with dry bean from crop emergence until 14, 28, 42, 56 and 70 days; then the plots were weeded and kept weed-free until harvest. Maximum weed-infested and weed-free periods of 14 weeks after dry bean emergence were maintained by hand weeding. Species composition, density, dry matter of weeds, and relation to reduction of dry bean seed yield were investigated. The major weed species were *Amaranthus* sp 41.5%, *Tribulus terrestris* 37.5%, *Sorghum halepense* 29%, *Echinochloa crus-galli* 25%, *Convolvulus arvensis* 24% and other species 21% of the total density. The highest dry matters were recorded for *Amaranthus* sp, *Tribulus terrestris* and *Sorghum halepense*, respectively. Experimental treatments had significant effects ($P<0.01$) on biological and grain yield and number of pod per plants. The maximum and minimum number of pods was obtained in WI_1 and WI_T at weed-infested period and WF_T and WF_1 by weed-free period, respectively. The number of pods per plant, biological and grain yield in the weed infested control (WI_T) were reduced by 84%, 97% and 98%, respectively, in comparison with the weed-free control (WF_T). The Gompertz and logistic equations were fitted to relative yields representing the critical weed-free and the critical time of weed removal, respectively. Accumulated thermal units were used to describe the critical periods. The critical period to prevent yield losses of 2.5 and 5% ranged from 87 to 1187 and 137 to 948 accumulated thermal units, respectively. Based on day after emergence, these periods were between 14 to 62 and 19 to 52 days, respectively. Weed competition before and after these critical periods had negligible effects on grain yield of dry bean. The results of this study suggest that weeds must be controlled during the first half of the dry bean growing season in order to prevent yield losses.

Keywords: Critical periods, weed control, dry bean, accumulated thermal units, weed interference.

چکیده:
دوره بحرانی کنترل علف هرز به دوره‌ای از چرخه زندگی گیاه اطلاق می‌شود که علف های هرز باید کنترل شده تا از کاهش اقتصادی عملکرد محصول جلوگیری شود. به منظور تعیین دوره بحرانی کنترل علف‌های هرز لوبیا یک آزمایش مزرعه‌ای در ایستگاه تحقیقاتی دانشگاه لرستان در سال ۱۳۸۵ انجام شد. آزمایش در قالب طرح بلوکهای کامل تصادفی با ۴ تکرار انجام شد. تیمارهای آزمایش شامل دوره‌های مختلف تداخل علف‌های هرز، و دوره‌های عاری از علف هرز بودند. در تیمارهای عاری از علف هرز، علفهای هرز به مدت ۱۴، ۲۸، ۴۲، ۵۶ و ۷۰ روز بعد از سبز شدن لوبیا کنترل شده و پس از هر دوره تا روز ۸۴ یعنی برداشت نهایی به علفهای هرز اجازه رشد داده شد. در تیمارهای تداخل به ترتیب ۱۴، ۲۸، ۴۲، ۵۶ و ۷۰ روز به علف‌های هرز اجازه رقابت داده شد و پس از هر دوره تا زمان برداشت نهایی محصول، کنترل شدند. ترکیب گونه‌های علف هرز، تراکم، وزن خشک و میزان کاهش عملکرد لوبیا در هر تیمار محاسبه شدند. علف های هرز غالب و مهم در این مطالعه سوروف، تاجخروس، خارخسک، قیاق و پیچک بودند. درصد کاهش عملکرد لوبیا در تیمارهای کنترل و تداخل به‌ترتیب با معادله‌های گامپرتز و لجستیک برای تعیین دوره بحرانی کنترل علف‌های هرز برازش داده شدند. واحد حرارتی تجمعی در طی فصل برای توصیف دوره‌های بحرانی کنترل علف‌های هرز به کار رفت. بر این اساس، دوره‌های بحرانی کنترل علف‌های هرز برای جلوگیری از کاهش عملکرد ۲/۵ و ۵ درصد به ترتیب از ۸۷ تا ۱۱۸۷ و ۱۳۷ تا ۹۴۸ واحد حرارتی تجمعی متغیر بوده است. بر اساس روز پس از سبز شدن، این دوره‌ها به ترتیب بین ۱۴ تا ۶۲ و ۱۹ تا ۵۲ روز بودند. اثرات رقابت علف‌های هرز قبل و بعد از این دوره‌ها روی عملکرد لوبیا در نظر گرفته نشدند.

