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RESPONSE OF SOME WINTER WHEAT CULTIVARS TO NITROGEN TOPDRESSING AND SOWING DENSITY

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Abstract

The aim of study was to assess the effects of interaction between nitrogen fertilization and sowing densities on grain yield of modern wheat cultivars. A two-year study of the wheat response to increasing doses of nitrogen fertilization and different sowing densities was carried out under rainfed conditions in the experimental field of the Institute of Field and Vegetable Crops, Novi Sad, Serbia. The experiment consisted of four nitrogen fertilization treatments (F): 0, 50, 100 and 150 kg N ha^{-1}; four winter wheat cultivars (C): NS 40S, NS Azra, NS Ilina and NS Petrija, and four sowing densities (D): 300, 500, 700 and 900 viable seeds m^{-2}. Analysis of variance showed statistically significant effects of cultivars and sowing densities, as well as interactions F×C, C×D and F×C×D on total variability of grain yield. Contribution of cultivars to the total sum of squares was highest, showing different response to various N-fertilization and sowing density treatments. On average, grain yield varied between cultivars from 9.82 (NS Petrija) to 10.74 t ha^{-1} (NS 40S). The highest grain yield was achieved with cultivar NS 40S under conditions of 100 kg N ha^{-1} and 900 viable seeds m^{-2}. However, in most cases differences between 500, 700 and 900 viable seeds m^{-2} were not statistically significant.

Keywords: *Winter wheat, yield, nitrogen topdressing, sowing density*

Introduction

Among the most relevant management factors for improving wheat yields and closing the yield gap are adequate mineral nutrition and the use of the optimum seeding rate for an appropriate plant density (Jaenisch et al., 2019; Lollato et al., 2019). Nitrogen is a primary nutrient limiting the grain yield of winter wheat and represents a significant cost for the growers. For all agricultural systems, especially in areas of higher production there is a constant need for adequate amounts of nutrients, mostly supplied as fertilizers. Recently, agricultural practices have focused on maximizing yields by increasing N-fertilization (Jaćimović et al., 2013; Zhang et al., 2016). 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). A better understanding of relationship between wheat grain yield and plant density could improve plant density recommendations according to specific environmental and genetics characteristics. Below-optimum seeding rates may reduce resource use efficiency, yield and final profit, and above-optimum seeding rates increase cost of production and might potentially decrease yield by increasing disease pressure, insects, and lodging (Lloveras et al., 2004; Laghari et al., 2011). Optimum plant densities vary greatly between areas, climatic conditions, soil, sowing time, and varieties. Wheat yield components have a strong compensation capacity depending on the availability of resources. However, this compensatory mechanism could differ across wheat genotypes (Aćin et al., 2019).

Consequently, defining the agronomic optimum plant density is crucial for future improvements in wheat yield (Bastos et al., 2020). Therefore, the objectives of this study were to quantify the variation in grain yield of the 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

Field trials with four winter wheat cultivars, increasing nitrogen topdressing rates and sowing densities were carried out in two successive growing seasons (2016/17 and 2017/18), under rainfed semi-arid conditions of the southern Pannonian Plain in the Vojvodina Province. The main objective of this study was to analyze the effects of N-topdressing, cultivars and sowing densities, as well as their interaction on wheat grain yield (GY). The trials were setup at experimental fields of Institute of Field and Vegetable Crops, Novi Sad (45°19'49" N; 19°49'53" E; 80 m a.s.l.). Treatments were arranged in a split-split-plot design with three replications. Main plots were assigned to the nitrogen topdressing rates, sub-plots to cultivars and sub-sub-plots to sowing densities. N-fertilization treatments (F) included unfertilized control (0 N) and three fertilization levels with 50 (50 N), 100 (100 N) and 150 kg N ha^{-1} (150 N). The second factor included four winter wheat cultivars (C): NS 40S, NS Azra, NS Ilina and NS Petrija, released by the Institute of Field and Vegetable Crops, while the third factor consisted of four sowing densities (D): 300, 500, 700 and 900 viable seeds per square meter. Each plot consisted of 10 rows, with row spacing of 0.10 m and length of 5 m. The soil type at the experiment site was a calcareous chernozem. The contents of sand, silt and clay in the soil were recorded as 37, 38 and 25%, respectively. The reaction of soil solution was slightly alkaline (pH = 7.52), with moderate content of humus (3.42%) and available phosphorus (15.46 mg/100 g of soil) and with high content of available potassium (25.64 mg/100 g). The soil was medium provided by total nitrogen content (0.19% N). Weather data were collected from the meteorological station located near the experimental fields. Air temperature, level and distribution of precipitation in autumn enabled fast emergence and establishment of good plant population in both growing season. Winter of 2016/17 was characterized by low temperature (especially in January), while winter of 2017/18 were moderately cold. Winter weather conditions in both years provided a high percentage of overwintering (averaged nearly 90%). Temperature in spring growing period was similar in both years. Previous analysis of the effects of years on GY at different N-rate and sowing densities (without considering the effect of cultivars) where not significant (data not shown), so the results of the experiment are presented as an average of both years. Preceding crop in both growing seasons was soybean. According to the results of soil analysis a fertilizer combination (NPK 11:52:0) was applied before ploughing in both growing seasons, while N-topdressing rates were applied at the beginning of March, before the beginning of stem elongation. Wheat cultivars were sown on recommended sowing date (mid-October). Pests, weeds and diseases were prevented or controlled by applying the recommended pesticides. Fusarium and symptoms of other diseases were not observed or were insignificant. All of the experimental units were combine-harvested at maturity stage (early July) and grain moisture content was corrected to 130 g kg^{-1}. Analysis of variance of GY was performed using GenStat 12th ed. (VSN International, Hemel Hempstead) while the treatments means were compared using Duncan's multiple range test.

