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Estimation of economic threshold for *Lathyrus aphaca* L. in wheat

Muhammad Aamir[1*], Ejaz Ahmad Khan[1], Mohammad Safdar Baloch[1], Muhammad Aslam[2]

[1] *Department of Agronomy, Faculty of Agriculture, Gomal University, Dera Ismail Khan, KPK, Pakistan*

[2] *Arid Zone Research Institute, Bhakkar, Punjab Pakistan*

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Abstract

For better weed management, knowledge of threshold weed density is very important. It gives us an idea to decide a suitable weed control method at proper time to stop economic loss. To avoid crop yield losses, assessment of weeds densities and their control by a successful method is extremely important in crop production. In this regard, a randomized complete block design field experiment was initiated during Rabi 2013-14 and 2014-15. The proposed study was comprised of 0, 4, 8, 16, 32, 64 and 128 plants of *L. aphaca* in m^{-2}. Data regarding leaf area, plants growth, height, spike bearing tillers, spike length, 1000-grain weight, biological and grain yield, harvest index, grain yield loss, relative competitive index, and economic threshold of *L. aphaca* were recorded by following standard procedures. Results showed that all *L. aphaca* density levels reduced wheat plant growth, yield and all yield contributing traits. Obviously, higher growth, yield and yield related traits were noted in controlled wheat plots. Among different *L. aphaca* density levels, more wheat leaf area index, crop growth rate, plant height (101.93. 101.35 cm), spike bearing tillers (400, 390), spike length (8.30, 8.25 cm), 1000-grain weight (45.30, 44.83 g), biological yield (11767, 11391 kg/ha), grain yield (4958, 4781 kg/ha) and harvest index (41.82, 42.0%) were observed at *L.* 4 plants of *aphaca* m^{-2} during both years. Minimum all these traits were recorded 128 plants of *L. aphaca* m^{-2}. The economic threshold level for *L. aphaca* in wheat was recorded 4.52 and 3.94 plants m^{-2} in the years 2013-14 and 2014-15, respectively. In conclusion, to prevent economic loss, *L. aphaca* must be controlled when density level exceeds 3.94 plants m^{-2}.

* **Corresponding Author:** Muhammad Aamir ✉ aamiruaf1530@gmail.com

Introduction

Weed invasion remains the key detriment and pervasive risk to high wheat production in Pakistan. Weeds can cause yield loss in wheat up to 48% (Khan and Haq, 2002). However, the extent of weeds-related reduction or loss depends on the density and type of a specific weeds species, their emergence time and duration of interference (Estorninos *et al*., 2005; Hussain *et al*., 2015; Fahad *et al*., 2015). Crops yield generally turns down with increased weeds density and extent of interference; and severe yield losses are observed when weeds and crops emerge at the same time (Zimdahl, 2007). Information regarding interference of weeds has a very important role to forecast crop yield losses due to weeds influx and to design suitable and sustainable weeds management system (Fahad *et al*., 2014).

It is observed that 45 species of weeds prevailed in wheat fields of throughout Pakistan (Hussain *et al*., 2017). Among various major weeds, *Lathyrus aphaca* L. (locally called crow pea.) has been identified as the emerging destructive and challenging broad leaf weed in wheat crop due to its survival aptitude under diverse climate conditions such as heat, water and drought stress. It is native to southern Europe, parts of Asia and North Africa; and has widely spread in many countries of the world (Sarker, 2011). It is a trailing or scrambling annual broadleaf weed of *Fabaceae* family having medium height (Marwat *et al*., 2013). With passage of time, it is becoming a main intimidation to sustainability and productivity of wheat growing areas (Chhokar *et al*., 2008).It is intricate to exterminate because it shatters seeds prior to crop maturity. The seeds buried or ploughed into soil, undergo dormancy and germinate/grow when conditions are suitable and favorable. It has small fibrous roots which have ability to penetrate into soil to a depth of several feet. It rigorously competes for growth resources such moisture; nutrient etc. and drastically decreases the wheat grain yield (Tiwari *et al*., 2016). The main reason of its wide spread incidence includes seed dispersal prior to wheat maturity, seeds dormancy for a longer period and, until recently, the lack of proficient and suitable herbicides for its successful control in wheat. The ability of dormant seeds to survive during rice period is a major fact for its prevalence in wheat-rice and cotton-wheat cropping system (Hussain *et al*., 2017).

Weed threshold studies provide an understanding of the crop-weed interaction. For better weed management, knowledge of threshold weed density is very necessary (Martin *et al.,* 2001). Threshold density level is the point in weed invasion (number or weight) at which crops yield tends to decrease. In weeds control, the significance of weed threshold level is constantly above board, because it is very helpful for the growers to use herbicides (Portugal and Vidal, 2009). Threshold density level is different for different types of weeds (Onofri and Tei, 2006). Assessment of weeds threshold level gives us a provocation to decide a suitable weed control method and time for specific weeds population to stop financial losses (Knezevic *et al.,* 2002). To evade or reimburse crops yield losses, assessment of weeds densities and their control by successful method is extremely essential in crop production (Deines *et al.,* 2004). There is no published data on *L. aphaca* and its respective interference and competitive ability against wheat. The objective of this study was to investigate economic threshold level of *L. aphaca* in wheat and effect of *L. aphaca* densities on growth and yield of wheat.

Materials and methods

Site and soil of experiments

Field experiment was conducted during the winter wheat growing season 2013-014 and 2014-115 on sandy loam soil with pH at 8.3 and 1.2% organic matter, at Research area of Arid Zone Research Institute Bhakkar (31.62^{o} N, 71.06^{o} E and 159 m ASL), Pakistan. Before conducting the experiments, seeds of *L. aphaca* were collected from several farmers' wheat fields in the Bhakkar District, Punjab, Pakistan.

