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Using Plant Density to Increase Competition Ability in More and Less Competitive Wheat Cultivars with Wild Oat

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Abstract: The effects various densities of wild oat and wheat on the growth and reproductive output of wheat and growth of wild oat were investigated in field study in 2004. The experiment was established as a factorial combination of wheat varieties (Rooshan and Niknejad) wheat density (recommended, recommended +25% and recommended+50%) and wild oat (0, 25, 50 and 75 plants m^{-2}) densities. The effect of wild oat density on wheat yield loss and the effect of wheat density on wild oat biomass were described with a rectangular hyperbola model. The presence of wild oat in wheat reduced grain yield of wheat, number of tiller, number of spike m^{-2} and the magnitude of this reduction was dependent on weed density. Increasing the density of wheat significantly reduced the unpleasant effects of wild oat on wheat. Wild oat biomass was decreased, as crop density increased. The maximum grain yield of Niknejad and Rooshan were achieved at its recommended +25% and recommended wheat density, respectively and increased density due to increase inter specific competition decrease grain yield at two cultivars. As wild oat density increased, Number of tiller per plant, spike m^{-2} decreased. The results indicated that higher densities of wild oat had heights negative effect on wheat yield and higher wheat densities were able to suppress biomass of this weed species.

Key words: Plant density, yield loss, wild oat, competition

INTRODUCTION

A major component of integrated weed management is the use of more competitive crops (Lemerle *et al*., 2001), Menana and Zandstra (2005). If a crop cultivar can tolerate weeds, it may reduce the need for synthetic herbicide, allow the use of less costly and more environmentally sound herbicides, decrease the number of cultivations, or improve yield stability in weedy fields (Lindquist *et al*., 1998; Lemerle *et al*., 2001). Large differences exist in the Competition Ability (CA) of field crops. Baghestani and Zand (2005) found that Niknejad had more CA than Rooshan. CA for Niknejadand Rooshan was 1.7 and 0.56, respectively on wild oat competition. Ponce and Santin (2001) had statement the semi-dwarf cultivar (Anza) than the tall wheat cultivar (Pané 247) is competitively superior to *A. sterilis*. This competitive superiority was related more to the height of the wheat plant and supposed competition for light than to tiller production. Increased seeding rates may provide a means by which to enhance the competitive ability of a particular genotype (Cousens and Mokhtari, 1998). Volunteer barley density had little or no effect on wheat yield at the high wheat seeding. Wheat yield loss was often lower and economic threshold values were higher at the higher wheat-plant densities (O'Donovan *et al*., 2007). Lemerle *et al*. (2004) concluded that interference of rigid ryegrass in wheat had adversely affected the biomass production of wheat plants and again increasing crop density reduced the negative impact of rigid ryegrass on wheat. Eslami *et al*. (2006) reported increasing the density of wheat substantially reduced the adverse effects of wild radish on wheat. As crop density increased, wild radish dry matter, LAI and seed production per unit area decreased. Scursoni and Satorre (2005) reported Barley biomass and yield were not affected by wild oat at high crop sowing densities, but for the low and medium barley densities, yield loss was almost 25% when 70 wild oat plants m^{-2} were established.

Wild oat density can have a considerable impact on crop-weed interactions mainly through competition for nutrients and water. Considerable research has been

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conducted to examine the effects of wild oat interference on crop yield (O'Donovan *et al*., 2000; Ponce and Santin, 2001; Baghestani and Zand, 2005). In Canada, 150 wild oat plants m^{-2} emerging 6 days before the crop reduced barley yield by 42% (O'Donovan *et al*., 2000). Integrated weed management practices, such as using more competitive wheat cultivars and increased plant density, potentially improve weed management (Holman *et al*., 2004). Yet, few studies compare competitive interactions of weeds with different crops. The goal of this research was to quantify the effects of *A. ludoviciana* interference on more and less competitive wheat cultivar yield and yield components over a range of crop and weed densities. We hypothesized, that increasing the plant density of wheat, would decrease the yield impact of *A. ludoviciana* on more and less competitive wheat cultivars.