Results and Discussion

According to ANOVA (Tab. 1), cultivars (C) and sowing densities (D), as well as interactions F×C, C×D and F×C×D showed statistically significant effects on the total GY variability, indicating different cultivar responses to N-fertilization (F) and sowing density (D). Cultivars explained 28% of total GY variance, while contribution of F×C and C×D interactions was lower, but significant, showing different response of cultivars to analyzed treatments. Similar observations are reported by Mirosavljević et al. (2019) and Aćin et al. (2019), emphasizing the necessity of adapting management practices to each individual cultivar.

Table 1. The ANOVA of wheat grain yield and relative contribution to the total sum of squares (%) of the main factors: N-fertilization (F), cultivar (C), sowing density (D) and their interaction

Source of variation	d.f.	s.s.	s.s. (%)	m.s.	v.r.	F pr.
F	3	2.104	2.8	0.701	0.54	0.670
C	3	20.995	27.6	6.998	26.89**	<0.001
F × C	9	6.571	8.6	0.730	2.81*	0.021
D	3	5.821	7.7	1.940	13.03**	<0.001
F × D	9	1.574	2.1	0.175	1.17	0.320
C × D	9	2.998	4.0	0.333	2.24*	0.026
F × C × D	27	7.413	9.7	0.275	1.84*	0.016

d.f. - Degrees of freedom, s.s. - Sum of squares, m.s. - Mean square, v.r. - Variance ratio (F-test), F pr. - Probability value corresponding to a variance ratio; * significant at 0.05; ** significant at 0.01.

The average GY in the trial (grand mean) for all treatments was 10.22 t ha^{-1} (Tab. 2). N-topdressing rates significantly altered GY of cultivars, resulting in GY increase in comparison with the control treatment. On average, the highest GY was observed at treatments 100 N (10.39 t ha^{-1}) and 150 N (10.23 t ha^{-1}), while absence of N application resulted in the lowest GY (10.10 t ha^{-1}). However, a comparison based on the Duncan's test showed no statistically significant differences in GY between N-rates of 150, 50 and 0 kg N ha^{-1}.

Table 2. Response of wheat grain yield (t ha^{-1}) to nitrogen topdressing, cultivars and sowing densities

