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Critical Period for Weed Control in Corn in the South-West of Iran

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Abstract: The Critical Period for Weed Control (CPWC) identifies the phase of the crop growth cycle when weed interference results in unacceptable yield losses. Field study was conducted in 2008 in the University of Shushtar at the South-West of Iran to determine CPWC of corn using a randomized complete block design with 12 treatments and 3 replications. The experiments consisted of 2 sets of treatments. In the first set, the crop was kept weed-free until the growth stages of V3, V6, V9, V13 and VT (based on phonological stages of corn development). In the second set, weeds were permitted to grow within the crop until the above-mentioned growth stages. The CPWC was determined with the use of 5 and 10% acceptable yield loss levels by non-linear regression method and fitting Logistic and Gompertz nonlinear equations to relative yield data. Increasing the duration of weed interference decreased corn yield significantly. The CPWC for weed control was from 5- to 9-leaf stage (17-36 DAP) to prevent yield losses of 5%. This period to prevent yield losses of 10% was 6- to 8-leaf stage (21-29 DAP). Results from this experiment suggest that weed control should be carried out between fifth to ninth leaf stages to provide maximum grain yield.

Key words: Corn, critical period, Gompertz, logistic, weed control

INTRODUCTION

Corn (*Zea mays* L.) is one of the most popular crops in Iran, where it is often grown for human and animal consumption. One of the most important factors in corn production is weeds. Weeds interference causes important yield losses worldwide with an average of 12.8% despite weed control applications and 29.2% in the case of no weed control (Isik *et al*., 2006). Mechanical and chemical methods are two main weed control methods in corn. Removing the weeds between plant rows is generally carried out by mechanical cultivation, while weeds on the rows are controlled by herbicides. Although controlling weeds base on these two methods is effective, they have some disadvantages or side effects that increase production costs when applied intensively. Intensive mechanical weed control causes soil erosion and crop injuries besides, it has a low efficacy against perennial weeds, whereas main disadvantages of the intensive use of herbicides are mostly associated with soil and water pollution (Torstenson, 1996) and the selection of herbicide resistant weed biotypes (Rubin, 1996).

To reduce the cost of intensive applications of weed control methods should be optimized. Therefore, determining appropriate weed management practices is important for

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corn production to ensure optimum grain and forage yield. Identify the Critical Period for Weed Control (CPWC) in major crops is one of the first steps in designing a successful Integrated Weed Management (IWM) system (Swanton and Weise, 1991). Critical period for weed control is defined as a period in the crop growth cycle during which weeds must be controlled to prevent yield losses (Knezevic *et al*., 2002). Controlling weeds base on CPWC lead to reduce costs and risks of intensive weed control. It also reduces the number of herbicide treatments as a result of better timing and efficiency which it leads to decrease the potential environmental contamination and the selection pressure for herbicide resistant weeds and help to optimize weed control methods (Hall *et al*., 1992).

Determination of CPWC is base on characterizing functional relationships between two separately measured competition components: crop yield as a function of the duration of weed interference to identify the beginning of CPWC and crop yield as a function of the duration of the weed-free period to identify the end of CPWC. In theory, weed competition before or after the CPWC will not reduce crop yield below acceptable levels (Williams and Masiunas, 2006). The length of the CPWC is dependent on site-specific factors, including climate variation; weed species composition and crop-specific production issues (Rajcan and Swanton, 2001).

