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Timing of Velvetleaf Management in Soybean (*Glycine Max* (L) Merrill)

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ABSTRACT

Velvetleaf (*Abutilon theophrasti* Medic) is one of the most important warm season weeds in soybean fields. To the aim of this study is to determine the critical period of velvetleaf control in two cultivars of soybean, Williams as indeterminate and Persian as determinate,with different growth patterns. . Theexperiment was conducted at the University of Agriculture and Natural Resources of Gorgan, Iran in 2007 using a randomized complete block design along with four replicates. The experiments consisted of two sets of treatments; one set was to keep the plot weed-free until the growth stages of 2- leaf (V_2), 4- leaf (V_4), 6- leaf (V_6) stages, beginning of flowering (R_1) and beginning of pod set (R_3). The second set was interference treatments that velvetleaf was allowed to grow within the plot throughout the above-mentioned growth stages. Weedy and weed-free checks were also included in the study. The effect of control treatments were significant on final height, branch number per plant, leaf area index, dry matter, yield, and pod number per plant, while seed number in pod and 100-seed weights of soybean were not significantly affected. The effects of interference treatments were significant on all traits except 100-seed weights. Using the Gompertz and Logistic equations it was found that the critical period of controlling velvetleaf in both cultivars under study, considering 5% allowed decrease in yield, was between 260 to 943 CGDD or 14-51 DAE, which is approximately from 2-leaf stage to beginning of flowering. With a 10% allowed decrease, is the number would be between 320 to 752 CGDD or 18-41 DAE, which is approximately 3 to 6-leaf growth stage for both cultivars.

Key word: Soybean, Velvetleaf, yield component, competitive periods

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INTRODUCTION

Using herbicides is an important component of successful soybean production in modern agriculture and since many herbicides are available to farmers, a biological vision should replace the unconditional use of such herbicides. Knowing the critical period for weed control in major crops can aid decision making on the right timing of weed removal in cropping systems and herbicides application (Eyherabide & Cendoya, 2002). Early research on weed competition used multiple comparison tests to calculate the critical period (Zimdahl, 1980). However Cousens, (1988) suggested that regression analysis is more appropriate and reliable in calculating the critical period.

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 with this hypothesis (Hall *et al*., 1992) determined that in Canada the beginning of the critical period for corn widely varied from the 3 to 14 leaf stages of corn and ended on average at the 14-leaf stage. Wide research show that there is no stable critical period for weed control in soybean (Hadizadeh & Rahimian Mashhadi, 1998). The beginning and duration of the critical period for weed control can vary depending on several factors, including the crop and weed characteristics, environmental variables (Hall *et al*., 1992), cultural practices and the assumptions made regarding the methods employed to determine the critical period for weed control.

For example, the critical period of *Sorghum halopens* control in soybean was determined to be 4-5 weeks after planting (Williams *et al*., 1984). The critical period of weed control in soybean was coinciding with V2 (with acceptable yield loss of 5%) in climate condition of Mashhad (Hadizade & Rahimiyan Mashhadi, 1998). (Chohocar & Balyan, 1999) reported that this period in soybean is 30-45 days after sowing and if weed-free condition was more than 45 days it would have resulted in 74% increase in grain yield of soybean. (Van Acker *et al*., 1993a) reported that the critical period of weed control in soybean is about 30 days after emergence. Fellows & Roeth (1992) show that the onset of the critical period of weed competition in soybean may be earlier than 2 weeks or later than 6 weeks after emergence.

Competitive crop cultivars are important matters of an integrated weed management program, they must have high leaf area index (LAI), height and dry matter accumulation during the reproductive period strongly affecting yield components. Decreasing leaf area of plant is one of the consequences of interference of weeds in relation to yield reduction.For example (Akey *et al*., 1990) reported that although soybean was taller than velvetleaf during early growth period but fast growth, high transition rate and more partitioning of photosynthesis to the stems in velvetleaf resulted in leaf senescence of lower part and more branching in upper part of velvetleaf. Thus soybean was not successful in competition. Kropff *et* *al*.,(1992) showed that leaf area index (LAI), leaf area growth rate, specific leaf area, and height increase determine the outcome of competition between sugar beet (*Beta vulgaris* L.) and common lambsquarters (*Chenopodium album* L.). In a simulation study Weaver *et al*. (1992) found that taller corn hybrids with greater leaf area index and dense canopy of tomato (*Lycopersicon esculentum*) had greater tolerance to velvetleaf (*Abutilon theophrasti*) (Lindquist & Mortensen, 1998; Lindquist *et al*., 1998).

Forcella, (1987) found that a tall fescue genotype with enhanced leaf area expansion was more able to maintain yield when competing with velvetleaf. Wheat (Challaiah *et al*., 1983) and potato (Sweet *et al*., 1974) cultivars that had greater LAI and intercepted more light were found to suppress weeds better. Barker *et al*.,(2006) and Evans *et al*., (2003a) found biomass partitioning coefficients of leaves increased in competition with weed more than weed-free condition but total biomass partitioning was less. In the tolerance mechanism of crops in regards to weeds, suitable biomass partitioning between different parts of plant is more important than total accumulated biomass (Evans *et al*., 2003b).

