weed-infested period at both locations (Table 6). The number of seeds per head was also affected by the length of weed free and weed infested period (Table 6). With an increase in weed free period from the stem elongation stage, the increase in number of seeds per head was not significant at Bajgah. The number of seeds per head in the weed infested control in Bajgah and Kooshkak was reduced by 58% and 60%, respectively, in comparison with the weed-free control. In this study, 1000-seed weight was not significantly affected by weed interference (data not shown).

The measured effects of weed interference on head number per plant and seed number per head are in agreement with the results of Huag *et al*., (1968) who showed that, during safflower development, the number of heads per plant and number of seeds per plant responded more to stress than did seed weight. Woolley *et al*. (1993), showed that in soybean, the number of pods per plant was significantly decreased by increasing duration of weed interference after planting, but the number of seeds per pods and 100-seed weight were not significantly reduced by weed interference. Head number per plant is the first yield component to be determined in the reproductive phase followed by seed per head and seed weight (Woolley *et al*., 1993). Thus, among yield components, head number per plant is likely to be the most sensitive yield component to weed interference.

Leaf Area Index: Leaf area index (LAI) was reduced by weed interference at both locations (Fig. 2). In all cases, the weed free control had the greatest LAI and the weed-infested control the lowest LAI. Also, the weed-free control reached its maximum LAI earlier and maintained a maximum LAI for a longer period than the weed-infested control.

Hall *et al.* (1992) observed that season long weed interference reduced the number of expanded and emerged leaves of corn from 8.8 to 5.7 and 14.4 to 9.4, respectively, and increased the number of senesced leaves from 1.6 to 3.1. In fact, weed interference decreased LAI by increasing the number of senesced leaves, and decreasing both the number of expanded leaves and leaf expansion rate. Dense weed infestation can reduce photosyntically active radiation (PAR) available to the lower leaves of the crop (Elakkad, 1983) and depletes available soil nitrogen and moisture levels, thereby reducing the longevity and expansion rate of lower leaves (Wolfe *et al*., 1988).

Results from both locations showed that weed control measures should not be delayed beyond stem elongation (average 140 days after planting). Also, depending on location and weed density, weed control must continue until flowering or head emergence stage. After this period, safflower would be able to compete with weeds to avoid yield losses.

Table 6. Effects of weed-free and weed-infested periods on yield components of safflower.

Growth stage	Number of heads/plant				Number of seeds/head			
	Bajgah		Kooshkak		Bajgah		Kooshkak	
	Weed free	Weed infested	Weed free	Weed infested	Weed free	Weed infested	Weed free	Weed infested
Emergence	8.9 c*	23.4 a	14.0 bc	19.5 a	21.4 c	31.5 ab	25.0 bc	30.8 ab
Leaf formation	16.6 b	19.3 ab	13.2 c	16.7 ab	24.5 c	35.2 a	21.6 c	31.7 a
Stem elongation	21.3 b	15.2 bc	17.6 abc	14.1 bc	23.5 c	34.9 a	24.8 bc	29.8 ab
Lateral stem elongation	19.3 b	15.3 bc	18.3 ab	13.9 bc	28.1 bc	29.9 abc	25.8 abc	25.0 abc
Head emergence	19.9 b	12.1 cd	19.4 a	12.6 bc	24.9 c	28.8 abc	28.0 abc	24.7 abc
Flowering	20.1b	13.8 c	19.6 a	13.0 bc	36.8 ab	23.6 bc	31.7 ab	21.8 abc
Ripening	21.4 b	14.1c	18.6 ab	12.4 bc	37.9 a	22.2 c	31.7 ab	17.6 c
Control	26.8 a	7.4 d	20.4 a	11.2 c	38.4 a	21.9 c	35.3 a	21.6 bc

*Means in each column followed by same letter are not significantly different at the 5% level (DuncanMean Range test).

Figure 2. Safflower Leaf Area Index (LAI) in weed-free and weed-infested control plots (averaged data from Bajgah and Kooshkak experiments).

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