

## WHEAT YIELD LOSS IN A TWO SPECIES COMPETITION WITH *Emex australis* AND *Emex spinosa*<sup>1</sup>

*Perdas de Rendimento do Trigo na Competição com Duas Espécies de Planta Daninha:  
*Emex australis* and *Emex spinosa**

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**ABSTRACT** - *Emex australis* and *E. spinosa* are significant weed species in wheat and other crops. Information on the extent of competition of the *Emex* species will be helpful to access yield losses in wheat. Field experiments were conducted to quantify the interference of tested weed densities each as single or mixture of both at 1:1 on their growth and yield, wheat yield components and wheat grain yield losses in two consecutive years. Dry weight of both weed species increased from 3-6 g m<sup>-2</sup> with every additional plant of weed, whereas seed number and weight per plant decreased with increasing density of either weed. Both weed species caused considerable decrease in yield components like spike bearing tillers, number of grains per spike, 1000-grain weight of wheat with increasing density population of the weeds. Based on non-linear hyperbolic regression model equation, maximum yield loss at asymptotic weed density was estimated to be 44 and 62% with *E. australis*, 56 and 70% with *E. spinosa* and 63 and 72% with mixture of both species at 1:1 during both year of study, respectively. It was concluded that *E. spinosa* has more competition effects on wheat crop as compared to *E. australis*.

**Keywords:** *Triticum aestivum*, yield loss, weed competition, *Emex australis*, *Emex spinosa*.

**RESUMO** - *Emex australis* e *E. spinosa* são espécies de plantas daninhas importantes para o trigo e outras culturas. Informações sobre o grau de competição das espécies do gênero **Emex** podem ser úteis para mensurar as perdas de rendimento do trigo. Foram conduzidos experimentos em campo para quantificar a interferência das densidades de plantas daninhas, testadas separadamente ou combinadas na proporção de 1:1, no crescimento e rendimento destas, nos componentes de rendimento do trigo e nas perdas no rendimento de grãos de trigo em dois anos consecutivos. A massa seca de ambas as espécies de plantas daninhas aumentou de 3 para 6 g m<sup>-2</sup> para cada planta daninha adicionada, ao passo que o número de sementes e o peso por planta diminuíram com o aumento da densidade de ambas as espécies de planta daninha, as quais causaram diminuição considerável nos componentes de rendimento - por exemplo, perfilhos com espigas, número de grãos por espiga, massa de mil grãos de trigo - com o aumento da densidade populacional das plantas daninhas. Com base na equação de regressão não linear hiperbólica, a perda de rendimento assintótico máximo na densidade de plantas daninhas foi estimada em 44 e 62% com **E. australis**, 56 e 70% com **E. spinosa** e 63 e 72% com a combinação de ambas as espécies na proporção de 1:1 durante os dois anos de duração do estudo, respectivamente. Concluiu-se que **E. spinosa** exerce efeito maior na competição com a safra de trigo em relação a **E. australis**.

**Palavras-chave:** *Triticum aestivum*, perda de rendimento, competição de plantas daninhas, *Emex australis*, *Emex spinosa*.

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## INTRODUCTION

Bio-economic weed management decisions are essential for precision agriculture. These decisions are based on estimates of weed population size, and the crop yield loss to be caused by that population and the most effective weed control practices to regain potential yield loss (Deines et al., 2004). Extensive herbicide use is one of the major tools for managing weed population and maintaining economical food supply in developed agriculture-based countries. However, increasing herbicide resistance in certain weeds, and higher input expenses and environmental hazards (Sanyal & Shrestha, 2009) induce greater pressure on food producers to reduce herbicide use. Integrated weed management practices are being developed to limit herbicides application in the environment (Sanyal & Shrestha, 2009). Weed threshold is one of the key components of an integrated weed management system that helps farmers to determine the need for herbicide application (Fleck et al., 2002).

Weed threshold studies provide an understanding of the crop-weed interaction. The majority of threshold research has been conducted with a single weed species in a single crop. This has been done empirically in wheat (Khan & Marwat, 2006), soybean (Fleck et al., 2002) and corn (Martinkova & Honek, 2001). Research on single weed species in a crop does not reflect the norm in a grower's field (Rosenbaum et al., 2011), because competitive index of weeds growing in mixture cannot be predicted where weeds species were growing individually (Deines et al., 2004). Mixture of weeds is less detrimental than the sum of their individual effect especially at high weed densities, because the effects of one weed species tend to obscure the effect of a second weed species (Toler et al., 1996).

Wheat is widely infested with *E. australis* Stenheil (three-cornered jack) and *E. spinosa* (spiny emex). Both weeds are associated with the family Polygonaceae. *Emex spinosa* is native to the Mediterranean region and Asia Minor, whereas *E. australis* is native to Southern Africa. Both weeds may co-exist in wheat fields and are difficult to distinguish after

cotyledonous leaf stage until fruiting (Javaid & Tanveer, 2014). In addition to competitive effects, these are problematic in winter crops because of their quick vegetative and reproductive growth, which adversely affects harvest efficiency and crop quality (Abbas et al., 2010). There is no published data on the mixture of *E. spinosa* and *E. australis* and its respective interference and competitive ability against wheat. The objective of this study was to analyze the reduction in tested wheat genotypes under the individual effect of *E. spinosa* or *E. australis* as well as the combined effect of both weed species.

## MATERIALS AND METHODS

Field experiments were conducted during the winter wheat growing season 2008-09 and 2009-10 on sandy loam soil with pH at 8.3 and 1.2% organic matter, at the Agronomic Research Farm, Department of Agronomy, University of Agriculture, Faisalabad (31° N and 73° E), Pakistan. In April 2008, seeds of *E. spinosa* and *E. australis* were collected at maturity (when the plants started senescence) from several farmers' wheat fields in the Layyah District (30° N, 70° E), Punjab, Pakistan. The mature brownish seeds were cleaned and dried for 7 days at room temperature (25 °C) and then stored in paper bags at room temperature until use in the experiment.