"Williams" and "Persian" are two commonly used commercial cultivars of soybean in Iran. Velvetleaf (*Abutilon theophrasti* Medic.) is a troublesome annual weed in many maize and soybean cropping systems in Gorgan, Iran. This study was conducted to study timing of velvetleaf management in two different cultivars of soybean with different growth pattern, Williams as indeterminate and Persian as determinate.

MATERIALS AND METHODS

The experiment was conducted in 2007 at the Experiment Station of Gorgan's Agriculture and Natural Resource University Iran. The soil type was clay loam, pH of 7.5-8 and 0.5% organic matter. The land was ploughed and cultivated before planting. According to local soil test recommendations, basal dose of 100 kg/ha phosphates ammonium, 300 kg/ha sulphur and 50 kg/ha urea were incorporated in to the soil. Seed dormancy was broken by immersing the seeds into sulfuric acid of 96%for 20 minute (Lacroix & Staniforth, 1964).

The experiments consisted of two series of treatments; the first set was control treatments that the plots were kept weed-free until the growth stages of 2, 4 and 6-leaf stages, beginning of blooming and beginning of pod set. The second set was interference treatments that velvetleaf was permitted to grow within the crop until the above-mentioned growth stages. Weedy and weed-free controls were also included in this study. The experimental design was a randomized complete block with four replications for the Williams and Persian cultivars.

Before planting soybean, treated velvetleaf seeds were planted symmetrically by hand on 17th of June then field was sprinkler-irrigated. Seeds of Williams and Persian cultivars were planted in 8 rows spaced 50 centimeters apart and irrigated up to field capacity threshold, on 20th of June. After planting, the entire field was sprinkler-irrigated till seedling establishment and furrow-irrigated until 2 weeks prior to harvest. After seedling emergence, velvetleaf seedlings were thinned to the density of 10 plants.m^{-1} of rows. All naturally occurring weed species were removed by hand throughout the growing season. No herbicides were used before and after planting or emergence.

Plant Sampling

Parameters such as plant height, leaf area and plant dry matter for both soybean cultivars and velvetleaf were measured at each mentioned growth stages. All measurements were made on plants in the middle row of the plots. Height was the distance from the ground to the highest leaf. The leaf area of green leaves was measured using an optical leaf area meter.

At maturity stage,18th October and 10th October 2006 for Williams and Persian cultivars, respectively, a 3-m length of the two central rows of each plot was harvested by hand to measure grain yield. Additionally, 100-seed weights were determined according to the recommendations of the International Seed Testing Association (ISTA). At harvest, number of branches, pods per plant and number of seeds per pod were measured on 20 randomly selected plants in the center rows of each plot, except the rows used for yield measurement.

Data Analysis

Analyses were conducted separately for each cultivar and data on plant growth parameters were subjected to analysis of variance.. Data were analyzed for comparison of means.($P<0.05$) . SAS statistical software (SAS, 1988) was used to analyze the data, including analysis of variance (ANOVA) and comparison of means based on a LSD procedure (Gomez & Gomez, 1984).

A logistic model provided the best fit for the maximum weed-infested period in the preliminary tests, therefore the model was also used to describe the effect of increasing duration of weed infestation on the yield of soybean (Ratkowsky, 1990) as follow as

$$Y = C + D/ (1 + \exp (-A + BX)) \quad [1]$$

Where Y is the yield as a percentage of the weed-free control, A and B are parameters that determine the shape of yield falling(A, is shape of the curve where yield fall is 50 percent and B is shape of the curve in the minimum of yield), C is the lower yield asymptote or minimum yield in the presence of weed interference, D is the difference between the upper and lower yield asymptotes, and X is the days after soybean emergence (DAE) or growth degree day (GDD), which is equal to weed infested duration from soybean emergence time until weed removal and control time. The Gompertz model was used to describe the effect of increasing length of weed-free period on soybean yield (Ratkowsky, 1990):

$$Y = A \exp (-B \exp (-KX)) \quad [2]$$

Where Y is the yield as a percentage of the weed-free control, A is the upper yield asymptote or maximum yield in the absence of weed interference, B and K are parameters that determine the shape of yield rising, and X is DAE or GDD, which is equal to the weed-free period from soybean emergence time. The critical period for velvetleaf control in soybean in regard to DAE or GDD was calculated for specific yield loss level of 10 and 5% for each cultivar. Relationship between soybean seed yield percentage and velvetleaf dry weight, and height, was obtained using of segmented models for both cultivars.

