AgroSym 2019

BOOK OF PROCEEDINGS

X International Scientific Agriculture Symposium
"AGROSYM 2019"
Jahorina, October 03-06, 2019

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Impressum

X International Scientific Agriculture Symposium „AGROSYM 2019“

Book of Abstracts Published by

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CIP - Каталогизација у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

631(082)

INTERNATIONAL Scientific Agricultural Symposium "Agrosym 2019" (10) (Jahorina)
Book of Proceedings [Elektronski izvor] / X International Scientific Agriculture Symposium "Agrosym 2019", Jahorina, October 03 - 06, 2019 ; [editor in chief Dušan Kovačević]. - East Sarajevo : Faculty of Agriculture, 2019

Način pristupa (URL): http://agrosym.ues.rs.ba/index.php/en/archive. - Библиографија уз радове. - Регистар.

ISBN 978-99976-787-2-0

COBISS.RS-ID 8490776

X International Scientific Agricultural Symposium “Agrosym 2019”
Jahorina, October 03-06, 2019, Bosnia and Herzegovina

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NITROGEN FERTILIZATION AND SOWING DENSITY INFLUENCE ON WINTER WHEAT YIELD AND YIELD COMPONENTS

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Abstract

Nitrogen management in winter wheat is one of the most studied agricultural practices. Optimization of nitrogen nutrition and sowing density requirements of specific winter wheat cultivar are major objectives for improvement of trade-offs between grain yield, environmental sustainability and maximum profitable production. Therefore, the aim of this study was to assess the effects of interaction between nitrogen fertilization and sowing density on grain yield and yield determinants of modern wheat cultivars. The trial consisted of five winter wheat cultivars, four top-dressing nitrogen doses and four sowing densities was carried out under rain-fed conditions at the experimental field of the Institute of Field and Vegetable Crops, Novi Sad, Serbia. The analysis of variance showed statistically significant effects of all three factors on studied traits, while significance of interactions between studied treatments varied among traits. On average, grain yield between cultivars varied from 8.64 to 9.69 t ha^{-1}. Generally, the highest grain yield was achieved under conditions of 100 kg N ha^{-1} treatment. By increasing N fertilization thousand grain weight decreased almost linearly, while maximum grain number per square meter was recorded with 100 and 150 kg N ha^{-1}. The highest yield and grain number per square meter were obtained under increased sowing densities (700 and 900 viable seeds m^{-2}), while the thousand grain weight had lower variation and the highest values were realized with 300 and 900 viable seeds m^{-2}. In conclusion, the presence of significant interaction between cultivars, N fertilization and sowing densities, indicated necessity to adjust different management practices to each cultivar in order to achieve highest grain yield potential.

Keywords: *Triticum aestivum L., nitrogen fertilization, sowing density, yield traits*

Introduction

Wheat is one of the oldest and most important cereal crops, widely cultivated for its grain which is a worldwide staple food. In Serbia, the southern part of the Pannonian plain, wheat is the main winter cereal crop with a harvested area over 550,000 ha. Wheat production needs to continue to grow with increasing demands, and both aspects increasing the yields and sustainability represent major challenges (Hawkesford, 2014). Production systems in the world vary greatly, depending on climatic and soil fertility factors. The agricultural areas of the Pannonian basin are characterized by a relatively short growing season, winter frosts, occasional spring heats and frequent drought stresses at the end of the grain filling period, which influences significant grain yields variations of many cereal crops across different growing seasons (Mirosavljević et al., 2018). For all agricultural systems, especially in areas of higher production there is a constant need for adequate amounts of nutrients, mostly supplied as fertilizers. Efficient nitrogen fertilization is one of the key elements for economical wheat production. Moreover, nitrogen is the most limiting nutrient for wheat production that affects grain yield and biomass production, as well as establishment of high grain weight and grain number per unit area (Lawlor et al., 2001). Adequate nitrogen use is also important in order to protect underground and surface water from pollution caused by the leaching of nitrates due to excessive and inappropriate fertilization (Vuković et al., 2008). Beside balanced nutrition, sowing density also plays an important role for achieving high yields with desirable grain quality. Optimum plant densities greatly vary across areas, diverse climatic and soil conditions as well as cultivar specificity. Due to the presence of different mechanisms of yield determination in wheat cultivars, each cultivar needs to be evaluated over wide range of fertilization and seeding rates to determine optimal combination of agronomic practices (Wiersma, 2002). Considering constant development of new wheat cultivars with specific requirements for appropriate management practices, there is a lack of information about their response to different fertilization and sowing density. Therefore, the objectives of this study were to quantify the variation in grain yield and main agronomic traits of the five new developed wheat cultivars across different N fertilization levels and sowing densities in order to improve wheat production under agroecological conditions of Pannonian Plain.

