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Research Article

Critical competition period of *Parthenium hysterophorus* L. in spring maize (*Zea mays* L.)

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The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Highlights

- Logistic equation used for estimation of parthenium competition period on relative yield of maize.
- Relative competitive index measured under parthenium infestation periods ranging from 2 WAE.
- Logistic model used for determing critical timing for parthenium removal in spring maize to avoid losses.

Abstract

Background: *Parthenium hysterophorus* L., commonly known as parthenium weed, poses severe economic and environmental hazards to the agro-ecosystems of Pakistan.
Objective: To estimate the yield loss and critical competition period of this weed in the spring sown maize crop.
Method: Field studies were conducted at an agronomic research area in the College of Agriculture at the University of Sargodha in Punjab-Pakistan during two consecutive year spring seasons (2014 and 2015). Treatments were comprised of viz., control plots (weed free), and parthenium competition durations of 2, 3, 4, 5 and 6 weeks after crop emergence (WAE), as well as weedy check for the full growing season of the crop.
Results: Study results showed that the prolongation in parthenium competition duration from 2 WAE to the full crop season resulted in an increase in dry weight up to 541% and 450% in the years 2014 and 2015, respectively. Plant height, stem diameter, biological yield, 1000 grain weight and grain yield decreased significantly at 2 or more WAE parthenium competition periods. The maximum reduction in plant height (8.8 and 11.3%), stem diameter (30.6 and 12.7%), cob number m^{-2} (35.8 and 33.9%), grain rows cob^{-1} (26.6 and 29.4%), 1000 grain weight (15 and 9.8%), grain (34.1 and 39.1%) and biological yield (31.4 and 27.9%) were recorded with the longest parthenium competition duration (6 WAE) during the years 2014 and 2015, respectively.
Conclusion: Based upon the results above, it is concluded that the critical competition period of parthenium in spring maize, as determined by a three-parameter logistic model, is 17 to 28 and 16 to 26 days after crop emergence during the years 2014 and 2015, respectively. Therefore, this weed must be controlled during these periods in order to avoid significant grain yield loss.

1 INTRODUCTION

Maize *(Zea mays* L.) crop is renowned as the king of cereal and is an important grain and fodder crop worldwide (Viruel et al., 2014). Maize ranks third after wheat and rice in Pakistan (Economic Survey of Pakistan, 2016-17). Maize has wide adaptability due to its successful production in tropical, subtropical and temperate regions of the world (Kumar et al., 2004). In Pakistan, the cultivated area of maize is 1.3 M ha with an annual production of 6.130 M tones and an average national yield of 4.59 t ha^{-1}. It accounts for 2.7% in value addition for agriculture and has a 0.5% share in the gross domestic product (Economic Survey of Pakistan, 2016-17). Despite a widespread adoption of high yielding hybrids, maize yield in Pakistan is still lower than the global maize producing countries based on global averages (5.15 t ha^{-1}). Among the agronomic factors responsible for a lower maize yield in the country, weed infestation is pivotal. Weeds often cause grain yield losses in maize up to 83% (Usman et al., 2001). Blackshaw et al. (2002) reported that the weed dry matter, weed species and their population significantly reduced crop yield. Naturally, maize is vigorous and a taller crop; therefore, it is sensitive to weeds only at the early growth stages (Kumar and Sundari, 2002). The allelopathic effect and weed competition with the crop contribute to significant reduction in crop yield. These factors contribute to an indirect effect on net monetary returns (Gupta, 2004).

