

# Interference and estimation of economic threshold level of *Alternanthera philoxeroides* in maize (*Zea mays* L.)

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## Abstract

Knowledge of economic threshold of emerging invasive weed *Alternanthera philoxeroides* (alligatorweed) is important to implement timely, efficient and economical weed control method for profitable maize production. Two-year field study consisting five density levels of *A. philoxeroides* viz. 0, 1, 2, 4 and 8 plants m<sup>-2</sup> was conducted to estimate the maize grain yield losses at different density levels and to determine economic threshold level (ETL) of *A. philoxeroides*. Maximum weed dry biomass (44.28 g m<sup>-2</sup>), N (9.02 kg ha<sup>-1</sup>), P (7.91-6.86 kg ha<sup>-1</sup>) and K (7.99 kg ha<sup>-1</sup>) were observed at 8 plants m<sup>-2</sup> *A. philoxeroides* density. The same weed density caused highest reduction maize plant height, number of grains per cob, 100 grain weight, grain weight per cob and biological yield of maize. Higher *A. philoxeroides* density also caused up to 62% reduction in maize grain yield and 21% reduction in grain protein contents as compared to weed free. ETL of *A. philoxeroides* was estimated to be 0.47 plants m<sup>-2</sup>, if this weed controlled chemically. Based on current findings complete control of this weed using chemical weed control is suggested to tackle yield losses in grain maize.

**KeyWords** alligatorweed, invasive weed, maize grain quality, NPK uptake, yield losses.

## Introduction

The concept of economic threshold level (ETL) of weed is an important yardstick to take decision whether to employ control measures or not keeping in view the economics of weed control methods in crops under inspection. ETL of a weed is the density at which weed control provide economic return over input costs of weed control method (Hamouz et al, 2013). It is crucial to determine for reducing the reliance of unnecessary use of synthetic weedicides, minimizing the cost and environmental pollution (Knezevic et al, 2002). Significant yield losses in maize occurred due to weeds that varied depending upon weed biomass, weed species and their density (Blackshaw et al, 2002). Due to weed interference in maize, yield may be reduced from 37 to 68%, on an average yield losses due to weed interference are 50% (Soltani et al, 2016). The grain yield losses of maize were 7-30% in the presence of *Trianthema portulacastrum* L. at density level of 3 to 18 plants m<sup>-2</sup> (Saeed et al, 2010b), 1.7-18.9% when *Imperata cylindrica* L. densities were between 4 and 16 plants m<sup>-2</sup> (Udensi and Chikoye, 2013), up to 91% when *Amaranthus palmeri* S. Wats. density was 0.5 to 8 plants m<sup>-2</sup> (Massinga and Currie, 2002) and 74% when *Datura stramonium* L. density was 10 plants m<sup>-1</sup> (Oljaca et al, 2007). ETL considerably varied with changing weed type, for instance *A. palmeri* and *Abutilon theophrasti* Medik. at 3 plants m<sup>-2</sup> caused

30-38% yield losses while *Imperata cylindrica* L. caused just 19% maize yield losses even at 16 plants m<sup>-2</sup> (Liphadzi and Dille, 2006; Udensi and Chikoye, 2013).

Weeds damage crops by competing for resources including mineral nutrients, water, light and space, and through release of phytotoxic compounds that inhibit crop growth (Zimdahl, 2007; Khaliq et al, 2011). Interference that involved both weed-crop competition and allelopathy is an important indicator of ETL for any weed (Zimdahl, 2007). Due to spreading growth type and efficient nutrients uptake *A. philoxeroides* caused severe competition for any associated crop (Shen et al, 2005). Additionally, inhibitory effect of various phytotoxins released from weeds has been reported on germination and growth of maize (Soufan et al. 2009; Ştef et al. 2015). *Alternanthera phalixroides* have strong allelopathic potential due to presence of various phytotoxins compounds that had been identified in this weed (Abbas et al, 2014). These phytotoxins showed inhibition in different crops and are major contributor in successful invasion of this weed in new ecosystems (Abbas et al, 2017). Allelopathic ability of *A. philoxeroides* in its flourishing invasion in new regions has been recorded by Xie et al. (2010) and Jinrong et al. (2006).

