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Effects of sowing density on yield and yield components of irrigated bread wheat cultivars

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Abstract. In order to determine effects of planting density on grain yield (GY), yield components and total dry matter (TDM) of bread wheat (*Triticum aestivum* L.), three new released cultivars, namely: M-70-4, Niknejad and Mahdavi were subjected to four sowing density, 350, 400, 450 and 500 seed/m^2 during 2007-08, 2008-09 in Kermanshah province, western Iran. A factorial experiment based on randomized complete block design (RCBD) with four replications was used. Combined analysis of data showed no significant difference among cultivars and seed densities, but 400 seed.m^{-2} and Mahdavi cv. produced the highest GY. Mahdavi cv. produced the highest TDM, HI and 1000 kernel weight (TKW) also and ranked in A class. Interaction effects of seed density and cultivar was significant. Based on regression analysis, increasing of seed density resulted in increasing of BY and spikes.m^{-2} and decreasing of HI and seed/spike. There was no reduction in TKW due to increasing of seed density. It seems that under Kermanshah province, a 400 seed.m^{-2} is recommendable to wheat growers and Mahdavi cv. will perform better than other genotypes.

Key words: Bread wheat, sowing density, grain yield, HI, yield components.

Introduction

Bread wheat is the most important crop and food stable of Iran. The area found under irrigated wheat production in Kermanshah province reaches up to 10.0000 ha annually. A high seeding rate is an undesirable custom between farmers and sometimes reaches 300 kg.ha^{-1}, causing wasting of resource and not being economical, can result in prevalent of diseases such as strip rust (Garrett & Mundt 2000, Kahrizi et al. 2010a, Kahrizi et al. 2010b, Garavandi et al. 2011). On the other hand, using a good seeding density can provide weeds suppression in wheat crop (Ijaz et al. 2007).

Cereals present a compensatory ability between yield components, so by reducing one component, its reduction will be balanced by another (Joseph et al. 1985). The relation between GY and yield components reported by some researchers (Ledt & Moss 1977, Sharma et al. 1987, Khabaz Saberi et al. 1993). Highest relation reported between GY and kernel per spike (Ledt & Moss 1977).

Cereals such as wheat show an optimum sowing density and grain yield can not increase more by using densities up to optimum, because yield components will reach a balance and there is no significance in increasing grain yield to high densities (Hanson 2001). Increase of spike per unit of area (Joseph et al. 1985, Sharma & Smith 1987, Varga et al. 2000, Hanson 2001) and reduction of seed per spike (Joseph et al. 1985, Zaheer et al. 2000, Hanson 2001) due to increasing of sowing density was reported. The correlation between grain yield and yield components in wheat presents the compensation ability of yield component in crop and the correlation coefficients between sowing densities is somewhat higher for yield components than grain yield (Sharma 1987).

Sowing density can influence some agronomic traits and yield components of wheat also. Reduction of seed weight due to increase of seeding rate (Varga et al. 2000) and reduction of harvest index (Zaheer et al. 2000.) was also reported.

In spite of the response of GY to seeding rate, depending on location and cropping period (Joseph et al. 1985; Azizi & Kahrizi, 2008), special densities are recommended for specific areas and cultivars (Joseph et al. 1985, Johnson et al. 1988, Ijaz et al. 2007).

Sustainability in agriculture and dual use of wheat production in some areas is important through the usage of residual for livestock feeding essence cultivation of cultivars with high biomass potential and good harvest index. Harvest index, HI, is used in some cases as a breeding trait in cereal yield improvement and its stability can be used as breeding index for selection of cultivars (Sharma & Smith 1987). Totally, there is a positive relation between HI and GY and this relation is stronger in dwarf cultivars. Positive correlation of GY, HI and total dry matter, TDM was also reported (Joseph et al. 1985). Increasing of TDM at high densities (Prasertsk et al. 1989) can indirectly affect grain yield at high sowing densities.

In some studies, no effects of seeding density and interaction of density × cultivar was reported (Khabaz Saberi et al. 1993); difference between years was seen in some cases (Sharma & Smith, 1987, Khabaz Saberi et al. 1993).