Parthenium weed (*Parthenium hysterophorus* L.) is a broadleaf plant and belongs to the Asteraceae family. It is a problematic weed posing a severe threat to crop production systems, and ultimately to animal and human health (Gnanavel and Natarajan, 2013). Parthenium has a high germination ability and can grow in variable temperature ranges (10 to 25 ºC) resulting in a significantly higher germination potential throughout the year (Tamado and Milberg, 2004). Parthenium is native to USA, Mexico and Argentina and has invaded many other countries including Pakistan (Adkins and Shabbir, 2014). Parthenium is considered a green menace in different Asian countries such as India, Nepal, Bangladesh, Pakistan, Vietnam, China and Sri Lanka (Shabbir and Bajwa, 2007). Parthenium is widely distributed in Punjab and Khyber Pakhtunkhwa and is adapted to agricultural and waste lands, particularly in rain fed areas (Javaid and Anjum, 2006; Khan et al., 2014). It ranks among the world's top 10 most notorious weed plants (Mishra et al., 2012) and prevails in almost thirty countries (Shabbir and Bajwa, 2007; Nigatu et al., 2010). Moreover, due to its competitive potential for available resources with crops, parthenium weed also applied noteworthy allelopathic obstruction to tackle germination and development of both monocot and dicot crops (Marwat et al., 2008; Kaur et al., 2014). Parthenium produces phenolics and sesquiterpene in its roots, leaves, inflorescence, pollen grains and seeds (Evans, 1997; Gnanavel and Natarajan, 2013). Additionally, the allelopathic effects of these chemicals decreased crop productivity. Similarly, Gnanavel and Natarajan (2013) reported fodder crop biomass and other crop yield losses of 90% and 40% respectively due to this weed infestation. Therefore, Pakistan and other countries of the world are facing a severe problem that is polluting natural and man-made ecosystems (Khan et al., 2013; Gnanavel and Natarajan, 2013).

For a successful and economical weed control strategy, information about critical thresholds and competition periods in infested crops should be known. This scientific information can act as a decision tool for farmers to control weeds. The critical weed competition period as defined by Nazir (1994) is the most appropriate during the crop growth period when maximum economic returns are gained by controlling weeds. Controlling weeds in light of the critical period for weed control (CPWC) is the most proper approach to streamline weed control application (Knezevic et al., 2002). Knezevic et al. (2002) described that knowledge about CPWC provided the proper timing for weed control. The first step in making suggestions for weed control should be to estimate CPWC for a particular weed in a particular crop (Martin et al., 2001). The CPWC varies from crop to crop and weed to weed due to different growth habits and agro-climatic conditions in which crop-weed competition starts (Knezevic et al., 2002). In the past, at global level, several studies were done to determine CPWC in maize. For a mixed weed flora, severe yield losses in maize occurred with weed competition between the first three to five weeks after the emergence of the plants (Dalley et al., 2006). Mahmoodi and Rahimi (2009) determined CPWC to avert 2.5% to 20% yield losses in maize to be 14 to 36 days after emergence. However, Sajid et al. (2012) reported that the satisfactory maize grain yield was obtained if weeds were controlled within 20 days after crop emergence. In maize, a parthenium weed competition duration of 35 days after emergence of the full crop growing season reduced the grain yield up to 21% and 53%, respectively (Safdar et al., 2016). When remembering that the end goal is to give a more accurate knowledge base to producers, the critical period for weed control should be determined particularly for a specific area by considering the weed composition and climatic conditions (Rajcan and Swanton, 2001; Knezevic et al., 2002).

Therefore, the present study was conducted to estimate the critical competition duration of parthenium weed in maize under the growing conditions of the semiarid region of Sargodha, Pakistan.

2 MATERIALS AND METHODS

The study was conducted on loamy soil with pH 7.8 ± 0.1, EC 2.18 ± 0.3 dS m^{-1}, organic matter content 0.7%, total N 0.05 %, accessible P 60 mg kg^{-1} and interchangeable K 80 mg kg under agro-ecological conditions of Sargodha, Punjab, Pakistan at the Agronomy Experimental Station in the College of Agriculture at the University of Sargodha (32.08° N and 72.67° E and altitude 193 m) during spring seasons 2014 and 2015 to study the competition duration of *Parthenium hysterophorus* in maize. The soil belonged to Hafizabad series (fine-silty, mixed, hyperthermic typic calciargids) and the texture was loam and heavy loam (Khan, 1986). The climatic conditions were subtropical semi-arid with a yearly normal precipitation of 400 ± 5 mm and more than 70% of precipitation happening between June and September (Source: Agro-Metrological Lab, University of Sargodha). The monthly average temperature was lowest at 10 °C in January and highest at 40 °C in July.