واژه‌های کلیدی: دوره بحرانی، کنترل علف هرز، لوبیا واحد حرارتی تجمعی (درجه روز)، تداخل علف هرز

INTRODUCTION

Dry bean (*Phaseolus vulgaris* L.) is an increasingly important cash crop for growers in western Iran. Effective weed control is essential to improve the yield of an uncompetitive crop such as the dry bean. Current challenging weeds in the region include green foxtail (*Setaria viridis* L. Beauv.), barnyard grass (*Echinochloa crusgalli* L. Beauv.), redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.) and annual nightshades (*Solanum* spp.). Malik *et al*. (1993) and Chikoye *et al*. (1995) have reported yield losses of up to 70% due to weed interference with beans in Ontario.

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). The critical period of weed competition has been defined (Zimdahl, 1980; Kropff *et al*., 1993b) as the time interval between the maximum weed-infested period, or the length of time that weeds which emerge with the crop can remain uncontrolled before they begin to compete with the crop and cause yield loss, and the minimum weed-free period, or the length of time that the crop must be free of weeds after emergence. However, as pointed by Hall *et al*. (1992), the critical period of weed competition is not necessarily the time of the most intense interference. Therefore, it may be better to use the term critical period for weed control instead of critical period of weed competition. The length of the critical period of weed control may vary depending on the acceptable yield loss first proposed in corn (*Zea* mays) (Hall *et al*., 1992), and later in soybean (*Glycine max* L. Merr.) (Van Acker., 1993) and white bean (*Phaseolus vulgaris* L.) (Woolley., 1993). This concept is closely related to the use of period thresholds., defined by Dawson (1986) as the length of time that a crop can tolerate weed competition before yield loss exceeds the cost of control. Early research on weed competition used multiple comparison tests to calculate the critical period (Zimdahl, 1988). However, Cousens

(1988, 1991) suggested that regression analysis is more appropriate and reliable in calculating the critical period.

The critical period has been traditionally defined in days or weeks after emergence, not stages of crop growth. In soybean, it occurred between 9 to 38 days after planting (van Acker *et al*., 1993) while 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 varied from the 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). Dawson (1964) showed that the first 5 to 7 weeks after planting field beans is the most critical period for weed control. Weeds emerging during this period were more competitive than later germinating weeds. Several investigators, reported a weed-free period of 50 days from seeding for corn in order to prevent yield loss in Mexico (Nieto H. *et al*., 1968); whereas, in the United States they reported a period of 3 to 6 weeks (Knake & Slife, 1969). The critical period for weed control in dry beans was 3 to 5 or 6 weeks after planting (WAP). Thus, weed control practices should begin no later than 3 WAP and continue until at least 5 or 6 WAP for maximum dry bean yields (Burnside *et al*., 1998). However, this method makes the comparisons among locations and years difficult because of different emergence dates and environments. So, it is preferred to define critical period based on growth stage or thermal time. In this way, in corn, leaf stages or accumulated thermal units could improve comparisons because the leaf appearance rate is highly dependent upon ambient temperatures (Tollenaar *et al*., 1979). Working from this hypothesis, Hall *et al*. (1992) determined that, in Canada, the beginning of the critical period for corn varied widely from the 3 to 14 leaf stages of corn and ended on average at the 14 leaf stage. Mainly, the concept of critical period of weed control (CPWC) based on growth stage or thermal time can be used to enhance the efficiency of herbicide use and other methods of weed management including cultivations better than traditional methods.

Critical period research is usually performed by keeping the crop free from weeds until certain predetermined times and then allowing the weeds to emerge, and alternatively growing weeds with the crop. The objective of this study was to determine the critical period of weed control in dry bean based on using thermal unit.

