Australian Journal of
Crop Science

AJCS

AJCS 5(11):1350-1355 (2011) ISSN:1835-2707

Critical period of weed control in soybean (*Glycine max*) as influenced by starter fertilizer

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Abstract

The critical period of weed control (CPWC) in crops depends on many factors including supply and availability of nutrients. In order to investigate the effect of starter fertilizer on the CPWC in soybean a field experiment in a randomized complete block design with four replications in a factorial arrangement was conducted at the Agricultural Research Farm of Razi University, Kermanshah, Iran. Two factors were examined: the first factor was the starter fertilizer levels (0 and 25 kg ha^{-1}) applied in the form of monoammonium phosphate and the second factor was the different weed interference periods. Results indicated that soybean seed yield and yield components were significantly decreased when the weed interference period was increased. Weedy condition for the entire growing season reduced seed yield by 36% as compared with full season weed free condition. In order to prevent > 5% seed yield loss soybean field must be kept weed-free from the V1 to R1 (9-47 days after crop emergence (DAE) or 111.20 to 743.05 accumulated thermal units (ATU) and between the V7 and R3 (26-52 DAE or 374.55 to 832.75 ATU) at 0 and 25 kg.ha^{-1} of starter fertilizer level, respectively. Generally, the use of starter fertilizer slightly delayed the end of the CPWC (by 5 days), but this condition shortened the CPWC by 12 days because of the later beginning of the CPWC (by 17 days). Practical implication of this finding is that application of monoammonium phosphate as starter fertilizer can reduce the time needed for weed control in soybean field and consequently lead to less herbicide application and cultivation.

Keywords: Fertilization, monoammonium phosphate, soybean, weed free, weed infested.
Abbreviations: ATU-accumulated thermal units, CPWC-critical period of weed control, DAE-days after crop emergence, WC-weedy control, WF-weed free, WFC-weed free control, WI-weed infested.

Introduction

Soybean (*Glycine max* [L.] Merr.) is an important oil seed crop that is widely grown as a valuable source of protein and vegetable oil for human nutrition in Iran. Soybean planting area in world and Iran is 99501101 and 84084 ha, respectively (FAO/STAT, 2009). In soybean, weed infestation is considered a persistent and complex constraint in many regions of the world, as it influences soybean growth and development through competition for nutrients, water and light (Vollmann et al. 2010) as well as the production of allelopathic compounds (Rice 1984; Bhowmik and Doll 1982). Weeds are a serious constraint to easy harvesting in soybean and can reduce yield and economic returns. Thus, weed control is considered a key factor for successful soybean production, and various weed management systems have been developed for that purpose (Buhler and Hartzler, 2004). Weed control in soybean can be labor intensive or involve the intensive use of herbicides in Iran. Intensive herbicide use can increase costs, pose a threat to the environment and may promote the development of herbicide resistance. The implementation of an integrated weed management (IWM) system is seen by many weed scientists as a means of achieving the goal of reducing the amount of herbicide used while still maintaining crop yield (Swanton and Weise 1991). The critical period of weed control (CPWC) is an important principal of an IWM program. It is a period in the crop growth cycle during which weeds must be controlled to prevent yield losses (Knezevic et al. 2002). Weeds that are present before or emerge after this period do not cause significant yield loss. Studies on the critical period of weed control are important in making weed control recommendations because they indicate the optimum time for implementing and maintaining weed control and reduce cost of weed control practices (Hall et al. 1992; Van Acker et al. 1993). In soybean, Van Acker et al. (1993) found that weeds emerging after the V3 to R1 stage did not affect soybean yield. Chhokar and Balyan (1999) reported that the critical period of weed control in soybean was found to be 30 to 45 days after sowing. In another study, Mulugeta and Boerboom (2000) suggested that weeds needed to be removed between the V2 to V4 stage to protect soybean yield. According to Knezevic et al. (2003) the critical time for weed removal in soybean coincided with V3, V2 and V1 for row spacing of 7.5, 15 and 30 inches, respectively. However, the competitive relationship between crop and weeds is highly dependent on many factors including the characteristics of the crop and the weeds, the environmental variables, the cultural practices (Knezevic et al. 2002) and supply and availability of nutrients (Evans et al. 2003; Di Tomaso 1995). The availability of nutrients can influence the timeliness and extent of early season competition from weeds (Weaver et al. 1992). Evans et al. (2003) reported that the addition of nitrogen fertilizer delayed the beginning and hastened the end of the critical period of weed control in corn. Their study showed that the effect of nitrogen fertilization on early season crop growth

Table 1. Weed species of the experimental field and their relative dry weights.