The experimental design was a randomized complete block design having three replications with a net plot size of 7 × 3 m with four crop rows. The trial consisted of seven treatments including weed free and parthenium weed competition for 2, 3, 4, 5 and 6 weeks after crop emergence (WAE) as well as a full growing season of the crop. Maize variety was hybrid (Hi-corn 11) and sowing was done on March 15th in 2014 and 2015 on ridges by a dibbling method. Seed rate was 25 kg ha^{-1}. Row-to-row distance and plant-to-plant distance was 75 cm and 25 cm, respectively. Fertilizer was applied at 120-80-60 kg ha^{-1} NPK. Phosphorus, potash and half nitrogen were applied at sowing. The leftover nitrogen was applied in two dosages as a top dressing at the tasseling and silking growth stages. Throughout the crop period, six irrigations were applied. Uniform natural parthenium density (about 25 plants m^{-2}) was maintained in all plots for the prescribed competition duration, whereas other weeds were removed manually. All cultural operations were kept normal and uniform. Harvesting started on July 10th in 2014 and 2015 at complete physiological maturity.

Meter rod was used to calculate the maize plant height at physiological maturity. For this purpose, ten plants were chosen randomly in every experimental unit and their length was calculated individually. To take data for parthenium weed dry weight and cob numbers per m^2, a quadrate of 1 m^2 was randomly placed at two different places in each experimental unit near crop maturity, and all parthenium plants were harvested with their averages calculated. For the measurement of stem diameter, 10 plants were chosen randomly in every experimental unit and their diameter was measured individually. For counting grain rows per cob, 10 cobs were randomly chosen at maturity from every experimental unit and then the averages were calculated. For the 1000 grain weight of maize, 10 cobs were selected randomly from each treatment and then shelled. The 1000 grain was counted manually and weighed with the help of a digital electric scale. All the cobs in each treatment were harvested and shelled using a mechanical sheller, then weighed, and noted in the record book. Grain yield per treatment was converted into Mg per hectare. Similarly, the biological yield of maize plant was measured on a per plot basis at the crop harvesting stage, and then converted into Mg per hectare. Relative competitive index (RCI) of parthenium was calculated by the formula of Jolliffe et al. (1984):

$$RCI = \frac{Y_{weed\,free} - Y_{weed}}{Y_{weed\,free}} \times 100$$

where $Y_{weed\,free}$ was yield of weed free plot and Y_{weed} was yield in the presence of weed.

The data, collected on a per treatment basis, was statistically analyzed with Fisher's analysis of variance technique, and the variation between treatment means were compared using LSD at a 5% probability (Steel et al., 1997). Graphs were made using Microsoft Excel (Version 2016), and correlation coefficients were also calculated in Microsoft Excel to discover the relationship among different maize traits.

To measure the effect of prolonging the parthenium competition period on relative grain yield of maize, a three-parameter based logistic equation was used. The iterative use of the NLIN procedure from SAS (SAS Institute, 2008), in line with Knezevic et al. (2002), employed the procedure to estimate the parameters of non-linear regression:

$$Y = ((1/(EXP(K * (T - X)) + F)) + ((F - 1)/F)) * 100$$

where *Y* is the relative maize grain yield (percent season long weed free control), *T* is time in days after crop emergence (DAE), *K* and *F* are constants and *X* is the point of inflection (DAT) (Knezevic et al., 2002).

3 RESULTS AND DISCUSSION

3.1 Parthenium dry weight (g m^{-2})

Data on plant dry weight of parthenium in maize crop as recorded at the end of different competition periods are presented in Figure 1. Data indicated that a linear increase in parthenium dry weight occurred along with an increase in it's competition period during both years of the study. The maximum dry weights (122.4 and 121.6 g m^{-2}) were recorded with the whole season parthenium competition at its lowest (19.0 and 22.4 g m^{-2}) with parthenium competition for 2 WAE during 2014 and 2015, respectively. More parthenium dry weight in a prolonged competition period was probably due to increased biomass accumulation as a result of the elongated growth duration. These findings are in close conformity to the observations of Maqbool et al. (2006) who demonstrated increased dry biomass of weeds in response to extending their competition duration from 15 to 60 days after crop emergence (DAE) in maize. Safdar et al. (2016) concluded that increasing parthenium weed competition in autumn planted maize from 35 to 105 DAE resulted in a linear increase in parthenium dry weight.