Experimental treatments, design and crop husbandry

The experiment was comprised of 0, 4, 8, 16, 32, 64 and 128 plants of *L. aphaca* m^{-2}. Seeds of *L. aphaca* were planted in a higher number than the required densities. However, after stand establishment, *L aphaca* plants more than required densities were removed manually to maintain required density during both the years of study. The wheat cultivar "Gomal-2008" was seeded on November 16, 2014 and November 18, 2015 using seed rate of 125 kg ha^{-1} with man pulled hand drill at 25 cm row spacing. Experiments were arranged in a Randomized Complete Block Design (RCBD) with four replications. All weeds other than *L. aphaca* were eradicated by hand pull soon after emergence during the entire period of the experiment. The recommended dose of NPK (120-100-60 kg ha^{-1}) fertilizers was applied based on soil test recommendation. Fertilizer sources were Urea (46% N), Diammonium phosphate (46% P and 18% N) and potassium sulphate (50% K_2O and 18% S).Above ground biomass of *L. aphaca* from an area of 1 m^{-2} was harvested 5 days before wheat harvesting and fresh weight was also recorded.

Collection of data and statistical analysis

Data regarding leaf area, plants growth, height, spike bearing tillers, spike length, 1000-grain weight, biological and grain yield, harvest index, grain yield loss, relative competitive index, and economic threshold of *L. aphaca* were recorded by following standard procedures. In wheat, number spike bearing tillers of wheat were counted in an area of 1 m^{-2} when spikes were fully emerged from flag leaf sheath. Ten plants were harvested from each plot to measure plant height and spike length. Thousand grains were collected from each plot and weighed at 12.0% moisture content. The crop was harvested on May 5, 2014 and May 3, 2015 and allowed for sun drying for 5 days in the field to record the biological yield and then threshed. Grain yield was adjusted to 12.0% moisture content. Harvest index (HI) was calculated as the ratio of grain yield to the total biological yield.

For leaf area index, plant samples were taken from a randomly selected unit area of each plot starting from 45 days after sowing at fortnight interval until 105 days after sowing. The leaf area was measured with leaf area meter (JVC TK-5310) and leaf area index (LAI) was calculated according to the method of Hunt (1978) using following formulae:

Leaf area index (LAI) = $\frac{Leaf area}{Ground area}$

For crop growth rate, plant samples were taken from a randomly selected unit area of 1 m^{-2}starting from 45 days after sowing at fortnight interval until 105 days after sowing. The harvested samples were sun-dried and then transferred to oven at 70°C for 3 days until constant weight was gained. Crop growth rate was calculated by using formulae of Hunt (1978) as given below:

Crop growth rate (CGR) = $\frac{W2 - W1}{t2 - t1}$

where

W_1 = Plant dry weight at t_1

W_2 = Plant dry weight at t_2

t_1 = time of 1^{st} harvest in days

t_2 = time of 2^{nd} harvest in days

Relative competition index was calculated by following formula (Grace, 1995; Goldberg *et al.*, 1999)

Relative competitive index (RCI= $\frac{Yweedfree - Yweed}{Yweedfree}$

Where *weed free* is crop yield when crop is free from weed and *Yweed* is yield of crop when weed is present.

For yield loss (%), a rectangular, nonlinear, hyperbolic regression model (Cousens 1985) was fitted to the wheat yield data and *L. aphaca* density to analyze the relationship between the wheat yield loss (YL) and *L. aphaca* density (d):

YL = $\frac{(id)}{\{1+\left[\frac{id}{A}\right]\}}$

where YL is the percentage of wheat grain yield loss due to crow pea, *i* is the percentage of yield loss per unit of weed density (*d*) as *d* →0, *A* is the asymptotic value of the maximum yield loss (%), as *d* → ∞'.

To calculate the economic threshold level (ETL), wheat grain yield estimated yield (Y_o) and weed competitively (β), whose reciprocal (1/β) is the *L. aphaca* density that reduces wheat grain yield by

50%, was calculated by nonlinear regression by using Cousens' model to determine the relationship between *L. aphaca* density (X) and grain yield (Y). ETL of *L. aphaca* was also calculated by using Cousens' equation:

$$ETL = \frac{Ch + Ca}{Y0 \times P \times L \times H} \quad \text{equation-2}$$

where ETL = economic threshold level(plants per m^{2}), Ch = cost of herbicide (Metsulfuron methyl + tribenuron methyl at 10 g a.i ha^{-1}) in US-dollars ha^{-1}, Ca= herbicide application cast in US-dollars ha^{-1},Y_0 = estimated weed free wheat grain yield (ton ha^{-1}), P = price of wheat grain (US-dollars ton^{-1} of grain yield);L = proportional wheat grain yield loss at each *L. aphaca* density per unit of plant and H = herbicide efficiency level (%). Estimated weed free wheat grain yield (Y_0) was considered as the average yield of 5.08 ton ha^{-1}. The price paid for wheat grain yield (P) was estimated from the value announced by Govt. of Pakistan during 2012-13 and 2013-14, which was $312.50 ton^{-1}. The value for herbicide efficiency (H) was established on 95 of control; a minimum of 80% weeds control is considered effective.

The collected were analyzed statistically by applying a computer package program MSTATC (Freed and Eisensmith, 1989) and treatments means were compared by employing least significant test at 5% probability level (Steel *et al.*, 1996). Graphical presentation of data were made in micro soft excel sheet.

Results and discussion

Plants leaf area index and growth rate

Plant leaves are one of the essential plant organs and are linked with photosynthesis and evapotranspiration. Hence, the measurement of leaf area and crop growth rate is necessary in agronomic and physiological studies. Leaf area index (LAI) and crop growth rate (CGR) increased with passage of time and reached its maximum limit till active growth period of crop and then begin to decline. Data showed that LAI and CGR of wheat decreased as *L. aphaca* density level increased. Obviously, wheat free from *L. aphaca* produced more LAI and CGR during both years of study. While among effect of *L. aphaca* densities on LAI and CGR of wheat, maximum LAI and CGR was noted where *L. aphaca* density level was 4 plants m^{-2}followed by 8 plants m^{-2}and so on during both experimental years (Figs 1&2).

