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ESTIMATION OF CRITICAL PERIOD OF EXOTIC INVASIVE WEED *ALTERNANTHERAPHILOXEROIDES* INTERFERENCE IN MAIZE

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Abstract

Alternanthera philoxeroides, a quickly spreading troublesome invasive weed of summer crops, is causing substantial yield losses in maize and other crops in Pakistan. Influence of *A. philoxeroides* at different weed free (full season, 3, 4, 5 and 6 weeks after crop emergence (WAE) and weedy periods (full season, 3, 4, 5 and 6 WAE) on maize was estimated during two consecutive years (2013 and 2014). The increasing weed competition periods increased weed dry biomass (up to 646%) and nutrient uptake (876-1377%). Weed competition caused reduction in maize plant height (14%), 100-grain biomass (22%), number of grains (31%) and grain biomass per cob (30%). Different *A. philoxeroides* competition periods caused up to 37% and 45% biological and grain yield losses of maize, respectively. Relative weed competitive index range was 3.14-45.10%. Four parameter logistic model predicted 0.26-6.04 WAE and 0.35-5.86 WAE as critical period of competition for *A. philoxeroides* to avoid 5% to 10% maize grain yield losses, respectively. The comparatively narrow window for competition period might be due to its fast and prostrate growth habit, high nutrient uptake and strong allelopathic potential. Appropriate management strategies would help to condense anticipated spread of *A. philoxeroides* and maize yield losses.

Key words: *Alternanthera philoxeroides***,** invasive weeds, logistic models, maize yield losses. NPK uptake.

Introduction

Alternanthera philoxeroides (Mart.) Griseb, commonly known as alligatorweed a fast spreading invasive weed is well adapted to diverse environmental conditions under both aquatic and terrestrial habitats (Julien & Stanle, 1999; Abbas *et al.*, 2017). It is native to South America, including Argentina, Brazil, Paraguay and Uruguay, but has become a serious invasive and problematic weed in more than 30 countries including Brazil, Australia, UK, USA, Europe and Asia (Gunasekera & Bonilla, 2001; Tanveer *et al.*, 2013). *Alternanthera philoxeroides* is identified as a problematic weed in rice, maize, sugarcane, cotton, soybean, millet, vegetables and fruit trees which emerges before or along with crops, grows fast and branches profusely, and has a prostrate growth habit that allows it to form a dense mat quickly (Shen *et al.*, 2005; Bassett, 2009). It poses serious threat to native vegetation through release of allelochemicals that could lead to loss of native plant species and successful invasion of this weed (Marwat *et al.*, 2008; Abbas *et al.*, 2017). Studies on *A. philoxeroides* competition with maize and potential yield losses due to this weeds are not available. However, overall average yield losses in maize due to weed interference are more than 50% (Soltani *et al.*, 2016). Maize yield losses varied significantly depending upon type of weed, for example, the grain yield losses of maize were up to 30%, 19%, 91% and 74% in the presence of *Trianthema portulacastrum* L., *Imperata cylindrica* L., *Amaranthus palmeri* S. Wats. and *Datura stramonium* L. respectively (Saeed *et al.*, 2010b; Udensi and Chikoye, 2013; Massinga and Curie, 2002; Oljaca *et al.*, 2007).

A phase or stage in the life history of crop when it is more vulnerable to the existence of weeds in their adjacent locality is considered as critical period of weed competition (CPWC) (Knezevic *et al.,* 2002; Evans *et al.,* 2003a). It is an important component to develop effective weed management plan that could help the farmers to determine the necessity, dose, type or time of herbicide application (Fleck *et al.,* 2002; Portugal & Vidal, 2009). The CPWC varies considerably with the weed species, density, time of emergence, the composition of weed flora, management practices and climatic conditions (Knezevic *et al.,* 2002; Zimdahl, 2004). According to Hans & Johnson (2002), season long interference of *Sorghum bicolor* (L.) Moench. resulted in 43% to 85% yield loss in maize crop. Safder *et al.,* (2016) reported that the competition of *Parthenium hysterophorus* in maize for 8 to 13 DAE (days after emergence) and 17 to 23 caused 5 and 10% grain yield losses. Effect of nutrient uptake by *A. philoxeroides* in maize yet has not been explored. Higher nutrients uptake potential of *A. philoxeroides* (Liu *et al.,* 2007) may reduce maize nutrient uptake and negatively influence the growth and yield of maize.