The experimental area was maintained with conventional tillage and the crop rotation was wheat-sorghum-wheat. The wheat cultivar "Sahar 2006" was seeded on November 12, 2008 and November 20, 2009 at 125 kg ha<sup>-1</sup> with man pulled hand drill at 25 cm row spacing. Experiments were arranged in a Randomized Complete Block Design (RCBD) with four replications. The recommended dose of NPK (120-100-60 kg ha<sup>-1</sup>) fertilizers was applied based on soil test recommendation. Before sowing, the weed seeds were soaked in water for 24 h and then air dried. Immediately after wheat sowing, *E. spinosa* and *E. australis* seeds were planted in a 25 cm band between wheat rows. Seeds of *E. australis* and *E. spinosa* were planted as a single weed species or in combination with both species in a higher number than the required densities.

The treatments consisted of a wheat crop with varying densities (4, 8, 16 and 32 plants m<sup>-2</sup>) of *E. australis* and *E. spinosa* each as a single weed species and as a mixed population of the two weed species. The ratio between the mixed weed population was 1:1. A weed free plot (control) was included in each replication. *Emex australis* and *E. spinosa* seedlings emerged within 2 weeks and were easily distinguished at the cotyledonous leaf stage in mixed weed species treatments. Cotyledonous leaves of *E. australis* had a dull green ovate shape whereas the leaves of *E. spinosa* were dark green and long with a narrow tip. The required weed densities were maintained with well-established plants by hand thinning. Weeds other than *E. australis* and *E. spinosa* were uprooted from each plot during the entire period of the experiment. Two to four plants of *E. australis* or *E. spinosa* were harvested at the time of maturity of weeds to count the number of seeds per plant. These seeds were dried at room temperature for 7 days and weighed for weed seed weight per plant. Aboveground biomass of *E. australis* or/and *E. spinosa* from an area of 1 m<sup>-2</sup> was harvested 3 days before wheat harvesting and fresh weight was recorded. The aboveground biomass was oven dried at 72 °C for 48 hours and weighed. Spike bearing and non-spike bearing tillers of wheat were counted in an area of 1 m<sup>-2</sup> when spikes were fully emerged from flag leaf sheath. Ten spikes were harvested from each plot and hand threshed to record spike length and number of grains per spike. Thousand grains were collected from each plot and weighed at 12.0% moisture content. The crop was harvested on April 20, 2009 and April 16, 2010 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.

### Data analysis

Data on crop and weed parameters were analyzed separately over the years and linear regression was fitted to the data of each year. A rectangular non-linear hyperbolic regression model (Cousens, 1985) was fitted to the wheat yield data and *Emex* species density to analyze the relationship between wheat yield loss (YL)

and *Emex* species density (d). The model equation was:

$$YL = (id)/[1+(id/A)]$$

where YL is percentage of wheat grain yield loss due to *E. australis* or *E. spinosa* separately or combined at 1:1, *i* is the percent yield loss per unit of weed density (*d*) as *d*→0, *d* represents weed density, *A* is the asymptotic value of the maximum yield loss (%), as *d*→∞. Parameter estimates were determined for the model using nonlinear regression techniques.

