The Critical period for weed control in spring maize in North-West India

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Abstract

Spring maize is becoming popular in Punjab state owing to its higher yield potential and is a new introduction. A field experiment was conducted at Punjab Agricultural University, Ludhiana with 12 treatments viz. crop kept weedy for 20, 30, 40, 50, 60 DAS, crop kept weed free for 20, 30, 40, 50, 60 DAS, weed free throughout and weedy check. The weed density showed a linear progression as the weedy interval was increased from 30 to 40 days, 40 to 50 days and 50 to 60 days. The results showed that yield attributes and grain yield declined with the increased duration of crop- weed interference period and increased with long weed free durations. Significant reduction in grain yield was recorded with increased weed infestation from 30 to 60 DAS, however, the differences observed between 20 and 30 days weedy were statistically at par. This suggested the tolerance of weed interference up to 30 days in spring maize. The 60 days weed free treatment resulted in grain yield statistically same with that of weed free throughout but significantly better from all other weed free duration treatments. This marked the end of critical period of crop-weed competition in spring maize. A significant negative linear correlation was observed for weed biomass and grain yield. The critical period of crop-weed competition in spring maize started at 30 DAS and ended at 60DAS. This period needs immediate attention for the adoption of weed control measure.

Keywords: critical period, crop-weed competition, spring maize, weed density

Introduction

Competition posed by weeds is a serious challenge in spring maize in North-West India as this crop encounters both summer and winter season weeds. Excluding environmental variables, yield losses in spring maize are mainly caused by competition from weeds. Heavy infestation of weeds alone have been reported to decrease the yield up to 35-80% because the weeds are the most important among other pests of this crop (Oerke and Dehne, 2004). Globally 10 per cent loss of agricultural production is due to competitive effect of weeds despite intensive control of weeds in most agricultural systems (Zimdahl, 2004). On the whole, weeds have the highest loss potential (37%) which is higher than loss potential of insect pests (18%), fungal and bacterial pathogens (16%) and viruses (2%) (Oerke, 2005). The extent of the losses in yield depends upon the type of weed flora infesting the crop field, weed emergence relative to crop emergence, weed density, intensity, stage of crop growth relative to keen competition period and duration of weeds infestation in the field. Weeds not only deter the crop growth by creating crop-weed competition for available resources but also cause serious losses in terms of yield, declining the quality of produce and harbour many associated disease causing pathogens and pests. The maximum loss in the maize grain yield is experienced when the weeds are not checked particularly during critical crop-weed competition period. It is the time interval between the maximum weed infested period or the length of time that the crop must be free of weeds after emergence (Nieto et al, 1968; Kropff et al, 1993). The critical period of weed control is determined by calculating the time interval between two components of weed interference. These are (1) the critical weed interference period or the maximum length of time during which weeds emerging soon after crop planting can coexist with the crop without causing unacceptable yield loss, and (2) the critical weed free period or the minimum length of time required for the crop to be maintained weed free before yield loss caused by late emerging weeds is no longer a concern (Evans et al, 2003; Hall et al, 1992). Hall et al (1992) used the same approach to determine the critical period of competition for maize and fitted Gompertz and logistic equations to data representing increasing duration of weed control and weed interference, respectively. The authors defined critical period as the duration without weed interference required in order to prevent crop yield losses of 2% or more, and showed that early weed control was not necessary. Such research may provide guidelines for optimizing management to avoid maximal competition between crop and weeds, and enable farmers to make more efficient use of resources for weed control. However, the critical period varies with the relative competitiveness of the crop and the weeds. Higher the weed flora competition, longer will be the period the crop must be kept weed-free to prevent significant yield losses.

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Thus, it is not enough to simply say that weed competition reduces the crop yield but there is need to explore the critical period of crop- weed competition which may otherwise seriously limit the crop yields. Therefore, this study aimed to estimate the optimum timing for weed control in spring maize and to determine the effect of the timing of weed removal and the duration of weed interference on maize yield under the growing conditions of Punjab in India.