Empirical models that quantify the influence of weed interference period on crop yield can offer valuable information to develop effective weed management plans (Knezevic *et al.,* 2002). Several attempts have been made to quantify competitive relationship of weeds and crop yield and quality (Zimdahl, 2004), which are commonly used to model weed crop competition and predict yield loss. However, to best of our knowledge no study has been conducted elsewhere in the world to investigate the competition between maize and invasive weed *A. philoxeroides*. *A. philoxeroides* is quickly invading weed of maize production system in Asia (Abbas *et al.,* 2017). Therefore, determination of the CPWC for *A. philoxeroides* in maize is necessary that would help maize growers to manage this weed. Study was planned to determine the competitiveness and CPWC of *A. philoxeroides* in maize. In addition, nutrient uptake potential of *A. philoxeroides* and its influence on maize growth and yield under different weedy and weed free durations was also appraised.

Materials and Methods

Site and soil: The research was performed at the Agronomic Research Area, University of Agriculture Faisalabad (UAF), Pakistan, during 2013 and 2014. Physico-chemical analysis of soil before sowing of maize crop for both years revealed that the site soil has 0.67-0.69%, 0.035%, 8.5-9.8 ppm and 205-210 ppm organic matter, total N, available P and available K, respectively. Soil texture type was sandy clay loam having 8.0 pH and 0.56-0.60 dS m^{-1} electrical conductivity. Weather data about rain fall, relative humidity and temperature during the course of study in 2013 and 2014 were obtained from Agricultural Meteorology Cell, UAF, Pakistan, located near the experimental field (Fig. 1).

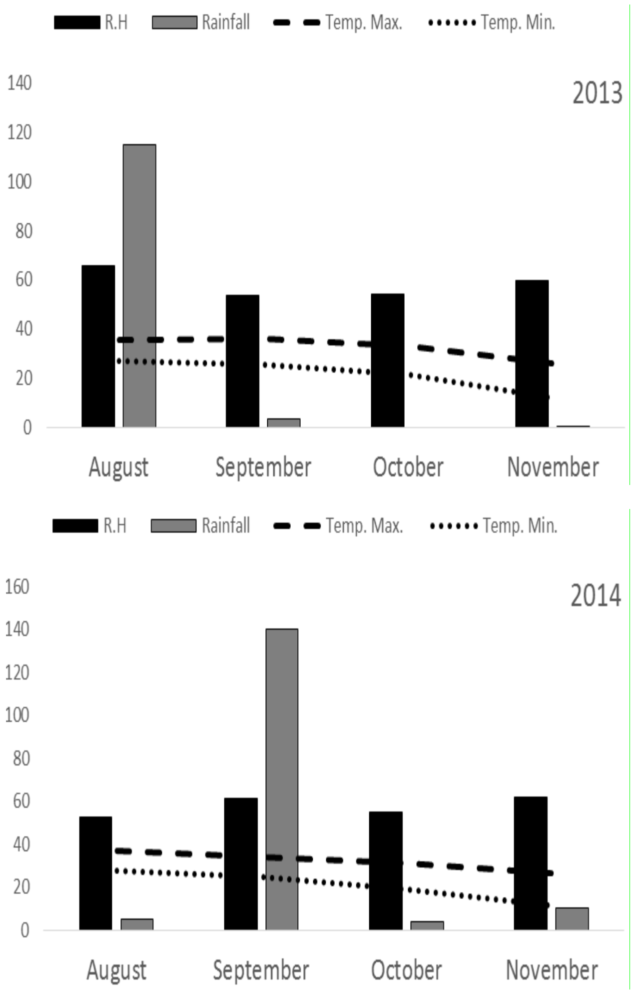

Fig. 1. Weather data of field for the growing period of crop in 2013 and 2014.

Experimental detail: Laser leveled field was cultivated twice followed by planking to prepare the fine seed bed. Maize hybrid 30R50 was planted on 75 cm apart ridges having 20 cm plant to plant distance using 20 kg ha^{-1} seed rate during 2013-14.Nitrogen, P and K at 250, 120 and 125 kg ha^{-1} was applied, the fertilizer sources for N, K and P were urea, diammonium phosphate and sulphate of potash, respectively. The 1/5th of N and full dose of P and K were broadcasted and incorporated in soil at seed sowing while remaining doses of N were applied when crop gained 1 foot height, at 2 feet, at 3 feet and at tasseling stage (5-7 days before tasseling) by fertigation method. Crop was irrigated eight times, each irrigation was three acre inches (75 mm). Each plot having 4 rows with 6 m length. Weed infestation treatments were practiced under randomized complete block design repeated four time. Naturally occurring other weed populations except *A. philoxeroides* were carefully uprooted with hand pulling without soil disturbance. In order to determine the CPWC different treatments of weedy and weed free periods including C_1 (weed free throughout growth period or control), C_2 (weed free for 3 weeks after crop emergence (WAE),C_3 (weed free for 4 WAE), C_4 (weed free for 5 WAE), C_5 (weed free for 6 WAE**)**, C_6 (weedy for full season), C_7 (weedy for 3 WAE), C_8 (weedy for 4 WAE), C_9 (weedy for 5 WAE) and C_{10} (weedy for 6 WAE) were maintained.