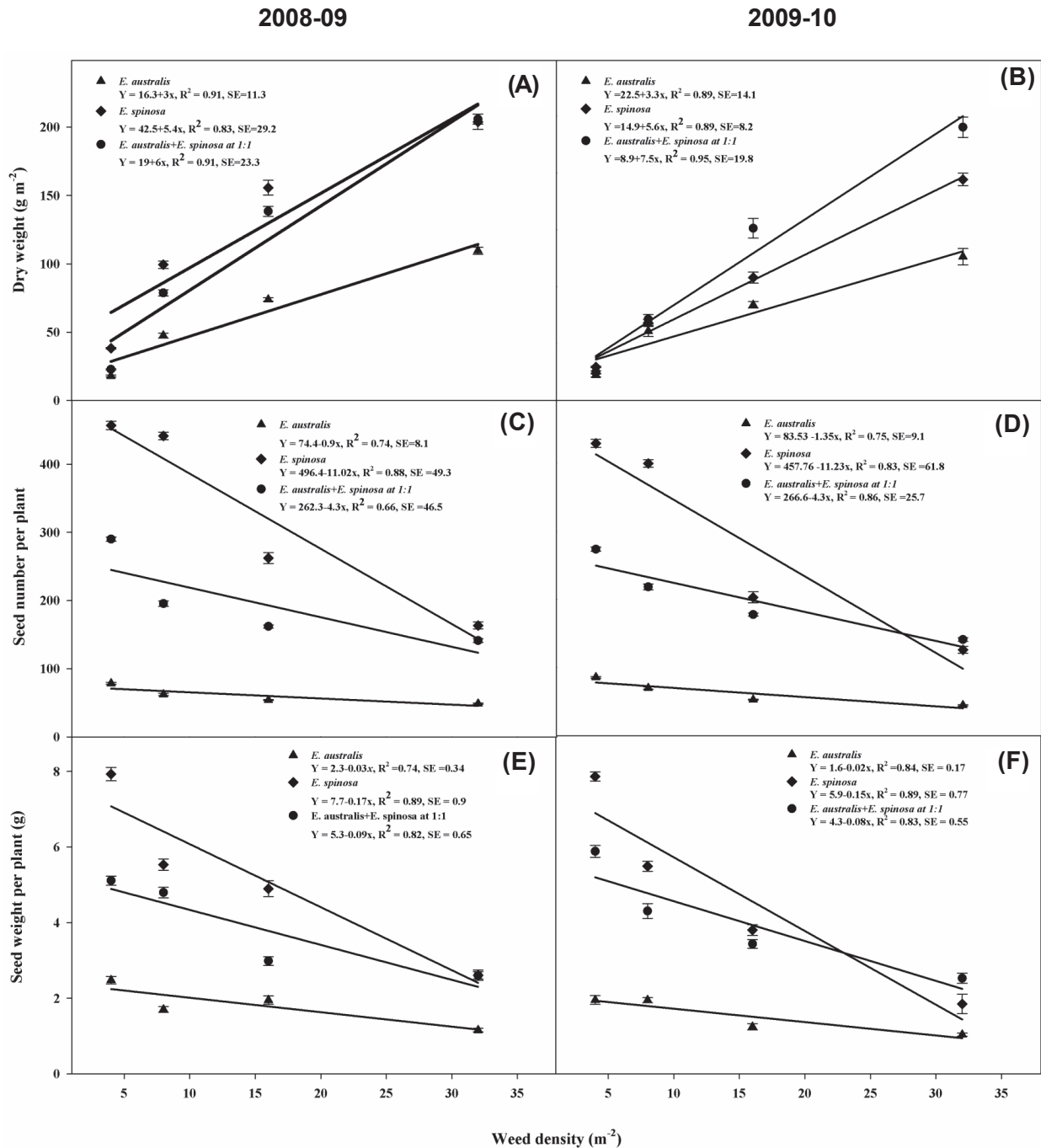
## RESULTS AND DISCUSSION

### Effects of *Emex* species densities on their growth, yield and yield attributes

The investigated plant densities of *E. australis* and *E. spinosa* exhibited significant differences in their dry weight values (g m<sup>-2</sup>) in both years (Figure 1A and B). At the lowest tested density, the dry weight of *E. australis* was 16.3 and 22.5 g m<sup>-2</sup> and increased by 3.0 and 3.3 g m<sup>-2</sup> with each increment in density of *E. australis* throughout 2008-09 and 2009-10, respectively. Similarly, the dry weight of *E. spinosa* was 42.5 and 14.9 gm<sup>-2</sup> at the lowest density and increased by 5.4 and 5.6 gm<sup>-2</sup> with each additional *E. spinosa* plant in 2008-09 and 2009-10, respectively (Figure 1A and B). In the mixture of *E. australis* and *E. spinosa* at 1:1 density treatments, total dry weight (m<sup>-2</sup>) of both weeds increased with increased density of each plant by 6 to 7.5 g m<sup>-2</sup> in both years.

*Emex australis* and *E. spinosa* densities significantly affected seed production per area (Figure 1C and D). Increasing density of *E. australis* and *E. spinosa* separately or mixed at 1:1 was described by an inverse linear relationship. In case of *E. australis* alone, maximum seed production per plant (74.4 in 2008-09 and 83.5 in 2009-10) was recorded at the lowest *E. australis* density. Regression model estimated a reduction of 0.9 seeds in 2008-09 and 1.35 seeds in 2009-10 with each additional plant m<sup>-2</sup> of *E. australis*. Maximum seeds per plant of *E. spinosa* were recorded at the lowest tested density and seeds production per plant decreased at the rate of 11 seeds with each additional plant of *E. spinosa* m<sup>-2</sup> (Figure 1C and D). In the case of the mixture of both species at 1:1, 262 and 267 seeds per





**Figure 1** - Effect of *E. australis* and *E. spinosa* density separately and combined at 1:1 on their various growth and yield parameters in the periods 2008-09 and 2009-10.

plant were recorded at the lowest density level in 2008-09 and 2009-10, respectively and seeds were decreased by 4.3 with each increment in weed density in both years (Figure 1C and D).

Varying population density of *E. australis* and *E. spinosa* had a significant effect on weed seed weight per plant during both years (Figure 1E and F). There was an inverse linear relationship between the seed weight of the

tested weed species and their population density. Seed weight of *E. australis* was maximized (2.3 g in 2008-09 and 1.6 g in 2009-10) at weed density of 4 plants  $m^{-2}$  and decreased by 0.03 and 0.02 g with each additional plant of *E. australis* in 1  $m^{-2}$  in 2008-09 and 2009-10, respectively. Reduction in seed weight per plant was higher in the case of *E. spinosa* with each increment in *E. spinosa* density  $m^{-2}$ , and maximum seed weight (7.7 g in 2008-09 and 5.9 g in 2009-10) was recorded at the lowest tested density level (Figure 1E and F). In the mixture of both species at 1:1, maximum seed weight per plant was recorded at the density of 4 plants  $m^{-2}$  and weight was decreased by 0.08-0.09 g with each additional plant of *E. australis* or *E. spinosa*.

### Effects of *Emex* species densities on wheat growth, yield attributes and yield

Spike bearing tillers directly contribute to final grain of wheat. Varying densities of *E. australis* and *E. spinosa* have significant effect on spike bearing tillers of wheat (Figure 2A and B). There was an inverse relationship between spike bearing tillers and the *Emex* tested species. In the absence of weed interference, spike bearing tillers were 442 and 401  $m^{-2}$  in 2008-09 and 2009-10, respectively. In case of *E. australis*, as its density increased, the spike bearing tillers ( $m^{-2}$ ) decreased by 3.7 to 4.2 for every increase in *E. australis* density in both years of study. Similarly, the regression model estimated that each additional plant of *E. spinosa* decreased the spike bearing tillers ( $m^{-2}$ ) by 4.2 in the first year and 4.6 in the second year of study. In case of mixture of both species at 1:1, each increment in weed density decreased the spike bearing tillers ( $m^{-2}$ ) by 3.7 in 2008-09 and 4.6 in 2009-10 (Figure 2A and B).