Liuqing et al. (2007) recorded 43-50% reduction in rice yield with *A. philoxeroides* density of 23-180 plants

m<sup>2</sup> at rice plant population of 100 m<sup>2</sup>. The economic threshold of *A. philoxeroides* was 4.02 plants m<sup>2</sup> with manual weed control in garlic fields (*Allium sativum* L.) (Shou-hui *et al*, 2008) and 1.39 plant m<sup>2</sup> in rice field with fluroxypyr-methyl application (Yu, 2008). No information is available regarding effect of *A. philoxeroides* on growth and final grain yield of maize in field conditions. Furthermore, no study has so far been conducted to estimate ETL of this troublesome invasive weed in maize elsewhere in the world. *Alternanthera philoxeroides* is an emerging threat to crop production worldwide. Thus, there is need to initiate study to find out sustained, cost-effective and eco-friendly management of this weed. Therefore, present two year field study was conducted to estimate the losses caused by this weed at different densities and to determine its ETL in maize.

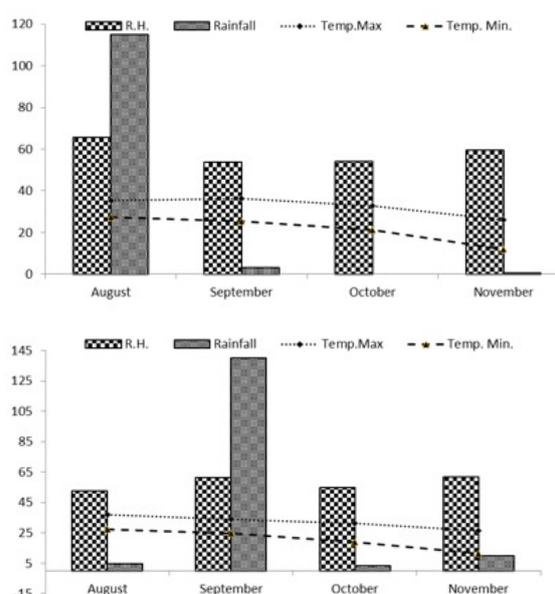
## Materials and Methods

### Site and soil

The proposed study was conducted at the Agronomic Research Area, Department of Agronomy, University of Agriculture, Faisalabad, Pakistan (Latitude 31.25° N, longitude 73.09° E and Altitude 184.4 m) during 2013 and 2014. Physico-chemical analysis of soil before sowing of maize crop for both years revealed that the site soil have 0.67-0.69%, 0.035%, 8.5-9.8 ppm and 205-210 ppm organic matter, total nitrogen, available phosphorus and available potassium, respectively. Soil texture type was sandy clay loam having 8.0 pH and 0.56-0.60 dS m<sup>-1</sup> electrical conductivity. Meteorological data (monthly precipitation, relative humidity, minimum and maximum temperature) during the growing seasons of 2013 and 2014 were obtained from Agricultural Meteorology Cell (Department of Agronomy, University of Agriculture, Faisalabad, Pakistan) located near the experimental field (Figure 1).

### Crop husbandry

Laser land leveling was carried out before soil preparation. During both years, seed bed was prepared by cultivating the soil 2-3 times with the tractor mounted cultivator followed by planking to make it flat. Maize hybrid 30R50 was used as a test crop. The crop was sown on 75 cm apart ridges with plant to plant distance of 20 cm. Seed rate of 20 kg ha<sup>-1</sup> was used. Nitrogen, phosphorus and potassium at the rate of 250, 120 and 125 kg ha<sup>-1</sup> were applied in the form of urea, diammonium phosphate (DAP) and sulphate of potash (SOP), respectively. 1/5<sup>th</sup> of N and whole of P and K was applied by broadcast method and incorporated into soil at the time of final seed bed preparation whereas remaining doses of N (one bag



**Figure 1** Meteorological data of field for the growing period of crop in 2013 and 2014

on every application) were applied at crop height of 1 foot, at 2 feet, at 3 feet and at tasseling stage (5-7 days before tasseling) by fertigation method. In total, eight irrigations, each of three acre inches, were applied to the crop. Five density treatments of *Alternanthera philoxeroides* including 0, 1, 2, 4 and 8 plants m<sup>2</sup> were maintained to evaluate the maize yield losses at different densities and to determine ETL.