In order to study the improved and recently released bread wheat cultivars, the present study, conducted under the conditions of Kermanshah province, western Iran, identified the highest GY and TDM potential of these genotypes and recommended an optimized seed density to wheat growers.

Materials and methods

In the present study, three recently introduced bread wheat cultivars of moderate zone of Iran, namely: M-70-4, Niknejad and Mahdavi were subjected to four sowing densities, 350, 400, 450 and 500 seed/m^2 during 2007-08, 2008-09 cropping periods in Kermanshah province, western Iran. A factorial experiment based on randomized complete block design (RCBD) with four replications was used. Each plot contains 12 rows of 12 m in length and a space of 20 cm between the rows (28.8 m2). The seed of each plot was calculated based on 1000 kernel weight (TKW) of sieved and treated seeds. Macro and micro nutrients were used according to soil tests. So, a 200: 150:0 kg/ha of ammonium nitrate, P_2O_5 and Potash was used respectively. Whole phosphate and half of ammonium nitrate was used before planting and the remaining ammonium nitrate was applied to plots at jointing and anthesis stages with equal rate using Zeadoks scale as top dressing. Planting was done by experimental plotter (Wintersteiger trade mark) at the last decade of October each year. Irrigation was done by using furrows according to the normal custom of the province and amounts of precipitation as needed. Normal crop protection operation and note taking was done also. Harvest Index, Total dry matter (TDM) and spike/m² was measured by harvesting a 0.5 × 0.6 m quadrate from soil surface of each plot; counting spikes, threshing to separate grain from straw and drying material at 75-80 C for 48 hrs. The seed/spike was calculated by random selection of 10 spikes from each plot also. Harvest index (HI) was calculated by using the following formula: HI= (Biological yield/Economical yield) × 100

Where biological and economical yield are TDM and grain yield per unit of area respectively.

An experimental plot harvester (Wintersteiger trade mark) was used and harvest was done at the last decade of June each year. To eliminate border effects, 1 meter of two sides of each plot was removed and plot length was reduced to 10 m (harvest area was 24 m2). Grain yield of Plots weighted by 0.1 g accuracy balance and SAS software was used to statically analysis assuming years as random, densities and cultivars as fixed factors.

Data on growth and yield components were collected using standard procedures and were analyzed statistically using Fisher's analysis of variance technique. Regression and correlation analysis was also run on grain yield and yield components (Steel & Torrie 1980, Kılıç & Gürsoy 2010).

Results and Discussion

Harvesting Index

Densities: The results of simple analysis indicate strong significant difference between densities (except the second year), cultivars and interaction of cultivars × densities. But because of the fluctuation of HI of cultivars over the years, significant differences between harvesting index of density and cultivars levels was not seen in combined analysis (Table 1). In the first year, 2007-08, density of 350 seed/m² showed maximum harvesting index (37.38) and ranked in A class, but in the second year, 2008-09, a significant difference between the densities was not observed. In combined analysis, density of 350 seed/m² showed the highest HI and placed it first, ranking in A class. In addition, increasing of density reduced HI (Table 2). This can be due to an increase of biological yield because of higher densities of plants per unit of area and relative stability of grain yield.

Cultivars: In simple analysis, cultivars showed a significant difference for HI, but due to the fluctuation of cultivars over the years (Cultivar M-70-4 in particular); this difference was not significant in the combined analysis (Table 1). In the first year test, M-70-4 showed the highest HI, ranking in first place without significant difference with Mahdavi, hence Niknejad showed the lowest HI and ranked in B class. In the second year Mahdavi and Niknejad were placed in a class and cultivars M-70-4, with a sharp drop in contrast with the first year due to hypersensitivity to leaf rust (caused by *Puccinia triticina*), ranked in b class and the last category. Based on results of combined analysis of data, Mahdavi was superior and showed the highest HI (Table 3).

Interactions: The highest HI of treatments (density × cultivar) in the final analysis (39.23) produced by treatments consist of 350 seed/m² and Mahdavi (Table 4). A significant difference was seen between the years and higher HI was observed in the second year. The interaction between density × year, year × cultivars and year × density ×cultivars was also significant.