MATERIALS AND METHODS

Field studies were conducted at Agricultural Research Station of Lorestan University in 2004. The soil was loamy (1.5% organic matter and pH 7.3). Plots were 2.5 m wide by 6 m long and consisted of 5 rows spaced 50 cm apart. Plots were irrigated as needed (10 times during the growing season). Naturally occurring weed populations were utilized in all experiments. The experimental design was a randomized complete block design with twelve treatments and four replications. Two series of weed removal treatments were included. In the first series, namely weed free periods, the plots were maintained weed free until 14, 28, 42, 56 and 70 days after crop emergence (DAE). Weeds were then allowed to develop until the final harvest (84 days). In the second series, namely weed infested periods weeds competed with dry bean from crop emergence until above periods and then removed until harvest. Control plots were kept free of weeds or left weedy throughout the growth period (84 days after emergence). Weeds were removed by hand pulling and hoeing.

Weed dry weight separating by species in each treatment was evaluated by harvesting four 0.5 x 0.5 m quadrates per plot. Weed samplings were done at the time of weed removal for treatments of weed infested periods and harvest in the treatments of weed free periods. Dry bean seed yields were harvested from 6 m^2 per plot.

At each 14 day period, the accumulated thermal units (ATU) were calculated according to the formula:

$$ATU = \sum_{i=1}^{n} (t_1 - 10^\circ C)\ when\ t_i \rangle\ 10^\circ C \qquad [1]$$

where ATU is accumulated thermal units from the emergence day to day "n" and t_i is the mean daily air temperature. Base temperature during the vegetative period (leaf expansion) was estimated to be 10°C according to local information (Andrade, 1995). The number of expanded leaves of crop (ligules fully developed) was recorded every 14 days until 84 days. Dry bean was hand harvested from the middle 7.5 m of the center three rows of each plot. Seed yields were adjusted to 14% moisture.

The Gompertz equation (Ratkowsky 1990) was used to describe the effect of increasing lengths of weed-free period on dry bean yield.

$$Y = A \exp(-B \exp(-KT)) \qquad [2]$$

where Y is the yield as a percentage of the weed free plot, A is the upper asymptote, B and k are parameters that determine the shape of the curve, T is the time in DAE, and exp refers to e (the base of the natural logarithm) raised to the specified power.

Logistic equation (Ratkowsky, 1990) was used to describe the increasing duration of weed interference on yield defined as:

$$Y = C + D/(1 + \exp(-A + BT)) \qquad [3]$$

where Y is yield as a percentage of the weed-free plot, A and B are parameters that determine the shape of the curve, C is the lower asymptote, D is the difference between the upper and lower asymptotes, and T is time in DAE.

The critical weed-free period and the critical time of weed removal were calculated by substituting relative bean yields (percent of control), into the Gompertz and logistic equations. Yields losses of 2.5, 5 and 10% were arbitrarily chosen to calculate the beginning and end of the critical period. All data were subjected to analysis of variance (ANOVA) and means were compared using the LSD Test. Parameter estimates were determined using an iterative least-squares procedure (SigmaPlot v.10.0). Excel and Sigma plot softwares were used to design curves.

RESULTS AND DISCUSSION

Weed Measurements

Weed density and composition are important factors that affect the critical period. The weed community composed of five species 42 days after dry bean emergence. The major weed species were *Amaranthus sp* 41.5%, *Tribulus terrestris* 37.5%, *Sorghum halepense* 29%, *Echinochloa crus-galli* 25%, *Convolvulus arvense* 24% and other species 21% of the total density. Increasing post-planting weed infested period increased weed dry matter per unit area and the whole season weed infestation produced the highest weed dry matter by 1910 $g.m^{-2}$. The highest dry matters were recorded for *Amaranthus* sp, *Tribulus terrestris* and *Sorghum halepense*, respectively. In weed free treatments, however, weed dry matter per unit area decreased gradually and declined from 1134 $g.m^{-2}$ in WF_1 to zero in whole season weed free. In the control plots, even the 14 days weed free period, there was a 40% reduction in weed dry matter, compared with whole season weed infestation. Weed free periods of 28, 42, 56 and 70 days and whole season weed free resulted in weed dry matter reduction of 49, 66, 76, 93 and 100%, respectively (Figure 1).