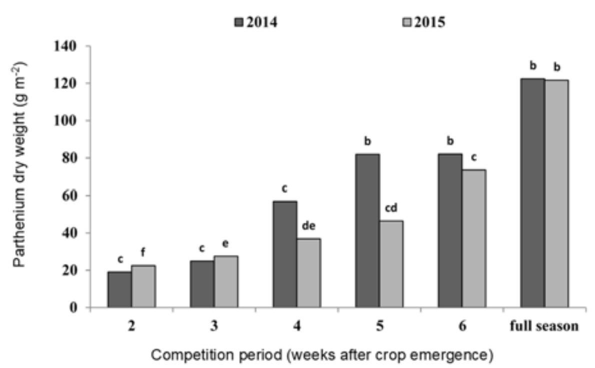


Figure 1 - Parthenium weed dry weight (g m^{-2}) under its different competition durations.

3.2 Plant height (cm)

Parthenium competition duration significantly reduced the plant height of maize with increasing parthenium weed competition durations. Maize plants from weed free plots produced significantly at maximum heights (227.6 cm and 231.6 cm in year 2014 and 2015, respectively) that greatly reduced at and beyond a parthenium competition period of 2 weeks after crop emergence (WAE). The minimum plant height (210 cm and 199 cm in year 2014 and 2015, respectively) of maize was observed with parthenium competition throughout crop season (Table 1). The decrease in the plant height of maize in response to an extension in the parthenium competition period was attributed to an enhancement in weed competition severity to water, nutrients (Irshad, 2000) and other input and environmental resources that slowed the vegetative growth of maize. Our findings are supported by the results of Alford et al. (2004) who discussed that weed competition duration up to 4 WAE led to a decrease in plant height.

3.3 Stem diameter (cm)

Data related to stem diameter (Table 1) showed that by increasing the parthenium competition duration, a gradual reduction in stem diameter was recorded during both years of study. An overview of the data revealed that a maximum stem diameter (1.73 cm and 1.97 cm in years 2014 and 2015) of maize was attained when the maize crop was kept free from weeds throughout its growth duration while a significant reduction in this trait started to occur by imposing parthenium competition up to a period of 2 and 3 WAE in year 2015 and 2014, respectively. Consequently, the lowest stem diameter (1.10 and 1.66 cm during year 2014 and 2015, respectively) was noted with treatment where parthenium was

Table 1 - Growth related traits of maize as influenced by different competition durations of parthenium weed

Competition period (WAE)	Plant height (cm)		Stem diameter (cm)		Biological yield (Mg ha^{-1})	
	2014	2015	2014	2015	2014	2015
Weed free	227.60 a	231.67 a	1.73 a	1.97 a	23.22 a	22.67 a
2	219.30 bc	223.67 b	1.54 ab	1.88 b	22.09 ab	21.67 b
3	221.00 b	219.33 c	1.34 bcd	1.85 c	21.60 b	20.00 c
4	216.67 cd	218.00 c	1.43 bc	1.82 d	19.83 c	19.33 d
5	214.68 de	210.33 d	1.30 bcd	1.77 e	17.30 d	17.80 e
6	212.00 ef	205.33 e	1.20 cd	1.72 f	15.93 de	16.33 f
Full season	210.00 f	199.00 f	1.10 d	1.66 g	14.36 e	15.00 g
LSD (P≤0.05)	0.99	0.43	10.21	0.21	4.62	1.58
CV	0.99	0.43	10.21	0.21	4.62	1.58

Figures sharing same letter (s) in a column do no differ significantly at 5% probability, WAE = weeks after crop emergence, CV = Coefficient of variability.

allowed to grow in maize throughout its life cycle. The linear decline in stem diameter of maize and an increasing competition duration of parthenium might be owed to an enhanced utilization of growth factors by parthenium weed at the expense of the maize crop, thus discouraging crop growth and development (Irshad, 2000). Our results are quite in line with those of El-Shibani (2006) who reported that weeds compete with crops for resources. Previous studies also showed the thickest stem in weed free plots gradually became thinner with an increase in weed competition duration (Uremis et al., 2009).