Increasing densities of *E. australis* and *E. spinosa* either as separate species or in the mixture of both species at a 1:1 ratio significantly increased non-spike bearing tillers ( $m^{-2}$ ) of wheat. There was a linear relationship between *Emex* species density and non-spike bearing tillers (Figure 2C and D). Minimum spike bearing tillers were recorded in the absence of weed interference and progressively decreased with increasing weed density. In the case of *E. australis*, a minimum

of 25 in 2008-09 and 33 in 2009-10 non-spike-bearing tillers ( $m^{-2}$ ) was recorded in weed free plots with addition of 2.7 to 2.7 non-spike bearing tillers ( $m^{-2}$ ) for every additional *E. australis* plant in both years of study. Similarly, there was an increase of 3.5 to 3.9 non-spike bearing tillers ( $m^{-2}$ ) with each increment in the density of *E. spinosa* ( $m^{-2}$ ) in both years of study. In the mixture of both species at 1:1, minimum non-spike bearing tillers (24.6 in 2008-09 and 27.8 in 2009) were recorded in the weed free plot and increased by 2.8 and 3.1 with each increment in weed density in 2008-09 and 2009-10, respectively (Figure 2C and D).

Number of grains per spike plays a vital role in determining final grain yield. Number of grains per spike was significantly affected with varying densities of *E. australis* and *E. spinosa* each either as a single species or in the mixture of both species at 1:1 ratio (Figure 2E and F). There was an inverse linear relationship between number of grains per spike and *Emex* species density. At the lowest density of *E. australis* (0 zero plants  $m^{-2}$ ), the model estimated 49.8 and 50.8 grains per spike in 2008-09 and 2009-10, respectively with a reduction by 0.32 grains in the first year and 0.40 grains in the second year with each increase in *E. australis* density. In the case of *E. spinosa*, maximum number of grains per spike was recorded in the absence of weed interference and decreased by 0.30 to 0.39 grains with every additional plant of *E. spinosa* in both years of study. In the mixture of both species at 1:1, the regression model estimated that there was a reduction in the number of grains by 0.36 in 2008-09 and 0.48 in 2009-10 with each increment in weed density level (Figure 2E and F).

The size of wheat seeds, evaluated as 1000-grains weight, was affected by *E. australis* and *E. spinosa* separately or in the mixture of both species. All density levels of *E. australis* and *E. spinosa* each as a single species significantly reduced 1,000 grain weight of wheat during both years (Figure 2G and H). The data indicated an inverse linear decrease in 1,000 grain weight with increasing density of weed species. In the absence of weed interference, the 1,000 grain weight of wheat was 46 to 48 g in both years. For each



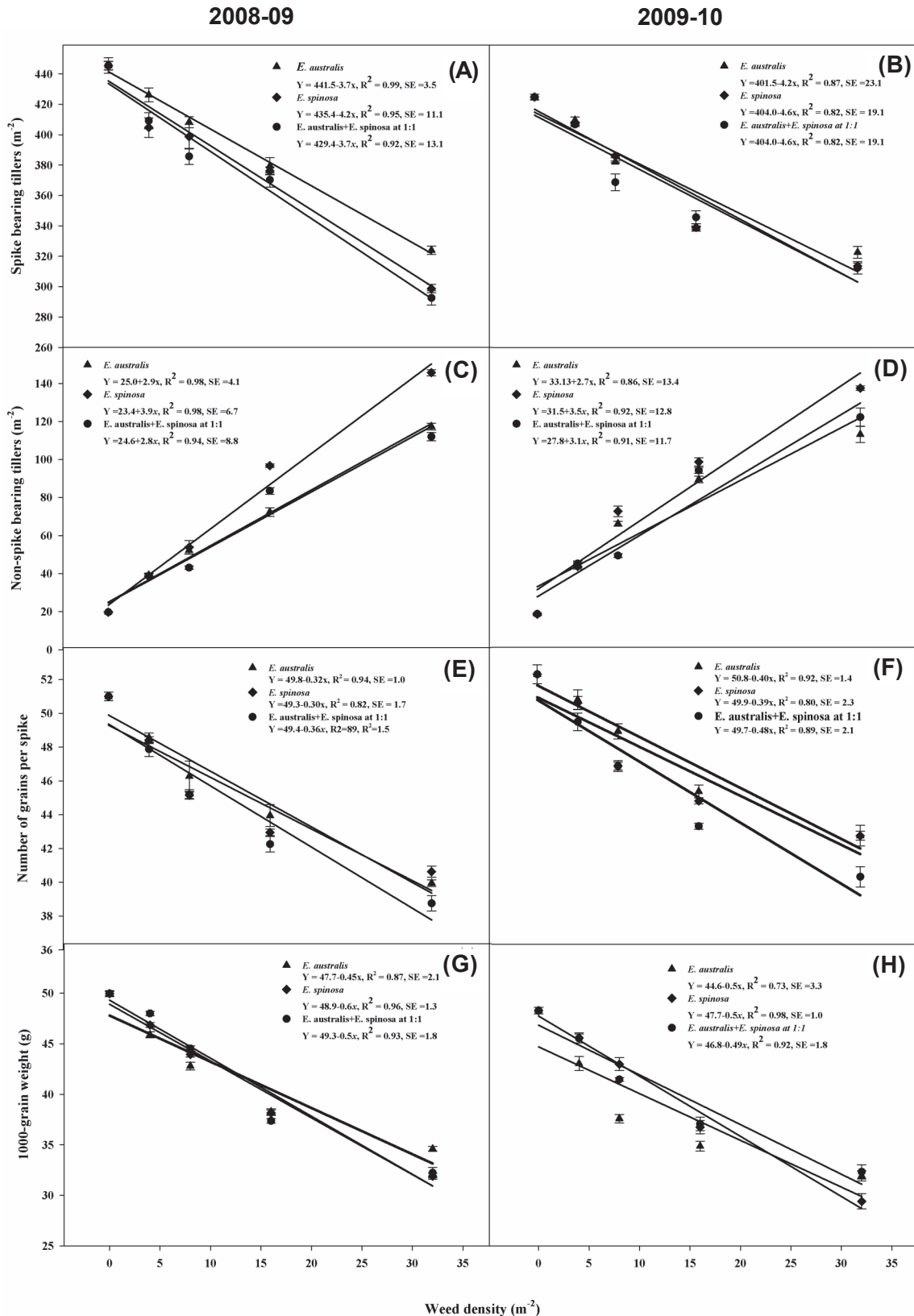


Figure 2 - Effect of *E. australis* and *E. spinosa* density separately and combined at 1:1 on yield components of wheat in the periods 2008-09 and 2009-10.