RESULTS AND DISCUSSION

Soybean Leaf Area

Reduction in maximum leaf area index (LAI_{Max}) was found in both cultivars due to increased length of the velvetleaf interference period and leaf area index. The effects of control treatments until 2- and 4-leaf stages were significant on maximum leaf area index of soybean while in interference treatments up to V_2 and V_4 there was no significant effect on LAI_{Max} in both cultivars when compared with the control (Table 1). Velvetleaf left beyond 4-leaf stage of soybean showed increase in LAI more than that of soybeans which could indicate of a one set competition. Leaf area index defines the ability of canopy to intercept PPFD and is an important factor in determining DM accumulation. Thus, any reduction in LAI below the canopy implies less PPFD interception and influences yield directly (Loomis *et al.*, 1968). Because velvetleaf has broad and wide leaves and produces most of its leaves above the soybean`s canopy, asuccessful strategy in the competition for light (Regnier & Harrison, 1993; Rajcan & Swanton, 2001). In this experiment, a longer presence of velvetleaf in the plots led to decrease in soybean yield when compared to the weed-free control.

In our study maximum LAI of soybean coincided approximately with pod set stage which had a polynomial equation (R^2=80) with soybean yieldin both cultivars (Figure 1).

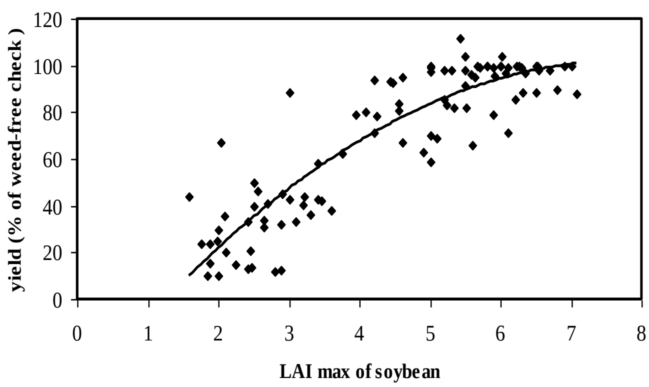

Figure 1. Relationship between Maximum leaf area index of soybean and soybean percent yield compared to weed-free check ($Y = -2.4387X^2 + 37.97X – 45.6$, $R^2 = 0.80$)

Eik andHanway (1966) also reported high positive linear correlation between leaf area of corn at silking and final grain yield. Evans *et al.*, (2003a) found that the relationship between grain yield and maximal leaf area was not linear but was positively correlated (R^2= 0.90).

Height and Dry Matter

An overall ANOVA indicated significant effect of control and interference treatments on the soybean dry matter and height (P < 0.0001) (data not shown). Increasing length of the weed interference period led to increased height of soybean. The highest soybean height belonged to weedy check that was 27% which is 38% more than weed-free check for Persian and Williams cultivars, respectively (Table 1).

In this study, more height and shading of velvetleaf led to increase in soybean height in the interference treatments. Higher competition for light in the interference treatments resulted in increase in crop eight which is brought about by the change of light quality for the crop (reduced R/FR ratio) (Rajcan & Swanton, 2001; Kropff *et al.*, 1993; Berkowitz, 1987). It seems that increase of soybean height is due to increase of internodes distances, and not to the increase of number of nodes (Akey *et al.*, 1990). Previous studies showed that in high competitive situation as internodes distances increase, the number of internodes which are the potential positions for branching and reproductive organs decrease, which this case is important for final grain yield (Adelusi *et al.*, 2006; Domiguez & Hume, 1978).

The final height of velvetleaf when compared with soybean height in weedy and weed-free controls was 2.3 and 2.9 times more than Persian cultivar and 2 and 2.5 times more than Williams cultivar, respectively.

In this study, increase in velvetleaf height resulted in severe decrease in soybean yield so when velvetleaf height reached to 60% of maximum height in weedy check the reduction of soybean yield was 93% when compared with weed-free check (Figure 2).

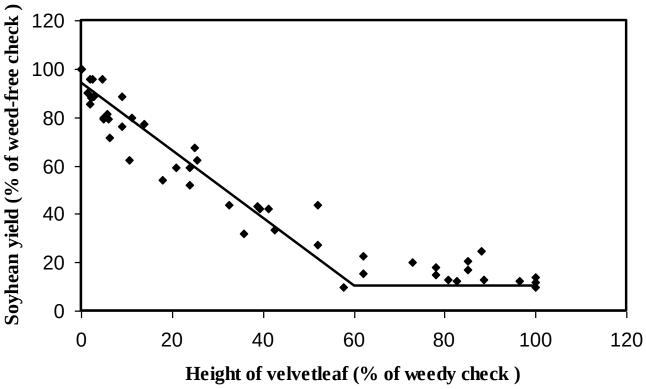

Figure 2. Relationship between height of velvetleaf and soybean percent yield compared to weed-free check ($Y = 94.2314 – (1.454 \times X)$, $X_0 = 60$, $R^2 = 0.95$)

Ngoujio *et al.*,(2001) reported that in the competition between velvetleaf and tomato, velvetleaf was taller than tomato during the growing season despite tomato reaching its maximum height. Weaver *et al.*, (1992) found that duration of the weed-free period in the plant was mainly dependent on the height and leaf area expansion of the weed.. The experiments also showed that taller weeds caused more yield losses in crop. Stoller & Woolley (1985) showed that a major strategy of velvetleaf for light-competition is the placement of leaves above the competing plants (over-topping), in a short crop, such as soybean, which requires a rise in height.