Weed species	Relative dry weight (%)
*Amaranthus retroflexsus**	54.4
*Xanthium strumarium**	21.5
Glycyrrhiza glabra	7.9
Sorghum halepense	6.6
Portulaca oleracea	4.3
Chenopodium album L.	3.2
Convolvulus arvensis L.	2.1

*Dominant weed species

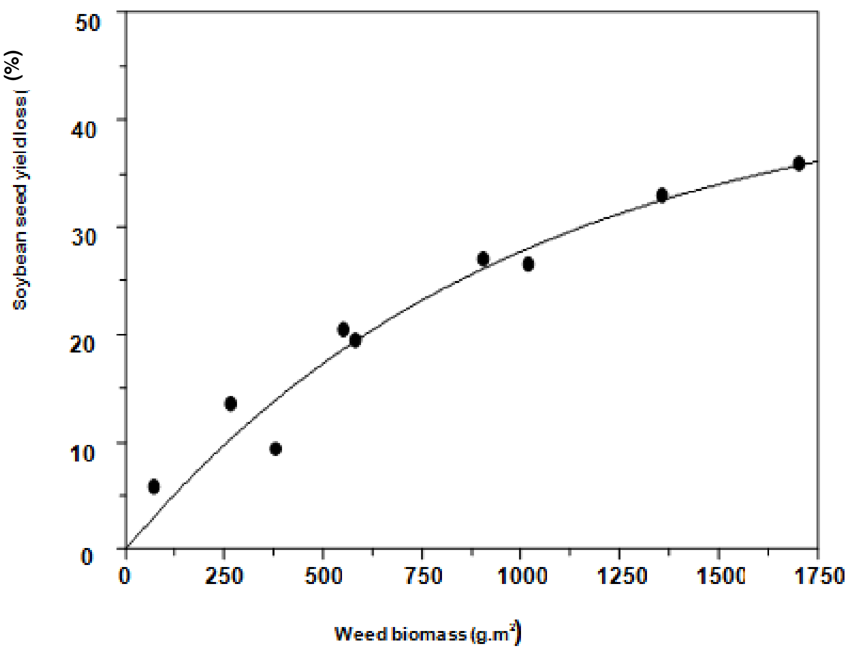

Fig 1. Relationship between weed biomass and soybean yield loss (%) as obtained using exponential regression model y = 43.365 (1-$e^{-0.001x}$), R^2 = 0.98. The points indicate the mean treatment values.

provided a competitive advantage for corn relative to weeds. However, we did not find any report on the influence of fertilizer application on critical period of weed control in soybean. Soybean is an atmospheric nitrogen fixing crop, but during two or three weeks of early season crop growth when the symbiotic relationship between the crop and the nitrogen fixing bacterium (*Bradyrhizobium japonicum*) has not been occurred, soybean plants are highly dependent on the soil nitrogen reserve. Moreover, phosphorus is an essential but non-mobile element in the soil, so the undeveloped seedling roots have difficulty obtaining the necessary amounts for proper growth. Even though a soil may have high fertility, the seedlings may not be able to obtain the necessary nutrients due to the limited size and density of the root system in the soil. Therefore, the use of a starter fertilizer containing nitrogen and phosphorus can supply essential nutrients for soybean seedlings during the early growth. However, starter fertilizer is not usually used by soybean growers in Iran. Therefore, the present study was conducted to investigate the effect of monoammonium phosphate as a starter fertilizer on the critical period of weed control in soybean. Mixed natural weed population was used to estimate the critical period that is applicable to typical field situations and timing of weed control was related to days after soybean emergence, crop development stage and accumulated thermal units.

Results and discussion

Crop development stages and parameter estimates for the Gompertz and logistic equations are shown in Table 3 and 4, respectively. The results indicated that soybean biological yield, seed yield and yield components were significantly decreased when the weed interference period was increased (Table 5). Weedy condition for all of the growing season reduced biological yield, seed yield, the number of pods per plant, the number of seeds per pod and 100-seed weight by 8.88, 36.00, 60.11, 17.83 and 25.90%, respectively when compared with full season weed free condition (Table 5). According to the regression models, in order to prevent > 5% seed yield loss, the maximum time weeds could be allowed to grow after soybean emergence (the beginning of the critical period) was 9 and 26 days after crop emergence (DAE) at 0 and 25 kg.ha^{-1} of starter fertilizer level, respectively (Table 6). These periods coincided approximately with the V1 and V7 of soybean development stage, respectively (111.20 and 374.55 ATU, respectively) (Table 6). Prior to these stages, weed presence did not notably affect the soybean seed yield. This can be attributed to the lack of a serious competition between the soybean plants and the weeds for acquiring the environmental resources before these stages. According to Gibson and Liebman, (2003) water and nutrients are often in

Table 2. Mean monthly temperatures during the experimental period.