additional *E. australis* m<sup>-2</sup>, the 1,000 grains weight decreased by 0.45 to 0.5 g. Similarly, every additional plant of *E. spinosa* caused a reduction of 0.5 to 0.6 g in 1,000 grains weight in 2008-09 and 2009-10, respectively. In the case of the mixture of both species at 1:1, reduction in 1,000 grains weight was estimated at 0.50 g in 2008-09 and 0.49 g in 2009-10 with each increment in density of *E. australis* or *E. spinosa* (Figure 2G and H).

Data on biological yield as affected by varying density levels of *E. australis* and *E. spinosa* showed that increasing density level of *E. australis* or *E. spinosa* in the mixture of both species at a 1:1 ratio m<sup>-2</sup> significantly decreased biological yield of wheat in both years. The regression model showed that biological yield had a linear negative relationship with *Emex* species density in both years of study (Figure 3A and B). Biological yield was estimated at 13,600-14,000 kg ha<sup>-1</sup> in the absence of weed interference in both years. Biological yield decreased by 62 and 82 kg ha<sup>-1</sup> with an increase of a unit in *E. australis* in 2008-09 and 2009-10, respectively. Similarly, every additional plant of *E. spinosa* caused a reduction of 83 and 81 kg in biological yield in 2008-09 and 2009-10, respectively. The mixture of both species at 1:1 resulted in a reduction of 93 and 72 kg ha<sup>-1</sup> with every additional plant of *Emex* tested species in both years (Figure 3A and B).

The final grain yield per unit area of a crop is formulated by a cumulative effect of various yield components. It is evident (Figure 3C and D) that density of *Emex* species affected the grain yield of wheat significantly in both years. In the regression model, the intercept term showed that grain yield was about 6,100 to 6,200 kg ha<sup>-1</sup> in the plot where weed density was maintained as zero in both years of study. The model estimated that wheat yield has a linear negative relationship with increasing density of the tested weeds. The yield was decreased by 77 and 90 kg ha<sup>-1</sup> with an increase of a unit in *E. australis* in 2008-09 and 2009-10, respectively. Similarly, every additional plant of *E. spinosa* caused a reduction of 76 and 95 kg ha<sup>-1</sup> in 2008-09 and 2009-10, respectively. In the case of the mixture of both species at 1:1, grain yield

was decreased by 75 to 84 kg ha<sup>-1</sup> with every additional plant of either weed (Figure 3C and D).

The regression model showed a linear negative relationship between straw yield and increasing weed density in 2008-09 and 2009-10 (Figure 3E and F). The model estimated about 7,700 to 8,300 kg ha<sup>-1</sup> straw yield in the absence of weed interference in both years. Each additional plant of *E. australis* caused a reduction of 8 and 12 kg ha<sup>-1</sup> in 2008-09 and 2009-10, respectively (Figure 3E and F). Every additional plant of *E. spinosa* caused a reduction of 22 and 17 kg ha<sup>-1</sup> in 2008-09 and 2009-10, respectively. Similarly, in the case of the mixture of both species, straw yield decreased by 28 kg ha<sup>-1</sup> in 2008-09 and 18 kg ha<sup>-1</sup> in 2009-10 with every additional plant of the tested *Emex* species.

Harvest index is a measure of the physiological efficiency of wheat to divert photo-assimilates into grain yield. It is evident from the data that *E. australis* and *E. spinosa* each as a single species or in the mixture of both species at varying densities significantly reduced the harvest index of wheat crop. The regression model estimated that there was a linear negative relationship between harvest index (%) and increasing density of *Emex* species (Figure 3G and H). The maximum harvest index was recorded in the absence of weed interference. For every increase in a unit plant of *E. australis*, there was a reduction of 0.4 to 0.5% in the harvest index of wheat in both years of study. In the case of *E. spinosa*, every additional plant reduced the harvest index from 0.5 to 0.6% (Figure 3G and H). In the mixture of both species at 1:1, the harvest index was reduced by 0.5% with each increment in population density of the tested weed species in both years of study.

The relationship between wheat yield losses and *E. australis* and *E. spinosa* (each as single species and in the mixture of both species at 1:1) was described by a rectangular hyperbolic regression model (Table 1). The model estimated that the parameter *i*, which described yield losses per plant of weed species as density approaches zero, was 5.1% in 2008-09 and 3.5% in 2009-10 with *E. australis*, 4.5% in 2008-09 and 3.9% in 2009-10 with *E. spinosa*, and 3.2% in 2008-09