Data collection and statistical analysis: Data regarding *A. philoxeroides*dry biomass and uptake of NPK were recorded. To estimate the effect on maize crop, maize growth, yield and quality traits were also determined. We determined N in *A. philoxeroides* by using Jackson (1962) procedure, while P was determined with methodology of Jones *et al.,* (1991). Chapman & Pratt (1961) flame photometer procedure was used to measure potassium (K).

The correlation among the maize grain yield (Y) and the *A. philoxeroides* competition periods in *A. philoxeroides* free and weedy plots was determined by using a four parameter log-logistic model (Knezevic *et al.,* 2007). So yield losses at different *A. philoxeroides* densities were calculated by four parameters log-logistic model. The model equation is as under:

$$Y = \frac{[C + (D - C)]}{[1 + \exp\{B(\log X - \log E)\}]}$$

Where Y is actual yield, X is time the x-axis expressed as week after emergence (WAE), C is the lower asymptote or minimum limit, D is the upper asymptote or maximum limit, E is the WAE giving a 50% yield between the lower and upper asymptote or minimum and maximum limit, and the parameter B is the slope of the line (rate of change) at E.

Data of the maize and *A. philoxeroides*were statistically analyzed by using Fisher's analysis of variance techniques (Steel *et al.,* 1997). To further test the difference between the different weed competition durations treatments the HSD test was applied at 5% probability level. The parameters for which the treatment response for both years was not differ statistically data were pooled and average used for analysis.

Results

Dry biomass (g m^{-2}) of *Alternanthera philoxeroides*: The results revealed significant influence of varying *A. philoxeroides* free and weedy periods on its dry biomass. Gradual decrease in *A. philoxeroides*dry biomass was obtained by increasing weed free and decreasing weedy period in maize (Table 1). Significantly highest dry biomass of *A. philoxeroides* (61.54 g m^{-2} and 62.18 g m^{-2}) was produced in plots where *A. philoxeroides* competition was for full season, while minimum dry biomass (8.24 g m^{-2} and 9.75 g m^{-2}) in plots where no weed control was done for 6 WAE. It was also recorded that the treatments with weed free for 3 WAE remained statistically at par with treatment having weedy for 4 WAE during both the years. The response of treatment with weed free for 4 WAE regarding dry biomass was remained similar with weedy for 3 WAE for both the years.

NPK uptake (kg ha^{-1}) of *Alternanthera philoxeroides*: The NPK uptake by *A. philoxeroides* showed a significant increase with decrease in weed free and increase in weedy period. Significantly the maximum N, P and K uptake (17.33 - 17.92 kg ha^{-1}, 1.40-1.62 kg ha^{-1} and 1.07 kg ha^{-1} in 2013 and 2014, respectively) by *A. philoxeroides* in maize was recorded in response to weedy for full season, which was followed by the treatment with weedy period for 6 WAE for both the years (Table 1). The lowest N, P and K uptake by *A. philoxeroides* (1.77-1.81 kg ha^{-1}, 1.40-1.62 kg ha^{-1} and 1.07 kg ha^{-1} in 2013 and 2014, respectively) was noted in the treatment with weed free for 6 WAE, that was statistically similar to the treatments with weed free for 4 and 5 WAE. The treatment with weed free for 3 WAE was remained statistically at par with weedy for 4 WAE during both years.

Plant height (cm) and yield contributing traits of maize: The data pertaining to maize plant height, 100-grain biomass, no. of grains and grain biomass of each cob was significantly influenced by different *A. philoxeroides* free and weedy periods (Table 2; Fig. 2). A perusal of data displayed that the more plant height (276.85 cm), 100-grain biomass (38.24 g), number of grains (457) and grain biomass (213 g) per cob of maize was observed with treatment comprising weed free throughout growth period (control) which was followed by that of weed free for 6 and 5 WAE. A steady reduction in plant height and yield contributing traits was recorded with decrease in *A. philoxeroides* free period and increase in weedy duration until full season weedy that resulted in maximum reduction in plant height and yield contributing traits.