Materials and methods

This study included five new winter wheat cultivars (NS Pudarka, NS Nafora, NS Petrija, NS Tavita and NS Ilina) released by the Institute of Field and Vegetable Crops, Novi Sad, Serbia. The cultivars were grown under field conditions with combinations of four top-dressed N fertilization levels and four sowing densities. N fertilization treatments included an unfertilized control (0 N) and N fertilization with 50 (50 N), 100 (100 N) and 150 kg N ha^{-1} (150 N), and sowing densities of 300, 500, 700 and 900 viable seeds m^{-2}. Treatments were arranged in a split-split-plot design with three replications. Main plots were assigned to the nitrogen levels, sub-plots to cultivars and sub-sub-plots to sowing densities.

The trial was set up at experimental fields of Institute of Field and Vegetable Crops, Novi Sad under rain fed conditions on carbonate chernozem, with soybean as a preceding crop in 2015/16 growing season. Crops were sown on recommended sowing date for southern Pannonian plain. A fertilizer combination (NPK – 11:52:0) was applied before ploughing to avoid N, P and K deficit, based on previous soil agrochemical analysis. The soil was prepared by ploughing along with two harrowing procedures. Each plot consisted of 10 rows, with row spacing of 0.10 m and length of 5 m. Pests, weeds and diseases were prevented or controlled by applying the recommended insecticides, herbicides and fungicides. No additional irrigation was applied. Grain yield (GY) was determined from combine-harvested plots in each of the three replications. Moisture content was determined using grain analysis computer (Model GAC2100, Dickey-John, Auburn, IL) and GY was corrected to 130 g kg^{-1} moisture. From harvested sample, thousand grain weight (TGW) was determined by three sets of 300 grains per plot and expressed as the weight of 1000 grains. Number of grains per m^2 (GN) was calculated as the ratio of the grain yield and the thousand grain weight. Analysis of variance (ANOVA) and data mean comparison by Duncan multiple range test were performed using Infostat (student version).

Results and Discussion

In combined analysis of variance cultivar (C) contributed the most to the total sum of squares of the studied traits (Tab. 1). Cultivars behaved differently under various N-fertilization (F) and sowing density (SD) treatments. The effect of F × C interaction was significant for all studied traits, with the highest influence of GY. The contribution of F × SD, C × SD and F × C × SD interaction was significant only for TGW.

Tab. 1. Relative contribution to the total sum of squares (%) and the level of significance for grain yield (GY), thousand grain weight (TGW) and grain number (GN) of wheat cultivars (C) under different fertilization (F) and sowing density (SD) treatments

Source of variation	Degrees of freedom	GY	TGW	GN
F	3	5.9**	17.4**	21.5**
C	4	13.4**	71.7**	27.8**
SD	3	8.2**	0.3**	5.5**
F × C	12	8.9*	4.9**	7.6**
F × SD	9	1.6^{ns}	0.4**	1.0^{ns}
C × SD	12	2.3^{ns}	0.6**	1.0^{ns}
F × C × SD	36	3.4^{ns}	1.8**	2.3^{ns}

* significant at 0.05; ** significant at 0.01; ns - not significant

Overall GY average of the analyzed cultivars in the trial was 9.16 t ha^{-1} (Tab. 2). N fertilization significantly altered GY of five winter wheats cultivars, resulting in GY increase in comparison with the unfertilized treatment. On average, the highest GY was observed at 100 N (9.50 t ha^{-1}) and 150 N (9.24 t ha^{-1}). However, absence of N application (control treatment) resulted in the lowest GY average of 8.80 t ha^{-1}. Moreover, cultivars differed significantly in GY, and the average values among cultivars ranged from 8.64 (NS Ilina) to 9.69 t ha^{-1} (NS Pudarka). Also, there was a significant influence of F × C interaction on GY, indicating different cultivar responses to N application, e.g., NS Petrija achieved the highest GY at 50 N, whereas NS Tavita at 150 N treatment. Similarly, various studies showed GY increase with nitrogen application as a result of enhanced tillering, higher biomass production, GN and GW. (Kristensen et al., 2008, Jaćimović et al., 2014; Yang et al., 2019). Although, negative influence of N-fertilizer application on GY (severe lodging) were recorded due to favorable conditions for organic matter mineralization and consequently higher mineral N content in the soil (Aćin et al., 2013; Aćin et al., 2014).