Month	Temperature (° C)	
	Mean max	Mean min
May	32.5	13.5
June	37.7	16.7
July	38.0	16.3
August	33.3	13.5
September	27.6	7.0
October	17.8	5.9

Table 3. Crop development stages at different days after soybean emergence (DAE) in related to accumulated thermal units (ATU).

Crop development stage	DAE	ATU
V1	9	111.20
V2	14	184.70
V3	19	264.15
V4	21	294.50
V5	23	326.15
V6	25	358.00
V7	26	374.55
R1	47	743.05
R2	50	796.35
R3	52	832.75
R4	65	1056.70
R5	82	1345.60
R6	95	1541.45
R7	105	1674.75
R8	131	1905.95

sufficient supply early in the season to support both the crop and weed seedlings and light competition does not occur until the weed canopy shades the crop. In other crops, it has been also reported that weed interference can be tolerated up to a certain period before it causes irrevocable yield loss (Mohammadi et al. 2005; Dawson 1986). However, the CPWC began later (by 17 days) when starter fertilizer was applied (Table 6). It is concluded that the use of monoammonium phosphate as a fertilizer at the early of the growing season when the biological nitrogen fixation has not been started can supply essential nutrients for soybean seedlings with the limited root systems and effectively reduce the competition between soybean and weeds. This led to the later beginning of the critical period of crop-weed interference. According to Weaver et al. (1992) the manipulation of edaphic factors including the alteration of soil nutrient supply can influence the crop-weed interference relationships, especially in determining the critical time of weed removal (the start of the critical period). Other researchers have also reported that the competitive ability of crops and weeds can be significantly affected by fertilizer application. For example, Tollenaar et al. (1994) found that the effect of weed interference on corn dry matter accumulation and grain yield was lower under high than under low soil nitrogen levels. Evans et al. (2003) also suggested that the application of nitrogen fertilizer delayed the beginning of the CPWC in corn. Their study revealed that the effects of nitrogen fertilization on early season crop growth provided a competitive advantage for corn relative to weeds. In our study, the end of the CPWC at the 5% yield loss level was at 47 DAE (R1 development stage or 743.05 ATU) and 52 DAE (R3 development stage or 832.75 ATU) for 0 and 25 $kg.ha^{-1}$ of starter fertilizer level, respectively (Table 6). The few weeds emerging after these periods accumulated little biomass (Table 5) and did not reduce soybean seed yield below the acceptable level, probably due to shading of the weeds by the crop resulting from the soybean canopy closure. Similar results were obtained by other researchers (Mohammadi et al. 2005; Martin et al. 2001; Malik et al. 1993; Swanton and Weise 1991). They found that the establishment and competition of weeds were reduced following crop canopy closure. In the present study, the end of the CPWC occurred slightly later (by 5 days) in the case of the starter fertilizer application. It may be due to the higher growth of the weeds than the crop resulting from their higher ability for utilizing the applied fertilizer which relatively prolonged the interference of the weeds and consequently delayed the end of the CPWC. This finding is in contrast with the result obtained by Evans et al. (2003) who reported that the application of fertilizer hastened the end of the CPWC in corn. It can be attributed to different competitive ability and fertilizer use efficiency between soybean and corn. However, the starter fertilizer shortened the CPWC by 12 days in the present study. It seems that the use of the starter fertilizer is more effective on the beginning of the CPWC. This is compatible with the findings obtained by Weaver et al. (1992) who suggested that the alteration of soil nutrient supply can influence the crop-weed interference relationships, especially in determining the onset of the CPWC. In the present study, there was a negative and significant correlation between soybean seed yield and weed biomass (r= -0.79). In other words, soybean seed yield loss increased as a response to increasing weed biomass (Fig. 1). In our study, for every 22.83 $g.m^{-2}$ weed biomass produced 1% soybean seed yield was lost. Moreover, increasing weed interference period reduced soybean yield components, but the reduction was higher for the number of pods per plant (60.11% vs. 17.83 and 25.90% for the number of seeds per pod and 100-seed weight, respectively), indicating more sensitivity of this yield component to weed interference than the other two

Table 4. Parameter estimates for the Gompertz and logistic equations under the two starter fertilizer (SF) levels. Standard errors have been shown in parentheses.