Minimum LAI and CGR of wheat crop were measured where 128 plants of *L. aphaca* were present in a unit area (m^{-2}) during both years of study. Higher LAI and CGR in weed free wheat were attributed due to earlier and better utilization of moisture, nutrients, space and solar radiations by wheat plants that resulted in better growth and development. While lower LAI and CGR in weed infested wheat plants were might be due to inter and intra plant competition for essential production resources, e.g., nutrients, water, light and physical space.

Table 1. Effects of *L. aphaca* densities on plant height, number of spike bearing tillers, spike length and 1000-grain weight of wheat.

L. aphaca densities	Plant height (cm)		Number of spike bearing tillers		Spike length (cm)		1000-grain weight (g)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
0plants m^{-2}	104.10 a	103.95 a	418 a	415 a	8.56 a	8.59 a	46.28 a	46.01 a
4 plants m^{-2}	101.93 b	101.35 ab	400 b	390 b	8.30 b	8.25 b	45.30 b	44.83 b
8 plants m^{-2}	100.02 c	99.40 bc	382 c	379 b	8.26 b	8.17 b	44.45 c	44.14 c
16 plants m^{-2}	97.02 d	96.50 c	360 d	355 c	8.21 b	8.01 b	43.28 d	43.16 d
32 plants m^{-2}	92.97 e	92.25 d	334 e	325 d	8.11 b	7.84 bc	42.01 e	41.66 e
64 plants m^{-2}	87.75 f	88.20 e	297 f	296 e	7.78 c	7.67 cd	39.76 f	39.84 f
128 plants m^{-2}	81.71 g	82.30 f	262 g	265f	7.51 d	7.45 e	37.35 g	37.19 g
LSD at 5%	0.99	2.91	9.96	13.99	0.23	0.30	46.28 a	46.01 a

Means sharing same case letter in a column do not differ significantly at P 0.05

These results are supported by Khaliq *et al.* (2013 and 2014) who recorded highest LAI and CGR in weeds free wheat crop while lowest LAI and CGR in weeds infested wheat crop. Similarly, Sahoo *et al.* (2017) reported more LAI weed free maize plants while minimum LAI in weed infested plants. Hassan and Khan (2012) investigated that wild oat (50 plants m^{-2}) significantly reduced leaf area of wheat.

Table 2. Effects of *L. aphaca* densities on biological yield, grain yield and harvest index of wheat.

L. aphaca densities	Biological yield (kg ha^{-1})		Grain yield (kg ha^{-1})		Harvest index (%)	
	2013-14	2014-15	2013-14	2014-15	2013-14	2014-15
0plants m^{-2}	11860 a	11425 a	5083 a	4913 a	43.22 a	43.00 a
4 plants m^{-2}	11767 a	11391 a	4958 b	4781 b	41.82 b	42.00 b
8 plants m^{-2}	11434 b	10922 b	4617 c	4476 c	40.37 c	41.00 c
16 plants m^{-2}	10799 c	10321 c	4245 d	4124 d	39.35 d	39.95 d
32 plants m^{-2}	10178 d	9640 d	3774 e	3676 e	37.10 e	38.15 e
64 plants m^{-2}	9538 e	8943 e	3293 f	3258 f	34.55 f	36.45 f
128 plants m^{-2}	8733 f	8191 f	2934 g	2849 g	33.57 g	34.77 g
LSD at 5%	271	318	52.94	82.47	0.87	0.65

Means sharing same case letter in a column do not differ significantly at P 0.05.

Wheat plants height (cm)

It was noted that *L. aphaca* densities progressively decreased height of wheat plants during both years of study. Maximum reduction plants height was recorded where 128 plants of *L. aphaca* were present in a unit area followed by 64 plants m^{-2} during both years of study (Table1). Taller wheat plants were noted where there was no any *L. aphaca* plant (control) during both years of study followed by 4 plants of *L. aphaca* (Table 1). Reduced wheat plant height at higher *L. aphaca* density level might be due to severe competition for nutrients, moisture and space, which suppressed wheat growth and development; and caused dwarfness. More plant height of wheat in weed free condition might be due to energetic start of seedlings catching more essential production resources, e.g., nutrients, water, light and physical space during entire growing season. The results of our study are supported by Khan *et al.* (2006) who said that height of wheat plant decreased in weed invaded plots as compared to weeds free wheat plants. Similarly, Oad *et al.* (2007) also depicted that *Morusalba*, *Avenafatua*, *Phalaris minor* and *Chenopodium album* reduced height of wheat plants at their higher densities. Sahoo *et al.* (2017) reported that weed free maize plant attained maximum height while minimum plant height was recorded in weed infested plants.

Table 3. Estimates for grain yield losses as affected by *L. aphaca*.

Parameter estimates (%)			
2013-14		2014-15	
i (SE)	*A* (SE)	*i* (SE)	*A* (SE)
2.60 (0.18)	42.40 (3.04)	2.67 (0.19)	41.97 (3.01)

i is the percent yield loss as weed density approaches zero, *A* is the asymptotic yield loss at high weed densities, and *SE* is the standard error.

Number of spike bearing tillers/m²

Number of spike bearing tillers in wheat is one of the imperative yield improving components, which boost the grain yield linearly in wheat crop. Data revealed that *L. aphaca* densities significantly reduced spike bearing tilers in wheat during both years of study (Table 1). Maximum tillers reduction in wheat was recorded where 128 plants of *L. aphaca* were present in a unit area followed by 64 plants of *L. aphaca*. Wheat crop produced more number of spike bearing tillers where there was no any *L. aphaca* plants (control) during both years of study followed by 4 plants of *L. aphaca* (Table 1). More number of spike bearing tillers in weed free plots might be due to the result of strong and vigorous seedlings, which took more available resources such as water, mineral nutrients, solar light interception and space etc.