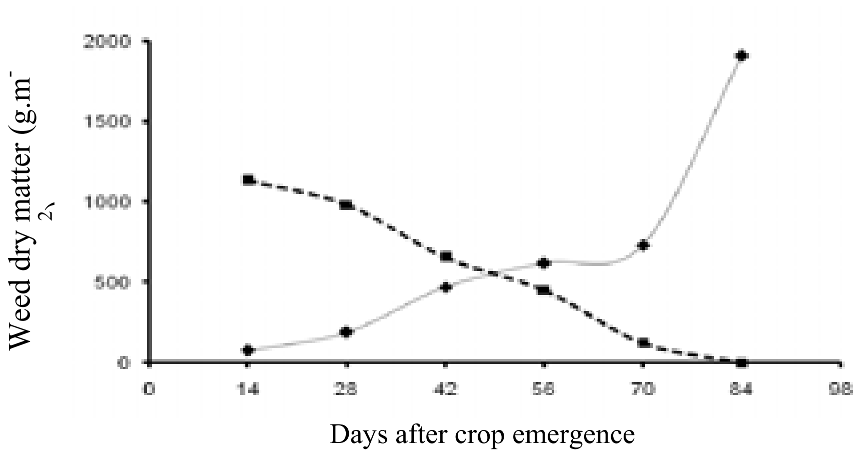


Figure. 1. Effect of weed-free (- - - - -) and weed-infested (———) treatments on the dry matter weight of weeds

Crop Measurements

Experimental treatments had significant effects ($P<0.01$) on biological and grain yield and the number of pod per plants, but had no significant effect on number of seed per pod and 100 seeds weight. The number of pods per plant significantly increased with increasing length of weed-free period and decreased with increasing length of weed-infested period (Figure 2). The maximum and minimum of these traits were obtained in WI_1 and WI_T in the weed-infested period and WF_T and WF_1 in the weed-free period, respectively. As weed interference periods started, dry bean biological and grain yield decreased. The maximum and minimum of these traits were obtained in WI_1 and $WI_{T,}$ respectively. Conversely, by increasing weed control periods, the biological and grain yield of dry bean increased (Figure 3&4) and maximum and minimum of these traits were obtained in WF_T and $WF_{1,}$ respectively. The number of pods per plant, biological yield and grain yield in the weed infested control (WI_T) were reduced by 84% , 97% and 98%, respectively, in comparison to the weed-free control (WF_T). In this study, 100-seed weight and number of seed per pod were 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) which showed that, during safflower development, the number of heads per plant and number of seeds per plant responded more significantly 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. Pod number per plant is the first yield opponent to be determined in the reproductive phase followed by seed per pod and seed weight (Woolley *et al*., 1993). Thus, among yield components, pod number per plant is likely to be the most sensitive yield component to weed interference.

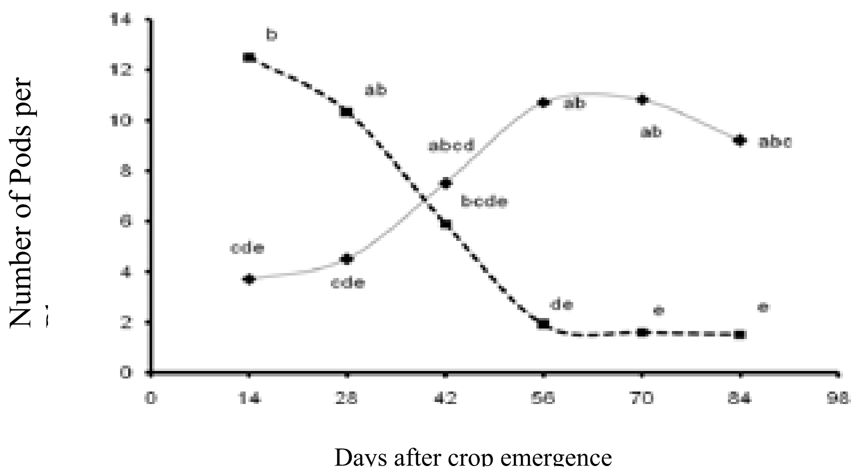


Figure. 2. Effect of weed-infested (- - - - -) and weed-free (———) treatments on number of pod of dry bean. Means followed by same letter are not significantly different at the 5% level (LSD test).