Materials and Methods

A field experiment was carried out at during 2012 at the Punjab Agricultural University, Ludhiana, India. The experimental site is situated at 30°54'N latitude and 75°48'E longitude with an altitude of 247 metre above mean sea level in the central plain region of Punjab state under Trans-Gangetic agro-climatic zone of India. The climate of this region is sub-tropical and semi-arid with very hot and dry summer from April to June, hot and humid conditions from July to September, cold winters from November to January and mild climate during February and March. The soil of the experimental area was sandy loam with 81.61% sand, 10.90% silt, and 7.49% clay, with available N, P, and K of 191.2, 14.6 and 159.1 kg ha^{-1}, respectively. The experiment was laid out with a plot size 7.0 m x 3.0 m and row to row distance of 60 cm and plant to plant distance of 20 cm. Maize cultivar «PMH 1» was sown on 14^{th} February, 2012. A set of weeding regimes comprised of twelve treatments was arranged in randomized complete block design, with four replicates. Two sets of treatments were imposed to represent both increasing duration of weed interference and the length of the weed-free period measured after planting. The first set of treatments established five levels of increasing duration of weed interference by delaying weed control from the time of crop emergence up to predetermined crop growth period (weedy up to 20, 30, 40, 50, and 60 days) at which weed control was initiated and maintained for the remainder of the growing season. The second set of treatments established five levels of increasing length of the weed-free period by maintaining weed control from the time of crop planting up to the above-presented crop growth stages before subsequently emerging weeds were left uncontrolled for the remainder of the season. In addition, season long weedy and weed-free controls were included. In the weed free full season treatment, weeds were removed frequently by repeated hand weeding to keep the crop free from weeds till harvest. However, in the weedy full season treatment weeds were left to grow, unrestrictedly, with the crop until harvest. At each harvest weeds were clipped at the soil surface, sorted by species, counted, and dried at 70°C to constant moisture content to obtain a measure of aboveground dry weed biomass. Dry matter accumulation by maize plants was analysed by harvesting two representative randomly selected plants every time at 60 DAS from each plot, sun dried and then dried in an oven at 60°± 2ºC to a constant weight. All yields are presented and analyzed on a dry weight basis to eliminate the error associated with adjusting moisture content. Yield data of individual plots were calculated as the percentage of their corresponding weed-free plot yields. The data of weed density were square root transformed. Where the ANOVA indicated that treatment effects were significant, means were separated at 5% level of significance with Fisher's Protected Least Significant Difference (LSD) test. Relative yield data were subjected to analysis of variance with the use of the PROC NLMIXED function of Statistical Analysis System (SAS 9.3), to assess the effect of the length of the weed-free period and increasing duration of weed interference on relative corn yields. The statistical significance of treatment was evaluated at 5% level of probability. Nonlinear regression analyses with the PROC NLMIXED function of SAS were used to estimate the relative yield of maize as a function of increasing duration of weed interference or as a function of the length of the weed-free period, according to the procedure outlined by Knezevic et al (2002). A three-parameter logistic equation, proposed by Hall et al (1992) and modified by Knezevic et al (2002) was used to describe the effect of increasing duration of weed interference on relative yield. The logistic equa-

Table 1 - Weed density of different weeds as influenced by different weedy and weed free intervals.