Table 4. Estimation of economic threshold of *L. aphaca* in wheat.

ETL plants m^{-2}	H	L	P (US\$ ton^{-1})	Y_o (t ha^{-1})	Ch+Ca (US\$)	Year
4.52	90	0.0039	310.50	4.54	14.85+7.50	2013-14
	90	0.0047	320.15	4.33	15.20+7.90	2014-15

Ch = herbicide cost, Ca = application cost, Yo = weed free corn yield, P = value per unit of sorghum fodder, L = proportional loss per unit weed density, and H = herbicide efficacy.

The reduction in spike bearing tillers in crow pea infested wheat was due to resources stress like moisture, nutrients, space and light etc. during tillering stage. *L. aphaca* densities caused intra and inter specific competition in wheat due to which more mortality of wheat tillers occurred. These results are in line with the findings of Spink *et al.* (2000) who stated that tillering process in cereals is mostly influenced by the competition for moisture, mineral nutrients, sun light, space etc. as compared to genetic potential of crop. Many other researchers such as Tessema *et al.* (1996) reported that number of spikes in wheat reduced by increasing weed density. Fast *et al.* (2009) pointed out that different weed species significantly reduced number of spike bearing tillers in wheat. Similarly, Ihsan *et al.* (2014) investigated that weeds reduced number of fertile tillers in rice crop.

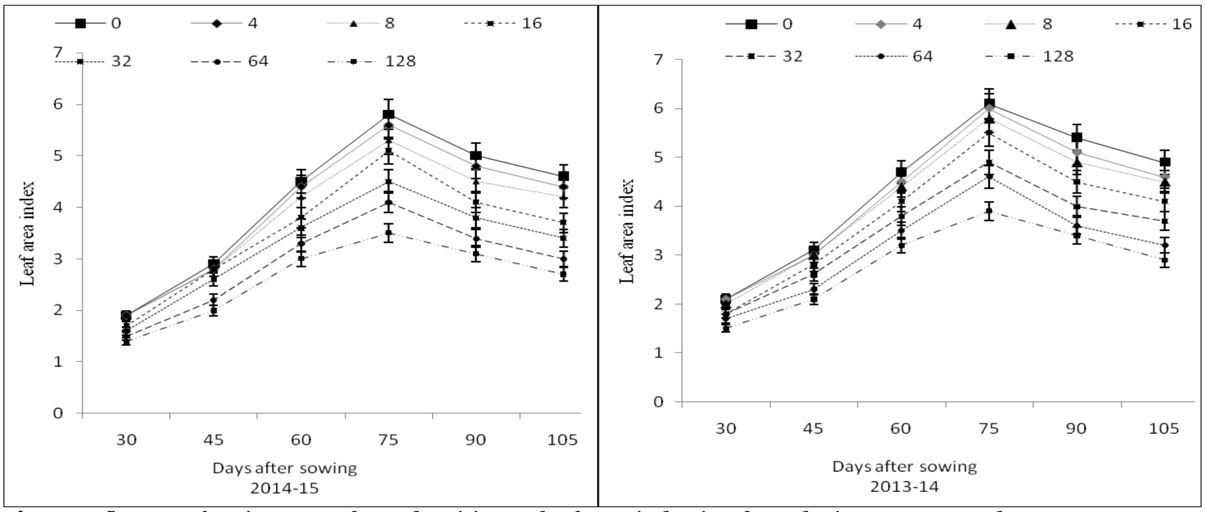

Fig. 1. Influence of various *L. aphaca* densities on leaf area index in wheat during 2013-14 and 2014-15.

Spike length (cm)

Wheat inflorescence is recognized as spike and its (spike) length has direct involvement in improving grain yield in wheat crop because larger spike could have a more number of grains. Data disclosed that as the *L. aphaca* densities increased, spike length decreased linearly. Although, all the *L. aphaca* densities decreased spike length of wheat but maximum spike length reduction was observed where 128 plants of *L. aphaca* were present in a unit area followed by 64 plants of *L. aphaca* (Table 1). Wheat plants free from *L. aphaca* (control) showed more spike length during both years of study followed by 4 plants of *L. aphaca* (Table1).More spike length in weed free wheat might be attributed due to the better simulative effect of the vegetative growth, which improved the photosynthetic rate and its translocation towards developing organs. Weed free wheat had no weed-crop competition and accumulated more obtainable environmental and ecological resources and resulted in better growth traits (Eldin *et al.*, 2016). These results are in line with findings of Tessema *et al.* (1996) Khan *et al.* (2008) and Mason *et al.* (2008) who reported that high weed density significantly reduced spike length.