MATERIALS AND METHODS

A field experiment was conducted in the 2004-2005 growing season at Plant, Pest and Disease Institute in Karj Iran. The factorial set of treatments was arranged within a randomized complete block design with four replicates. Individual plot size was 2.4 m wide by 6 m long. Treatments consisted of two cultivars Niknejad and Rooshan (as more and less competitive respectively), 3 plant densities, their recommended density (Table 1); recommended density +25% and recommended density +50% and 4 wild oat densities (0, 25, 50 and 75 plants m^{-2}). Wheat cultivar was sown on 10th November 2004 by hand in rows 30 cm apart. The seeds of wild oat were broadcast by hand on the soil surface between wheat row immediately after sowing the wheat. Wild oat seedling density was determined at the 1 to 2-leaf stage of wild oat in two 0.25 m^{-2} quadrates positioned approximately 1 m from the front and back of each plot. For this trial sowing date, crop density and N fertilization were different for each cultivar and set as recommended for maximum yield (Table 1). Other management practices were kept similar for two cultivars.

Grain yields were determined by harvesting a 1* 1 m area in each plot. The area outside the harvest plot was used for sampling of above-ground biomass. Yield component was taken as the average of 30 counts of ears in 0.1 m^2 rings randomly placed in each plot. The harvest index was calculated as the ratio of dry matter grain yield to wheat above-ground dry matter. The yield and yield component and biomass data were subjected to analyses of variance using the ANOVA procedure of the SAS statistical analysis system (SAS Institute, 1996).

Table 1: Cultivars, year of release and their corresponding optimum density

Cultivars	Niknejad	Rooshan
Year of release	1995	1951
Optimum density (Plants m^{-2})	400	300
Weight of 1000 seeds	37	44.5
Yield (t ha^{-1})	6.70	3.5
Origin	Icarda	Tabas (Iran)

Regression analyses: Competitive Index (CI) was calculated on the basis of the following equation (Zand and Becki, 2002):

$$CI = \frac{V_i}{V_{mean}} \times \frac{W_i}{W_{mean}} \qquad (1)$$

Where V_i is the yield of each weed-infested cultivar, V_{mean} the mean wheat yield in all weed-free plots, W_i the biomass of wild oat in each weed-infested plot and W_{mean} the mean biomass of wild oat in all weed-infested plots.

The effect of the crop on the weed was evaluated by analysing the relationship between *A. ludoviciana* biomass and *A. ludoviciana* plant density for each plant density of wheat separately. The model selected to fit the data was the rectangular hyperbolic equation proposed by Cousens (1985):

$$Y = \frac{I*D}{1+\frac{I*D}{A}} \qquad (2)$$

where y is the biomass in g m^{-2} of *A. ludoviciana*, D is the weed density in plants m^{-2}, I is the weed biomass per unit weed density as D approaches zero and A is the maximum weed biomass at infinite weed density.

The effect of the weed on the crop was evaluated by analysing the relationship between weed density and wheat grain yield separately for each plant density, using the rectangular hyperbola described by Cousens (1985):

$$Y = Ywf\left[1-\frac{I*D}{100\left[1+\frac{I*D}{A}\right]}\right] \qquad (3)$$

where y is the yield of wheat, Ywf is the weed-free yield, I is the yield as weed density approaches zero, A is the maximum yield at infinite weed density and D is the weed density in plants m^{-2}.

RESULTS AND DISCUSSION

Effect of cultivar: In both weed-free and weed-infested conditions, Niknejad had greater grain yield compared to

Table 2: Effects of cultivar, plant density and weed density on some wheat traits and wild oat biomass

Treatments	Grain yield (kg ha^{-1})	CI	No. of tillers (plant^{-1})	No. of spike (plant^{-1})	Wild oat biomass (g m^{-2})
Cultivar					
Niknejad	5442.5	1.173762	2.525	644.0286	121.9333
Rooshan	3408.06	0.490065	1.991667	349.6538	114.4417
LSD (0.05)	149.21	0.033	0.133	49.71	2.05
Plant density					
Recommended	4446.87	0.797401	2.525	464.1363	130
Recommended+25%	4586.56	0.832316	2.3125	495.2544	116.2875
Recommended+50%	4242.40	0.866023	1.9375	531.1329	108.275
LSD (0.05)	182.75	0.041	0.163	60.88	2.52
Weed density					
0	5046.542	0	2.616667	634.4357	0
25	4540	1.094451	2.35	549.0813	98.9375
50	4107.083	1.10358	2.083333	445.6813	103.0333
75	4007.5	1.129622	1.983333	358.1664	106.6167
LSD (0.05)	211.02	0.047	0.188	70.32	2.91
CV (%)	8.2	9.92	14.49	24.57	4.27