Tab. 2. Grain yield (t ha^{-1}) of wheat cultivars across fertilization and sowing density treatments

Cultivar	**N-fertilization**				**Sowing density**				**Average**
	0 N	**50 N**	**100 N**	**150 N**	**300**	**500**	**700**	**900**	
NS Pudarka	9.52^{a-c}	9.61^{ab}	9.90^{a}	9.73^{ab}	9.52^{a-d}	9.45^{a-e}	10.02^{a}	9.77^{a-c}	**9.69^{a}**
NS Nafora	9.09^{a-d}	9.90^{a}	9.48^{a-c}	9.44^{a-c}	8.77^{a-d}	9.59^{a-d}	9.73^{a-c}	9.82^{ab}	**9.48^{ab}**
NS Petrija	8.69^{cd}	9.33^{a-c}	9.45^{bc}	8.93^{b-d}	8.59^{ef}	8.73^{d-f}	9.48^{a-e}	9.60^{a-d}	**9.10^{bc}**
NS Tavita	8.31^{d}	8.32^{d}	9.14^{a-d}	9.72^{ab}	8.57^{ef}	8.93^{b-f}	8.91^{b-f}	9.07^{b-e}	**8.87^{cd}**
NS Ilina	8.37^{d}	8.26^{d}	9.53^{a-c}	8.40^{d}	8.09^{f}	8.57^{ef}	8.88^{c-f}	9.02^{b-e}	**8.64^{d}**
Average	**8.80^{c}**	**9.08^{bc}**	**9.50^{a}**	**9.24^{ab}**	**8.71^{b}**	**9.05^{b}**	**9.40^{a}**	**9.46^{a}**	**9.16**

Different letters represent significant differences (p<0.05; Duncan multiple range test)

On average for examined cultivars, significantly highest yields were achieved with 700 and 900 viable seeds m^{-2}. In general, GY of each cultivar improved with increasing sowing densities, but due to the absence of C × SD interaction, differences were not significant for most of the cultivars, except for NS Petrija and NS Ilina (Tab. 2). In agroecological conditions of Serbia, optimal SD of winter wheat varieties should vary between 500 and 600 viable seeds m^{-2}, thus producing a sufficient number of good quality spikes. Plants compensate lower population densities by increasing production and survival of tillers and, to a lesser extent, increasing grain numbers per spike (Bokan and Malesevic, 2004). However, although low plant density induces a higher GN and GW per spike, generally this is not sufficient to compensate for the lower spike density per m^{2} generated by a lower tiller density. Therefore, an appropriate increase in plant density to balance yield component factors would appear to be an appropriate agronomic management strategy for enhancing wheat grain yield (Li et al., 2016). The grand mean of TGW was 43.8 g, and it was significantly affected by the change in nitrogen top-dressing doses (Tab. 3). TGW values decreased with higher application of nitrogen, ranged from 46.6 g in 0 N to 41.9 g in 150 N treatments. Moreover, significant differences among cultivars were recorded for TGW, where average values varied from 38.0 g to 49.2 g, for NS Ilina and NS Tavita, respectively.

Tab. 3. Thousand grain weight (g) of wheat cultivars across fertilization and sowing density treatments

Cultivar	N-fertilization				Sowing density				Average
	0 N	50 N	100 N	150 N	300	500	700	900	
NS Pudarka	45.6^{d}	44.1^{ef}	44.2^{ef}	44.6^{e}	45.1^{bc}	44.7^{b-d}	44.1^{d}	44.5^{cd}	**44.6^{c}**
NS Nafora	48.1^{c}	45.5^{d}	43.5^{f}	43.7^{f}	45.4^{b}	45.3^{b}	44.9^{b-d}	45.1^{bc}	**45.2^{b}**
NS Petrija	45.4^{d}	43.4^{f}	41.0^{h}	38.1^{i}	42.4^{e}	40.9^{f}	42.0^{e}	42.6^{e}	**42.0^{d}**
NS Tavita	51.5^{a}	49.9^{b}	47.5^{c}	48.0^{c}	49.7^{a}	49.3^{a}	49.0^{a}	49.0^{a}	**49.2^{a}**
NS Ilina	42.4^{g}	38.4^{i}	36.1^{j}	35.1^{k}	37.9^{h}	37.4^{h}	37.9^{h}	38.7^{g}	**38.0^{e}**
Average	**46.6^{a}**	**44.3^{b}**	**42.4^{c}**	**41.9^{d}**	**44.1^{a}**	**43.5^{b}**	**43.6^{b}**	**44.0^{a}**	**43.8**