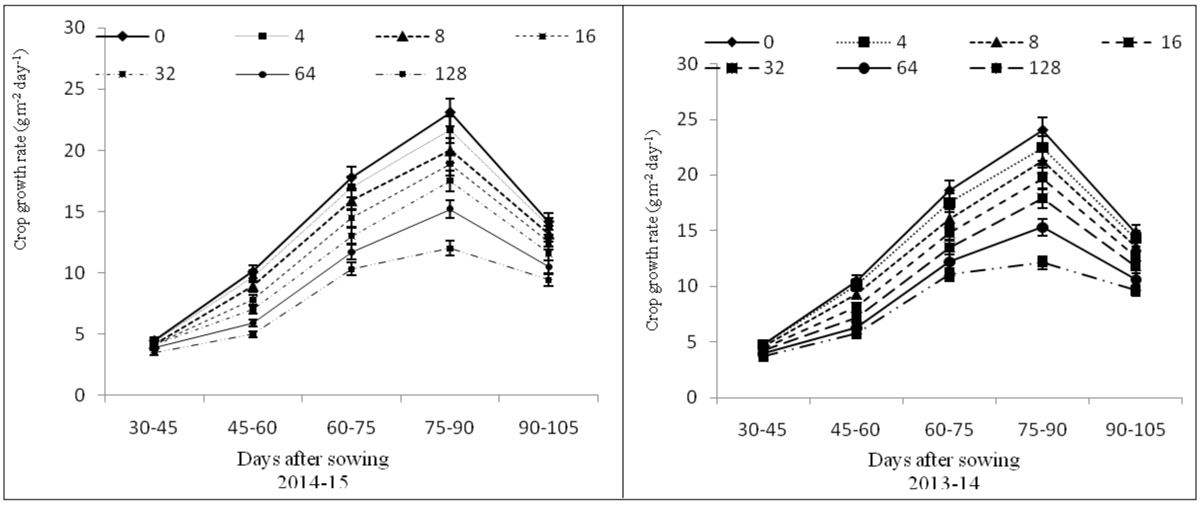

Fig. 2. Influence of various *L. aphaca* densities on crop growth rate in wheat during 2013-14 and 2014-15.

1000-grain weight (g)

In wheat crop, 1000-grain weight is considered as the most important yield contributing component of grain yield. It was noted that 1000-grain weight progressively decreased as *L. aphaca* densities increased. Although, all the *L. aphaca* densities reduced 1000-grain weight but more reduction was noted where 128 plants of *L. aphaca* were present in a unit area followed by 64 plants of *L. aphaca* (Table 1).

Higher 1000-grain weight was recorded where wheat plants were kept free from *L. aphaca* (control) during both years of study followed by 4 plants of *L. aphaca* in a unit area (Table 1).

The higher 1000-grain weight in weed free wheat was attributed due to optimum crop stand and favorable environment because wheat did not face weed-crop competition and continued its growth and development. Ultimately, the optimal crop population took adequate supply of all the growth resources for photo-assimilates and produced higher 1000-grain weight. Decrease in 1000-grain weight of wheat plants might be due to stress caused by *L. aphaca* during the post-an thesis and grain-filling stages that affected photosynthesis availability and translocation towards the developing grains thus resulting in poor grains weight.

These outcomes are supported by Oad1*et al.* (2007) who reported that higher densities of *Avena fatua*, *Melilotus alba* and *Chenopodium album* progressively lowered 1000-grain in wheat crop.

Alike, Ihsan1 *et al.* (2014) investigated that weeds decreased 1000-grain weight in rice crop Safdar *et al.* (2015) illustrated that 100-garin weight in maize crop diminished when parthenium weed density level 5 plants m^{-2} or above.

Biological and grain yield (kg/hectare)

Biological and grain yield are very important parameters for any crop to show its total output performance. Biological and grain yield also depend upon species, growing season and other different ecological and environmental factors. It was noted that biological and grain yield progressively decreased as *L. aphaca* densities increased from 4 plants per unit area to onward. More reduction in biological and grain yield was noted where 128 plants of *L. aphaca* were present in a unit area followed by 64 plants of *L. aphaca* (Table 2).

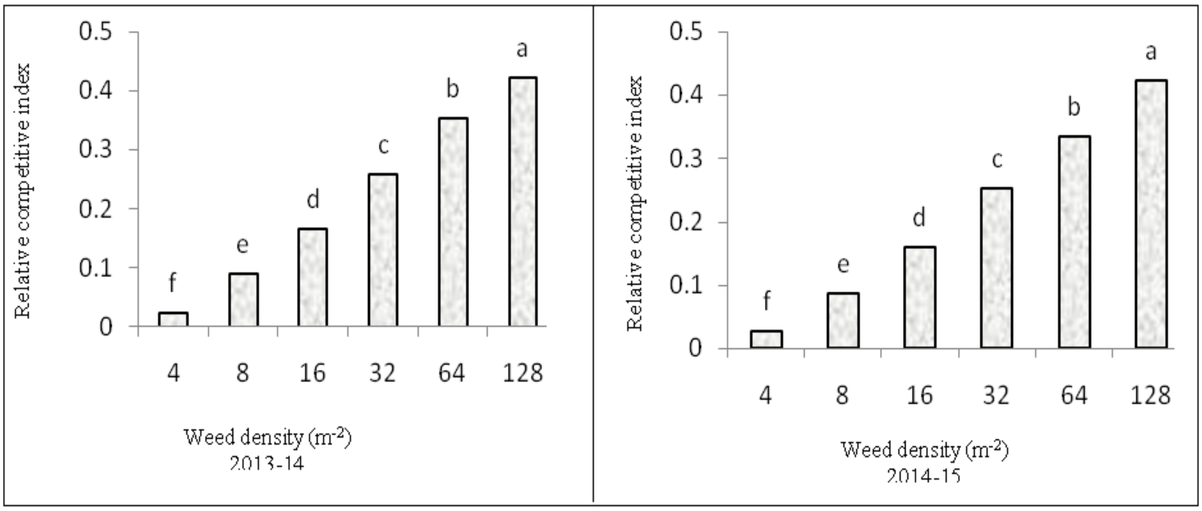

Fig. 3. Relative competitive index of wheat crop as affected by L. aphaca densities during 2013-14 and 2014-15. LSD value at 5% probability level for comparison 0.0106 (2013-14) and 0.0153 (2014-15).

More biological and grain yield was recorded where wheat plants were kept free from *L. aphaca* (control) during both years of study, which was statistically similar to where 4 plants of *L. aphaca* were present in a unit area (Table 2).