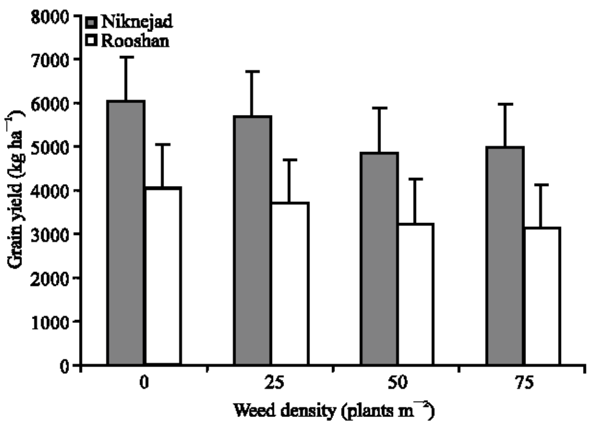

Fig. 1: Effect of increasing wild oat density on grain yield in two cultivars. Standard error bars represent standard errors of the means

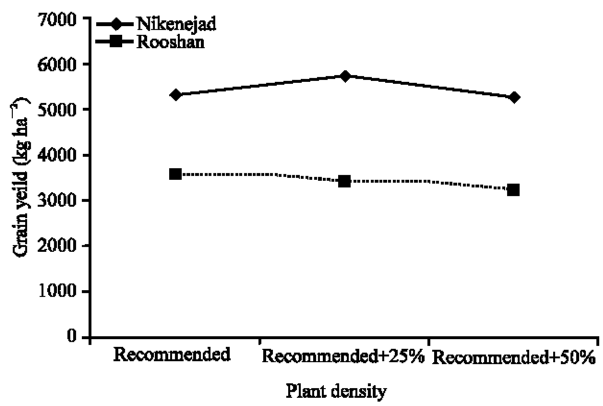

Fig. 2: Effect of increasing plant density on grain yield in two cultivars

the Rooshan (Fig. 1). High genetic potential, high harvest index and having more ear number per square meter caused more yield in Niknejad. Zand and Rahimian Mashhadi (2003) also reported in both weed-free and weed-infested conditions, new cultivars (Ghods, Alamot and Alvand) had greater grain yield compared to the older cultivars (Omid, Bezostaya and Azadi). Niknejad also had higher Competitive Index than Rooshan (Table 2). Increase in the competitive index was mainly due to higher wheat grain yield, Leaf Area Index (LAI) and dry matter accumulation under weed-infested conditions (data was not shown). Increase in the competitive index was mainly due to higher wheat grain yield and lower weed dry matter in new wheat cultivars compared to old cultivars under weed-infested conditions (Zand and Rahimian Mashhadi, 2003).

Effect of plant density: The wheat density had significant effects ($p<0.01$) on all growth and seed production attributes of both wheat and *A. ludoviciana* (Table 2). Competition index was increase with increasing of wheat density. The highest competition ability was observed in the highest wheat density (Table 2). O'Donovan *et al.* (2000) reported that increasing the seeding rate improved the competitiveness of different barley varieties, but the yield was higher only in some situations. Increasing wheat density to recommended+25% cause increase grain yield in Niknejad but more increasing wheat density reduced grain yield. Rooshan grain yield did not increase with an increase in wheat density (Fig. 2). Increasing inter and intra specific competition, loading and infertile tillers probably resulted grain yield reduction in this variety. This result indicated that increasing plant density in tall cultivar is not useful. Silvertown and Charlesworth (2001) found that density increases to higher levels cause relatively small yield reductions due to the asymptotic relationship between yield and density. Menana and Zandstra (2005) also found that wheat yield increased in all cultivars with an increase in the seeding rate, from 150 to 200 kg ha^{-1}, but yield did not increase significantly at the seed rate of 250 kg ha^{-1}.

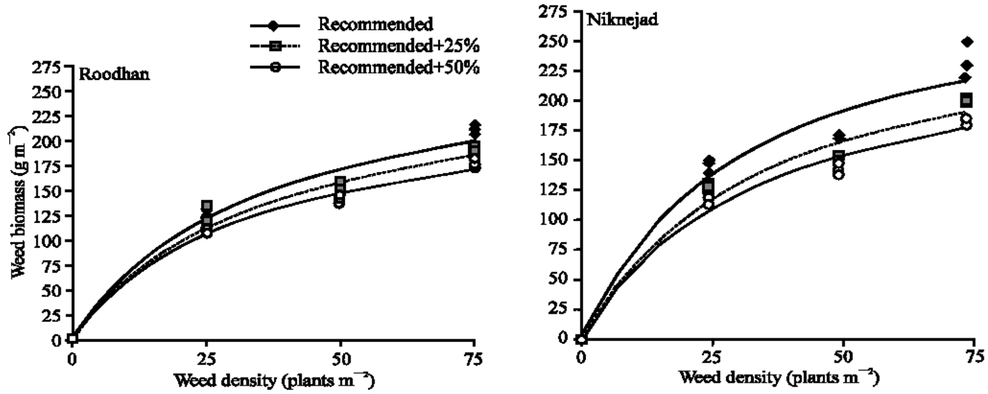

Fig. 3: Relationships between the biomass (g m^{-2}) and the density (plants m^{-2}) of *A. ludoviciana* at the different barley densities. Response curves are those from the parameters given in Table 4