Biological and grain yield (t ha^{-1}) of maize: The maize biological and grain yield were significantly influenced by different *A. philoxeroides* free and weedy periods (Table 3). *Alterrnanthera philoxeroides* free plots throughout growth period produced more biological (27.03 t ha^{-1}) and grain (9.85 t ha^{-1}) yieldas compared to other treatments that was statistically similar to weed free for 6 WAE. Conversely the minimum biological and grain yield (17.09 t ha^{-1} and 5.47t ha^{-1}, respectively) of maize was produced in treatment having no weed control and weed compete with crop till maturity, that was not different according to HSD test to that of weedy condition for 6 WAE.

Relative competitive index (RCI) of *A. philoxeroides*: Different *A. philoxeroides* free and weedy periods in maize caused significant influence on relative competitive index (RCI). The RCI tended to increase linearly by reducing *A. philoxeroides* free and increasing weedy periods. The minimum RCI (3.14 and 2.26% in years 2013 and 2014, respectively) was given by *A. philoxeroides*free period of 6 WAE which was followed by that of *A. philoxeroides* free period for 5 WAE, weedy period for 3 WAE, weed free for 3 WAE and 4 WAE weedy periods for 4, 5 and 6 WAE (Fi. 2). The maximum RCI (45.10 and 43.69% in years 2013 and 2014, respectively) was recorded by treatment where *A. philoxeroides* competition with maize was for full season (Fig. 3).

Estimation of maize grain yield losses through log-logistic model and critical period of weed crop competition: The maize grain yield was significantly decreased by increasing the duration of *A. philoxeroides* and maize competition (Fig. 3 and Table 4). The lowest maize grain yield (5.48 t ha^{-1} and 5.49 t ha^{-1}) was predicted in 2013 and 2014, respectively when weed control was delayed for 16 WAE as shown in Table 4. Contrastingly, the highest maize grain yield (12.82 t ha^{-1} and 13.32 t ha^{-1}) was predicted in 2013 and 2014 when weed removal was delayed for 3 WAE. The 50% grain yield was reduced as weed interference duration with maize was reached at 1.0 WAE and 1.1 WAE in 2013 and 2014, correspondingly suggesting that *A. philoxeroides* control is necessary by this time to avoid 50% yield loss in the form of maize grain. The anticipated decrease rate in maize grain yield at this time was 2.47 t ha^{-1} and 2.99 t ha^{-1} in 2013 and 2014, respectively.

Table 1. Dry biomass and nutrients uptake of *A. philoxeroides* (g m^{-2}) at its different densitiesin maize.

	Dry biomass (g m^{-2})		`N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})
	2013	2014	2013	2014	2013	2014	Two years average
Weed free throughout growth period (Control)	-----	-----	-----	-----	-----	-----	-----
Weed free for 3 WAE	26.02 d	27.61 c	6.56 d	7.53 d	5.14 d	5.34 c	5.48 d
Weed free for 4 WAE	14.57 e	18.07 d	3.58 e	3.77 e	2.78 e	3.33 d	3.17 e
Weed free for 5 WAE	11.48 ef	12.98 ef	2.62 e	2.75ef	2.03 ef	2.24 de	1.72 fg
Weed free for 6 WAE	8.24 f	9.75 f	1.77 e	1.81 f	1.40 f	1.62 e	1.07 g
Weedy for full season	61.54 a	62.18 a	17.33 a	17.92 a	13.34 a	13.11 a	15.81 a
Weedy for 3 WAE	12.54 ef	15.86 de	2.95 e	3.30 e	2.30 ef	2.86 de	2.36 ef
Weedy for 4 WAE	28.33 d	30.12 c	7.27 d	8.22 d	5.73 d	5.90 c	6.13 d
Weedy for 5 WAE	38.90 c	40.33 b	10.31 c	10.70 c	8.07 c	8.13 b	8.98 c
Weedy for 6 WAE	52.04 b	58.14 a	14.22 b	14.84 b	11.04 b	11.99 a	13.36 b
HSD	4.815	4.995	1.858	1.697	1.335	1.265	1.237

Means sharing different letters in a column differ significantly according to Tukey's honestly significant difference (HSD) test($p \leq 0.05$)