Dry matter differences of soybeans in various interferences and control periods were significant ($p < 0.0001$). In both cultivars, significant loss in total soybean dry weight began when weed removal was delayed until V_6, and the cause would be rapid increase in velvetleaf dry weight and its LAI. Dry matter accumulation of soybeans in the interference treatments til V_6, R_1, R_3 stages in weedy check compared with free check, were 42, 60, 80 and 82.4% less for Persian cultivar and 28, 38, 54, and 60% less for Williams cultivar (Table 1).

Weed-infested conditions for the entire growing season led to 60 an 82% reduction in soybean dry weight, compared with full-season weed-free treatments, of Williams and Persian cultivars, respectively (Table 1). Traore *et al.*, (2003) in grain sorghum, and Ngouajio *et al.*, (2001) in tomato, found that dry matter accumulation in different cultivars grown in the presence of weed was drastically reduced compared to cultivars grown in free weed conditions.

In control weedy treatments, reduction of soybean dry matter when weed was not controlled until V_2 and V_4 stage was significant in Williams and Persian cultivars, respectively (Table 1). Soybean competition was good enough to prevent dry matter losses when weeds germinated beyond V_2 and V_4 stages in the Williams and Persian cultivars, respectively. Bedmar *et al.*, (1999) mentioned that weed biomass at harvest was reduced when corn was kept weed free for 10-20 days after emergence (5-6 leaf corn stage). Bhan & Kukula (1987) pointed out that beneficial effect of reduced weed competition is apparent from the increased dry matter accumulation in chickpea, which is ultimately reflected in seed yield. Reduction of crop yield as a response to increasing weed dry weight has been reported in many researches (Adelusi *et al.*, 2006; Knezevic *et al.*, 2003; VanAkcer, 1992).

In this study also the soybean yield was decreased by increasing the velvetleaf dry weight. The reduction trend of soybean yield against velvetleaf biomass in the two cultivars were similar, which a segmented model was fit for data from both cultivars (Figure 3).

Deduction of soybean yield will be beyond 88%, if velvetleaf biomass reaches to 650 g m^{-2}, while further increase in velvetleaf biomass has no further effect on the reduction of soybean yield (Figure 3).

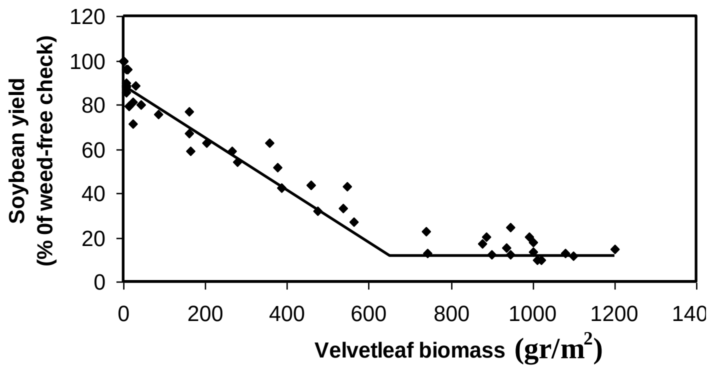

Figure 3. Relationship between biomass of velvetleaf and soybean percent yield compared to weed-free check ($Y = 88.888 – (0.119 × X)$, $X_0 = 650$, $R^2 = 0.97$)

Overall, 1% of soybean seed yield was lost for every 7.3 g/m^{-2} increase in velvetleaf dry weight.

In both cultivars under study, few weeds emerged after the two-leaf and four-leaf stages of soybean, and those that did emerge accumulated little shoot biomass. The canopy closure by the soybean may have prevented the weeds from establishment after the two-leaf and four-leaf stages in Williams and Persian cultivars, respectively. Weed biomass proved to be a better indicator of weed interference than weed density (Wooley *et al.*, 1993). Strahan *et al.* (2000) reported that by increasing period of interference, weed dry weight increased which will decrease by increasing control period. In addition, weed biomass accumulation at harvest was dramatically reduced when soybean was kept weed free til at least the V_2 and V_4 stage of growth.

Few weed seedlings emerged after these stages of growth and were not considered to represent a problem for mechanical harvesting.