Table 3: Estimates of parameters for the hyperbolic regressions (Eq. 2) of yield (kg ha^{-1}) against weed density (plants m^{-2}). Standard errors of estimates in parentheses

Cultivars	Plant density	I	A	Adj R^2	Estimated reduction (%)
Niknejad	400	9.84(3.65)	310.18(70.38)	0.97	-
	500	8.09(2.52)	279.53(57.70)	0.98	9.88
	600	7.69(1.81)	255.69(38.60)	0.99	17.56
Rooshan	300	8.12(2.90)	297.12(73.50)	0.97	-
	375	7.62(1.69)	271.52(40.93)	0.99	8.61
	450	7.49(1.39)	244.68(28.69)	0.99	17.64

The component of yield which showed significant response to plant density are presented in Table 2. Number of tillers and number of spike m^{-2} were the components which were affected by plant density. Maximum of tillers were absorbed in recommended density and increase plant density to 50% decreased 23% number of tillers. Decrease in fertile tillers with increasing plant density related to low essential supply for growth for one plant. Maximum of spike m^{-2} was achieved in recommended+50% density. More plant in high plant density caused increase of spike m^{-2}.

Weed biomass showed significant response to increasing of wheat density (Table 2). The relation between *A. ludoviciana* biomass and weed density were hyperbolic in shape in two cultivars with R^2 being 0.79 or higher indicating that *A. ludoviciana* biomass depend on plant and weed densities (Fig. 3). Izauierdo *et al.* (2003) also reported that *L. rigidum* biomass related to weed and plant density. Low crop densities allowed individual weed plants to become larger, but the high intraspecific competition which occurred at high *L. rigidum* densities caused this relationship to reach a plateau. The A parameter (maximum biomass achieved by the weeds) ranged from 310.18 to 255.69 g m^{-2} in Niknejad and from 297.12 to 244.68 g m^{-2} in Rooshan in recommended and recommended+50% plant density. The I parameter ranged from 9.84 to 7.69 in Niknejad and from 8.12 to 7.49 in Rooshan in recommended and recommended+50% plant density (Table 3). As expected, the lowest I values were always found in the highest crop densities in two cultivars, supporting the concept that high crop stands tend to reduce the aggressiveness of the weed. Scursoni and satorre (2005) found wild oat biomass increased linearly with weed density but was reduced by increasing barley seeding rates.

Effect of *A. ludoviciana* density: Wheat grain yield was affected by different densities of *A. ludoviciana* in two cultivars (Table 2). The highest grain yield were found in weed free condition in two cultivars (Fig. 1). Grain yield reduction was 10.12, 18.80 and 19.95% in 25, 50 and 75 plant m^{-2} weed density. In both cultivars as *A. ludoviciana* density increased, the wheat yield decreased substantially.

There was a hyperbolic relationship between *A. ludoviciana* density and wheat yield loss. The maximum grain yield estimated by the Y_{wf} parameter of the model declined with increasing wheat density (except in recommended+25% in Niknejad) from 6.31 to 5.80 t ha^{-1} (8.08%) in Niknejad and from 4.20 to 3.63 (13.73%) in Rooshan. The parameter I, which represents yield loss per *A. ludoviciana* plant, showed a steady decline with increasing wheat density in two cultivars (Table 4). However, the relative change in I was considerably greater in Niknejad. The maximum yield loss (parameter A) also showed a consistent reduction with

Table 4: Estimates of parameters for the hyperbolic regressions (Eq. 3) of yield (t ha^{-1}) against weed density (plants m^{-2}). Standard errors of estimates in parentheses

Cultivars	Plant density	Y_{wf} (t ha^{-1})	I	A	Adj R^2
Niknejad	400	6.31(0.30)	0.87(0.75)	44.19(30.06)	0.57
	500	6.40(0.11)	0.52(0.25)	31.47(14.52)	0.79
	600	5.80(0.14)	0.46(0.34)	30.70(21.57)	0.64
Rooshan	300	4.20(0.09)	0.63(0.23)	60.91(31.63)	0.86
	375	3.96(0.18)	0.61(0.56)	49.94(53.07)	0.52
	450	3.63(0.11)	0.52(0.39)	36.98(28.16)	0.63