Total Dry Matter

Densities: A simple data analysis of each year shows a significant increase of TDM because of increasing of seed density confirmed by Prasertsk et al. (1989). In the first and second year, maximum TDM was produced by density of 500

Table 1. Mean squares for different characters in bread wheat based on analysis of data (2007-08 and 2008-09). (GY: Grain Yield; HI: Harvest index, TDM: total dry matter, Ft: Fertile tillers, St: Straw)

S.O.V	df	Mean of Square				
		GY	HI	TDM	Ft	St
Year (Y)	1	10512.009**	92.887**	2435397.327**	28865.785**	1340094.946**
Replication×Y	6	19186.843	8.170	73097.914	11103.57	25070.073
Density (D)	3	163.728^{ns}	6.079^{ns}	86564.611^{ns}	33725.043^{ns}	49531.485^{ns}
Y×D	3	1428.932**	6.645**	161345.066**	10149.339**	54255.219**
Cultivars (C)	2	17692.768^{ns}	20.539^{ns}	113634.673^{ns}	83151.988*	2123.518^{ns}
Y×C	2	7079.015**	30.781**	32906.476**	3510.314**	39473.392**
D×C	6	544.942^{ns}	1.510**	14529.024**	5998.805**	5645.371*
Y×C×D	6	2439.236**	1.316**	24188.351**	824.823**	12471.508**
Error	66	141.305	2.744	31609.966	3772.416	14733.114
CV%		6.32	4.34	8.99	9.64	9.90

** Significant difference at 1 %, * significant difference at 5 %, ns: non significant, CV: coefficient of variation

Table 2. Effect of density on grain yield, total dry matter, HI and yield components of studied cultivars. (TDM: total dry matter, TKW: 1000 kernel weight).

Density (seed/m²)	Grain Yield (gr/m²) +	TDM (gr/m²)+	HI (%)+	TKW (gr)++	Kernel/spike ++	Spike/m² +
350	597.0^{a}	1906^{a}	38.77^{a}	41.77^{a}	33.33^{a}	590.6^{a}
400	597.6^{a}	1991^{a}	38.30^{a}	41.19^{a}	29.82^{b}	624.9^{a}
450	592.2^{a}	1966^{a}	37.67^{a}	41.40^{a}	29.18^{bc}	659.6^{a}
500	597.6^{a}	2051^{a}	37.79^{a}	41.48^{a}	27.17^{c}	674.5^{a}
LSD	ns	ns	ns	ns	2.3220**	ns

** Significant difference at 1 %, +: data of 2007-2009, ++: data of 2007-08 only.

Table 3. Data of grain yield, total dry matter, HI and yield components of cultivars.

Cultivars	Grain Yield (gr/m²) +	TDM (gr/m²)+	HI (%)+	TKW (gr)++	Kernel/spike ++	Spike/m² +
M-70-4	601.8[a]	1948[a]	38.23[a]	39.93[b]	30.11[ab]	679.0[a]
Niknejad	570.2[a]	1941[a]	37.28[a]	36.50[c]	31.20[a]	652.7[a]
Mahdavi	616.2[a]	2047[a]	38.88[a]	47.95[a]	28.31[b]	580.5[b]
LSD	ns	ns	ns	1.4510**	2.0110**	40.73**

** Significant difference at 1 %, +: data of 2007-2009, ++: data of 2007-08 only.

Table 4. Statistical classification of GY, HI, TDM, fertile spikes and straw per square meter (data of 2007-2008 and 2008-2009)..