Table 1. Percentage values of weed-free control for morphological traits under different weed-free (WF) and weed-infested (WI) treatments assessed at soybean harvest for two cultivars

Treatments	Williams			Persian		
	Soybean leaf area index	Soybean height	Soybean dry weight	Soybean leaf area index	Soybean height	Soybean dry weight
WF V_2	77 b	122a	63 b	74 b	121.7 a	50 b
WF V_4	87 ab	118 b	88 a	77 b	96 b	62 b
WF V_6	96 a	101 c	89 a	91a	95.8 b	100 a
WF R_1	98 a	98 c	100 a	98 a	97 b	104 a
WF R_3	00 a	100 c	98 a	99 a	104 ab	102 a
WFC	100a	100 c	100 a	100 a	100 b	100 a
WI V_2	99 a	109 c	99 a	100 a	101 b	100 a
WI V_4	98 a	105 c	98 a	97 a	95 b	90 a
WI V_6	72 b	117 b	72 b	67 b	103 ab	58 b
WI R_1	61 c	130 a	62 b	59 c	123 a	40 b
WI R_3	50 d	133a	46 c	48 d	118 ab	20 c
WC	48 d	138 a	40 c	45 d	127 a	18.6 c

WFC, weed-free control. WC, weedy control (unweeded for all of the season)

Soybean Yield and Yield Components

Grain yields (% of weed-free check) resulting from the different periods of weed competition in both cultivars are shown in table 2. Highly significant ($P < 0.001$) differences were found between treatments in both cultivars. The weedy control gave a 76 and 90% reduction compared to weed- free treatment in Williams and Persian, respectively.

Higher grain yield mean was observed in weed-free check of Williams that was 30% more than Persian cultivar (data not shown).

In both cultivars reduction in grain yield was the result of, increase in length of the weed interference period, simultaneous reduction in plant dry weight, number of branches, pods per plant and seed number per pod (Table 2). This was supported by significant and positive correlation between seed yield and plant dry weight, number of branches, pods per plant and seed number per pod, in both cultivars (0.99, 0.85, 0.97, and 0.61, for Williams and 0.97, 0.89, 0.91, and 0.59 for Persian). A similar result was reported for soybean, where weed interference also occurred mainly through the reduced number of pods and branches per plant (Orwick & Schreiber, 1979; VanAcer *et al.*,1993b; Chhokar & Balyan,1999).

In this study, averaged weight of 100-seed was not significantly reduced by velvetleaf interference and thus there was no significant correlation between the 100-seed weight and seed yield (0.32 and 0.15 for Williams and Persian cultivars, respectively).

There was a significant difference in the averaged seed number per pod in the weedy check for Persian cultivar, and in weedy check and interference until R_3 for Williams, when compared with their free control treatments.

Reduction trend of seed number per pod may be because of miscarriage of ovum, tiny seeds and also less seed loading which led to increase percentage of single seed per pod. Apparently, seed number per pod has nospecial effect on changes in grain yield as a result of velvetleaf interference. This was supported by small correlations between seed yield and seed number per pod (0.61 and 0.54 for Williams and Persian cultivars, respectively).

The average number of pods per plant of either cultivar was significantly decreased by increasing duration of weed interference after planting. The reduction in pod number per plant due to weed interference varied between cultivars.

In Persian, the reduction in pod number by increase in duration of velvetleaf interference was greater than in the Williams (data not shown).This is supported by (Kelly *et al.*, 1987) who found that indeterminate cultivars (as a group) had greater yield stability than determinate cultivars. These results are in agreement with work by (Adams, 1967 & Bennet *et al.*, 1977) which showed that the greatest negative response to stress during bean development occurred in the pod number. Pod number per plant is the first yield component determined in the reproductive phase followed by seeds per pod and seed weight (Adams, 1967). Thus pod number per plant is likely the most sensitive yield component to weed interference. The findings of the present study showed that grain yield and number of pods per plant were affected by velvetleaf interference. Hagood *et al.* (1980) reported that 1.4–40 density of *Abutilon theophrasti* plants per square meter decreased number of pods in plant. These results indicate that the 100-seed weight is not significantly affected by interference and control treatments. Generally in interference treatments because of decrease in pod number per plant, assimilates were distributed within less pods and thus the 100-seed weight showed no differences when compared with control treatments in which pod number per plant was increased because of favorable conditions, therefore assimilates were distribute within more pods.

In Williams, seed yield was 76% less when velvetleaf was allowed to compete all season long, in comparison to velvetleaf control in the full season. When velvetleaf introduction was delayed till the 6-leaf stage, soybean seed yield increased by 45%. Similar yield values were observed with the other introduction periods (V_6 to R_3) (Table 2). These data suggest that if velvetleaf competition is delayed til V_6 or later, soybean seed yields would not be significantly reduced. Other researchers have recorded similar yield trends when johnsongrass (*Sorghum halepense* Pers.) and smellmelon (*Cucumis melo*) emergence is delayed in corn and cotton, respectively (Ghosheh *et al.*, 1996; Tingle & Steele, 2003).

Soybean effectively competed with velvetleaf till V_4 before a yield loss was observed. When velvetleaf was allowed to compete with soybean at V_6, R_1, R_3, and during full season, soybean seed yield reduced 33 to 76%.

These data suggest that effective control measures should be implemented before the6-leaf stage (Table 2). Croster and Masiunas, (1998) showed that the best pea yields resulted when eastern black nightshade was controlled during the first 2 weeks of the growing season.