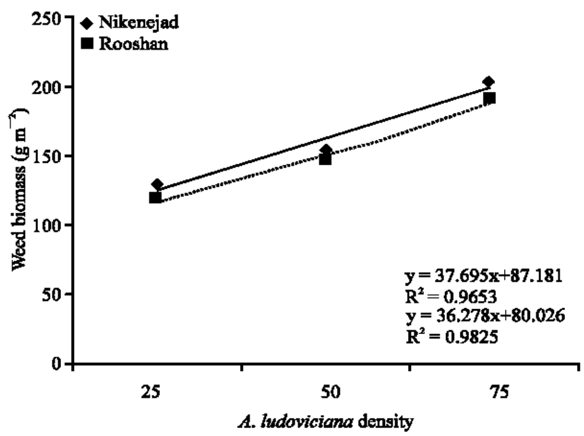

Fig. 4: Relationships between *A. ludoviciana* biomass and *A. ludoviciana* density (plants m^{-2})

increasing crop density. Carlson and Hill (1985) examined the effect of wild oat and wheat density on wheat yield. Yield reductions resulting from wild oat competition were much greater at lower seeding rates. Wheat sown to achieve a plant density of 100 plants m^{-2} suffered a yield reduction of 20% from an infestation of 5.5 wild oat plants m^{-2}; however, with a wheat density of 700 plants. m^{-2}, 38 wild oat plants m^{-2} would have to be present in order to cause similar yield loss, yield loss was almost 25% when 70 wild oat plants m^{-2} were established.

The *A. ludoviciana* had significant effects ($p<0.01$) on number of tillers and number of spike m^{-2}. The maximum number of tillers and spike m^{-2} was achieved in weed free condition, as *A. ludoviciana* density increased to 75 plants m^{-2}, number of tillers and spike m^{-2} decreased 24.13 and 43.54%, respectively (Table 2). Izquierdo *et al.* (2003) found that density of ears was the component which was affected by competition with *L. rigidum*. This component had the highest losses due to *L. rigidum* competition, with estimated reduction of 30%-60% depending of location. As expected, increasing *A. ludoviciana* density corresponded with increase *A. ludoviciana* biomass. *A. ludoviciana* biomass exhibited significant linear increase with increasing *A. ludoviciana* density on two cultivars (Fig. 4).

CONCLUSION

This study indicates that wheat varieties vary in their ability to compete with *A. ludoviciana*. Niknejad compete better with *A. ludoviciana*, because of its higher Leaf Area Index, densely canopy, higher dry matter accumulation, higher growth rate and tiller number. Zhao *et al.* (2006) reported that erect genotypes had greater vigor, quicker early growth, greater yield under competition and stronger weed suppressive ability than droopier genotypes. Mennan and Zandstara (2005) concluded that, although Bezostaja was nearly 10% shorter than other cultivars, it was more competitive and produced the highest yield in weed-free plots and weed-infested plots. Our result with *A. ludoviciana* agree with this report. Studies in Winter Wheat (Mennan and Zandstara, 2005) Spring Wheat (O'Donovan *et al.*, 2007), Barley (Watson *et al.*, 2006), Winter Lentil (Tepe *et al.*, 2005) and rice (Zaho *et al.*, 2006) have reported extensive genetic variation for CA.

Increasing plant density has long been proposed as a method for improving weed management and negating the effects of weed interference on crop yield. The study showed that in two cultivars yield losses were greatest at the lowest plant density (recommended density) and yield loss from *A. ludoviciana* lessened as plant density increased (Fig. 4). Present result confirm pervious reports, where increased plant density decreased crop yield loss due to weed interference (Mennan and Zandstara, 2005; Eslami *et al.*, 2006; Olsen *et al.*, 2006; McDonald *et al.*, 2007). At higher densities, it is expected that wheat will be at competitive advantage because more crop plants in a given area will capture resources at faster rate and fewer resources will be available for weeds.

A noteworthy finding in this study was that although, the use of more competitive cultivar and higher plant density may not completely eliminate *A. ludoviciana* competitive effects at high *A. ludoviciana* densities, the use of both tactics results in a more competitive cropping system and may allow for reduction in herbicide rate. Information gained from the current study will be used to develop more integrated programs for weed management in winter wheat production systems.

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