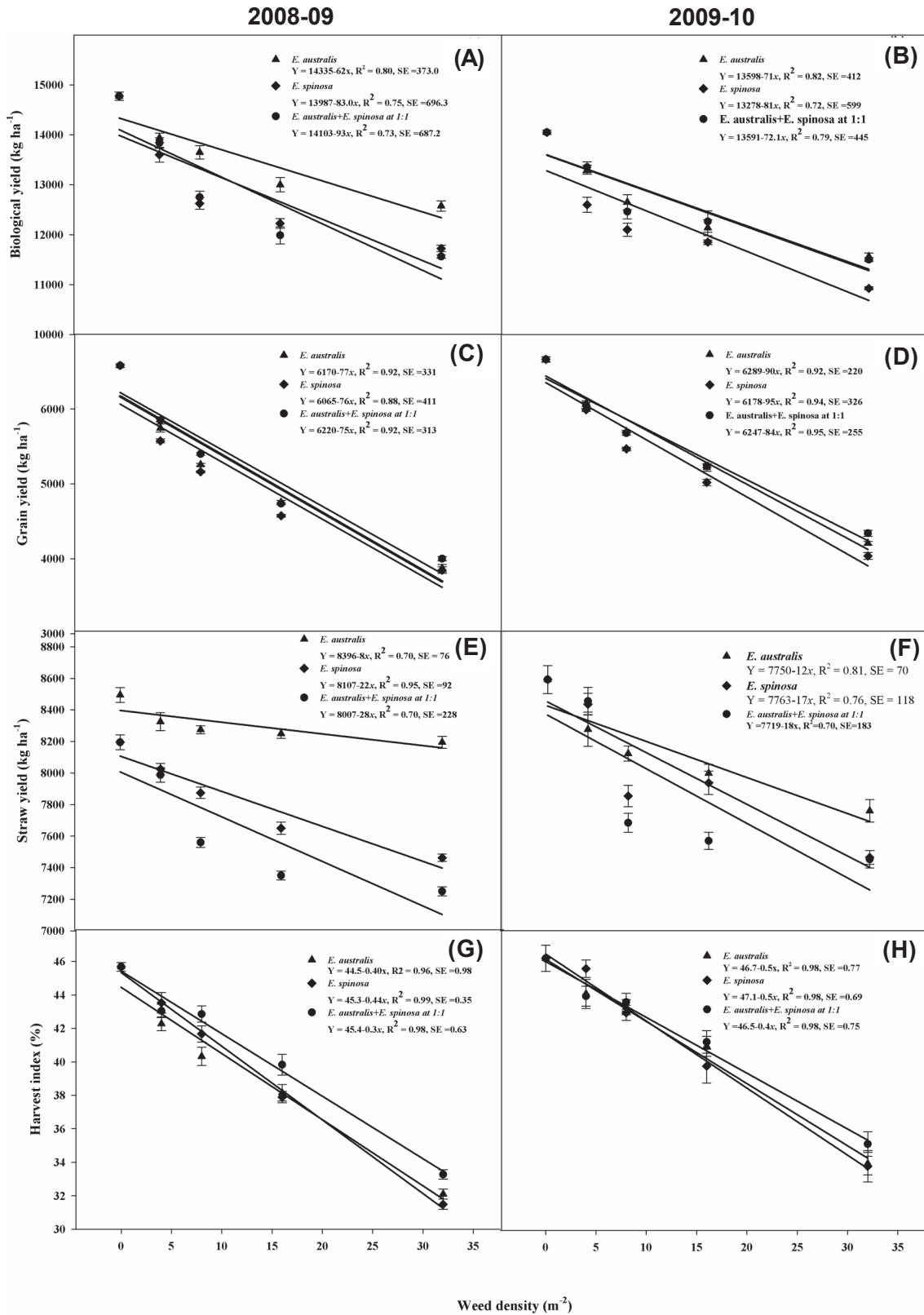


Figure 3 - Effect of *E. australis* and *E. spinosa* density separately and combined at 1:1 on yield components and wheat yield in the periods 2008-09 and 2009-10.



and 2.9% in 2009-10 with a mixture of both species at 1:1 (Table 1). The value of maximum yield losses of wheat (*A*) was 44.4% with *E. australis*, 56.9% with *E. spinosa* and 763.4% with the mixture of both *E. australis* and *E. spinosa* at 1:1 in 2008-09. However, the value of maximum yield losses of wheat (*A*) was 62.5% with *E. australis*, 70.1% with *E. spinosa* and 72.1% with the mixture of both *E. australis* and *E. spinosa* at 1:1 in 2009-10.

*Emex australis* and *E. spinosa* established in wheat as problem weeds. These weeds have vigorous, prostrate growth and numerous branches, and produce abundant biomass. A large seed bank of these weeds may be added to soil, which leads to frequent plant germination under favorable moisture and temperature. When the two species were compared in terms of dry matter accumulation, seed number per plant and seed weight per plant, *E. spinosa* produce higher dry matter and number of seeds or weight per plant. The weeds that completed their reproductive stage produced numerous seeds which act as a potential source for future infestation. Our data showed that *E. spinosa* is a fast-growing weed with the potential to produce large numbers of seeds. The results were supported by Mishra et al., (2006) who reported that weed dry weight ( $\text{g m}^{-2}$ ) was significantly increased by increasing weed density up to a certain level. Aziz et al. (2009) reported that the number of *Galium aparine* seeds per plant was higher at low weed density and the number of weed seeds increased with an increase in its density. The sum of the individual effect of the two weed species was lower for weed/weeds dry matter accumulation, number of seeds per plant and seed weight when compared with the mixture

of both species. In this study, it was observed that a comparatively lower density of *E. australis* or *E. spinosa* plants (4 plants  $\text{m}^{-2}$ ) was comparable with a high density of 32 plant  $\text{m}^{-2}$ , when these grown alone or in combination at 1:1. The higher number of seeds per plant resulted in higher seed weight per plant. These results were further supported by Abbas et al. (2010) who depicted that the seed weight of *E. australis* was higher at its lower density level. Our data suggested that the seed weight per plant of *E. spinosa* was higher than that of *E. australis*. This might be due to a higher number of seeds per plant produced in *E. spinosa*.

The two weed species varied in their competitive ability. However, spike bearing tillers reduced with increasing densities of both species. The reduction in spike bearing tillers might be due to stress for resources competition caused by the weeds. Competition of both species either as an individual effect or the sum of the individual effect and the mixture of weeds was similar for spike bearing tillers. The effect of increasing density on productive tillers has been reported by many researchers. Tessema et al. (1996) reported that fertile spikes per unit area were reduced by weed competition due to an increase in weed density.