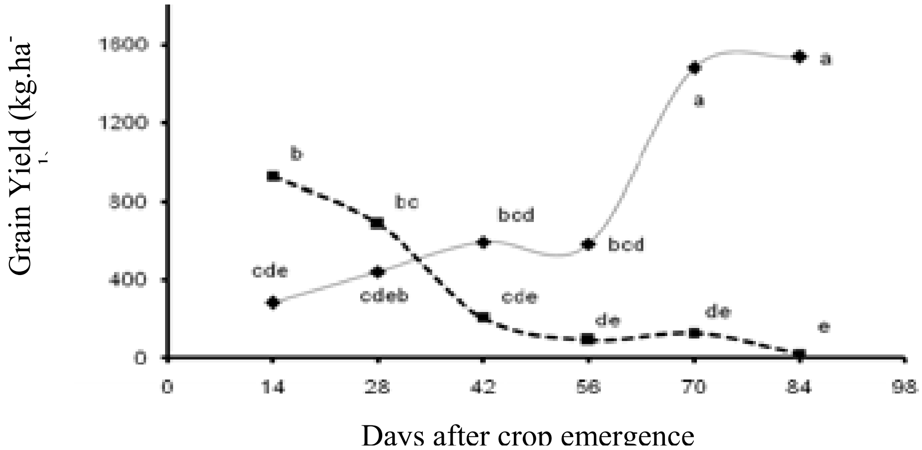


Figure. 3. Effect of weed-infested (- - - -) and weed-free (——) treatments on grain yield of dry bean. Means followed by same letter are not significantly different at the 5% level (LSD test).

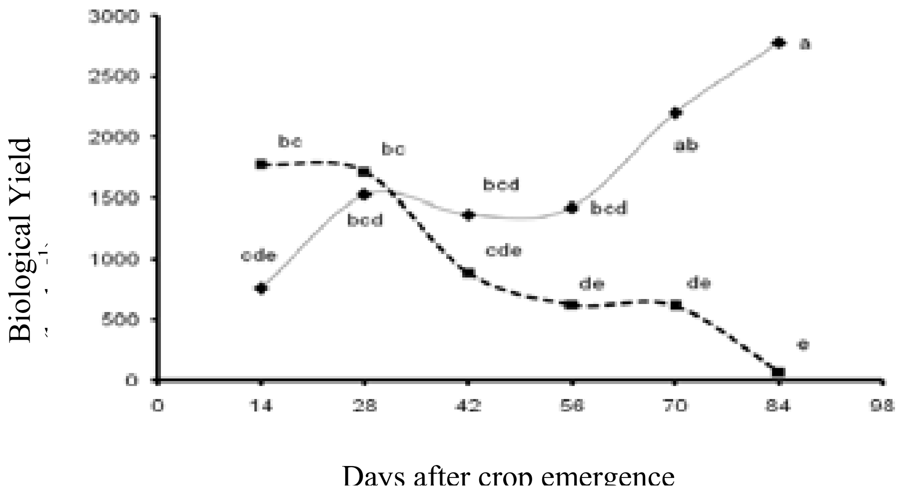
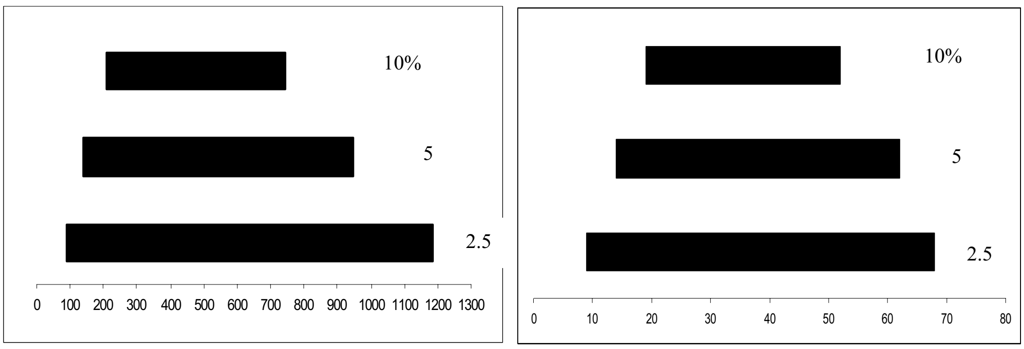


Figure. 4. Effect of weed-infested (- - - -) and weed-free (——) treatments on biological yield of dry bean. Means followed by same letter are not significantly different at the 5% level (LSD test).