3.4 Number of cobs m^{-2}

Data in Table 2 indicated that maize competition duration with parthenium significantly affected the cob number m^{-2}. Weed free plots produced the maximum number of cobs m^{-2} (15.6 and 17.6 during the year 2014 and 2015, respectively). However, it suffered significant decline when employing parthenium competition up to and beyond 2 and 6 WAE periods in the year 2015 and 2014, respectively. The minimum cob number m^{-2} (9.6 and 10.3 in the year 2014 and 2015, respectively) was observed with parthenium competition throughout crop growth duration. The linear declining trend in cob number with increased parthenium competition duration was due to a decreased utilization of moisture and nutrients (Irshad, 2000) by maize. Minimum cob numbers m^{-2} of maize in plots suffered from weed competition for longer duration has also been reported by Nawab et al. (1999). Our results are supported by those of Anafjeh and Chaab (2012) who found reduced cob number m^{-2} with increased weed competition. Moreover, cob numbers m^{-2} was relatively greater in weed free plots because of the lack of weed competition which resulted in efficient utilization of nutrients by the crop (Maqbool et al., 2006).

3.5 Grain rows cob^{-1}

A linearly declining trend was observed by the grain rows cob^{-1} of maize in response to an increasing competition duration of parthenium weed in both years. Maize plants harvested from weed free plots showed statistically maximum grain rows cob^{-1} (15 and 17) while minimum grain rows cob^{-1} (13 and 9 during 2014 and 2015, respectively) were observed with parthenium competition throughout crop duration. An overview of the data revealed that by increasing the parthenium competition duration, a significant reduction in grain rows cob^{-1} started from 3 and 6 WAE in the year 2014 and 2015, respectively (Table 2). In weed free treatments, maize plants utilized all the input and environmental resources without any weed competition that favored its growth and development. However, with the increase in competition duration, its supply of moisture and nutrients was gradually reduced (Irshad, 2000). A significant decline in grain rows per cob of maize occurred by increasing the parthenium competition duration which was probably due to an increased severity of parthenium competition that limited the maize cob growth.

3.6 1000 grain weight (g)

Data related to thousand grain weight (Table 2) of maize indicated that as parthenium competition duration was prolonged, thousand grain weight of maize also suffered from a significant successive decline during both study years. An overview of the data revealed that maximum 1000 grain weights (298 g and 289.3 g in the year 2014 and 2015, respectively) were attained with weed free control which showed a significant decline at and beyond a parthenium infestation period of 2 WAE during both years. However, minimum 1000 grain weight (248.7 g and 263.3 g in 2014 and 2015, respectively) was observed with plots subjected to parthenium competition throughout the maize growing season. The decreasing trend in thousand grain weight with an increase in competition duration might be due to the prolonged competition stress by parthenium that coincided with the grain development phase of the crop. Our results are in accordance with Khan and

Table 2 - Grain yield and yield components of maize as influenced by different competition durations of parthenium weed

Competition period (WAE)	No. of cobs m^{-2}		Grain rows cob^{-1}		1000 grain weight (g)		Grain yield (Mg ha^{-1})	
	2014	2015	2014	2015	2014	2015	2014	2015
Weed free	15.60 a	17.60 a	15.00 a	17.00 a	298.00 a	289.30 a	10.82 a	11.60 a
2	14.00 ab	15.60 b	15.67 a	16.00 ab	283.30 b	295.30 b	9.80 b	9.90 b
3	13.30 abc	14.60 c	16.66 a	15.33 bc	277.00 bc	293.00 c	9.20 bc	9.70 c
4	12.30 abcd	13.60 d	16.00 a	14.00 cd	270.00 cd	288.30 d	8.88 c	8.50 d
5	11.60 bcd	12.60 e	13.33 ab	13.00 de	259.60 de	285.00 e	7.82 d	7.66 e
6	10.00 cd	11.60 f	11.00 b	12.00 e	253.30 ef	272.30 f	7.13 e	7.10 f
Full season	9.60 d	10.30 g	13.60 ab	9.33 f	248.60 f	263.30 g	6.87 e	6.67 g
LSD ($P \leq 0.05$)	3.3500	0.3563	3.7700	0.6587	10.9000	0.47700	0.6400	0.3563
CV	15.23	3.27	14.65	5.84	2.27	0.2	4.22	3.11

Figures sharing same letter (s) in a column do no differ significantly at 5% probability, WAE = weeks after crop emergence, CV = Coefficient of variability.