Higher biological and grain yield in *L. aphaca* free wheat plots might be due to that wheat plants enjoyed unshared necessary growth resources throughout growing season and produced more, leaf area, plant height, tillers and other yield contributing components. Thus, due to improvements in all yield contributing traits, wheat produced higher biological and grain yield. These results are in line with findings of Abbas *et al.* (2010) who investigated that high density of *E. australis* progressively minimized biological yield of wheat. Alike, Oljaca *et al.* (2007) depicted that by increasing weeds density biological and grain yield significantly reduced. Saeed *et al.* (2012) also reported sever yield reduction in maize by increasing weed density. Similarly, Javaid *et al.* (2016) reported that *E. spinosa* and *E. australis* significantly decreased biological yield of yield. Armin and Asghripour (2011) described that wild oat at high density decreased grain yield of wheat by decreasing number of spike bearing tiller per plant and number of spike per unit area. Javaid *et al.* (2016) reported that wheat produced lower yield due to presence of weeds. Similarly, Siddiqui and Subhan (2004) reported lower wheat grain yield with the increase in weeds densities. Similarly, Sahoo *et al.* (2017) affirmed that weed free maize plant gave more grain yield while lower grain yield was recorded in weed infested plants.

Harvest index (%)

The physiological efficiency of plants to switch the total dry matter into grain yield is known as harvest index. Results showed that *L. aphaca* densities significantly affected harvest index of wheat during both years of study. Wheat crop showed maximum harvest index where there was no competition of *L. aphaca* (control) during both years of study followed by where 4 plants of *L. aphaca* were present in unit area (Table 2). Minimum harvest index was recorded where 128 plants of *L. aphaca* were present in a unit area followed by 64 plants (Table 2). More harvest index might be due to better growth of wheat, better utilization of nutrients, moisture and solar interception, higher photosynthesis rate, more remobilization of stem reserves and transportation of the photo-assimilates from vegetative tissues to the grains. While reduction in harvest index might be due to low wheat above-ground biomass, poor growth, lower efficiency of crop to translocate photo-assimilates from vegetative tissues to the grains due to weed-crop, inter and intra plant completion. Our results are in line with findings of Abbas *et al.* (2010) who accounted lower harvest index in wheat due to presence of weed (*E. australis*). Alike, Sahoo *et al.*

(2017) accounted that weed free maize plant showed maximum harvest index while minimum harvest index was witnessed in weed infested plants. Similarly, Javaid *et al.* (2016) illustrated that weeds densities significantly dropped off harvest index in wheat crop. Safdar *et al.* (2015) also stated harvest index of maize plants decreased when parthenium weed density level was above 5 plants m^{-2}.

Relative competitive index (RCI)

The RCI (Fig.3) showed a linear trend and increased as *L. aphaca* density increased. There was maximum competition index at *L. aphaca* density level of 128 plants m^{-2} during both years of study followed by 64. Minimum relative competitive index was noted at *L. aphaca* density level of 4 plants m^{-2}(Fig. 3).

The increase in yield reduction with increasing *L. aphaca* density might be due to sever weed-crop competition. Our findings are parallel with the results of Morales-Payan (2000), who stated 63% reduction in tomatoes yield with increasing 0-12 *parthenium* plants m^{-2}. Bridges *et al.* (1992) also reported 4 to 54% reduction in peanut yield as density of *Euphorbia heterophylla* increased from 1-32 plants in 5 m long row. Javaid *et al.* (2016) who affirmed that weeds competed with wheat and significantly decreased yield. Similarly, Cowan *et al.* (1998) maintained 0 to 2 and 0 to 100 plants m^{-1} of pigweed and barnyard grass respectively in soybean crop. Results of their study showed that barnyard grass had competitive index from 0 to 1 and pigweed had from 0.075 to 0.40. Similarly, Zubair *et al.* (2011) also reported yield loss due to weed–crop competition.

Wheat yield loss by model estimation

Data regarding wheat grain yield loss by model estimation due to *L. aphaca* densities has shown in Table 3. Table showed that at *i* parameter (when weed density is $d>0$), *L. aphaca* caused 2.60 and 2.67% wheat grain yield during 2013-14 and 2014-15, respectively. While at asymptotic weed density (when $d \rightarrow \infty$, maximum weed density), the estimation of wheat grain yield loss by *L. aphaca* was 42.40 and 41.97% during 2013-14 and 2014-15, respectively (Table 4). These findings are in line with those of Javaid *et al.* (2016) who investigated that higher yield loss (44 and 56%) occurred at asymptotic weed density with *Emex australis* and *Emex spinosa*, respectively.

Economic threshold of L. aphaca

The economic threshold level (ETL) of *L. aphaca* was calculated by estimating the herbicide cost of 14.85 US$ and 15.20 US$, application cost 7.50 US$ and 7.90 US$, value of wheat grain US$ 310.50 and 320.15 in 2013-14 and 2014-15, respectively. Herbicide efficiency was supposed to be 90% irrespective of the year. The economic threshold level (ETL) (Table 4) was estimated to be 4.52 and 3.94 plants m^{-2} in the years 2013-14 and 2014-15, respectively.

Studies showed that among different *L. aphaca* density levels, high wheat leaf area index, crop growth rate, plant height, spike bearing tillers, spike length, 1000-grain weight, biological yield, grain yield and harvest index were observed at *L.* 4 plants of *aphaca* m^{-2} during both years (2013-14 and 2014-15). Minimum all these traits were recorded in 128 plants of *L. aphaca* m^{-2}.

The economic threshold level for *L. aphaca* in wheat was recorded 4.52 and 3.94 plants m^{-2} in the years 2013-14 and 2014-15, respectively. The results of the present study will be helpful for wheat growers for economic control of *L. aphaca*. *L. aphaca* causes different losses at different densities. To prevent economic loss, *L. aphaca* must be controlled when density exceeds 3.94 plants m^{-2}.