The favorable environmental condition at the early growth stage produced more spike and fewer non-spike bearing tillers that produced maximum tillers at the end of the tillering stage. More spike and fewer non-spike bearing tillers in weed free treatment might be due to maximum availability of resources (moisture, nutrients, light and space) than that of plots with weeds. These

**Table 1** - Estimates for grain yield losses as affected by *E. australis* and *E. spinosa* separately and combined at 1:1

Weed species	Parameter estimates (%)			
	2008-09		2009-10	
	<i>i</i> (SE)	<i>A</i> (SE)	<i>i</i> (SE)	<i>A</i> (SE)
<i>Emex australis</i>	5.1 (0.8)	44.4 (3.8)	3.5 (0.4)	62.5 (5.8)
<i>Emex spinosa</i>	4.5 (0.5)	56.9 (4.8)	3.9 (0.3)	70.1(5.4)
<i>Emex australis</i> + <i>E. spinosa</i> at 1:1	3.2 (0.3)	63.4 (5.8)	2.9 (0.2)	72.1 (5.4)

*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.



results are in line with those from Spink et al. (2000), who reported that tillering cessation is mainly affected by the competition for nutrients, moisture, light and space rather than genetic potential to produced tillers within the crop. Our data suggested that a linear increase in non-spike bearing tillers occurred with an increase in the density of *E. australis* or *E. spinosa*. The mortality of wheat tillers could be due to intra-specific and inter-specific competition. However, *E. spinosa* was a more competitive species than that of *E. australis*. These results are in line with those from Fu & Ashley, (2006) who investigated the interference of three weed species [*Amaranthus retroflexus* (redroot pigweed), *Galinsoga ciliate* (hairy galinsoga) and *Digitaria sanguinalis* (large crabgrass)] with bell paper. They established weed densities of 0, 1, 2, 4, 8, 16, 32 plants m<sup>-1</sup> for each species. Weed density reduced bell paper yield and *A. retroflexus* was the most competitive species at the lowest population and *D. sanguinalis* was the least competitive species.

Increasing densities of *Emex* species in wheat progressively decreased the number of wheat grains per spike. At higher weed density, limited resources are available at the grain filling stage, as the presence of weeds shared these resources. These findings are supported by Hammad et al. (2010), who suggested that weed density of 42 plants m<sup>-2</sup> significantly reduced the number of wheat grains per spike. In our results, interference of both species was not different for number of grains per spike. These results are supported by Rosenbaum et al. (2011) who studied interference of *Ambrosia artemisiifolia* (common ragweed) and *Xanthium strumarium* (common cocklebur) with tall fescue pastures. Tall fescue biomass, yield and nutritive value were marginally influenced by increasing densities of *A. artemisiifolia* and *X. strumarium* but there was no difference between two species for competition. The observed decrease in 1,000 grain weight with increasing densities of the *Emex* species was linked with resource availability in weed-infested plots. These findings are supported by Oad et al. (2007), who reported that *Chenopodium album*, *Melilotus alba* and *Avena fatua* significantly reduced

1,000 grain weight of wheat with an increase in their densities levels. The two *Emex* species have different competition behavior for 1000-grain weight. Similar results were also reported by Toler et al. (1996), who studied the competitive relationship among smooth pigweed, johnsongrass and soybean. Weed densities of 1, 2, 4, and 8 plants 4.6 m<sup>-2</sup> were maintained for each species. Both weeds were grown alone and in combination. In the mixed weed population, smooth pigweed shared 80% of the total weed biomass. Johnson grass weeds reduced soybean yield gradually. Our data suggested that the highest level of weed density (32 plants m<sup>-2</sup>) progressively decreased biological yield over control. This might be due to considerable weed biomass production per unit area with the highest weed density within available resources. These results are in line with those from Abbas et al. (2010), who reported that increasing density of *E. australis* significantly reduced wheat biological yield. *Emex australis* and *E. spinosa* also significantly differed in interference with wheat. These results are supported by Deines et al. (2004), who studied the interference of *Helianthus annuus* and *Sorghum bicolor* in corn. Multiple species caused 60% yield loss. These losses were 49.2% for *Helianthus annuus* and 4.2% for *S. bicolor*. The results indicated that *H. annuus* has 11 times more competitive ability than *S. bicolor*. Competitive index for *H. annuus* and *S. bicolor* was 10 and 0.9, respectively. The reduction in grain yield due to an increase in *E. australis* or *E. spinosa* or in the mixture of *E. australis* and *E. spinosa* density is explained by the observed decrease in yield components such as spike bearing tillers, number of grains per spike and 1,000 grain weight. The reduction in yield at different weed densities has been studied by many researchers. Khan & Marwat (2006) studied the interference of *Silybum marianum* (holy thistle) in wheat at 0, 3, 6, 9, 12 and 18 holy thistle plants m<sup>-2</sup>. Wheat grain yield was reduced with increasing holy thistle density. Aziz et al. (2009) reported that increasing *Galium aparine* density significantly reduced wheat grain yield. The reduction in grain yield was 4% to 32% with an increase in *G. aparine* from 18 to 72 plants m<sup>-2</sup>. Similarly, Zimdahl et al. (2004) confirmed that at low weed densities, there was no or little effect on crop yield, and as weed density

continues to increase, crop yield drops quickly but never goes down completely to zero. Yield loss due to *E. spinosa* densities was more than that of *E. australis*. This might be due to more competitive ability of *E. spinosa* than *E. australis*. *Emex spinosa* produced more biomass, number of weed seeds and seed weight as compared to *E. australis*.