Density (seed/m²)	Cultivars	Yield (gr/m²)	HI (%)	TDM (gr/m²)	Fertile spikes (m²)	Straw (gr/m²)
350	M-70-4	613.8[a]	39.02[a]	1921ab	642.4[bcd]	1169[ab]
	Niknejad	568.2[a]	38.05[a]	1820[b]	570.3[ef]	1132[b]
	Mahdavi	609.0[a]	39.23[a]	1978[ab]	599.2[f]	1202[ab]
400	M-70-4	598.4[a]	37.71[ab]	1966[ab]	671.6[abc]	1205[ab]
	Niknejad	572.1[a]	37.11[ab]	1977[ab]	625.0[cde]	1247[ab]
	Mahdavi	622.4[a]	39.07[a]	2029[ab]	578.0[ef]	1240[ab]
450	M-70-4	601.6[a]	37.97[ab]	1920[ab]	691.8[ab]	1192[ab]
	Niknejad	565.1[a]	36.56[b]	1961[ab]	696.8[ab]	1247[ab]
	Mahdavi	610.0[a]	38.48[ab]	2017[ab]	590.3[def]	1243[ab]
500	M-70-4	593.6[a]	37.23[ab]	1984[ab]	710.1[a]	1247[ab]
	Niknejad	575.6[a]	37.41[ab]	2005[ab]	718.8[a]	1258[ab]
	Mahdavi	623.5[a]	38.73[ab]	2163[a]	594.7[def]	1331[a]
LSD		70.32**	2.1970**	288.30**	81.46**	161.00*

** Significant difference at 1 % level
* Significant difference at 5 % level

and 450 seed/m² respectively. While, in combined analysis density of 500 seed/m² produced the highest TDM. Increasing dry matter, accompanied by a non increase of grain yield can explain decrease of HI because of increasing of density. In simple and combined analysis, lowest TDM was produced by density of 350 seed/m² without any significant difference with other densities (Table 1 and 2).

Cultivars: In simple analysis, cultivars showed no significant differences for TDM production (except second year). However, in simple and combined analysis, Mahdavi produced maximum dry matter followed by M-70-4 and Niknejad. On a whole, based on the results of combined analysis, significant difference between the cultivars was not found (Table 3). It showed that Mahdavi is very productive for TDM and it is an advantage for dual purpose of this genotype under farming system of province, where straw and remaining of crop will be used for feeding of livestock after harvest (Kahrizi et al. 2010b).

Interactions: Interaction of density × cultivars in simple and combined analysis was significant. Significant difference between the years was observed also, and more TDM was produced in the first year. The main reason is reduction of TDM of M-70-4 cultivar due to high infection of leaf rust. The interactions of density × year, year × cultivars, and year × density × cultivars were also significant. In the combined analysis, the highest TDM (2165 gr/m²) was produced by treatment consisting from Mahdavi and density of 500 seed/m².

Grain Yield

Densities: Simple and combined analysis of grain yield indicates non significant differences between densities (Table 1 and 2), which confirm the results of Khabaz Saberi et al. (1993), Sharma et al. (1987) and Prasertsk et al. (1989). The compensatory ability of wheat is the main reason of this phenomenon that enables crop justified yield components and remain grain yield over a wide range of sowing densities. However, an increase of yield was observed in some cases (Sharma 1987) due to increase of seeding rate.

Cultivars: The significant difference between cultivars were also observed: this difference was more sever in the first year, but in the second year, due to a sharp drop of yield of M-70-4, this difference was significant at the level of 5% only. In 2007-08 period, M-70-4 and Mahdavi ranked in class a, but in the second year, Mahdavi showed priority and ranked in class **a**; yield of M-70-4 declined sharply and ranked in the last category due to high sensitivity to cereal leaf rust and sever damage of disease. On a whole, in combined analysis there was no significant difference between cultivars, where Mahdavi produced the highest yield (Table 3). In simple and complex analysis, Niknejad showed the lowest yield.

Interactions: Interaction of densities × cultivars (treatments) was significant in the first year at 1% level and the highest yield produced by treatment consists from M-70-4 and density of 350 seed/m², while treatment of Niknejad and density of 400 seed/m² produced the lowest yield. In the second year, interactions were significant only at 5% level; treatment consisting of Mahdavi and density of 500 seed/m² produced the highest yield. In combined analysis, there was no significant difference among treatments but the highest yield (623.5 gr/m²) produced by treatment consists of Mahdavi and density of 500 seed/m² (Table 4).