### Data collection and statistical analysis

$$Y = Y_{vf} \left( 1 - \frac{ixd}{100(1 + i \times d)} \right) \quad (1)$$

Data regarding *A. philoxeroides* dry weight and uptake of NPK were recorded. Maize growth, yield and quality traits including plant height, 100-grain weight, biological yield, grain yield, protein and oil contents were also determined. Nitrogen in *A. philoxeroides* was analyzed according to Jackson (1962), while phosphorus was analyzed using the vanadate-molybdate spectrophotometric procedure (Jones *et al*, 1991). Potassium was determined by a flame photometer (Chapman and Pratt 1961). Mzize grain oil content was determined by using method Soxhlet method as described by Low (1990). Nitrogen content of maize grain samples was determined by using micro-Kjeldhal distillation method (Anonymous, 1980) and then the crude protein contents in grains were calculated by using the following formula.

$$\% \text{ Crude protein} = \% \text{ Nitrogen} \times 6.25 \quad (2)$$

A nonlinear hyperbolic regression model (Eq. 1) (Cousens 1985) was fitted to analyze the relationship between rice yield ( $Y$ ) and *A. philoxeroides* density ( $d$ ). The model equation was as follow:

Where  $Y$  is the simulated rice yield at particular density of *A. philoxeroides*,  $Y_{wf}$  is the weed free crop yield,  $i$  is the percentage yield loss per unit of *A. philoxeroides* density ( $d$ ),  $d \rightarrow 0$ ,  $A$  is the asymptotic value of the maximum yield loss (%) as  $d \rightarrow \infty$ .

Economic threshold level (ETL) of *A. philoxeroides* was estimated by using the cost of controlling this weed with the value of rice grain yield achieved by herbicide application. Cousens (1987) equation 2 was used to calculate ETL.

$$ETL = (Ch + Ca) / (Y_{wf} PLH)$$

**Table 1. Dry weight and nutrients uptake of *A. philoxeroides* (kg ha<sup>-1</sup>) at its different densities in maize**

A. philoxeroides density (m <sup>-2</sup> )	Dry weight (g m <sup>-2</sup> )	N uptake (kg ha <sup>-1</sup> )	P uptake (kg ha <sup>-1</sup> )		K uptake (kg ha <sup>-1</sup> )
	Average of two years	2013	2014	Average of two years	
Zero (Control)	-----	-----	-----	-----	-----
1	8.56 d	2.42 d	1.96 c	1.68 d	1.84 c
2	13.66 c	3.52 c	2.62 c	2.41 c	2.76 b
4	23.37 b	5.47 b	4.18 b	3.97 b	4.52 b
8	44.28 a	9.02 a	7.91 a	6.86 a	7.99 a
HSD	2.74	1.050	1.147	0.591	0.598

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

Where  $Ch$  is herbicide cost (US\$ ha<sup>-1</sup>),  $Ca$  is herbicide application cost (US\$ ha<sup>-1</sup>),  $Y_{wf}$  is weed free rice yield (t ha<sup>-1</sup>),  $P$  is value per unit of crop (US\$ t<sup>-1</sup>),  $L$  is proportional loss per unit *A. philoxeroides* density, and  $H$  is herbicide efficacy (a proportional reduction in *A. philoxeroides* density by herbicide treatment).

Data of the rice and *A. philoxeroides* were statistically analyzed by using Fisher's analysis of variance techniques (Steel *et al*, 1997). The honestly significant difference (HSD) test was applied at 5% probability level to test the significance of treatment means. The parameters in which the year effect was non-significant the data of two years were thus pooled-up to get average.