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References

Abbas RN, Tanveer A, Ali A, Zaheer ZA. 2010.Simulating the effect of Emex australis densities and sowing dates on agronomic traits of wheat. Pakistan Journal of Agricultural Science **47(2),** 104-110.

Armin M, Asghripour M. 2011. Effect of plant density on wild oat competition with competitive and non- competitive wheat cultivars. Agricultural Sciences in China **10(10),** 1554-1561. https://doi.org/10.1016/S1671-2927(11)60151

Bridges DC, Brecke BJ, Barbour JC. 1992. Wild poinsettia (Euphorbia haterophylla) interference with peanut (Arachis hypogaea). Weed Science **40,** 37-42. https://www.jstor.org/stable/4045149

Chhokar RS, Singh S, Sharma RK. 2008. Herbicides for control of isoproturon resistant little seed canary grass (Phalaris minor) in wheat. Crop Protection **27,** 719-726. https://doi.org/10.1016/j.cropro.2007.10.004

Cousens R. 1985. A simple model relating yield loss to weed density. Annals of Applied Biology **107,** 239-252. https://doi.org/10.1111/j.1744-7348.1985.tb01567.x

Cowan P, Weaver SE, Swanton CJ. 1998. Interference between pigweed (Amaranthus spp.), barnyardgrass (Echinochloa crus-galli), and soybean (Glycine max). Weed Science **46,** 533-539. https://doi.org/10.1017/S0043174500091050

Deines SR, Dille JA, Blinka EL, Regehr DL, Staggenborg SA. 2004. Common sunflower (Helianthus annuus) and shatter cane (Sorghum bicolor) interference in corn. Weed Science **52,** 976-983. https://www.jstor.org/stable/4046771

Eldin B, Ahmed AM, Ahmed FE, Dessougi II. 2016. Assessments of the relationship between effective leaf area, yield components and protein content in wheat (Triticum aestivum L.) under water stress conditions at eastern Sudan. Scholars Journal of Agriculture and Veterinary Sciences **3,** 155-159.

Estorninos JEL, David R, Gealy, Edward E, Gbur, Ronald E, Talbert. 2005. Rice and red rice interference. II. Rice response to population densities of three red rice (Oryza sativa) ecotypes. Weed Science **53,** 683-9.

Fahad S, Hussain S, Saud S, Hassan S, Muhammad H, Shan D, Chen C, Wu C, Xiong D, Khan SB, Jan A, Cui K, Huang J. 2014. Consequences of narrow crop row spacing and delayed Echinochloa colona and Trianthema portulacastrum emergence for weed growth and crop yield loss in maize. Weed Research **54,** 475-483. https://doi.org/10.1111/wre.12104

Fast BJ, Medlin CR, Murray DS. 2009. Five cool-season annual grass weeds reduce hard red winter wheat grain yield and price. Weed Technology **23(2),** 206-213.

Freed RD, Eisensmith S. 1989. MSTAT-C, A software package for the design management, and analysis of agronomic experiments. Michigan State University, East Lansing, MI.

Goldberg DE, Rajaniemi T, Gurevitch J, Stewart-Oaten A. 1999. Empirical approaches to quantifying interaction intensity: competition and facilitation along productivity gradients. Ecology **80,** 1118-1131. https://doi.org/10.1890/0012-9658(1999)080[1118:EATQII]2.0.CO;2

Grace JB. 1995 On the measurement of plant competition intensity. Ecology **76,** 305-308. http://dx.doi./10.2307/1940651

Hassan G, Khan H. 2012. Effect of wild oats (avena fatua L.) density on wheat yield and its components under varying nitrogen regimes. Pakistan Journal of Botany **39,** 2585-2594.

Hunt R. 1978. Plant Growth Analysis. Edward Arnold, UK. p 26-38.

Hussain I, Ahmad HB, Rauf S, Aslam M, Aulakh AM. 2015. Effect of sowing time on quality attributes of wheat grain. International Journal of Biosciences **6,** 1-8.

Hussain I, Ahmad R, Farooq M, Wahid A. 2013. Seed priming improves the performance of poor quality wheat seed. International Journal of Agriculture and Biology **15,** 1343-1348. http://dx.doi.org/10.15192/PSCP.ASR.2014.3.1.1218

Hussain S, Khaliq A, Bajwa A, Matloob A, Areeb A, Ashraf U, Afeez A, Imran M. 2017. Crop growth and yield losses in wheat due to little seed canary grass infestation differ with weed densities and changes in environment. Planta Daninha **35,** e017162328. http://dx.doi.org/10.1590/s0100-83582017350100073.

Ihsan MZ, Khaliq A, Matloob A, El-Nakhlawy FS, Atta R, Ahmed A, Daur I, Aslam Z. 2014. Influence of herbicides applied alone or supplemented with manual weeding on weed growth, rice yield and grain quality in direct seeded rice (Oryza sativa L.). Philipp Agric Scientist **97,** 395-402.

Javaid MM, Tanveer A, Rashid A, Yaseen M. 2012. Studies on ecology, competition and control of two Emex species (Emex australis and Emex spinosa) in wheat (Triticum aestivum L.). Ph.D. Thesis, University of Agri. Faisalabad, Pakistan, p 101.

Javaid MM, Tanveer A, Ali HH, Shahid MA, Balal RM, Aqeel MA. 2016. Wheat yield loss in a two species competition with Emex australis and Emex spinosa. Planta Daninha **34,** 35-46. http://dx.doi.org/10.1590/S01008358201634010000 4

Khaliq A, Gondal MR, Matloob A, Ehsan Ullah, Hussain S, Murtaza G. 2013. Chemical weed control in wheat under different rice residue management options. Pakistan Journal of Weed Science **19,** 1-14.

Khaliq A, Hussain M, Matloob A, Tanveer A, Zamir SI, Afzal I, Aslam F. 2014. Weed growth, herbicide efficacy indices, crop growth and yield of wheat are modified by herbicide and cultivar interaction. Pakistan Journal of Weed Science **20(1),** 91-109.