Parameters	Gompertz parameters					Logistic parameters				
	A	M	B	R^2	RMSE	A	M	B	R^2	RMSE
Without SF	101.70 (2.98)	30.90 (8.09)	-21.2 (9.17)	0.98	2.15	70.50 (11.10)	44.50 (17.44)	-1.91 (3.47)	0.97	3.63
With SF	102.20 (2.47)	31.70 (5.88)	-16.50 (5.53)	0.99	1.61	74.80 (1.98)	46.00 (3.11)	-4.78 (1.41)	0.99	1.66

Table 5. Mean comparison of the studied traits under the different treatments. Standard errors have been shown in parentheses.

Treatment	Traits					
	Seed yield ($g.m^{-2}$)	Biological yield ($g.m^{-2}$)	Pods/plant	Seeds/pod	100-seed weight (g)	Weed biomass ($g.m^{-2}$)
WF 15 DAE	218.97 (2.78) fg	563.91 (13.26) bc	40.99 (1.60) f	2.47 (0.062) c	10.18 (0.18) b	908.60 (43.80) c
WF 30 DAE	241.84 (2.47) de	583.04 (9.23) abc	54.80 (3.25) e	2.65 (0.016) b	10.02 (0.20) b	584.14 (90.54) d
WF 45 DAE	272.22 (2.91) bc	620.33 (11.11) ab	64.14 (2.85) d	2.69 (0.014) b	11.11 (0.10) a	381.95 (70.94) e
WF 60 DAE	282.38 (3.23) ab	609.15 (7.30) abc	76.70 (1.75) b	2.81 (0.014) a	11.35 (0.21) a	75.50 (39.14) f
(WFC)	300.16 (5.11) a	626.44 (10.49) a	81.19 (1.67) a	2.86 (0.017) a	11.39 (0.18) a	0.00 (0.00)f
WI 15 DAE	259.60 (18.95) cd	594.60 (45.16) abc	70.97 (2.28) c	2.69 (0.034) b	11.08 (0.20) a	270.00 (57.29) e
WI 30 DAE	238.71 (6.28) def	613.27 (12.14) abc	53.22 (2.89) e	2.62 (0.017) b	9.63 (0.19) c	554.80 (39.66) d
WI 45 DAE	220.28 (6.40) efg	610.02 (21.97) abc	41.31 (2.43) f	2.53 (0.023) c	9.98 (0.35) bc	1023.03 (100.27) c
WI 60 DAE	201.29 (5.81) gh	558.54 (22.22) c	33.91 (1.02) g	2.36 (0.062) d	8.77 (0.24) d	1359.05 (79.26) b
WC	192.09 (4.26) h	570.80 (27.10) abc	32.39 (0.72) g	2.35 (0.094) d	8.44 (0.28) d	1708.00 (77.48) a
LSD (0.05)	21.82	59.76	4.17	0.08	0.36	164.50

Abbreviations: DAE, days after crop emergence; WFC, weed-free control (weeded for all of the growing season); WC, weedy control (un-weeded for all of the growing season); LSD, least significant difference.

components. It can be concluded that the harmful effect of weed interference is more apparent from the reduced number of pods per plant in soybean which is ultimately reflected in seed yield. Similar results were reported by Chhokar and Balyan (1999) for soybean and by Mohammadi et al. (2005) in chickpea.

Materials and methods

The study was carried out in 2009 at the Agricultural Research Farm of Razi University, Kermanshah, western Iran (latitude 34° 18′ N, longitude 47° 4′ E, altitude 1350 m above sea level). The climate is characterized by mean annual precipitation of 478 mm and mean annual temperature of 13.8° C. The soil type was silty clay with an average pH of 8.1 and about 0.8% organic matter. The land was plowed and disked before planting. The soybean cultivar was 'Williams' (a cultivar that is commonly planted in the region). Soybean seeds were inoculated with *Bradyrhizobium japonicum* bacterium prior to sowing. The crop was planted on 22 May 2009. Soybean is a summer and irrigated crop in western Iran; therefore, it is not dependent on seasonal rainfall. Irrigations were carried out at 7-9 day intervals throughout the growing season. The experiment was conducted in a randomized complete block design with four replications in a factorial arrangement.

Two factors were examined: the first factor was the starter fertilizer levels (0 and 25 kg ha^{-1}) applied in the form of monoammonium phosphate (11-52-0) (the starter fertilizer was applied according to the soil test recommendation) and the second factor was the different weed interference periods consisted of five initial weed-free (WF) periods (in which, plots were kept free of weeds for 0, 15, 30, 45 and 60 days after crop emergence (DAE) and then weeds were allowed to grow until harvest) and five initial weed-infested (WI) periods (in which, weeds were allowed to grow for 0, 15, 30, 45 and 60 DAE, after which the plots were kept free of weeds until harvest). Weed removal within and between the plant rows was carried out manually. Each plot consisted of six soybean rows of 5 m long with row spacing of 50 cm and with 5 cm between plants on the same row.