Treatments	Weed density (Number m^{-2})									
	Chenopodium album	*Oenothera laciniata*	*Medicago denticulata*	*Rumex dentatus*	Total BLW's*	*Phalaris minor*	*Digitaria sanguinalis*	Total grasses	*Cyperus rotundus*	Total Grasses +BLW +Sedges
Weedy up to 20 DAS	3.63f	3.64d	3.26c	2.94d	6.55d	3.82c	1.00g	3.82d	1.00e	7.53g
Weedy up to 30 DAS	5.59d	5.93b	3.96b	4.61b	10.06b	5.60a	1.00g	5.60c	1.00e	11.33d
Weedy up to 40 DAS	7.39b	6.00a	4.13ab	6.08a	11.90a	5.56a	2.76f	6.17bc	1.00e	13.41c
Weedy up to 50 DAS	6.59c	6.44a	4.51a	6.04a	11.82a	5.48a	3.26e	6.31b	3.86d	13.89b
Weedy up to 60 DAS	7.39b	5.94b	3.37c	6.41a	11.78a	5.60a	5.00c	7.46a	4.62bc	14.64b
Weed free up to 20 DAS	7.34b	6.95a	1.83e	5.96a	11.73a	4.78b	6.01a	7.65a	5.60a	15.05a
Weed free up to 30 DAS	6.49c	5.41b	1.74e	4.72b	9.73b	4.47b	5.66ab	7.16a	4.86b	12.96c
Weed free up to 40 DAS	4.62e	4.74c	1.53f	3.14c	7.31c	2.81d	5.13b	5.79c	4.84b	10.42e
Weed free up to 50 DAS	3.70f	4.03c	1.00g	1.77e	5.58e	2.22d	4.00d	4.48d	4.48bc	8.33f
Weed free up to 60 DAS	2.18g	2.34e	1.00g	1.00f	3.06f	1.00e	3.35e	3.33e	4.03c	5.91h
Weed free throughout	1.00h	1.00f	1.00g	1.00f	1.00g	1.00e	1.00g	1.00f	1.00e	1.00i
Weedy Check	8.12a	6.34a	2.23d	6.34a	12.20a	4.89ab	6.07a	7.86a	5.62a	15.52a

Least square means within a column followed by the same letter do not differ significantly according to Fisher's protected least significant difference (LSD) test where $P < 0.05$. *BLW-Broad leaf weeds.

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Table 2 - Effect of weed infestation durations on yield attributes of spring maize.

Treatments	Stem girth (cm)	N° of cobs plant^{-1}	N° of grains cob^{-1}	100 grain weight (g)	Grain weight per cob (g)	Cob length (cm)	Cob girth (cm)	Barrenness (%)	Shelling percentage	Grain yield (q ha^{-1})	Stover yield (q ha^{-1})
Weedy up to 20 DAS	8.83a	1.23a	349.5a	27.3a	95.5a	18.1a	12.1a	3.98f	75.32a	75.27ab	152.45a
Weedy up to 30 DAS	8.75a	1.21a	332.0a	27.0a	88.1b	17.7a	11.8b	4.25e	73.20b	71.32b	151.70a
Weedy up to 40 DAS	8.27b	1.13b	303.8b	25.2b	80.7c	15.8b	10.9c	5.10d	68.85d	63.94d	138.53b
Weedy up to 50 DAS	7.75c	1.06c	263.5c	22.6c	55.4e	14.3c	10.4d	6.03b	64.10e	57.76e	125.32c
Weedy up to 60 DAS	6.48e	0.97d	230.5d	20.6d	47.3f	12.8de	9.6f	7.40a	60.40f	43.02f	110.35d
Weed free up to 20 DAS	6.30e	0.96d	222.8d	20.8d	44.6f	11.8e	9.4f	7.20a	58.93g	42.39f	108.37d
Weed free up to 30 DAS	6.93d	1.04c	243.0d	22.4c	52.5e	13.2d	10.2e	6.25b	60.43f	57.45e	124.30c
Weed free up to 40 DAS	7.63c	1.06c	267.3c	23.2c	56.5e	14.6c	10.3e	5.70c	65.43e	64.75d	130.55b
Weed free up to 50 DAS	8.60ab	1.12b	294.8b	24.5b	71.5d	16.8b	10.6d	4.73de	70.92c	69.50c	138.85b
Weed free up to 60 DAS	8.58ab	1.19a	341.8a	27.1a	92.7a	18.0a	12.2a	3.93f	72.05bc	74.76ab	149.38a
Weed free throughout	8.95a	1.24a	351.5a	27.7a	97.2a	18.3a	12.4a	3.75f	74.08ab	77.98a	154.60a
Weedy Check	6.08e	0.93d	214.3e	20.5d	44.2f	11.9e	9.4f	7.78a	58.3g	39.78f	102.37d