In Persian, soybean grain yield with the velvetleaf present in full season was 90% less than velvetleaf control in the full season.

When velvetleaf was allowed to compete with soybean for only up to 2-leaf stage, a yield reduction of 6 and 4% was observed for Persian and Williams cultivars, respectively (Table 2). Gargouri and Seely (1972) reported 10 to 44% pea yield losses when wild oat were removed 2 or 4 weeks after emergence, but with weed removal before these stages no seed yield loss was observed .Here we provide additional evidence that early velvetleaf control is crucial for optimal soybean yield.

Table 2. Percentage values of weed-free control for Soybean yield and yield components under different weed-free (WF) and weed-infested (WI) treatments assessed at soybean harvest for two cultivars

Treatments	Williams					Persian				
	Branches/ plant	Pods/ plant	Seeds/ pod	100-seed weight	Soybean grain yield	Branches/ plant	Pods/ plant	Seeds/ pod	100-seed weight	Soybean grain yield
WF V_2	66 c	42 c	96 a	N.S	40 c	28 b	33 b	96 a	N.S	29 c
WF V_4	74 b	65 b	97 a	N.S	63 b	83 a	56ab	100 a	N.S	84 b
WF V_6	101 a	99 a	99 a	N.S	85 a	89 a	88 a	96 a	N.S	93 a
WF R_1	102 a	101a	98a	N.S	92 a	89 a	95 a	99 a	N.S	102 a
WF R_3	100 a	100a	99 a	N.S	99 a	82 a	83 a	101 a	N.S	98 a
WFC	100a	100a	100a	N.S	100 a	100 a	100a	100 a	N.S	100 a
WI V_2	104 a	98 a	99 a	N.S	96 a	96.7 a	99 a	102 a	N.S	94 a
WI V_4	102 a	97 a	100a	N.S	90 a	99 a	89 a	96 a	N.S	88 a
WI V_6	68 b	70 b	98 a	N.S	67 b	88 a	47 b	99 a	N.S	55.5 b
WI R_1	56 c	52 c	95 a	N.S	41 c	44 b	34 c	100 a	N.S	30.7 c
WI R_3	54 c	39 c	83 b	N.S	28 d	21 bc	22 d	100 a	N.S	12 d
WC	49 c	36 c	79 b	N.S	24 d	14 c	18 d	87 b	N.S	10 d

WFC, weed-free control. WC, weedy control (unweeded for all of the season)
N.S: Non Significant

The Gompertz and Logistic models generally described the data well, as indicated by the C.V and R^2 values (Table 3). Cousens, (1988) suggested the Gompertz equation is useful to describe the relationship between the lengths of the weed control and grain yield. Hall *et al*., (1992) also suggested the use of Logistic equation for determination of the influence of increase in duration of weed interference on yield. The crop developmental stage at which weed interference occurs is an important factor in determining potential yield losses.

The length of weed-free period, required to prevent yield loss, varied for the different cultivars and accepted levels of yield loss (Table 4). If a 5% yield loss gives a marginal benefit compared with the cost of weed control, so the beginning of the weed-free period required to prevent more than a 5% yield loss ranged from 260 to 431 CGDD (approximately 14 to 24 DAE or 2-3 leaf stages) when a yield loss of 10% was acceptable, beginning of the weed-free period ranged from 320 to 528 CGDD (approximately 18-29 DAE or 3-4 leaves) for Persian and Williams cultivars, respectively (Table 4; Figure 4). Prior to these times, velvetleaf presence did not influence the soybean seed yield.

Soybean growth and development are sufficiently plastic at 2 to 4-leaf stages to recover yield potential after velvetleaf is removed. 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 (Dawson, 1986). In our study, the end of the critical period of velvetleaf interference to prevent more than > 5% crop yield loss ranged from 770 to 943 CGDD (approximately 42 to 51 DAE or 7- leaf stage to R1) and for less than 10% crop yield loss was from 643 to 752 CGDD (approximately 35 to 41 DAE or 5- to 6-leaf stage) for Persian and Williams cultivars, respectively (Table 4; Figure 4). These stages coincided with the soybean canopy closure in both cultivars. The few weeds emerging after the mentioned stages accumulated little shoot biomass and did not affect the seed yield. Soybean canopy closure may have reduced both establishment and competitive ability of later emerging weeds. Other researchers have also reported that the establishment and competition of weeds were reduced following crop canopy closure (Swanton & Weise, 1991; Malik *et al*., 1993; Martin *et al*., 2001).