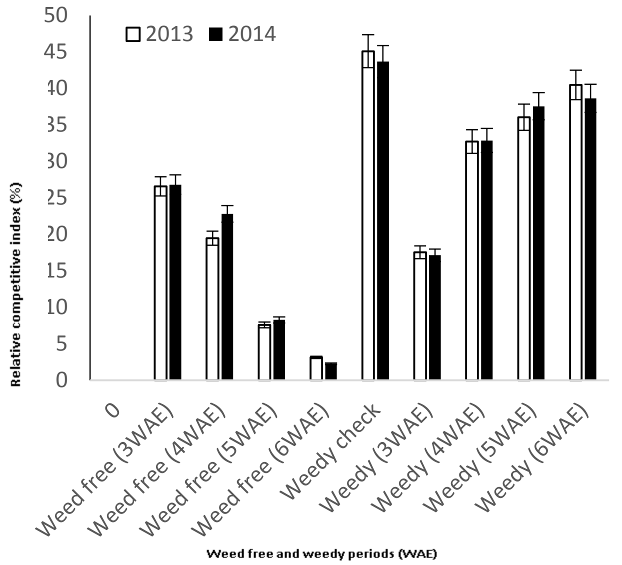

Fig. 2. Effect of different *A. philoxeroides* free and weedy periods on *A. philoxeroides* relative competitive index (RCI).

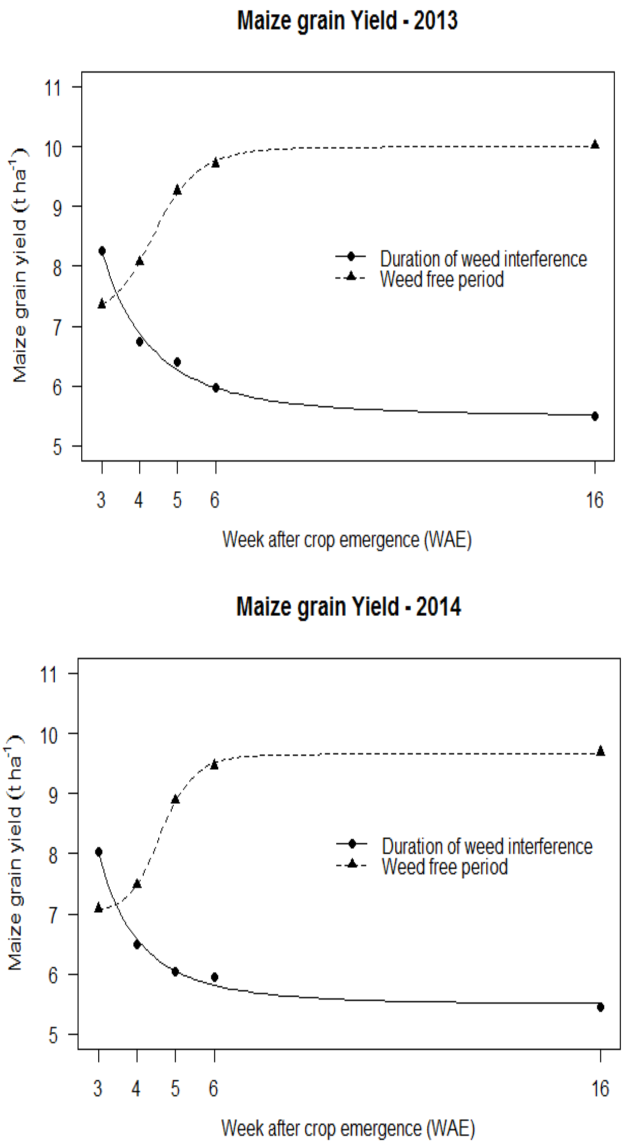

Fig. 3. Effect of weed free and weedy periods on grain yield (t ha^{-1}).

Table 2. Effect of different densities of *A. philoxeroides* (plants m^{-2}) on plant height, grain yield and yield components of maize.