Gul (2006) who found a similar reduction in thousand grain weight of wheat in response to competition with wild oat weed. Through utilization of soil and climatic resources in the field without weeds, maize plants can attain maximum grain weight per cob (Maqbool et al., 2006). A reason for a low thousand grain weight might be due to poor growth of the leaf area index and crop growth rate in the treatments where weeds competed with maize for longer durations. Weed infestation is also a reason for lower maize seed weight which was observed by Johnson et al. (1998). A linear drop in 1000 grain weight of autumn planted maize in response to a prolongation in parthenium infestation period from 35 to 105 DAE was also noticed by Safdar et al. (2016).

3.7 Grain yield (Mg ha^{-1})

Results revealed that a maximum grain yield (10.8 use same unit in thought-out the paper either use Mg ha^{-1} and 11.6 Mg ha^{-1} in the year 2014 and 2015, respectively) was attained with weed free control that suffered from a significant reduction at and beyond the parthenium competition duration of 2 WAE. A minimum grain yield (6.9 Mg ha^{-1} and 6.7 Mg ha^{-1} in 2014 and 2015, respectively) of maize was obtained from plots subjected to whole crop season parthenium infestation (Table 2). The reduction in grain yield of maize, with an extension in parthenium infestation duration, was due to the decrease in number of cobs m^{-2}, grain rows cob^{-1} and 1000 grain weight of maize by an aggravated weed competition stress faced by maize due to the parthenium. There was a significant positive strong relationship of the grain yield of maize with plant height, stem diameter, cob number m^{-2}, and 1000 grain weight as revealed by correlation analysis (Table 3). Values of relative competitive index (RCI) under different parthenium infestation periods were compared in Figure 2 which highlighted a variation from 9% to 36% and 15% to 42%, during the years 2014 and 2015, respectively, in RCI of parthenium under periods ranging from 2 WAE to the whole growing period. Our results are corroborated with the findings of Ansar et al. (1996) and Kumar and Sundari (2002). In weedy check plot, the decline in maize yield is due to the slow crop growth rate due to weeds which ultimately reduced the grain weight per cob (Hatam and Khattak, 1994; Ansar et al., 1996; Kumar and Sundari, 2002). Our results are supported by the findings of Safdar et al. (2016) who calculated grain yield reduction of up to 53% with parthenium infestation for a full growing season of autumn maize.

3.8 Biological yield (Mg ha^{-1})

Stalk yield, pith and grain yield constitute biological yield that varied due to climatic conditions and crop husbandry factors. Data related to biological yield (Table 2) indicated that this parameter also decreased with parthenium competition durations. A significant decrease in biological yield of maize was recorded with an increase in parthenium competition duration during both 2014 and 2015. An overview of the data revealed that the maximum biological yield (23.2 Mg ha^{-1} and 22.6 Mg ha^{-1} in the study year 2014 and 2015, respectively) was attained with weed free control. However, a significant decline started to occur by employing parthenium weed competition for a period of 2 WAE. Consequently, maize plants from plots that were kept infested with parthenium throughout the crop duration gave the minimum biological yield (14.4 Mg ha^{-1} and 15 Mg ha^{-1} in year 2014 and 2015, respectively). Reduced biological yield with increasing parthenium competition duration seems to be due to resultant decrease in underlying parameters such as plant height, stem diameter, significant positive strong relationship of biological yield of maize with plant height, number of plants m^{-2}, grain yield and yield contributing traits. There was a

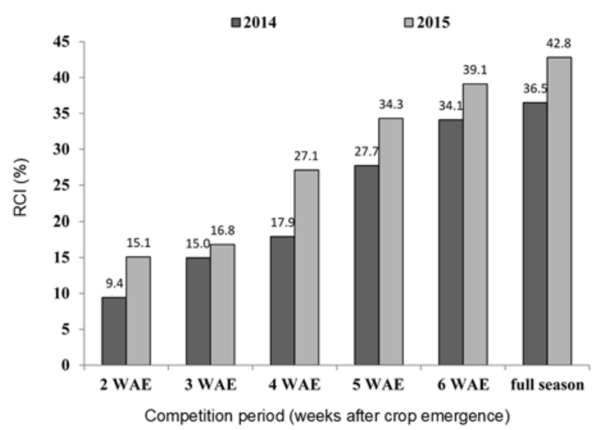


Figure 2 - Relative competitive index (RCI) of parthenium under its different competition durations.