In general, the critical time for weed free condition varied between cultivars and accepted percentage of yield lose. The length of the critical period of velvetleaf required in Williams cultivar to prevent yield loss, was somewhat less than the Persian cultivar probably due to difference in their growth habit. Regardless of variability in the extent and occurrence of the critical period of velvetleaf control, critical period of velvetleaf control for an accepted yield loss was variable across the both cultivars and varied between 260 to 943 CGDD or 14-51 DAE, which is approximately from 2-leaf stage to beginning of flowering. Other authors have reported critical weed-free periods in a similar range, from 14 to 42 DAE for soybean in competition with single weed species (Eaton *et al*., 1976; Harris and Ritter, 1987; Stoller *et al*., 1987; Zimdahl, 1987) and community weeds (Van acker *et al*., 1993b; Knezevic *et al*., 2003). This weed-free period indicates that duration of a residual herbicide in soybean need not to be greater than 51 DAE, or at beginning of flowering stage of soybean growth, in order to prevent a yield loss greater than 5%.

Table 3. (A) Coefficient estimates (along with standard errors) for the Gompertz equation (increasing length of weed-free period in the two cultivars). (B) Coefficient estimates (and standard errors) for the Logistic equation (increasing length of weed-infested period in the two cultivars).

	Parameter estimates					
cultivars	**A**	**B**		**K**	**R^2**	**C.V**
(A)*						
Williams	102.4 (3.05)	2.16 (0.24)		0.057 (0.0063)	0.95	0.908
Persian	99.00 (2.73)	3.91 (1.22)		0.00602 (0.00109)	0.91	1.176
	A	B	C	D	R^2	C.V
(B)**						
Williams	5.88 (1.13)	0.14 (0.026)	14.03(3.50)	87.48(5.29)	0.97	0.254
Persian	3.96 (0.57)	0.005 (0.0007)	3.34 (3.08)	96.34(5.17)	0.94	0.404

*Where A is the upper yield asymptote or maximum yield in the absence of weed interference, B and K are parameters that determine the shape of the curve or shape of yield rising. **Where A and B are parameters that determine the shape of the curve or shape of yield falling, C is the lower yield asymptote or minimum yield in the presence of weed interference, D is the difference between the upper and lower yield asymptotes.

Table 4. The critical duration of velvetleaf-infested period and the critical length of velvetleaf free period in soybean in days after crop emergence (DAE), crop development stage and cumulative growth degree day (CGDD), as calculated by the Gompertz and Logistic equations for each cultivar for 5 and 10% yield loss levels.

	Critical duration of weed-infested period						Critical duration of weed-free period					
ALYL[a]	**5%**			**10%**			**5%**			**10%**		
Cultivars	**DAE**	**Crop stage[b]**	**CGDD**	**DAE**	**Crop stage**	**CGDD**	**DAE**	**Crop stage**	**CGDD**	**DAE**	**Crop stage**	**CGDD**
Williams	24	V_3	431	29	V_4	528	51	R_1	943	41	V_6	752
Persian	14	V_2	260	18	V_3	320	42	V_7	770	35	V_5	643

a: Accepted Levels of Yield Loss
b: According to Fehr and Caviness

Weed control under these conditions should be based on post-emergence herbicides and/or cultivation, but if any yield loss is unacceptable, control practices must begin as soon as possible after soybean emergence.

It is suggested that velvetleaf interference will not reduce soybean yields under normal environmental conditions if velvetleaf is controlled in a timely manner with post-emergence herbicides.

The results showed that soybean tolerates weed interference till the 2-3 leaves stage, so post-emergence herbicides must be sprayed before this stage to control the weeds effectively. With the aid of known critical period of weed control it is possible to avoid unnecessary control measurements, to give up the use of long persistent soil herbicides and to use post-emergence herbicides more consciously, even with lower doses than recommended (Knezevic *et al*., 2002).

Variability in the occurrence of the critical period of weed control may be attributed to a number of factors including differences in growth characteristics of cultivars and the crops (Burnside, 1979; Zimdahl, 1980).

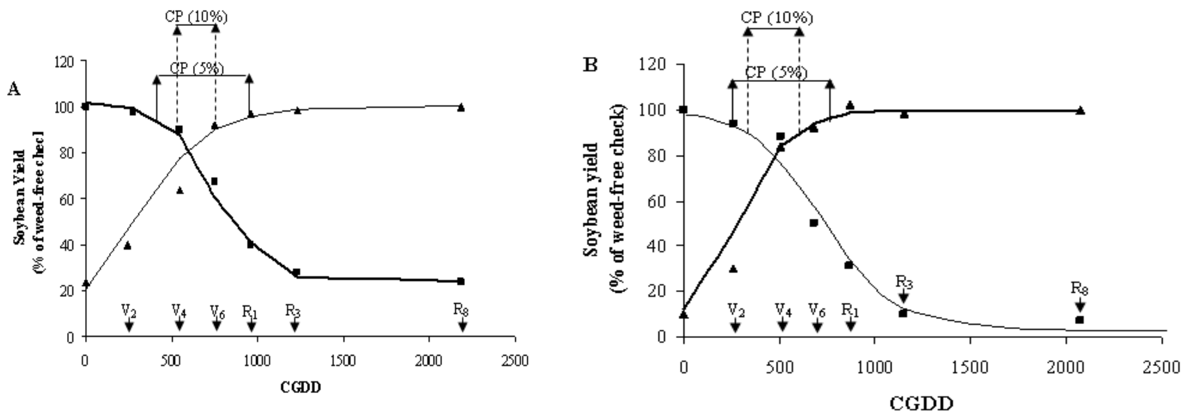

Figure 4. Soybean yield response to increasing length of velvetleaf-free period (▲) and duration of velvetleaf infestation(■) in cumulative growth degree day for Williams (A) and Persian (B) estimated from Gompertz and Logistic equations (statistical information on the regression lines is given in Table 2).