Yield loss with *E. spinosa* was higher than that of *E. australis* and the mixture of both species. *Emex spinosa* produced more height and biomass, reduced light penetration for wheat crop and resulted in yield loss. These results are in line with those from Wish et al. (2002), who reported that a rectangular hyperbolic model adequately represented the loss in chickpea yield with increasing density (0-32 plant m<sup>-2</sup>) of wild oat or turnip weed. Even low densities of <10 plants m<sup>-2</sup> caused 50% reductions in yield, particularly with turnip weed. The *i* parameter, a measure of relative competitiveness of the weed with a particular crop, was 6.0 for both wild oat and turnip weed in chickpea (Wish et al., 2002). Radicetti et al. (2012) reported that *i* parameter differed between chickpea genotypes and ranges from 9.6% in C133 to 13.4% in C6150, when grow with knotgrass.

Data from this research provide useful information for wheat growers to make a decision with respect to the control of *Emex* species. Both species at their maximum density would have probably resulted in the highest competition towards the crop. However, the results from this study suggested that extensive measures should be taken in case of *E. spinosa* as compared to *E. australis*, and plant density should be below 4 plants m<sup>-2</sup> in order to prevent severe wheat yield loss.

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## LITERATURE CITED

ABBAS, R. et al. Simulating the effect of *Emex australis* densities and sowing dates on agronomic traits of wheat. **Pak. J. Agric. Sci.**, v. 47, n. 2, p. 104-110, 2010.

AZIZ, A. et al. Density dependent interactions between cleavers (*Galium aparine*) and wheat (*Triticum aestivum*) planted at different times. **Pak. J. Agric. Sci.**, v. 46, n. 4-7, p. 258-265, 2009.

COUSENS, R. A simple model relating yield loss to weed density. **Ann. Appl. Biol.**, v. 107, n. 2, p. 239-252, 1985.

DEINES, S. R. et al. Common sunflower (*Helianthus annuus*) and shattercane (*Sorghum bicolor*) interference in corn. **Weed Sci.**, v. 52, n. 6, p. 976-983, 2004.

FLECK, N. G.; RIZZARDI, M. A.; AGOSTINETTO, D. Threshold level as a criteria for arrowleaf sida control decision in soybeans. **Planta Daninha**, v. 20, n. 3, p. 421-429, 2002.

FU, R.; ASHLEY, R. A. Interference of large crabgrass (*Digitaria sanguinalis*), redroot pigweed (*Amaranthus retroflexus*), and hairy galinsoga (*Galinsoga ciliata*) with bell pepper. **Weed Sci.**, v. 54, n. 2, p. 364-372, 2006.

HAMMAD, H. M. et al. Influence of organic manures on weed dynamics and wheat productivity under low rainfed area. **Crop Environ.**, v. 1, n. 1, p. 13-17, 2010.

JAVOID, M. M.; TANVEER, A. Germination ecology of *Emex spinosa* and *Emex australis*, invasive weeds of winter crops. **Weed Res.**, v. 54, n. 6, p. 565-575, 2014.

KHAN, M. A.; MARWAT, K. B. Impact of crop and weed densities on competition between wheat and *Silybum marianum* Gaertn. **Pakistan J. Bot.**, v. 38, n. 4, p. 1205-1215, 2006.

MARTINKOVA, Z.; HONEK, A. The effect of time of weed removal on maize yield. **Rostlinna Vyroba-UZPI (Czech Republic)**, n. 47, n. 5, p. 211-217, 2001.

MISHRA, J. S.; SINGH, V. P.; YADURAJU, N. T. Wild onion (*Asphodelus tenuifolius* Cav.) interference in lentil and chickpea crops and its management through competitive cropping. **Weed Biol. Manage.**, v. 6, n. 3, p. 151-156, 2006.

OAD, F.; SIDDIQUI, M.; BURIRO, U. Growth and yield loss in wheat due to different weed densities. **Asian J. Plant Sci.**, v. 6, n. 1, p. 173-176, 2007.

RADICETTI, E.; MANCINELLI, R.; CAMPIGLIA, E. Combined effect of genotype and inter-row tillage on yield and weed control of chickpea (*Cicer arietinum* L.) in a rainfed Mediterranean environment. **Field Crops Res.**, v. 127, n. 1, p. 161-169, 2012.

ROSENBAUM, K. K.; BRADLEY, K.; ROBERTS, C. A. Influence of increasing common ragweed (*Ambrosia artemisiifolia*) or common cocklebur (*Xanthium strumarium*) densities on forage nutritive value and yield in tall fescue pastures and hay fields. **Weed Technol.**, v. 25, n. 2, p. 222-229, 2011.



SANYAL, D.; SHRESTHA, A. Direct effect of herbicides on plant pathogens and disease development in various cropping systems. **Weed Sci.**, v. 56, n. 1, p. 155-160, 2009.

SPINK, J. H. et al. Effect of sowing date on the optimum plant density of winter wheat. **Ann Appl. Biol.**, v. 137, n. 2, p. 179-188, 2000.

TESSEMA, T.; TANNER, D.; HULLUKA, M. Grass weed competition with bread wheat in Ethiopia: I. Effects on selected crop and weed vegetative parameters and yield components. **African Crop Sci. J.**, v. 4, n. 4, p. 399-409, 1996.

TOLER, J. E.; GUICE, J. B.; MURDOCK, E. C. Interference between johnsongrass (*Sorghum halepense*), smooth pigweed (*Amaranthus hybridus*), and soybean (*Glycine max*). **Weed Sci.**, v. 44, n. 2, p. 331-338, 1996.

WISH, J. et al. The effect of row spacing and weed density on yield loss of chickpea. **Crop Pasture Sci.**, v. 53, n. 12, p. 1335-1340, 2002.

ZIMDAL, R. L. **Weed-crop competition**. A review. New York: John Wiley & Sons, 2004. 220 p.