Crop development stages were recorded on 10 randomly selected plants in each plot at 7 day intervals, beginning from soybean emergence. High natural weed populations were observed in the experimental field. At maturity, soybean plants at a 4 m length from the two center rows of each plot were harvested by hand and allowed to dry to a constant weight and weighed and biological yield (total aboveground dry weight) was determined. Subsequently, they were threshed and cleaned and seed yield was calculated. Additionally, 100-seed weights were determined according to the recommendations of the International Seed Testing Association (ISTA) (Draper, 1985). Before harvesting, the number of pods per plant and the number of seeds per pod were measured on 10 randomly selected plants in the centre rows of each plot, except from the rows that were used for yield measurement. Weed biomass was also measured by harvesting weeds at the ground level in three random 0.5×0.5 m quadrats in each plot at harvest and before each weed removal for the weed-free and the weedy treatments, respectively.

Weed species were initially distinguished, then separately dried at 80° C to constant weight and weighed. Weed species of the field and their relative dry weights ((dry weight of each weed species/ total dry weight of all weed species) × 100) are shown in Table 1. These are nearly common weeds in soybean fields of the region.

Accumulated thermal units were calculated using the following equation:

$$ATU = \Sigma[(T_{max} + T_{min}) /2 - 10]$$

Where ATU is the accumulated thermal units from emergence to day n and T_{max} and T_{min} are maximum and minimum daily temperatures, respectively, 10 is soybean base temperature (Wang et al. 1987). Mean monthly temperatures during the experimental period are shown in Table 2.

Data analysis

Equations describing crop yield response to weed interference were fitted to the soybean yield data using nonlinear regression. The Gompertz equation (Ratkowsky 1990) was used to describe the effect of increasing duration of weed-free period on soybean seed yield:

$$Y = A\exp [-\exp (-B (T-M))]$$

Where Y is the yield as a percentage of the weed-free control, A is the upper asymptote, M is the point of inflection, B is parameter that determines the shape of the curve, and T is time in DAE. A logistic equation (Ratkowsky 1990) was used to describe the effect of increasing lengths of weed-infested period on the seed yield of soybean:

$$Y = A + [(100 - A) / (1 - \exp (B (T - M))]$$

Where, Y is the yield as a percentage of the weed-free control, A is the lower asymptote, M is the point of inflection, B is parameter that determines the shape of the curve, and T is time in DAE. Yield loss of 5% was chosen to calculate the beginning and end of the critical period. Using the derived equations, the critical duration of the weed-free period and the critical length of weed-infested period were calculated for specific yield loss level in DAE under the two starter fertilizer treatments. This yield loss level was approximately judged to be acceptable, taking into account the present economics of weed control, e.g. the cost of weed control, soybean prices and yield gain. Subsequently, the calculated DAE was related to the observed crop development stage and accumulated thermal units. Correlation coefficient between the soybean seed yield and weed biomass was calculated using the data of these traits obtained from all plots. Moreover, relationship between soybean seed yield loss and weed biomass was obtained using an exponential regression model. Data analyses were carried out using SAS (SAS Institute 2003).

Conclusion

In general, this study revealed that the CPWC in soybean varied in length between the two starter fertilizer levels. It ranged from 9 to 52 DAE (V1 to R3 or 111.20 to 832.75 ATU). The starter fertilizer application slightly delayed the end of the CPWC (by 5 days), but this condition shortened the CPWC by 12 days because of the later beginning of the CPWC (by 17 days). Practical implication of this finding is that application of monoammonium phosphate as starter fertilizer in kermanshah region can reduce the time needed

Table 6. The critical duration of weed-infested period (the beginning of the CPWC) and the critical length of weed-free period (the end of the CPWC) in soybean in days after crop emergence (DAE), crop development stage (CDS) and accumulated thermal units (ATU), as calculated by the Gompertz and logistic equations for 5% level of soybean yield loss under two starter fertilizer (SF) levels.

	Critical duration of weed-infested period for specified yield loss			Critical length of weed-free period for specified yield loss		
	DAE	CDS	ATU	DAE	CDS	ATU
Without SF	9	V1	111.20	47	R1	743.05
With SF	26	V7	374.55	52	R3	832.75

for weed control in soybean field and consequently lead to less herbicide application and cultivation. Moreover, the later weed control operations needed at the start of the soybean growing season resulted from the starter fertilizer application is very important because of the high vulnerability of the soybean seedlings to cultivation and herbicide application.

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