tion modified slightly from that proposed by Hall et al (1992) to describe the increasing duration of weed interference on relative yield (weedy curve) was fitted: Y = [(1 / {exp[a × (T - b)] + c }) + [(c -1) / c]] × 100, where Y is the yield (% of season-long weed-free yield), T is the time (x-axis expressed as duration of weed interference in days after sowing [DAS]), b is the point of inflection (DAS), a and c are constants. The Gompertz model has been shown to provide a good fit to yield as it is influenced by increasing length of the weed-free period (weed-free curve) (Hall et al, 1992): Y = a exp (- b exp (- cT)) where Y is the yield (% of season-long weed-free yield), a is the yield asymptote, b and c are constants and T is the time (x-axis expressed as length of weed free period in DAS).

Results and Discussion

The weed population was composed of seven major species and the weeds in the experimental plot were *Chenopodium album*, *Oenothera laciniata*, *Medicago denticulata*, *Rumex dentatus*, *Phalaris minor*, *Digitaria sanguinalis*, and *Cyperus rotundus*. *Chenopodium album* was the most dominant and abundant of various broadleaf weed species recorded in the experimental plots. Weeds of both summer and winter seasons were observed in the experimental area. During the initial phase of crop growth, low temperature in month of February and March favoured the growth of winter weed flora. With subsequent rise in temperature during month of April onwards, summer weed flora germinated. Among the different categories of weed flora observed, broadleaf weeds dominated.

Weeds population helps to determine the magnitude of pressure exerted on the crop. The major weed flora of experimental field consisted of *Chenopodium album*, *Oenothera laciniata*, *Medicago denticulata*, *Rumex dentatus*, *Phalaris minor*, *Digitaria sanguinalis*, and *Cyperus rotundus*. The weed density in weed infested treatments was recorded at their respective period of completion. However, in case of weed free treatments, it was recorded only at harvest. The data on major weed flora (Table 1) is discussed as below: *Chenopodium album* was the most dominant and abundant of various broadleaf weed species recorded in the experimental plots. The maximum density of *Chenopodium album* was recorded in the season long weedy treatment (8.12 m^{-2}) which was significantly higher from all other treatments (Table 1). The weed density recorded in 60 days weedy plot (7.39 m^{-2}) was statistically at par with the crop remained weed free for 20 days (7.34 m^{-2}). This might be due to the effect of low temperature on delayed germination of *Chenopodium album* in 20 days weed free crop which later on got statistically at par with 60 days weedy crop due to long weed seed germination window afterwards. The minimum density recorded in season long weed free crop (1.0 m^{-2}) which was closely followed by crop kept weed free for a period of 60 days (2.18 m^{-2}) and significantly different from all other treatments. The weed density recorded in weed free treatments of longer duration was reduced than weedy treatments due to the reason that temperature and climatic requirements were not in favour of weed seed germination. The data on *Oenothera laciniata* recorded at different weed interference intervals is presented in Table 1.

Among all the weed infestation intervals, season long weed free treatment recorded the lowest number (1.0 m^{-2}) of *Oenothera laciniata* density. The maximum density was recorded in crop kept weed free for 20 days (6.95 m^{-2}) which was statistically at par with the population observed in the season long weedy treatment (6.34 m^{-2}) and that remained weedy for a period of 50 days (6.44 m^{-2}). This was closely followed by treatment kept weedy for 40 days (6.00 m^{-2}) which was statistically at par with the density recorded in crop kept weedy for 30 days (5.93 m^{-2}), crop remained weedy for 60 days (5.94 m^{-2}) and that remained weed free up to 30 days (5.41 m^{-2}). The reduction in weed density in treatments in which crop was kept weed free for a duration longer than 40 days might be due to the less germination of weeds later in the crop season. The data regarding weed density of *Medicago denticulata* in Table 1 revealed that the maximum density was recorded in the crop remained weedy for a period of 50 days (4.51 m^{-2}) which was at par with the number recorded in crop kept weedy for a period of 40 days (4.13 m^{-2}) but significantly different from all other treatments. Minimum weed density was observed in the treatments that remained weed free for 50 days (1.00 m^{-2}) and beyond this interval.