In general, due to fluctuations of cultivars yield, a significant difference was not found between them in combined analysis, but Mahdavi produced the highest yield over all densities (Table 4). A significant difference was not found between densities, but densities of 400 and 500 seed/m^2, produced the highest yield. So, regarding economical aspects and in order to prevent lodging and infection of prevalent diseases, 400 seed/m^2 density is preferred and recommended to wheat growers of province (Table 2). Interaction of year × density, year × cultivars and year × density × cultivars was significant at 1 % level also. These results confirm reports of Khabaz Saberi et al. (1993) and Anderson et al. (1986).

Yield Components

Fertile Spikes:

Densities: Simple and combined analysis showed increase in the number of fertile spikes due to increasing of sowing density, which confirm results of Joseph et al. (1985) and Sharma et al. (1987). In the first year, 2007-08, there was no significant difference between densities (Table 5); where the density of 500 seed / m^2 produced the highest fertile spikes/m^2. In the second year, densities of 450 and 500 seed/m^2 produced the most fertile spikes/m^2, ranked in class **a**. In the combined analysis, density of 350 and 500 seed/m^2 produced the lowest and highest number of fertile spikes/m^2 respectively, but no significant difference was found between level of densities (Table 1 and 2).

Cultivars: A significant difference was observed between cultivars in simple analysis (Table 5). With a similar trend in simple and combined analysis, M-70-4 and Niknejad was placed in class a, and Mahdavi ranked in class b (Table 3). It means that M-70-4 has a high potential of tillering and Mahdavi should compensate low tillering ability by other yield components attaining highest grain yield.

Interactions: In the first year, treatment consisting of M-70-4 and 500 seed/m^2 produced 736 fertile spikes/m^2, which ranked in class a (Table 6), while in the combined analysis, treatment consists of Niknejad and density of 500 seed/m^2 that showed highest fertile spikes/m^2 (Table 4). This means significance of interaction of density × cultivars and presenting significant difference between experimental treatments. A significant difference was observed between the years and the first year of experiment, 2007-08, produced higher fertile spikes. Interaction of year × cultivars, year × density and year × density × cultivars were significant also (Table 1).

Kernel per spikes:

Densities: Increasing of planting density, caused a significant reduction trend in kernels per spike confirming the results of Joseph et al. (1985) and Zaheer et al. (2000). Maximum kernels/spike (i.e. 33.3) was observed in density of 350 seed/m^2 that ranked in A class. In contrast, density of 500 seed/m^2 showed the lowest kernels /spike and was placed in C class (Table 2).

Cultivars: A significant difference between cultivars was seen also. The Niknejad showed highest kernels/spikes (31.2) followed by M-70-4, which ranked in A class. Mahdavi produced the lowest kernel per spikes and was placed in B class (Table 3).

Interactions: Interaction of density × cultivars was significant also and the highest kernel per spikes produced by treatment consisted from 350 seed/m^2 and M-70-4 (Table 6).

1000 kernel weight (TKW):

Densities: Effect of planting density on grain TKW showed no particular trend, and in this case, a significant difference between treatments was not found. This is confirmed by the results of Zaheer et al. (2000), Hanson (2001) and Prasertsk et al. (1989); opposite of Varga et al. (2000). However, density of 350 seeds/m^2 showed maximum TKW (Table 2 and 5).

Cultivars: A strong significant difference was observed between cultivars and Mahdavi showed the highest TKW (47.95 gr) that ranked in first place and A class (Table 3). M-70-4 and Niknejad were placed in B and C classes respectively.

Interactions: The density × cultivars interactions were significant also and the highest TKW (48.83 gr) produced by treatment was composed from 500 seed/m^2 and Mahdavi (Table 6).