N-fertilization (F)	Cultivar (C)	Sowing density (D)				Average (F × C)	Average (F)
		300	500	700	900		
0 N	NS 40S	9.62^{l-q}	10.76^{a-i}	10.96^{a-d}	10.98^{a-c}	**10.58**^{BC}	**10.10**^{B}
	NS Azra	10.32^{b-p}	10.36^{b-p}	10.12^{b-p}	9.84^{h-q}	**10.16**$^{C-E}$	
	NS Ilina	9.92^{f-q}	10.28^{b-p}	10.33^{b-p}	10.26^{b-p}	**10.19**$^{C-E}$	
	NS Petrija	9.15^{q}	9.11^{q}	9.68^{l-q}	9.93^{f-q}	**9.47**^{F}	
Average (F × D)		**9.75**^{D}	**10.13**$^{B-D}$	**10.27**$^{A-C}$	**10.25**$^{A-C}$	-	-
50 N	NS 40S	10.52^{a-m}	10.82^{a-g}	10.77^{a-i}	11.08^{ab}	**10.80**^{AB}	**10.17**^{B}
	NS Azra	9.67^{l-q}	9.81^{h-q}	10.01^{d-q}	10.39^{b-p}	**9.97**^{E}	
	NS Ilina	10.33^{b-p}	10.42^{b-n}	10.45^{a-m}	10.33^{b-p}	**10.39**$^{B-E}$	
	NS Petrija	9.75^{k-q}	9.47^{n-q}	9.42^{pq}	9.54^{m-q}	**9.54**^{F}	
Average (F × D)		**10.07**$^{B-D}$	**10.13**$^{B-D}$	**10.16**$^{B-D}$	**10.34**^{AB}	-	-
100 N	NS 40S	10.79^{a-h}	10.93^{a-e}	11.04^{ab}	11.38^{a}	**11.03**^{A}	**10.39**^{A}
	NS Azra	9.76^{j-q}	10.03^{c-q}	10.54^{a-l}	10.38^{b-p}	**10.18**$^{C-E}$	
	NS Ilina	9.94^{f-q}	10.16^{b-p}	10.38^{b-p}	10.87^{a-f}	**10.34**$^{C-E}$	
	NS Petrija	9.90^{f-q}	10.26^{b-p}	9.85^{g-q}	9.97^{e-q}	**10.00**^{E}	
Average (F × D)		**10.10**$^{B-D}$	**10.35**^{AB}	**10.45**^{AB}	**10.65**^{A}	-	-
150 N	NS 40S	9.80^{i-q}	10.73^{a-j}	10.68^{a-k}	10.95^{a-d}	**10.54**$^{B-D}$	**10.23**^{AB}
	NS Azra	9.62^{l-q}	10.15^{b-p}	10.27^{b-p}	10.41^{b-o}	**10.11**^{DE}	
	NS Ilina	9.44^{o-q}	10.52^{a-l}	9.69^{l-q}	10.33^{b-p}	**10.00**^{E}	
	NS Petrija	10.45^{a-m}	10.48^{a-m}	10.41^{b-n}	9.81^{i-q}	**10.29**$^{C-E}$	
Average (F × D)		**9.83**^{CD}	**10.47**^{AB}	**10.26**$^{A-C}$	**10.37**^{AB}	**Average (C)**	
Average (C × D)	**NS 40S**	**10.18**^{CD}	**10.81**^{AB}	**10.86**^{A}	**11.10**^{A}	**10.74**^{A}	**Grand mean: 10.22**
	NS Azra	**9.84**^{D}	**10.09**^{CD}	**10.23**^{CD}	**10.26**^{CD}	**10.10**^{B}	
	NS Ilina	**9.91**^{D}	**10.35**^{C}	**10.21**^{CD}	**10.45**^{BC}	**10.23**^{B}	
	NS Petrija	**9.81**^{D}	**9.83**^{D}	**9.84**^{D}	**9.81**^{D}	**9.82**^{C}	
Average (D)		**9.94**^{B}	**10.27**^{A}	**10.29**^{A}	**10.40**^{A}	-	

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

Moreover, cultivars differed significantly in GY, with average values ranged from 9.82 (NS Petrija) to 10.74 t ha^{-1} (NS 40S). Cultivars NS Azra and NS Ilina had a statistically equal GY. Also, there was a significant influence of F×C interaction on GY, indicating that cultivars responded differently to N treatments. Thus, the cultivars NS 40S and NS Azra achieved the highest GY at 100 N, NS Ilina at 50 N and NS Petrija at 150 N. Various studies showed GY increase with nitrogen application as a result of enhanced tillering, higher biomass production and main yield components (Aćin et al., 2019; 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).

On average for examined cultivars, the highest grain yield was achieved with 900 viable seeds m^{-2} (Tab. 2). However, no statistically significant difference was found among treatments with 900, 700 and 500 viable seeds m^{-2} (10.40, 10.29 and 10.27 t ha^{-1}, respectively). All previously listed sowing densities achieved significantly higher GY compared to the treatment with 300 viable seeds m^{-2} (9.94 t ha^{-1}). In general, GY of most cultivars (except NS Petrija) improved with increasing sowing densities to the highest value, but due to the relatively small contribution of C×D interaction to GY, differences between sowing densities were significant only for cultivars NS 40S and NS Ilina (Tab. 2). Similar results are reported by Aćin et al. (2019) who stated that increase in plant density was followed by increase in GY, without significant differences between 500-900 viable seeds m^{-2}. Moreover, interaction of C×D for GY was significant for only two (of five) analyzed cultivars, with lowest values obtained at 300 viable seeds m^{-2}. Plants may 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 grain number and weight 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 management strategy for enhancing wheat GY (Li et al., 2016).