## Results and discussions

### *Alternanthera philoxeroides* dry weight (g m<sup>-2</sup>) and uptake of NPK (kg ha<sup>-1</sup>) at different densities in maize

Varying densities of *A. philoxeroides* had a significant effect on its dry weight per unit area (Table 1). A perusal of data displayed that *A. philoxeroides* dry weight had a gradual rise with increase in its density from 1 to 8 plants m<sup>-2</sup>. The significantly highest dry weight (44.28 g m<sup>-2</sup>) of *A. philoxeroides* was produced at density of 8 plants m<sup>-2</sup> which was followed by that of *A. philoxeroides* density level of 4 plants m<sup>-2</sup>. However, the lowest *A. philoxeroides* dry weight of 8.56 g m<sup>-2</sup> was observed at a density of 1 plant m<sup>-2</sup>. Increase in density increased weed dry weight per unit area due to more number of plants of weeds (Mamun *et al*. 2013). According to studies by Mehmood *et al*. (2015) increasing *A. philoxeroides* density in rice field had linear increase in *A. philoxeroides* dry weight.

Year effect on N and K uptake by *A. philoxeroides* was non-significant, therefore data were pooled and average data were discussed. However, year effect regarding P-uptake by *A. philoxeroides* was found to be significant therefore data of individual years were given and discussed. A successive linear increase in N-uptake by *A. philoxeroides* was observed by increasing its density from 1 to 8 plants m<sup>-2</sup> (Table 1). *Alternanthera philoxeroides* at density of 8 plants m<sup>-2</sup> attained significantly the highest uptake of N (9.02 kg ha<sup>-1</sup>). It was followed by that of 4 plants m<sup>-2</sup> (5.47 kg ha<sup>-1</sup>) of *A. philoxeroides*. The minimum N uptake by *A. philoxeroides* (2.42 kg ha<sup>-1</sup>) was recorded at its density of 1 plant m<sup>-2</sup>. Results regarding P uptake by *A. philoxeroides* also showed a linear increasing trend as *A. philoxeroides* density was increased from 1 to 8 plants m<sup>-2</sup>. The highest P uptake (7.91 and 6.86 kg ha<sup>-1</sup>) by *A. philoxeroides* was noted at density of 8 plants m<sup>-2</sup> during year 2013 and 2014, respectively. The lowest P uptake (1.96 kg ha<sup>-1</sup> in 2013 and 1.68 kg ha<sup>-1</sup> in year 2014) was obtained in plots where *A. philoxeroides* density was kept minimum (1 plant m<sup>-2</sup>). The K uptake was also significantly affected by *A. philoxeroides* density. Mehmood *et al*. (2017) reported significant dry biomass increase and uptake of NPK with increasing density of *A. philoxeroides* in transplanted rice. Similar to N and P, K uptake was increased significantly in a linear trend. Previously it has been reported that N, P and K uptake by broad-leaf weeds (*Datura stramonium* L., *Cannabis sativa* L., *Amaranthus chlorostachis* Willd., *Chenopodium album* L. and *Chenopodium hybridum* L.) was enhanced with increasing their densities in maize crop (Lehoczky and Reisinger, 2003). Amer and

Zahid (2006) recorded highest N uptake (86.34 kg N ha<sup>-1</sup>) by *Echinochloa crus-galli* at 16 barnyard grass plants m<sup>-2</sup> in rice crop as compared to low densities.

### Maize growth and yield

Results shows that *A. philoxeroides* caused significant reduction in plant height of maize with increasing *A. philoxeroides* density. The tallest plants of maize (263.14 cm) were produced in control treatment where no *A. philoxeroides* plant was allowed to compete with crop (Table 2). No statistically significant reduction in plant high was observed until *A. philoxeroides* density was raised beyond 2 plants per m<sup>2</sup>. The succeeding

*roides* density from 0 to 8 plants m<sup>-2</sup> could be the result of stress by *A. philoxeroides* competition especially at grain filling stage of maize. Two-year means data regarding number of grains and grain weight per cob of maize (Table 2) showed that *A. philoxeroides* density significantly influenced it. A gradual reduction in number of grains and grain weight per cob of maize was observed with increase in *A. philoxeroides* density. Maize plants from weed free plots (control) produced the maximum number of grains (437.8) and grain weight (193.4 g) per cob. This value did not statistically decrease until *A. philoxeroides* density reached up to 2 plants m<sup>-2</sup>, whereas, the minimum number of

**Table 2 Effect of different densities of *A. philoxeroides* (plants m<sup>-2</sup>) on growth and yield attributes of maize**