Regression analysis

Based on the regression analysis the GY with HI was significant regression model with GY= -164.621HI + 19.994 linear regression equation ($P<0.01$) and R^2= 0.68**. Other variables were not statistically significant regression model with GY. Among studied variables the fertile tillers (Ft) had significant relationship with HI=44.90Ft-0.011 regression equation ($P<0.05$) and R^2= 0.45*. Other variables had no statistically significant regression model with HI

Correlations

Correlation analysis of yield components with a simple regression showed a significant and positive relationship of TKW with grain yield, confirming that the results of Kabaz Saberi et al. (1993) are consistent, but this relationship was not very strong (r = 0.53). Correlation of TKW with the number of spikes per unit of area and the grains per spike were significant, weak and negative. These results were also obtained by Joseph et al. (1985). No strong correlation was observed between kernel per spikes and spikes per unit area with yield. Significant and positive relationship between total dry matter and grain yield (r = 0.52), total dry matter and

Table 5. Mean squares for yield components in bread wheat (based on data of 2007-2008 period only)..

S.O.V	df	Means of squares		
		Fertile spikes	Kernel/spike	TKW
Replicate	3	16934.278	6.551	13.946
Density	3	5706.333^{ns}	78.9672**	0.681^{ns}
Cultivars	2	45905.813**	34.028**	522.470**
Density × Cultivars	6	2067.146**	3.301**	2.835**
Error	33	3832.929	4.330	2.255
CV		9.46 %	6.97 %	3.62 %

** Significant difference at 1 %, * significant difference at 5 %, ns: non significant, CV: coefficient of variation

Table 6. Response of yield components of cultivars to densities (data of 2007-2008)..

Densities (seed/m^2)	Cultivars	Fertile spikes/m^2	Kernel/spike	TKW (gr)
350	M-70-4	684.0^{ab}	34.35^{a}	40.08^{b}
	Niknejad	611.5^{ab}	34.17^{a}	$37.42b^{cd}$
	Mahdavi	600.0^{ab}	31.45^{abc}	47.80^{a}
400	M-70-4	700.8^{ab}	30.33^{abcd}	40.40^{b}
	Niknejad	640.0^{ab}	32.00^{ab}	36.55^{cd}
	Mahdavi	609.3^{ab}	27.13^{cd}	46.63^{a}
450	M-70-4	703.5^{ab}	28.80^{bcd}	39.47^{bc}
	Niknejad	678.5^{ab}	30.60^{abcd}	36.17^{d}
	Mahdavi	576.5^{b}	28.15^{bcd}	48.55^{a}
500	M-70-4	736.0^{a}	26.98^{cd}	39.78^{b}
	Niknejad	706.0^{ab}	28.02^{bcd}	35.83^{d}
	Mahdavi	611.0^{ab}	26.22^{d}	48.83^{a}
LSD		119.70**	4.0220**	2.9020**

**least significant difference at 1 %

spikes per unit area (r = 0.46) was seen, but this relationship despite of being significant, was weak. Also a negative and significant relationship between harvest index and total dry matter (r = 0.32) and harvest index with spikes per unit area (r = 0.27) was seen, but these relationships were very weak. The spikes per unit of area and harvest index, also with yield showed a positive and weak relationship.

Based on correlation analysis, the density is positively correlated with TDM (0.59*) and straw (0.76**) significantly.

Summary

In general, planting density had no significant effect on yield, but the yield components were affected significantly by sowing density. A significant difference was observed between grain yield of cultivars and Mahdavi showed priority. With increasing of planting density, the number of fertile spikes and total dry matter per unit of area increased, but the number of kernel per spikes decreased. The 1000 kernel weight showed no particular trend, and no significant difference was observed for TKW in this study. The increase of the number of fertile spikes per unit area was neutralized and mitigated by reduction of kernels per spikes resulted in stability of grain yield. Also, in high densities due to the increase of total dry matter and yield stability, harvest index was reduced. The highest correlation was seen between yield and 1000 kernel weight. Total dry matter showed a positive and significant relation with yield also, but the relationship between harvest index and total dry matter was negative and significant. According to the results of this study Mahdavi cultivar and 400 seed/m^2 density is recommendable to wheat growers of Kermanshah province. The correlation between GY and HI (0.82) was positive and significant (P<0.01). Based on regression analysis the GY with HI was significant regression model. Other variables had not significant regression model with GY.

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