Table 3 - Correlations coefficients (r) of different yield related traits in maize as affected by competition duration with Parthenium hysterophorus (∗−P<0.1, ∗∗−P<0.01 n = 3)

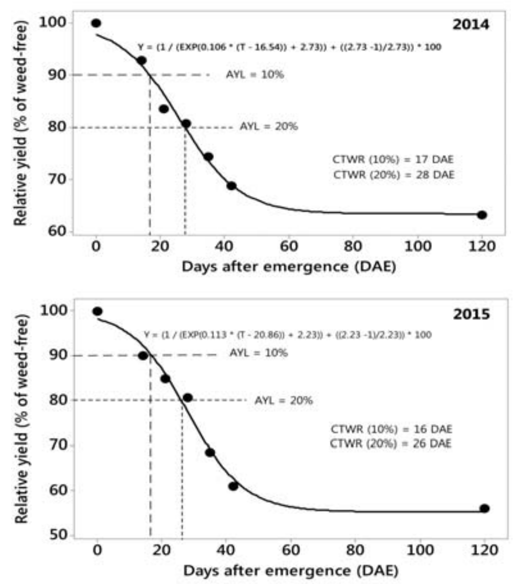
Parameter	Plant height (cm)		Number of plants m^{-2}		Stem diameter (cm)		Number of cobs m^{-2}		Grain rows cob^{-1}		1000 grain weight (g)	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Grain yield	0.92*	0.94*	0.13	0.95*	0.92*	0.96**	0.98**	0.97**	0.48	0.88	0.99**	0.60
Biological yield	0.88	0.98**	-0.09	0.92*	0.82	0.97**	0.94*	0.97**	0.55	0.96**	0.94*	0.78

stem diameter, cob numbers m^{-2}, and grain rows cob^{-1} and 1000 grain weight as shown by correlation studies (Table 3).

An increase in competition duration creates a dwindling effect on biological yield. Our results are similar to the findings of Armin et al. (2007) who stated that an increase in weed completion duration shows a negative effect on biological yield. The outcome of the study indicated that biological yield is considerably influenced by weed competition duration. Competition posed by parthenium during the entire growing season of crop caused a decrease in biological yield (Sajid et al., 2012).

3.9 Estimation of critical timing of weed (parthenium) removal (CTWR) in spring maize

The logistic model showed that relative grain yield of maize was best fitted for parthenium competition period during both years (Figure 3) which means that there was a significant effect of weedy periods on maize grain yield. The data in Table 4 showed that the coefficients for three parameters have been used for fitting the logistic model. The model depicted that CTWR of parthenium in spring maize to avoid 10% and 20% losses in grain yield were 17 and 28 DAE in the year 2014, and 16 and 26 DAE in the year 2015. Safdar et al. (2016) estimated CTWR of parthenium to prevent 5% and 10% grain yield reduction in autumn sown maize was 8 to 13 and 13 to 23 DAE, respectively.



The critical timing for parthenium weed removal (CTWR) to achieve 5% and 10% of acceptable yield loss (AYL) are provided.

Figure 3 - Logistic model showing relative grain yield of maize at different parthenium competition durations during year (A) 2014 and (B) 2015.

Table 4 - Estimates (standard error) of three parameter used in logistic equation (Y= ((1/ (EXP (K* (T-X)) + F)) + ((F-1)/ F)) *100) for estimating the effect of timing of weed removal on relative maize grain yield

Year	Coefficients		
	X	K	F
2014	16.54 (1.95)	0.106 (0.015)	2.73 (0.140)
2015	20.86 (1.81)	0.113 (0.016)	2.23 (0.116)

Data fit to equation, where X is the point of inflection (days after crop emergence), K and F are constants.

4 Conclusions

The consolidated results of two years' research showed that parthenium competition with maize could reduce 36% to 42% of its grain yield. Moreover, the critical competition period of parthenium weed for spring maize was 17 to 28 DAE during 2014 and 16 to 26 DAE during 2015. In conclusion, this weed must be controlled during these periods to avoid 10% to 20% grain yield losses during 2014 and 2015, respectively.

5 Contributions

AR: conceived idea, designed research methodology, manuscript final reading and approval. RQ: manuscript writing, statistical analysis, data interpretation, manuscript final reading and approval. MES: data interpretation, data collection. A-ur-R = manuscript writing, data interpretation. HMRJ, and ZH: literature review. RM, and NF: statistical analysis. MS: literature search. MA: data interpretation.

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