The CPWC is established by calculating the time interval between two components of weed interference: the critical weed-free period, the minimum length of time required for the crop to be maintained weed free before yield loss caused by subsequent emerging weeds is no longer of concern and the critical duration of weed interference, the maximum length of time before early emerging weeds can grow and interfere with the crop before unacceptable yield loss is incurred (Weaver and Tan, 1983). Previous studies showed different beginning and end of CWPC for corn and it was highly dependent on the density, competitiveness and emergence periodicity of the weed population (Halford *et al*., 2001; Knezevic *et al*., 2002; Evans *et al*., 2003). For example, Hall *et al*. (1992) determined the beginning of the CPWC for corn varied from the 3- to 14-leaf stages of the crop and ended consistently with the 14-leaf stage, whereas Ferrero *et al*. (1996) reported the beginning of CPWC with the 1- and 7-leaf stages and ending with the 7 and 10-leaf stages of the crop. Bedmar *et al*. (1999) stated a critical period of weed control between 5 to 7 leaf stage of corn. In a study which was conducted in Iran, critical period of weed control in corn was reported from 5- to 15-leaf stage to prevent yield losses of 5%. This period to prevent yield losses of 2.5, 10 and 20% was 4 to 17-leaf stage, 6- to 12-leaf stage and 8- to 9-leaf stage, respectively (Mahmoodi and Rahimi, 2009). Since, different studies in different regions showed various results of critical period for weed control, it is necessary to determine CPWC for a particular region in order to provide precise information. Therefore, the objectives of this study were to evaluate the effect of the timing of weed removal and the duration of weed interference on corn yield and determine the optimum timing for weed control in corn.

MATERIALS AND METHODS

Field experiment was conducted in 2008 at the Shushtar University Experiment Station in the Southern West of Iran (32°3' North latitude, 48°50' East longitude, 67 m). The soil type was clay loam with 0.2% organic matter and pH 7. Soil preparation and cultural practice were conducted according to local practices for corn production. Corn seeds, cultivar SC704, planted at a population density of 66,600 plants ha^{-1}. Planting date was 16 July. Each plot was consisted of five rows. Fertilizers were applied at the rate of 205 kg N ha^{-1} with 50% applied at the time of sowing and 50% at the time of 7-8 leaf-stage of corn approximately 28 DAP and 112 kg P ha^{-1} at sowing. The experimental design was a randomized complete block (RCBD) with 3 replications. Two sets of treatments were imposed to represent both weedy and weed-removal. The first set of treatments was consisted of five levels of weed interference, was established by postponing weed control from the time of crop planting until predetermined crop growth stages (weedy up to V3, V6, V9, V13 and VT) at which time, weeds were removed and plots remained weed-free throughout the rest of the season. The second set of treatments was comprised of five levels of the weed-free periods by weeding from the time of crop planting up to the above-mentioned crop growth stages subsequently emerging weeds were left uncontrolled for the rest of the season. In addition, season long weedy and weed-free controls were included.

Weeds were removed by hoeing. In order to determine the density and species of weed, weeds were excavated from three 1 m^2 quadrates on each side of the three middles corn rows, sorted by species and counted. The corn was harvested from the centre two rows over 3 m^2 within each plot. Cobs were threshed and subsequently dried at 70°C to constant moisture content for 48 h and grain yield per plot was determined. Data were analyzed and means were compared using the LSD test at the 0.05 significance level (Gomez and Gomes, 1984).

In order to determine CPWC, yield data of individual plots were calculated as the percentage of their corresponding weed-free plot yields. The PROC MIXED function of Statistical Analysis System (SAS, 1999) was used to analyze the relative yield data, to assess the effect of the length of the weed-free period and increasing duration of weed interference on relative corn yield. The statistical significance of treatment was evaluated at 5% level of probability.

Nonlinear regression analysis with the PROC NLMIXED function of SAS were used to estimate the relative yield of Corn. The effect of increasing duration of weed interference on relative yield was described by a three-parameter logistic equation (Knezevic *et al*., 2002) to determine the beginning of the CPWC. The following logistic equation used was:

$$Y = [(1/De^{(K(T-X)}+F)+((F-1)/F]\times 100$$

where, Y is the relative yield (percent of season-long weed free yield), T is the duration of weed interference measured from the time of corn planting in DAP, X is the point of inflection in DAP and F and K are constants.