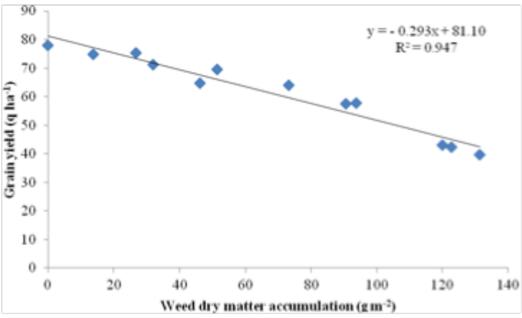

Figure 1 - Regression of weed dry matter accumulation (g m^{-2}) on grain yield (q ha^{-1}) of spring maize

This revealed the germination inhibition of *Medicago denticulata* due to non compliance of germination requirements in these treatments. The weed density in 30 days weedy treatment (3.96 m^{-2}) was significantly higher to that recorded in the treatment kept weedy for 20 days (3.26 m^{-2}). The maximum density of *Rumex dentatus* was recorded in the crop kept weedy for 60 days (6.41 m^{-2}) which was at par with the density observed in season long weedy treatment (6.34 m^{-2}). Moreover, this density in 60 days weedy crop was at par with weed density recorded in 50 days weedy plot (6.04 m^{-2}), 40 days weedy crop (6.08 m^{-2}) and 20 days weed free crop (5.96 m^{-2}). The minimum density was recorded in season long weed free crop (1.0 m^{-2}) and that kept weed free for 60 days (1.00 m^{-2}) which was closely followed by crop kept weed free for a period of 50 days (1.77 m^{-2}) which differ significantly from all other treatments (Table 1).The total density of broadleaf weeds was recorded to be maximum in the weedy check treatment (12.20 m^{-2}) which was statistically at par with the weed density recorded in crop kept weedy up to 40 days (11.90 m^{-2}), crop weedy for 50 days (11.82 m^{-2}), crop weedy for 60 days (11.78 m^{-2}) and that remained weed free for 20 days (11.73 m^{-2}). The minimum weed density was recorded in season long weed free crop (1.0 m^{-2}) which was closely followed by crop kept weed free for a period of 60 days (3.06 m^{-2}).

The data on *Phalaris minor* recorded at different weed interference intervals is presented in Table 1. Among all the weed infestation intervals, season long weed free treatment and crop kept weed free for a period of 60 days recorded the lowest (1.00 m^{-2}) *Phalaris minor* density. The maximum density was recorded in crop kept weedy for 60 days (5.60 m^{-2}) which was statistically at par with the population observed in the season long weedy treatment (4.89 m^{-2}), weedy for a period of 50 days (5.48 m^{-2}),weedy for 40 days (5.56 m^{-2}) and weedy for 30 days (5.60 m^{-2}). The reduction in weed density in treatments having progression in weed free period duration might be due to the poor germination of *Phalaris minor* later in the crop season due to unfavourable environmental variables.

The maximum density (6.07 m^{-2}) of *Digitaria sanguinalis* was recorded in the crop kept season long weedy which was at par with the density observed in crop kept weed free for 20 days (6.02 m^{-2}) and that kept weed free for 30 days (5.66 m^{-2}). Moreover, this density in 60 days weedy crop (5.00 m^{-2}) was significantly different from weed density recorded in 50 days weedy plot (3.26 m^{-2}) and 40 days weedy crop (2.76 m^{-2}). Weed density recorded in 50 days weed free crop (4.00 m^{-2}) was statistically at par with the density observed in 60 days weed free crop (3.35 m^{-2}). The minimum density (1.00 m^{-2}) was recorded in season long weed free crop, weedy for 20 days and that kept weedy for 30 days (Table 1). The total density of grasses was recorded to be the maximum in the weedy check treatment (7.86 m^{-2}) which was statistically at par with the weed density recorded in crop kept weedy up to 60 days (7.46 m^{-2}), crop weed free for 20 days (7.65 m^{-2}) and that remained weed free for 30 days (7.16 m^{-2}). The minimum weed density was recorded in season long weed free crop (1.00 m^{-2}) which was closely followed by crop kept weed free for a period of 60 days (3.33 m^{-2}). The differences of weed density recorded in 30 days weedy crop (5.60 m^{-2}), 40 days weedy crop (6.17 m^{-2}) and 50 days weedy crop (6.31 m^{-2}) were non significant (Table 1).The minimum density of *Cyperus rotundus* (1.00 m^{-2}) was recorded in crop kept weedy for 20 day, 30 days, 40 days, and weed free throughout. This showed that the initial phase of crop growth marked by low temperature and adverse environmental variables delayed the germination of *Cyperus rotundus*. The maximum density (5.62 m^{-2}) of *Cyperus rotundus* was recorded in the crop kept season long weedy which did not differed significantly from the density observed in crop kept weed free for