Critical Period of Weed Control

Regression analysis has been suggested as a more appropriate and useful method for determining the critical period of weed control comparing to the mean comparison tests (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. Likewise, the greater the percentage loss, the less time required for weed control. The length of the critical period required to prevent more than a 2.5% and 5% and 10% yield loss ranged from 87 to 1187 ATU (approximately 9 to 68 DAE) and 137 to 948 ATU (approximately 14 to 62 DAE).When a yield loss of 10% was acceptable, the critical period ranged from 206 to 745 ATU (approximately 19 to 52 DAE) (Figure 5).



ATU **DAE**

Figure 5.The critical period of weed control in dry bean, from logistic and Gompertz equation ,respectively for three predetermined levels of crop yield loss. DAE: days after emergence; ATU: accumulated thermal units.

Table 1. Parameter estimates for the Gompertz and logistic equations.

Gompertz Parameters				Logistic Parameters				
A	B	K	R^2	A	B	C	D	R
97.34	0.08	0.16	0.44	21.06	0.63	9.52	91.00	0

The critical period of weed control should be a useful guide for weed control recommendations in dry bean. Thus, cultivation of dry bean 3 to 6 WAP should provide effective weed control if weeds in the row can be covered by rolling soil into the row with the cultivator. If growers want to use pre plant incorporated or pre mergence herbicides, they should apply them with enough soil residual activity to control weeds until 5 or 6 WAP. A post emergence herbicide may be applied even before 3 WAP if weeds are not killed rapidly, and if the herbicide does not have 2 to 3 week residual activity against all weeds, a grower should plan to cultivate 5 or 6 WAP. Redroot pigweed is a weed species that could emerge late in the growing season, however, this late weed growth did not reduce dry bean yields. Several researchers (Kropff *et al*., 1993a; Frantik, 1994) established the importance of time of emergence of the weeds. Generally, weeds that emerge simultaneously with the crop or shortly after the crop cause severe yield losses at very low densities. However, when the period of emergence is postponed the magnitude of yield loss decreases. Ford & Pleasant (1994) established that competition from weeds may be reduced when dry bean germinates quickly and forms a canopy that shades emerging weed seedlings. The beginning of the critical period was defined as the crop stage or days after crop emergence when weed interference reduces yields by a predetermined level. The end of the critical period was defined as the crop stage or days after emergence until the crop must be free of weeds in order to prevent a predetermined level of yield loss (Hall *et al*., 1992). The Gompertz and logistic models generally described the data well, as indicated by the R^2 values (Table1). The results indicated that in order to prevent >10% yield loss, the maximum time which weeds could be allowed to grow after crop emergence (the beginning of the critical period) was 9 DAP and ATU, respectively (Figure 5). Prior to these times, weed presence did not influence the chickpea seed yield. Correlation between grain yield of dry bean and weed dry matter are shown in figure 6. The results indicate that decreased grain yield of dry bean by 23 $g.m^{-2}$ occurs when the weed dry matter increased by 1000 gm^{-2}.

Correlation between maximum height of dry bean and weed dry matter are shown in weed free and weed infested treatments in figures 7 and 8. Considering the results, weed dry matter increased by 1000 gm^{-2}, height of dry bean decreased by 2 cm and 4.5 cm in weed free and weed infested treatments, respectively.

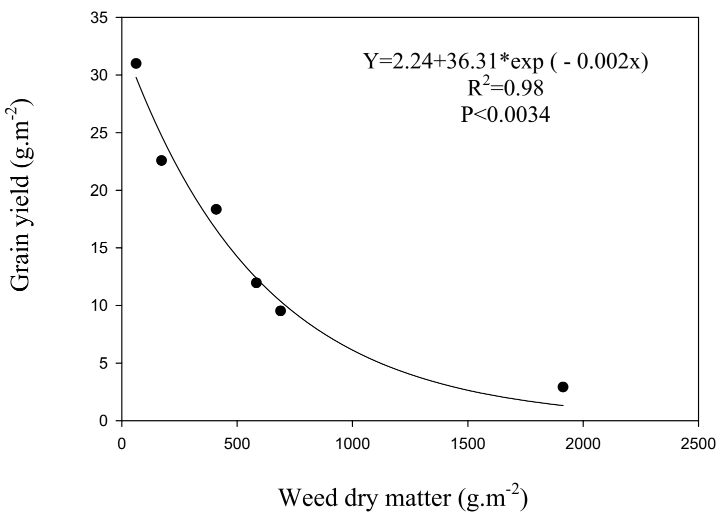


Figure 6 . Correlation between grain yield of dry bean and weed dry matter in infested treatments