In this study, since all conditions in the research were constant (e.g. climate, soil parameters, agronomic practices and weed characteristics) therefore the differences in the critical period of two cultivars is attributed to characteristics of the cultivar.

As the Persian cultivar was more sensitive to velvetleaf interference than Williams, it also had a higher yield reduction. This information could be used by farmers to target mechanical weeding operations to control weeds at the stage with maximum benefit to the crop.

Conclusions

The results of this study indicate that velvetleaf is a serious weed problem in soybean production. The critical period of weed control, based upon an arbitrary 5% level of yield loss, varies between 260 to 943 CGDD or 14-51 DAE, which represents approximately V_2 to R_1 stages of the crop growth. We have confirmed that the timing of significant yield loss varies between two soybean cultivars, as (Zimdahl, 1988) noted that the critical period is not an inherent property of the crop. The variation of weed biomass is in reverse to variation in crop yield. Increase in length of interference period led to reduce in soybean dry weight, number of branches, pods per plant, seed number per pod and finally reduction of soybean yield. Weeds that emerged after the 2- to 4-leaf soybean stage (14-29 DAE) grow in a competitive disadvantage in regard to the crop. The beginning of the critical period corresponded with the beginning of an increase in total velvetleaf biomass at the 2- to 4-leaf stage of soybean growth.

Knowledge of the critical period of weed control and the morphological changes occurring in the crop may provide useful information upon future weed control recommendations.

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چکیده

گاوپنبه یکی از مهم ترین علف‌های هرز تابستانه در مزارع سویا می باشد . به منظور یافتن دوره بحرانی کنترل علف هرز گاوپنبه در دو رقم سویا با الگوهای رشدی متفاوت (رقم ویلیامز به عنوان رقم رشد نامحدود و رقم سحر یا پرشین به عنوان رقم رشد محدود) آزمایشی در دانشگاه علوم کشاورزی و منابع طبیعی گرگان در سال ۲۰۰۷ با استفاده از طرح بلوک های کامل تصادفی در چهار تکرار صورت گرفت . برای تعیین دوره بحرانی گاوپنبه از دو سری تیمار استفاده شد؛ تیمارهای تزاحم که در آنها تا مراحل دو برگی، چهار برگی، شش برگی، اوایل گلدهی و اوایل غلاف‌بندی سویا، به گاوپنبه اجازه تزاحم داده شد و از آن پس تا انتهای فصل رشد تمامی علف های‌هرز کنترل شدند. در کنار این تیمارها یک تیمار به عنوان شاهد تزاحم در نظر گرفته شد که به گاوپنبه اجازه حضور در تمام طول فصل رشد داده شد . سری دوم، تیمارهای کنترل بودند که در آنها تا مراحل رشدی یاد شده علف های‌هرز کنترل و از آن پس به گاوپنبه تا انتهای فصل رشد اجازه تزاحم داده شد . این تیمارها نیز همراه با شاهد کنترل (کنترل تمامی علف‌های‌هرز در طول فصل رشد) بودند. اثر تیمارهای کنترل بر ارتفاع نهایی سویا، تعداد شاخه جانبی د ر بوته، شاخص سطح برگ، وزن خشک، عملکرد و تعداد غلاف در هر بوته سویا معنی دار گشت اما بر تعداد دانه در غلاف و وزن صد دانه سویا تأثیر معنی داری نگذاشت. اثر تیمارهای تزاحم نیز بر تمام صفات فوق به غیر از وزن صد دانه معنی دار گردید . حساس‌ترین جزء عملکرد به حضور گاوپنبه، تعداد غلاف در بوته بود . نتایج این تحقیق بر اساس معادلات برازش داده شده گامپرتز و لجستیک بر حسب درجه- روز رشد، نشان داد که دوره بحرانی کنترل علف هرز گاوپنبه در دو رقم سویا با ۵٪ کاهش عملکرد مجاز بین مراحل دو برگی (۱۴ روز پس از کاشت، معادل ۲۶۰ CGDD) تا اوایل گلدهی (۵۱ روز پس از کاشت، معادل ۹۴۳ CGDD) قرار دارد و در هر دو رقم با در نظر گرفتن ۱۰٪ کاهش عملکرد مجاز دوره بحرانی بین مراحل سه برگی (۱۸ روز پس از کاشت، ۳۲۰ CGDD) و شش برگی (۴۱ روز پس از کاشت، ۷۵۲ CGDD) می‌باشد.

کلمات کلیدی: سویا، گاوپنبه، اجزا عملکرد، دوره رقابت