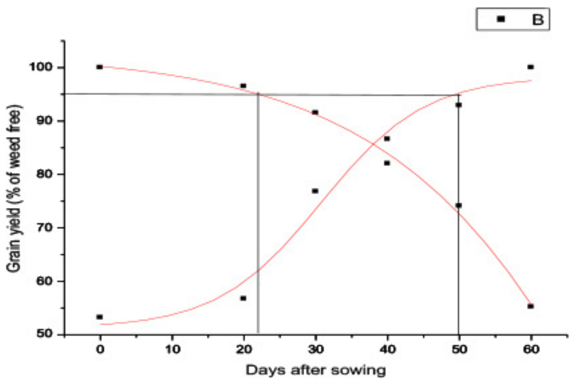

Figure 2 - The Critical Period of Weed Competition (CPWC) representing length of weed control period required to protect crop yield from >5% yield loss. The Critical Timing for Weed Removal (CTWR) as determined from the logistic model, or the weedy curve, fit to data representing an increasing duration of weed interference and the Critical Weed-Free Period (CWFP) as determined from the Gompertz model, or the weed-free curve, fit to data representing an increasing duration of weed-free period. *B represents actual grain yield.

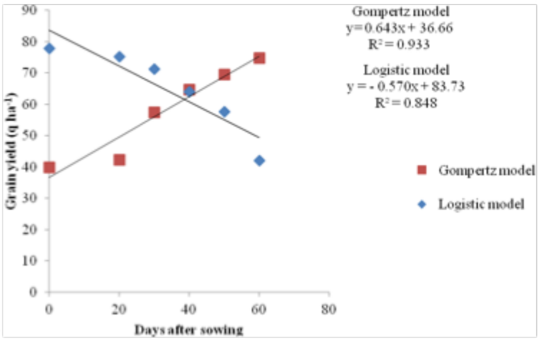

Figure 3 - Regression equations representing the fitness of the Logistic and Gompertz equations curves.

20 days (5.60 m^{-2}). The weed density observed in the crop weed free for 30 days (4.86 m^{-2}), weed free for 40 days (4.84 m^{-2}) and weed free for 50 days (4.48 m^{-2}) was statistically at par with each other (Table 1). The total weed density of broadleaf, grasses, and sedges recorded to be the maximum in the weedy check treatment (15.52 m^{-2}) which was statistically at par with the weed density recorded in crop kept weedy up to 60 days (14.64 m^{-2}) and crop kept weed free for 20 days (15.05 m^{-2}). The minimum density was recorded in season long weed free crop (1.00 m^{-2}) which was followed by crop kept weed free for a period of 60 days (5.91 m^{-2}). The weed density recorded in 40 days weedy crop (13.41 m^{-2}) was statistically at par with the density recorded in 50 days weedy crop (13.89 m^{-2}) and significantly different from 60 days weedy crop (14.64 m^{-2}). The total weed density in 20 days weedy crop also remained low (7.53 m^{-2}) which might not be sufficient in dry matter and other traits which could bring about significant reduction in crop yields as compared with weed free throughout and 60 days weed free crop interval (Table 1).