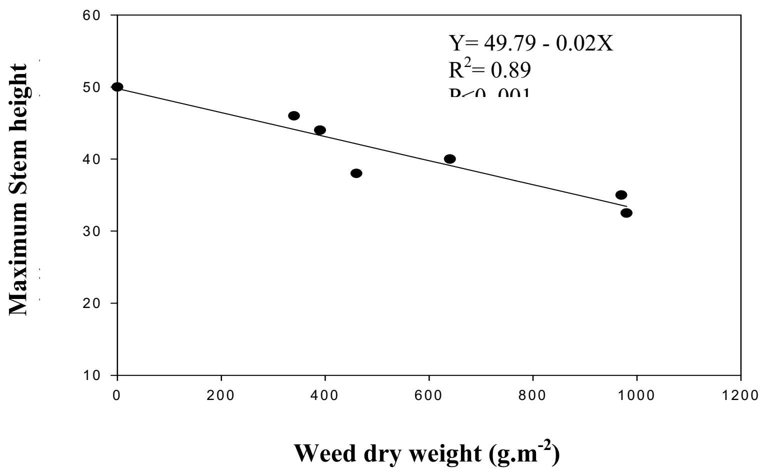


Figure 7. Correlation between weed dry matter and maximum height of dry bean stem in weed free treatments.

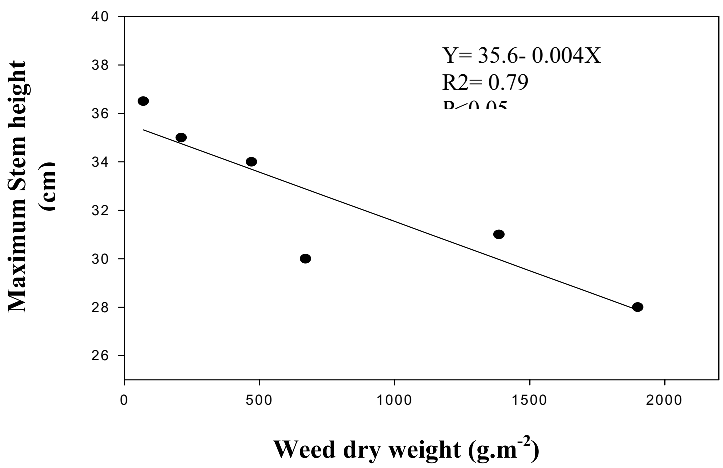


Figure 8. Correlation between weed dry matter and maximum height of dry bean stem in weed infested treatments.

Conclusion

Results indicate that increasing weed infestation duration and decreasing weed-free period led to decrease in dry bean grain, biological yield and number of pod per plant. The loss percentage for the mentioned characters for full-season weed infestation were 99%, 97%, and 83% as compared to the control (full-season weed-free), respectively. Weed infestation till 28 days after emergence of dry bean caused a small loss in the grain and biological yield, but this reduction was not significant. The length of the critical period required to prevent more than 2.5% , 5% and 10% yield loss ranged from 87 to 1187 ATU (approximately 9 to 68 DAE) and 137 to 948 ATU (approximately 14 to 62 DAE).When the yield loss of 10% was acceptable, the critical period ranged from 206 to 745 ATU (approximately 19 to 52 DAE). Development of any management system requires knowledge on the behavior of weeds in the agro ecosystem, including possible effects on crop yields. The approach of the critical period of weed control is part of this knowledge that would allow the development of strategies for integrated weed management. The results of this study suggest that weeds must be controlled during the first half of the dry bean growing season in order to prevent yield losses. The results of the experiments contribute to the development of an IWM system for cv. Khomein in Lorestan.

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