The three-parameter Gompertz equation, modified slightly from the proposed form by Hall *et al*. (1992) was used to determine the end of the CPWC and describe the effect of increasing duration of weed-free period on relative yield and. The model has the following form:

$$Y = A\times \exp(-Be^{(-KT)})$$

where, Y is the relative yield (percent of season-long weed free yield), A is the yield asymptote or maximum yield in the absence of weed interference, B and K are constants and T is the length of the weed-free period after corn planting in DAP. Acceptable yield loss levels of 5 and 10% were used to determine the CPWC.

RESULTS AND DISCUSSION

During the experiment 5 weed species were observed. Barnyard grass (*Echinochloa crus-galli*), Redroot Pigweed (*Amaranthus retroflexus*) Common Purslane (*Portulaca oleracea*), Ground Cherry (*Physalis* sp.) and Yellow Nutsedge (*Cyperus esculentus*) were the emerged weeds in this experiment. Barnyard grass and Redroot Pigweed were the most

Table 1: The population density (plants m^{-2}) of weed species in the experimental area in weed-infested

	Weed density (Plants m^{-2})					
Weed species	3 leaf	6 leaf	9 leaf	12 leaf	Tasselling	LSD
Echinochloa crus-galli	33.67ab	36.33a	33.20b	20.0c	23.00c	7.81
Amaranthus retroflexus	10.00c	19.33a	15.00ab	14.0bc	14.33bc	4.69
Portulaca oleracea	9.66a	8.66ab	9.00ab	7.0b	7.33b	2.17
Physallis sp.	5.00ab	4.33ab	3.67abc	3.0bc	2.00c	2.22
Cyperus esculentus	8.00ab	8.00ab	9.00a	4.0bc	3.00c	4.13
Total	66.30b	76.60a	66.00b	52.6c	49.50c	9.50

Different letters indicate significant differences in mean values

Table 2: Influence of different weed-free and weedy periods on corn grain yield

Period	Average yield (t ha^{-1})	Yield (%)
Weed-free period		
Whole season weed-free	10/77d	100.00
V3	3/98cd	36.95
V6	10/01a	92.94
V9	10/72a	99.50
V12	10/7a	99.35
VT	10/45a	97.00
Weedy period		
Whole season weedy	3/87d	35.93
V3	10/49a	97.40
V6	7/78b	72.23
V9	4/41c	40.94
V12	4/39c	40.76
VT	4/24cd	39.36

Different letters indicate significant differences in mean values

common weeds in the experiment and represented 70% of the total weed population in the experiment. According to Table 1, there was a considerable increase in weed density until corn 6 leaf stage. Weed density decreased significantly between corn 9 leaf stage to tasselling stage. It may explained by wider rows which provided additional space for early-season weed growth and later canopy closure, which influenced change in the quality and quantity of light available for weed growth due to crop shading effects (Knezevic *et al*., 2003).

Grain yield was significantly reduced by weed competition. According to Table 2, weed interference till corn 3 leaf stage did not influence the corn yield. It may because of having lower sensitivity to weeds at early season stage in corn. However, corn yield was decreased considerably by increasing duration of weed interference after 6 leaf stage. Only 35.93% of the grain yield was obtained in the case of no control as compared with whole season weed-free conditions. LAI of corn was significantly decreased by weed interference. It was significantly dropped up to 10, 22, 34, 43 and 53% when weeds infested to V3, V6, V9, V12 and R1 stages of corn, respectively (data not shown). Previous study showed positive correlation between leaf area and final grain yield (Evans *et al*., 2003). Since, there was a considerable decrease in LAI, corn yield was reduced gradually. These results showed that the control of weeds in corn fields until the 3-leaf stages could not prevent grain yield loss. This may because high recruitment ability of weeds in this experiment. Due to successive weed control from emergence till 6-leaf stage in corn, decreased weed density significantly (data not shown), there was no significant difference in grain yield between controlling weed till 6-leaf and whole season weed- free treatments.