A. philoxeroides density (m <sup>-2</sup> )	Plant height (cm)	100-grain weight (g)	Number of grains per cob	Grain weight per cob (g)	Biological yield (t ha <sup>-1</sup> )		Grain yield (t ha <sup>-1</sup> )	Grain yield losses (%)
					2013	2014		
Average of two years					2013	2014	Average of two years	
Zero (Control)	437.8 a	37.83 a	437.8 a	193.4 a	26.30 a	24.67 a	9.43 a	----
1	402.4 ab	34.64 b	402.4 ab	184.2 a	24.63 ab	22.89 ab	8.67 b	8.06
2	369.9 bc	33.73 bc	369.9 bc	171.1 b	23.43 bc	21.43 bc	7.94 c	15.82
4	353.2 c	33.37 bc	353.2 c	161.4 b	21.26 c	19.56 c	7.08 d	24.95
8	335.1 c	31.44 c	335.1 c	145.7 c	18.56 d	16.95 d	6.08 e	35.46
HSD	38.323	2.611	38.323	12.625	2.174	2.286	0.574	

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

reduce in plant height of maize with increase in *A. philoxeroides* density could be the result of increased inter-specific competition between crop and *A. philoxeroides* for similar growth resources. More weed dry weight and NKP uptake at higher density might be also reason for less maize height. These results are in accordance with those of Sarabi et al, (2013) who recorded that plant height of maize reduced significantly at 16 to 20 *C. album* plant density (m<sup>-2</sup>). In another study, Hussain et al, (2011) observed that plant height of forage maize raised with increase in plant density of *X. strumarium* from 0 to 6 plants m<sup>-2</sup> but it gradually declined when density of this weed was raised beyond 6 plants m<sup>-2</sup>.

The 100-grain weight of maize given in table 4 indicated a significant decrease with increasing density of *A. philoxeroides*. The highest 100-grain weight (37.83 g) of maize was attained from plots which were kept weed free. *A. philoxeroides* even at very low density (1 plant m<sup>-2</sup>) caused significant decrease in 100-grain weight of maize (Table 2). The minimum 100-grain weight (31.44 g) of maize was recorded at *A. philoxeroides* density of 8 plants m<sup>-2</sup>. The significant reduction in 100-grain weight of maize by increasing *A. philoxe-*

grains (335.1) and grain weight (145.7 g) per cob was produced at 8 plant m<sup>-2</sup> density of *A. philoxeroides*. Karimmojeni et al, (2010) also recorded a linear decline in grain weight of maize with *D. stramonium* at 4, 8, 12 and 16 plants m<sup>-2</sup> densities. Kiranjit et al, (2016) reported that increasing weed competition in maize caused decline in 100 grain weight, number of grains and grain weight per cob.

Biological yield of maize was significantly influenced by different *A. philoxeroides* densities during both years of study, with significant year effect (Table 2). The maximum biological yield (26.30 and 24.67 t ha<sup>-1</sup>) of maize was obtained with weed free control during 2013 and 2014, respectively. There was significant reduction in biological yield of maize as *A. philoxeroides* density increased from 2 to 8 plants m<sup>-2</sup>. However, minimum values (18.56 and 16.95 t ha<sup>-1</sup>) of this parameter were noted at the maximum *A. philoxeroides* density (8 plants m<sup>-2</sup>) during years 2013 and 2014, respectively. Decline in biological yield of maize by enhancing *A. philoxeroides* density may be attributed to lessen in growth and yield attributing parameters. A linear reduction in biological yield of maize fodder with increase in *X. strumarium* density from 0 to 12 plants

m<sup>2</sup> has also been recorded by Hussain et al, (2011). Saeed et al. (2012) reported that with increasing density of *T. portulacastrum* the biological yield of maize was decreased. Saleem et al, (2016) reported significant reduction in biological yield of maize due to weed competition; minimum maize yield was achieved in full season weed-crop competition plots.