Different letters represent significant differences ($p<0.05$; Duncan multiple range test)

Differences in TGW were also observed due to the effects of various SD (Tab. 3). Highest TGW values were recorded with 300 and 900 viable seeds m^{-2}, for all studied cultivars. In comparison with 500 and 700 viable seeds m^{-2}, differences were not have considerable extent, but statistically significant. However, effects of SD on GY were not significant for cultivars NS Nafora and NS Tavita. According to Valerio et al. (2013), TGW did not reveal an effect on the yield variations, due to a change in SD rates. Similar results have been reported, where the TGW appears to be less affected by seeding density but significantly affected by environment and cultivar (Lloveras et al., 2004; Hiltbrunner et al., 2005). However, increase in SD from 500 to 650 viable seeds m^{-2} resulted in increase of TGW, as higher plant density provides a greater number of primary tillers per m^2, which causes the formation of grains with larger size and weight (Zecevic et al., 2014). An increase in N application resulted in an increase in GN, with a trial average of 21109 (Tab. 4). For all examined cultivars, the highest GN were obtained at 100 N and 150 N treatments, respectively, followed by 50 N and 0 N treatment with the lowest value.

Tab. 4. Grain number of wheat cultivars across fertilization and sowing density treatments

Cultivar	N-fertilization				Sowing density				Average
	0 N	50 N	100 N	150 N	300	500	700	900	
NS Pudarka	20859^{d-f}	21803^{c-e}	22462^{b-d}	21809^{c-e}	21112^{c-e}	21135^{c-e}	22721^{a-c}	21965^{a-d}	**21733^{b}**
NS Nafora	18950^{f}	21782^{c-e}	21838^{c-e}	21577^{c-e}	19439^{e-g}	21191^{c-e}	21726^{a-d}	21792^{a-d}	**21037^{b}**
NS Petrija	19112^{f}	21491^{c-e}	23067^{bc}	23436^{bc}	20353^{d-f}	21482^{b-d}	22648^{a-c}	22624^{a-c}	**21776^{b}**
NS Tavita	16147^{g}	16667^{g}	19249^{f}	20229^{ef}	17324^{h}	18164^{gh}	18253^{gh}	18551^{f-h}	**18073^{c}**
NS Ilina	19790^{ef}	21497^{c-e}	26437^{a}	23972^{b}	21570^{a-d}	23125^{a-c}	23610^{a}	23392^{ab}	**22924^{a}**
Average	**18972^{c}**	**20648^{b}**	**22611^{a}**	**22204^{a}**	**19960^{b}**	**21019^{a}**	**21791^{a}**	**21665^{a}**	**21109**

Different letters represent significant differences ($p<0.05$; Duncan multiple range test)

Furthermore, cultivars differed significantly in GN, with an average for all F and SD treatments ranged from 18073 (NS Tavita) to 22924 (NS Ilina). Due to the significant F × C interaction cultivars responded differently to various N treatments. So, cultivars NS Tavita and NS Ilina achieved the highest GN at 150 N and 100 N, respectively, while the increase in N doses resulted in not significant GN variation for NS Pudarka.

In addition, an increase in plant density was followed by increase in the GN, with no significant differences between 500, 700 and 900 viable seeds m^{-2} (Tab. 4). However, interaction of C × SD for GN was merely significant for cultivars NS Nafora and NS Petrija, with lowest values obtained at 300 viable seeds m^{-2}.

Conclusion

Nitrogen fertilization, cultivars, sowing densities and their interactions showed significant influence on GY and grain yield components, whereas cultivar had the highest contribution to the total sum of squares. Nitrogen application resulted in additional yield increase when compared to 0 N, and highest average GY for all examined cultivars and sowing densities was recorded at 100 N treatment. Similarly, N application increased GN up to the 100 N, but conversely, led to significant TGW decrease at higher N doses. In general, highest average GY were achieved with 700 and 900 viable seeds m^{-2}, without significant differences for most of the examined cultivars. Moreover, no significant differences in GN were recorded between 500, 700 and 900 viable seeds m^{-2}. Finally, the significant influence of interactions indicate the importance of constant examination of simultaneous effects of different nitrogen doses and sowing densities on grain yield formation in wheat cultivars in order to adjust management practice for a specific cultivar.

Acknowledgement

This paper presents the results of the project TR-31066 *"Modern breeding of small grains for present and future needs"*, supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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