Table 3 shows estimated parameters for logistic and Gompertz equations to determine critical period of weed control. The Gompertz (weed free) and logistic (weedy) curves were fitted to determined the critical weed-free period and critical timing of weed removal overlapped in a manner that resulted in a CPWC where the critical timing of weed removal preceded the end of the critical weed-free period. The length of the CPWC in corn in this

Table 3: Estimated logistic and Gompertz parameters to determine the critical timing of weed control for corn

Logistic model		Gompertz model	
Parameters	Value (SE)	Parameters	Value (SE)
K	0.23 (0.6)	A	102.10 (4.3)
F	25.40 (2.4)	B	1.37 (0.1)
X	1.65 (0.1)	K	0.08 (0.1)
$R^2 = 0.95$		$R^2 = 0.97$	

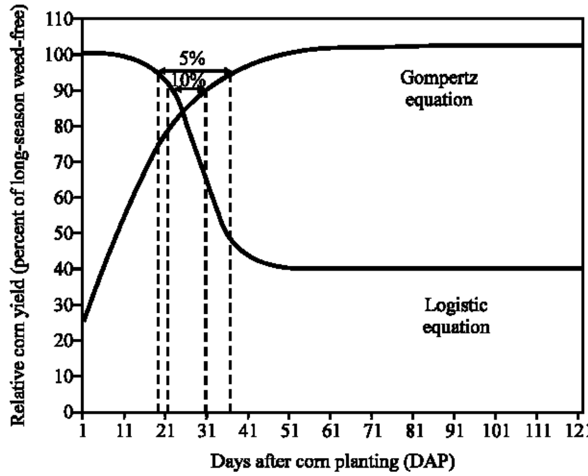

Fig. 1: Effect of weed interference on total yield of corn. Increasing duration of weed interference and fitted curves as calculated by the logistic equation; increasing weed-free period and fitted curves as calculated by the Gompertz equation

experiment was 20 and 9 days with 5 and 10% acceptable yield loss levels, respectively. The beginning of the CPWC was at fifth leaf stage of corn (17 DAP) at 5% acceptable yield loss and sixth leaf stage of corn (21 DAP) at 10% acceptable yield loss, respectively (Fig. 1). The CPWC for acceptable yield loss of 5 and 10% ended at ninth leaf stage (36 DAP) and eighth leaf stage (29 DAP) (Fig. 1).

A variety of CPWC durations among several studies have been reported. For instance, there were large differences in the CPWC in corn in studies conducted at different sites with different weed populations in the South-Eastern of the United States (Norsworthy and Oliveira, 2004). Hall *et al.* (1992) reported the CPWC for corn were the 3- to 14- and 4-6- to 10-12-leaf stages of corn for acceptable yield loss of 5 and 10%, respectively. Dogan *et al.* (2004) stated that weed control should be carried out between the 3- and 7-10-leaf stages of corn to provide maximum grain yield.

The differences between our result and others can be explained by different factors like environmental conditions and weed species diversity which have high effects on determining critical period for weed control.

CONCLUSION

Increasing the duration of weed interference led to reduce corn yield significantly. In order to prevent the significant yield loss, our results suggest that based on 5% acceptable yield loss, corn can tolerate weeds interference until 17 days after planting and weed control measures can be postponed up to 5-leaf stage. The crop should be kept weed-free until ninth corn leaf stage (36 DAP) in order to prevent yield loss in excess of 5%. Although, among growers generally tend to keep fields weed-free as long as possible immediately after crop emergence to provide a long-term weed-free environment for corn and for this reason, they may apply soil herbicides in many cases and mechanical control and post-emergence herbicide applications are often repeated several times unnecessarily. Consequently, it could lead to cost effective and harms the environment. Therefore, adjusting the weed control timing to CPWC is an important way of reducing the costs and potential hazards of weed control treatments. According to the results of the CPWC, growers could improve timing of post emergence herbicide applications and hand weeding. Further studies should be conducted to determine the CPWC in other areas where weed populations are different from those are reported here.

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