The final grain yield of a crop is collective of different yield components. It is obvious from the data that grain yield of maize depicted significant reducing trend with rise in *A. philoxeroides* density. The highest grain yield (9.43 t ha<sup>-1</sup>) of maize was achieved from weed free plots. However, it tended to show significant reduction from *A. philoxeroides* density of 1 plant m<sup>-2</sup>. While, maize grain yield was significantly less (6.08 t ha<sup>-1</sup>) in plots where *A. philoxeroides* density was 8 plants m<sup>-2</sup>. The table (2) depicted that maize grain yield was declined ranging from 8.06 to 35.46 % with *A. philoxeroides* density from 1-8 plants m<sup>-2</sup>. Decline in grain yield of maize due to rise in weed density is explained by the observed reduction in yield components. The main yield components which contributed towards more grain yield of maize seem to be the number of grains per cob, 100-grain weight and grain weight per cob. Significant decline in grain yield of maize by increasing *Amaranthus retroflexus* density from 0 to 65 plants per meter per crop row was reported by Sheibany et al, (2009). Likewise, Karimmojeni et al, (2010) recorded a linear decrease in maize grain yield with increase in densities of *X. strumarium* or *D. stramonium* from 4 to 16 plants m<sup>-2</sup>. They also indicated that main grain yield loss by *X. strumarium* was owing to weed competition during early growth stage resulting in greater decrease in grain number. Though, *D. stramonium* owing to its indeterminate growth habit presented more competition during grain filling stage thus resulted further decrease in grain weight of maize. The raise in crop yield loss of maize due to rise in *A. philoxeroides* density might be due to more competition stress practiced by maize plants as weeds limit the resource base area for crop plants. Mehmood et al, (2017) reported significant decrease (21 to 23%) in grain yield of transplanted rice due to *A. philoxeroides* interface at varying densities. Our results are analogous with those of Saeed et al, (2010b) who also observed that percent grain yield reduction in maize enhanced with increasing *T. portulacastrum* density m<sup>-2</sup>. A grain yield loss from 4 to 30% in maize was noted with different density levels of *T. portulacastrum*. These research findings are also in close agreement with those of Sarabi et al, (2013) who concluded that maize grain yield losses were more than 70% at higher plant densities (16 to 20 plant m<sup>-2</sup>) of common lambsquarters (*C. album*).

**Table 3 Effect of different densities of *A. philoxeroides* (plants m<sup>-2</sup>) on grain protein and oil content (%) of maize.**

<i>A. philoxeroides</i> density ( plants m <sup>-2</sup> )	Protein content (%)	Oil content (%)
<b>Average of two years</b>		
Zero (Control)	10.73 a	3.01
1	10.34 ab	3.97
2	10.01 bc	3.94
4	9.57 c	3.94
8	8.86 d	3.94
HSD	0.491	NS

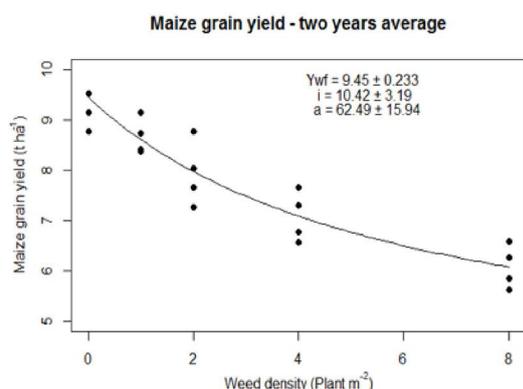
Means sharing different letters in a column differ significantly according to Tukey's honestly significant difference (HSD) test ( $p < 0.05$ ). NS indicate non-significant.

### Grain protein and oil content (%) of maize

The data depicted that *A. philoxeroides* densities significantly influenced grain protein content of maize (Table 3). Highest grain protein content (10.73%) was recorded in maize plants harvested from weed free control plots. A significant decline in grain protein content started to occur at *A. philoxeroides* density of 2 plants m<sup>-2</sup>. However, lowest grain protein content (8.86 %) of maize was recorded at *A. philoxeroides* density of 8 plants m<sup>-2</sup>. The decline in grain protein content with increasing *A. philoxeroides* density was attributed to decreased N uptake by maize due to increased crop-weed competitiveness. The grain oil content of maize as affected by different *A. philoxeroides* densities are given in (Table 3). Response of oil contents were statistically non-significant however more oil contents were calculated at low weed density and weedy free plots as compared to plots having more weed density. Protein content in maize grain improved due to greater availability of N and P at a lower weed density as compared to higher density, which in turn increased N content of grain partly due to the accelerating effect of this nutrient on protein synthesis. Pooryousef-Myandoab et al, (2011) had noted a decrease in protein content of maize grain with increasing density of *C. album* weed. According to Mehmood et al (2017) the extent of increase in total grain protein content varied at different density levels of *A. philoxeroides* from minimum (5.98-6.82 %) at the higher density level and maximum (6.98-8.12%) recorded at the zero level of alligator weed