Yield and yield attributes

Maximum stem girth was registered in the season long weed free crop which did not vary significantly from the stem girth recorded in crop kept weed free for a period of 60 days and that remained weedy for 20 and 30 days. The stem girth was significantly reduced as the weed interference period was increased from 30 to 40 days. Furthermore, a significant reduction in stem girth was recorded when the crop was remained weedy for 50 days. The minimum stem girth was recorded in crop kept season long weedy which was statistically at par with the crop remained weedy for 60 days and that kept weed free for 20 days. A significant increase in stem girth was found as the weed free duration of crop was increased from 30 to 50 days. The stem girth recorded at 40 days weed free period was significantly higher than that of 30 days weed free period and the stem girth significantly increased from 40 days weed free period as when crop was given 50 days weed free period. The number of cobs per plant varied significantly in crop kept under different durations of weedy interference and weed free periods. The crop kept season long weed free resulted in the maximum number of cobs per plant which was at par with the crop kept weedy for 20 days and that for 30 days. The crop kept weed free up to 60 days produced statistically at par number of cobs per plant as that of season long weed free crop. However, the number of cobs per plant was significantly reduced as the weed interference period was increased from 30 to 40 days. Further, these got reduced significantly to 1.06 in crop kept weedy for 50 days. The lowest number of cobs per plant were recorded in crop kept season long weedy was statistically at par with the crop remained weedy for 60 days and that kept weed free for 20 days. Thus, it can be concluded that the increase in the weed interference interval from 30 days onward brought significant reduction in the number of cobs per plant and this reduction showed a linear negative significant reduction trend in crop kept weedy up to 60 days. The increase in weed free duration resulted in significant increase in number of cobs per plant as weed free period increases from 40 to 60 days. The results were in conformity with Maqbool et al (2006) who reported significantly lowest number of cobs per plant recorded in plots where weeds were allowed to grow until harvest or for 60 days after emergence. The number of grains per cob was recorded to vary significantly among various treatments of weed interference and weed free durations. The minimum number of grains per cob were recorded in the crop which was kept season long weedy which was statistically at par with the crop kept weedy for 60 days and that remained weed free for 20 days. The maximum number of grains were recorded in the crop kept season long weed free which was at par with the crop kept weed free for 60 days and that kept weedy for 20 days and that remained weedy for 30 days. The long weed free duration in these treatments caused better accumulation of photosynthates in source as indicated by more number of leaves per plant and higher leaf area index (data not shown) which resulted in better accumulation of dry matter and movement of photosynthates towards developing sink (grains) as compared with increased weedy infestation durations. A significant reduction in number of grains per cob was recorded as the weed interference interval was increased from 30 to 40 days. This got further significantly reduced as weed infestation was prolonged to 50 days and a more significant reduction on increasing weed interference to 60 days. This may be attributed to the reason that as the weed interference period increased, the weeds rob the crop of all inputs that would have otherwise available for grain filling and development. As a result, the total amount of photosynthates would have reduced resulting in lower number of grains per cob in crop with wide crop-weed interference period. The results are in agreement with studies conducted by Maqsood et al (1999). Evans et al (2003) reported

Table 3 - Parameters estimates with standard errors of the three parameter Logistic model and Gompertz model.

Logistic Model			Gompertz Model		
Parameters	Value	SE	Parameters	Value	SE
a	-0.0676	0.00782	A	0.00614	0.0160
b	0.0139	0.00655	B	2.3032	4.8357
c	101.3	2.0460	C	501.7	2462.1

* a is asymptote, b and c are constants.

that the yield loss associated with the critical period of weed control in maize is driven by reduction in kernel number per plant.