A. philoxeroides density (plants m^{-2})	Plant height (cm)	100-grain biomass (g)	Number of grains per cob		Grain biomass per cob (g)		Biological yield (t ha^{-1})	Grain yield (t ha^{-1})	
			2013	2014	2013	2014		2013	2014
Weed free throughout growth period (control)	276.85 a	38.24 a	462.30 a	452.60 a	215.90 a	211.85 a	27.03 a	10.02 a	9.68 a
Weed free for 3 WAE	254.24 def	33.04 cd	285.00 cde	374.55 bcd	179.85 cde	177.10 de	21.04 ef	7.36 cd	7.09 de
Weed free for 4 WAE	259.13 cde	34.18 bc	397.10 cde	390.05 bc	190.30 bcd	181.80 cd	22.27 de	8.07 c	7.48 cd
Weed free for 5 WAE	269.36 abc	37.22 a	430.80 abc	424.00 ab	209.90 ab	204.85 abc	25.13 bc	9.26 ab	8.88 ab
Weed free for 6 WAE	274.42 ab	38.14 a	458.35 ab	449.85 a	213.70 ab	208.30 ab	26.49 ab	9.71 a	9.46 a
Weedy for full season	237.46 g	29.67 f	326.90 g	310.90 e	152.30 f	146.05 f	17.09 i	5.50 f	5.45 g
Weedy for 3 WAE	264.15 bcd	35.98 ab	412.40 bcd	403.80 abc	197.55 abc	188.00 bcd	23.51 cd	8.26 bc	8.02 bc
Weedy for 4 WAE	251.97 ef	32.46 cde	379.00 def	354.60 cde	178.50 cde	177.10 de	20.09 fg	6.74 de	6.50 ef
Weedy for 5 WAE	246.72 fg	31.32 def	351.80 efg	348.45 cde	169.35 def	165.30 def	18.94 gh	6.41def	6.05 fg
Weedy for 6 WAE	243.74 fg	30.34 ef	333.25 fg	324.85 de	159.95 ef	154.80 ef	17.86 hi	5.96 ef	5.94 fg
HSD	10.966	2.578	48.716	59.573	24.301	23.098	1.802	1.172	0.925

Means sharing different letters in a column differ significantly according to Tukey's honestly significant difference (HSD) test ($p \leq 0.05$)

Table 3. Correlation matrix between yield and yield components of maize.

Yield components	Grain biomass per cob (g)	Number of grains per cob	100-grain biomass (g)	Grain yield (t ha^{-1})
	Two-year (2013 and 2014) means			
Grain yield (t ha^{-1})	0.96**	0. 94**	0.96**	

** Indicates significant at $p \leq 0.01$

Table 4. Parameter estimates, followed by standard errors in parentheses for four parameters log-logistic model characterizing the relationship between maize yield and duration of weed competition periods of *A. philoxeroides* in maize.

Factor	Year	Weedy peroids (parameter estimates)				Model fit
		C	D	B	E	
Grain yield	2013	5.480 (0.069)	12.817 (7.716)	2.468 (0.225)	1.001 (0.695)	Four parameter-Log-logistic
Grain yield	2014	5.492 (0.087)	13.315 (8.527)	2.998 (0.377)	1.119 (0.839)	Four parameter-Log-logistic

C is the lower asymptote or minimum limit, D is the upper asymptote or maximum limit, E is the WAE giving a 50% response of maximum limit (D), and B is the slope of the line or rate of change at 50% response of maximum limit

Table 5. Parameter estimates, followed by standard errors in parentheses for four parameters Log-logistic model characterizing the relationship between maize yield and duration of weed free periods of *A. philoxeroides* in maize.

Factor	Year	Weed free period (parameter estimates)				Model fit
		C	D	B	E	
Grain yield	2013	7.259 (0.086)	10.003 (0.056)	8.019 (0.803)	4.461 (0.066)	Four parameter-Log-logistic
Grain yield	2014	7.045 (0.091)	9.641 (0.073)	9.093 (1.562)	4.639 (0.075)	Four parameter-Log-logistic

C is the lower asymptote or minimum limit, D is the upper asymptote or maximum limit, E is the WAE giving a 50% response of maximum limit (D), and B is the slope of the line or rate of change at 50% response of maximum limit

Table 6. Log-logistic model and his parameter estimate at 5% and 10% AYL, followed by standard errors in parentheses for weed-crop competition of *A. philoxeroides* in maize.