### Grain yield losses and ETL

By fitting the rectangular hyperbola to maize grain yield, the estimated weed-free grain yield ( $Y_{wf}$ ) of maize was 9.45 t ha<sup>-1</sup> (Figure 2). The "i" is the percent decrease of yield reduction with unit increase of *A. philoxeroides* density and "a" is the maximum yield reduction (62%)



**Figure 2** Non-Linear regression between maize grain yield and *A. philoxeroides* density

when 8 plants  $m^{-2}$  of *A. philoxeroides* was maintained in maize crop. There was good agreement between predicted and observed yield as *A. philoxeroides* density increased, showing that competition between maize and *A. philoxeroides* was described well by the hyperbolic model.

Keeping the herbicide cost US\$ 14.98, application cost US\$ 9.91, value per unit of crop US\$ 75; ETL of *A. philoxeroides* was estimated to be 0.47 plants per  $m^2$  (Table 4). The herbicide efficiency irrespective of year and herbicide was presumed to be 0.72.

**Table 4** Parameter estimates and economic threshold Level (ETL) of *A. philoxeroides* in maize

Year	Ch+Ca (US\$)	Y <sub>0</sub> (t ha <sup>-1</sup> )	P (US\$ ton <sup>-1</sup> )	L	H	ET (plants m <sup>-2</sup> )
Two year Average	14.98 + 9.91	9.45	75.07	0.1042	0.72	0.47

C<sub>n</sub> = herbicide cost, Ca = application cost, Y<sub>0</sub> = weed free corn yield, P = value per unit of crop, L = proportional loss per unit weed density, and H = herbicide efficacy

The price of harvested product is major aspect to determine the ETL, the high value to maize grain and more biomass due to spreading nature of *A. philoxeroides* was major reason for low ETL of this weed. Recently, ETL of *A. philoxeroides* was estimated 1.5 plants per  $m^2$  in transplanted rice (Mehmood et al, 2017). Safdar et al, (2015) reported significant grain yield losses of maize at low density (1 plant  $m^{-2}$ ) of *Parthenium hysterophorus*. Findings are also supported by Tironi et al, (2016), they reported that higher economic value of sugarcane reduced the weed ETL to very low level. They also concluded that cost and efficacy of weed control method influence the ETL, higher cost and fewer efficacies increase the ETL level and the other way around.

The ETL of *A. philoxeroides* could be more less if the seed production of this weed is also included, because even less number of weed can produce many seeds that could cause significant loss in subsequent crop. When the seed production variable was considered, the ETL of *B. brizantha* reduced to very small number of weed plants  $m^{-2}$  (Parsons et al, 2009). Further studies related to ETL of *A. philoxeroides* should also consider the seed production variable to establish the optimal ETL.

Additionally, strong allelopathic potential of *A. philoxeroides* might also be a major factor for low ETL of this weed (Abbas et al, 2017). Kwon et al, (2008) estimated the 3.4 and 4.6 plant  $m^{-2}$  ETL densities for *E. crus-galli* and *S. planiculmis*, respectively. The economic threshold of *A. philoxeroides* was 4.02 plants  $m^{-2}$  when manual weed control was adopted for its control in garlic (*Allium sativum*) fields (Shou-hui et al, 2008). These studies indicate that weed species have different modes of growth, reproduction and levels of threshold density (Onofri and Tie, 2006). Farmers should control this weed completely in maize fields to reduce yield losses.

The current findings conclude that *A. philoxeroides* caused strong competition in maize due to high biomass production and NPK uptake. It significantly reduced maize growth, yield and quality of grains. The estimated ETL of this weed in grain maize is 0.47 plants  $m^{-2}$ . Complete control of this weed is suggested to tackle yield losses in maize.

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