The weight of 100 grains varied significantly in crop kept under different durations of weedy interference and weed free periods. The crop kept season long weed free resulted in the maximum 100 grain weight which was at par with the crop kept weedy for 20 days and that remained for 30 days. The crop kept weed free up to 60 days produced statistically at par 100 grain weight as that of season long weed free crop (Table 2). However, 100 grain weight significantly reduced as the weed interference period was increased from 30 to 40 days. Furthermore, a significant reduction was recorded when the crop was remained weedy for 50 days. The lowest 100 grain weight was recorded in crop kept season long weedy which was statistically at par with the crop remained weedy for 60 days and that kept weed free for 20 days. Thus, it can be concluded that the increase in the weed interference interval from 30 days onward brought significant reduction in 100 grain weight and this reduction showed a linear negative significant reduction trend in crop kept weedy up to 60 days. Thus, the crop-weed competition period brought significant reduction in 100 grain weight which onsets at 30 days and lasts for 60 days after sowing. The poor source size under prolonged weedy conditions from 30 days period to a weed interference period of 60 days as was evident from growth factors and reduced translocation and advanced physiological maturity led to lower 100 grain weight. Riaz et al (2007) reported that maximum test weight was recorded in treatments with less weed densities significantly higher than the test weight recorded in weedy check. Similar results were also reported by Patel et al (2006). The increase in weed free duration resulted in increase in number of cobs per plant as weed free period increases from 30 days to 60 days. Increase in the 100 grain weight was found to be significantly higher in crop remained weed free for 60 days as compared with crop kept weed free for 50 days. The grain weight per cob was recorded to vary significantly among various treatments of weed interference and weed free durations. The minimum grain weight per cob was recorded in the crop which was kept season long weedy which was statistically at par with the crop kept weedy for 60 days and that remained weed free for 20 days. However, maximum grain weight per cob was recorded in the crop kept season long weed free which was at par with the crop kept weed free for 60 days and that kept weedy for 20 days. Reduction in maize seed weight due to weed infestation was also reported by Johnson et al (1998). Maximum cob length was recorded in the season long weed free crop which did not vary significantly from the length recorded in crop kept weed free for a period of 60 days and that remained weedy for 20 and 30 days. The cob length got significantly reduced as the weed interference period was increased from 30 to 40 days. Furthermore, a significant reduction in cob length was recorded when the crop was remained weedy for 50 days. The minimum cob length was recorded in crop kept season long weedy which was statistically at par with the crop remained weedy for 60 days and that kept weed free for 20 days. The cob length recorded at 40 days weed free period was significantly more than that of 30 days weed free period which in turn significantly reduced from that recorded in 50 days weed free period. The cob length recorded in crop with weed free duration of 60 days was significantly higher than that of cob length obtained in 50 days weed free duration. The cob girth varied significantly in crop kept under different durations of weedy interference and weed free periods. The crop kept season long weed free resulted in the maximum cob girth which was at par with the crop kept weedy for 20 days and weed free up to 60 days. However, the cob girth significantly reduced as the weed interference period was increased from 20 to 30 days. This further was significantly reduced to 10.9 cm in crop kept weedy for 40 days.

Correlation between grain yield and other characters

The correlation coefficients between grain yield and weed dry matter is presented in Figure 1. The correlation among weed dry matter accumulation and grain yield was highly significant but negatively correlated ($R^2 = 0.947$). The parameter estimates with standard errors of the three parameter Logistic model and Gompertz model used to determine the critical timing of weed removal for spring maize are presented in Table 2. The models were fitted to the relative grain yields of spring maize as a function of increasing duration of weed interference and increasing length of weed free period (in days after sowing) as presented in Figure 2. Goodness of fit was studied in terms of value of R^2 (Figure 3). The model was well fit and significant based on 5% acceptable yield loss, results suggested that spring maize can tolerate weed interference until 22 DAS at which weed control measures should start. The crop should be kept weed free until

50 DAS in order to prevent yield loss in excess of 5 percent (Table 2).

Conclusion

The overall appraisal of study indicated that in spring maize, the critical crop weed competition period started from 30 days after sowing and ended at 60 days after sowing. The study revealed that an initial phase of 20 days weed interference with crop resulted in a non significant difference of crop yield as compared with 30 days of weed interference. The results were statistically at par with season long weed free treatments which suggested that crop can tolerate a weedy situation up to 30 days after sowing beyond which weed interference with crop brought significant crop losses. The gradual increase in weed free interval significantly increased crop yield and yield attributes up to 60 days period which was at par with results from season long weed free crop treatment. This suggested to maintain a weed free situation maximum to a period of 60 days after sowing of spring maize. Adopting weed management beyond 60 days did not bring significant increase in crop yield.

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