Factor	AYL	Beginning of CPWC (WAE)	End of CPWC (WAE)
Grain yield 2013	5 %	0.263 (0.318)	6.431 (0.332)
Grain yield 2014	5%	0.419 (0.349)	6.049 (0.226)
Grain yield 2013	10%	0.356 (0.421)	5.862 (0.232)
Grain yield 2014	10%	0.3538 (0.436)	5.655 (0.164)

AYL represents acceptable yield loss at 5 and 10%
CPWC = critical period of weed competition

Increase in weed free period increased the grain yield of maize. The lowest maize grain yield (7.26 t ha^{-1} and 7.05 t ha^{-1} during 2013 and 2014, respectively) was predicted when *A. philoxeroides* removed till 3 WAE (Fig. 3 and Table 5). Conversely, the highest maize grain yield (10.0 t ha^{-1} and 9.64 t ha^{-1} in 2013 and 2014, respectively) was predicted when *A. philoxeroides* removed till 16 WAE. The 50% increase in maize grain yield in weed free period was reached at 4.46 WAE and 4.64 WAE in 2013 and 2014, respectively suggesting that weed free period till that time can boost the 50% maize grain yield. The anticipated increase rate in maize grain yield at this time was 8.01 t ha^{-1} and 9.09 t ha^{-1} in 2013 and 2014, respectively.

In 5% AYL, the duration of CPWC of alligatoweed began at 2 DAE and 3 DAE and continued until the 45 DAE and 43 DAE in 2013 and 2014, respectively (Table 6). In 10%, AYL the duration of CPWC of alligatoweed began at 3 DAE and continued until the 41 DAE and 40 DAE in 2013 and 2014, respectively. Further, it can be accomplished from the study that 6 weeks after crop emergence for weed free and 3 weeks for infestation was the critical period of *A. philoxeroides* competition. Further reduction in *A. philoxeroides* free period and increase in weedy period yield more reduction in grain yield up to 38% over weed free control.

Discussion

Increasing in *A. philoxeroides* dry biomass with decreasing *A. philoxeroides* free period and extending weed-crop competition period was attributed to the long time benefited by *A. philoxeroides* to grow and develop ensuing into further accumulation of photosynthates and more biomass. Maqbool *et al.,* (2006), observed that increase in weed interference duration (15 to 60 DAE) in maize, increased weed dry biomass. Safdar *et al.,* (2016) observed that increasing *P. hysterophorus*competition period resulted in an increase its dry biomass. They recorded that maximum dry biomass was obtained by entire season weed-crop competition and minimum *P. hysterophorus*weed dry biomass was produced in plots having *P. hysterophorus* competition with maize crop for 35 DAE. Ali *et al.,* (2015) recorded that dry biomass of *Rhynchosia capitata* showed gradual increase as the competition duration of weed with crop increased. Season long competition of *R. capitata* in mungbean (*Vigna radiata* L.) produced maximum weed dry biomass.

Increase in NPK uptake by *A. philoxeroides* with decreasing weed free and extending weedy period might be due to more plant biomass buildup with prolonged growth and development duration. Lindquist *et al.,* (2007) concluded that N uptake by broadleaf weed (*A. theophrast*) was increased significantly by extending infestation period (0 to 100 DAE). In another study, Anjum *et al.,* (2007) recorded maximum N, P and K uptake by *T. portulacastrum* when it was permitted to grow in cotton for entire crop season till maturity.Ikram *et al.,* (2012) concluded that the uptake of P by weeds in cotton was increased gradually with increase in weed competition duration. Mehmood (2017) (missing) recorded that maximum N, P and K uptake by *A. philoxeroides* in rice was obtained where *A. philoxeroides* was allowed to compete for till crop maturity. Gaikwad and Pawar (2003) revealed that uncontrolled weed plots exhibited fast weed growth causing in rapid uptake of K from soil. In another study, Khan *et al.,* (2018) recorded that increasing weed competition period in chickpea and weed management practices reduced the chickpea growth and yield. Tanveer *et al.,* (2015), reported that the increase density of *Euphorbia dracunculoides*in chickpea crop showed liner increase in nutrient uptake by weed.

The significant reduction in maize plant height with regard to decline in *A. philoxeroides* free and increase in *A. philoxeroides* infestation duration was due to reduced maize growth and development as a result of nutrients uptake by weed and severe inter-specific crop-weed competition. Due to horizontal and spreading growth of *A. philoxeroides* it could not put any vertical competition for space to maize that might also be reason for low high in plots with more competition duration. Saeed *et al.,* (2010a) reported reduction in plant height in reaction to weed competition, effect was also more prominent with long competition durations.

Decrease in no. of grains per cob with reduction in weed free period and extension in weedy period was due to more competition for nutrients and space especially at flowering and fertilization stage. Nasrollahzadeh *et al.,* (2015), recorded that with long duration of weed competition and less weed free period, the number of grains per cob and grain biomass tended to decline. The no. of grains in weed free period was enhanced 51% as compared with weedy conditions. Evans *et al.,* (2003b) recorded that increase in the period of weed interference significantly decreased number of seeds per cob of maize. Asif *et al.,* (2017) recorded a gradual decrease in these yield contributing traits with increase in *P. hysterophorus* weed-crop competition duration, the entire season weed free period ensured maximum potential of these traits.