Khan M, Haq N. 2002. Wheat crop yield loss assessment due to weeds. Sarhad Journal of Agriculture **18,** 443-453.

Khan I, Hassan G, Marwat K, Khan M. 2006. Inter specific competition of tall and dwarf wheat cultivars with wild oats (Avena fatua L.). Pakistan Journal of Weed Science **12(3),** 151-156.

Khan IA, Hassan G, Marwat KB. 2008. Interaction of wild oats (Avena fatua L.) with spring wheat (Triticum aestivum L.) seeded at different rates. Pakistan Journal of Botany **40(3),** 1163-1167.

Knezevic SZ, Evans SP, Blankenship EE, Van RC, Acker, Linsdquist IL. 2002. Critical period for weed control: the concept and data analysis. Weed Science **50,** 773-786. https://doi.org/10.1614/00431745(2002)050[0773:CPFWCT]2.0.CO;2

Martin SG, Van RC, Acker, Friesen LF. 2001. Critical period of weed control in spring canola. Weed Science **49,** 326-333. https://doi.org/10.1614/00431745(2001)049[0326:CPOWCI]2.0.CO;2

Marwat SK, Usman N, Rehman K. 2013. Weeds of Wheat Crop and Their Control Strategies in Dera Ismail Khan District, Khyber Pakhtun Khwa, Pakistan. American Journal of Plant Sciences **4(01),** 66-76.

Mason H, Goonewardene L, Spaner D. 2008. Competitive traits and the stability of wheat cultivars in differing natural weed environments on the northern Canadian prairies. The Journal of Agricultural Science **146(01),** 21-33. https://doi.org/10.1017/S0021859607007319

Mishra JS, Singh VP, Yaduraju NT. 2006. Wild onion (Asphodelus tenuifolius cav.) interference in lentil and chickpea crops and its management through competitive cropping. Weed Biology and management **6(3),** 151-156. https://doi.org/10.1111/j.1445-6664.2006.00211.x

Morales-Payan JP. 2000. Interference of increasing Parthenium hysterophorus L. population densities with tomato (Lycopersicon esculentum Mill.). In: Abstract of the 3rd. International Weed Science Congress. Foz do Iguaçu, p 73.

Oad F, Siddiqui M, Buriro U. 2007. Growth and yield losses in wheat due to different weed densities. Asian Journal of Plant Science **6,** 173-176. http://dx.doi.org/10.3923/ajps.2007.173.176

Oljaca S, Vrbnicanin S, Simic M, Stefanovic L, Dolijanovic Z. 2007. Jimson weed (Datura stramonium L.) interference in maize. Maydica **52(3),** 329-333.

Onofri A, Tei F. 2006. Competitive ability and threshold levels of three broad leaf weed species in sunflower. Weed Research **34,** 471-479. https://doi.org/10.1111/j.1365-3180.1994.tb02044.x

Portugal JM, Vidal RA. 2009. Economic levels of weed injury on crops: Concepts, definitions and calculation models. Planta Daninha **27(4),** 869-877. http://dx.doi.org/10.1590/S010083582009000400026

Saeed U, Marwat KB, Gul B, Hussain Z. 2012. Effect of weed density on leaf area index and biological yield of maize. Pakistan Journal of Botany **44,** 1939-1942.

Safdar ME, Tanveer A, Khaliq A, Riaz MA. 2015. Yield losses in maize (Zea mays) infested with parthenium weed (Parthenium hysterophorus L.). Crop Protection **70,** 77-82. https://doi.org/10.1016/j.cropro.2015.01.010

Sahoo TR, Hulihalli UK, Mangaraj S, Pradhan SR. 2017. Effect of weed control methods on growth, dry matter accumulation and yield of maize. International Journal of Agricultural Science and Research **7,** 241-246.

Sarker A, Kumar S, Bejiga G, Ahmed S, Nakkoul H. 2011. Genetic improvement of grass pea for low neurotoxin (b-ODAP) content. Food Chemistry Toxicology **49,** 589-600. https://doi.org/10.1016/j.fct.2010.06.051

Sester M, Delanoy M, Colbach N, Darmency H. 2004. Crop and density effects on weed beet growth and reproduction. Weed Research **44(1),** 50-59. https://doi.org/10.1046/j.1365-3180.2003.00372.x

Steel RGD, Torrie JH, Dickey DA. 1996. Principles and procedures of statistics: A biometrical approach, 3rd edition. McGraw Hill Co, New York.

Siddiqui MH, Oad FC, Jamro GH, Subhan F. 2004. Effect of planting time, planting density and weed control on the grain yield of bread wheat-Mehran-89. Indus Journal of Plant Science **1,** 188-191.

Spink JH, Semere T, Sparkes DL, Whaley JM, Foulkes MJ, Clare RW, Scott RK. 2000. Effect of sowing date on the optimum plant density of winter wheat. Annals of Applied Biology **137,** 179-188. https://doi.org/10.1111/j.1744-7348.2000.tb00049.x

Tessema T, Tanner D, Hulluka M. 1996. Grass weeds competition with bread wheat in ethiopia: I. Effects on selected crop and weed vegetative parameters and yield components. African Crop Science Journal **4(4),** 399-409.

Tiwari P, Kumar B, Kaur M, Kaur G, Kaur H. 2016. Phytochemical screening and extraction: A review. International Pharmaceuticals Science **1,** 98-106.

Zimdahl RL. 2007. Fundamentals of weed science. 3ª.ed. New York: Elsevier, p 151-6.

Zubair J, Safdar ME, Aziz A, Ashraf M, Akhtar N, Atif Ali A, Maqbool MM. 2011. Effects of weed crop competition period on weeds. Pakistan Journal of Weed Science Research **17(1),** 51-63.