Reduced 100-grain biomass with reduction in *A. philoxeroides* free period and increase in weedy period may possibly be due to happening of *A. philoxeroides* competition pressure at grain filling phase of maize that adversely influenced grain growth and development. Swanton *et al.,* (2015) observed that weed crop interference at early growth stages of maize caused reduction in final maize grain yield, more yield losses were occurred at long weed competition period (Check English). Nasrollahzadeh *et al.,* (2015) concluded that 100-grain biomass was enhanced by increasing the weed-free duration and weed interference period.

In this study, key factors accountable for decline in maize grain biomass due to decrease in *A. philoxeroides* free period and increase in weedy period appear to be the no. of grains per cob and 100-grain biomass. Asif *et al.,* (2017) observed a significant reduction in maize fodder biomass as the weed competition duration with maize crop was increased. In another study, Safdar *et al.,* (2016) found a gradual decrease in grain biomass per cob along with increase in *P. hysterophorus* weed-crop competition duration.

The steady reduction in biological and grain yield of maize with decreasing weed free and increasing weedy duration was possibly due to decrease in the major yield traits as noted in our study. Lindquist *et al.,* (2010) recorded that weed infestation in maize for duration of 7 WAE caused 24% reduction in maize yield as compared to control. In another study, Gholami (2014) recorded significant decrease in yield of maize when employed to weed infestation up to 5 WAE. A positive relationship of maize grain yield was established with major yield contributing traits including no. of grains per cob (r = 0.94), 100-grain biomass (r = 0.96) and grain biomass of each cob (r = 0.96) of maize (Table 2).

Our findings about RCI are analogous with the results obtained by those of Lutz (2007). They calculated a grain yield reduction of 40-60% in maize with weed-crop competition for entire growing duration. In the same way, Maqbool *et al.,* (2006) demonstrated 51% decrease in yield due to entire cropping season weed infestation. Safdar *et al.,* (2016) reported that different *P. hysterophorus* competition periods in maize starting from 35 days after crop emergence to full season weed competition caused 24-52% losses in maize grain yield.

The early start of critical period of *A. philoxeroides* and narrow window for weed-crop competition might be due to its strong allelopathic potential (Marwat *et al.,* 2008; Abbas *et al.,* 2017) and high competition ability of this weed with crop plants (Mehmood *et al.,* 2017). High nutrient uptake of *A. philoxeroides* as compared to other weeds like *P. hysterophorus* might also be a major reason for narrow window of critical competition period (Safdar *et al.,* 2016; Asif *et al.,* 2017). Similarly Lutz (2007) recorded 40-60% grain yield decline in response to weed infestation. Nasrollahzadeh *et al.,* (2015) found that grain yield reduced significantly with extending weed infestation period and diminishing length of weed free period. They further revealed that the highest and the lowest grain yield was obtained in full season weed-free treatment and full-season weed competition treatment, respectively. They recorded 67% decline in grain yield with full season weedy conditions compared with entire season weed free treatment. These results are in accordance with those of Mehmood (2017) who demonstrated that critical period of weed-crop competition with *A. philoxeroides* in transplanted ricewas four weeks after transplanting. Maqbool *et al.,* (2006) reported decrease in yield of maize as weed and crop interface duration with crop was increased from 15 to 60 DAE. Furthermore, the maximum grain yield reduction up to 51% was noted in plots with weed-crop competition for entire cropping season. Recently, Gholami (2014) revealed substantial decline in grain yield of maize by weed infestation period of 35 DAE as compared weed free control. Amiri *et al.,* (2014) found that critical time of weed removal ranged from 21 to 19 days after planting to avoid yield losses of 5% in maize. Safdar *et al.,* (2016) recorded 53% reduction in maize grain yield with *P. hysterophorus*competition duration ranging from 35 DAE to throughout growing season. Thus understanding of weed competition duration on crop yield is important to develop effective weed management plan to ensure effective, economical and eco-friendly weed control.

In conclusion, *A. philoxeroides* has significant inhibitory effect on maize growth and yield depending on the time of weed competition. It has short critical weed competition period in maize so timely weed control is suggested to tackle maize yield losses. In the scenario of quick invasion of this troublesome weed, appropriate management strategies are needed to be optimized for *A. philoxeroides* control to overcome its anticipated spread and crop losses in future.

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