Response of examined wheat cultivars to N-topdressing and sowing density was subjected to regression analysis in order to find optimal values of N in topdressing and optimal sowing density for maximum GY of each cultivar (Fig. 1).

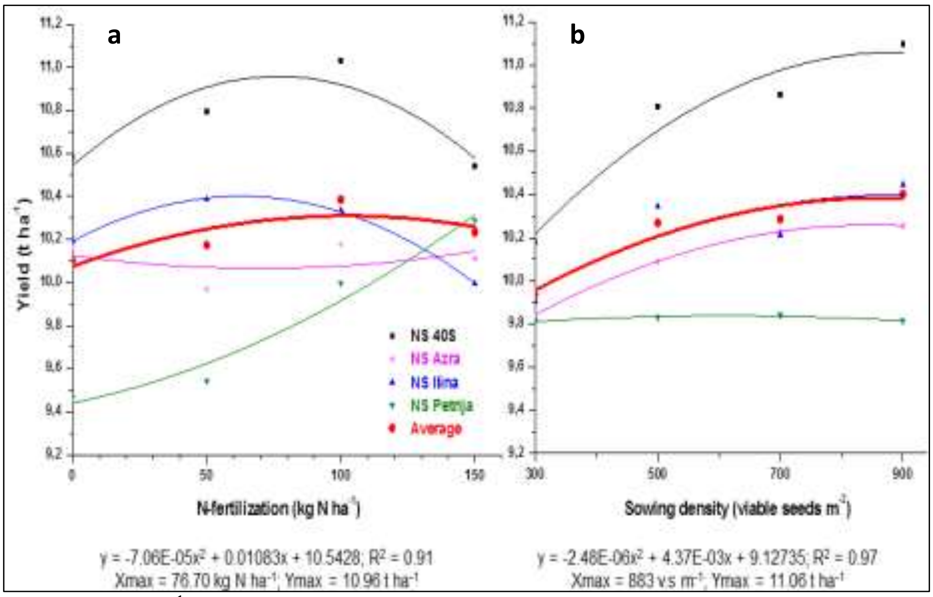

Figure 1. Grain yield (t ha^{-1}) of wheat cultivars across N-topdressing (a) and sowing density treatments (b) and the corresponding regression equations

Effects of the applied N rates in topdressing on GY (on average for all sowing densities) followed the quadratic regression model, for both individual cultivars and average, with different coefficients of determination (Fig 1a). The amounts of N for the theoretical maximum GY varied between cultivars. Thus, for cultivar NS 40S the theoretical maximum GY can be achieved with 77 kg N ha^{-1}, for NS Ilina with 63 kg N ha^{-1}, while the regression curve for cultivar NS Petrija had a constant growth tendency, without possibility to determine the optimal N dose, which also applies to the NS Azra. On average for all cultivars, the theoretical maximum GY (10.31 t ha^{-1}) could be achieved by topdressing with 102 kg N ha^{-1}.
Optimal sowing densities also differed between cultivars (Fig 1b). To achieve the maximum yield, the optimal sowing density for cultivar NS 40S was 883 viable seeds m^{-2}, for NS Azra 847, NS Ilina 889 and NS Petrija 610 seeds m^{-2}. On average for cultivars, the optimal sowing density for maximum GY was 862 viable seeds m^{-2}. However, as pointed out above, no significant differences were found between 500, 700 and 900 seeds m^{-2}, and from an economic point of view the optimal sowing density can be considered 500 viable seeds m^{-2}. While the literature reports a wide range of models representing GY as a function of seeding rate, the quadratic is usually the most often reported to represent lodging and other potential yield losses due to increased pressure of insects and diseases at high populations (Fischer et al., 2019). Our results are in agreement with findings of Otteson et al. (2007), who reported that individual genotypes responded differently to varying seeding rates.

Conclusion

The results from this study indicated different cultivar responses to N-topdressing and sowing density treatments. The highest GY was observed with 100 and 150 kg N ha^{-1}, without significant differences between 150, 50 and 0 kg N ha^{-1}. Cultivars differed significantly in GY and the average values ranged from 9.82 to 10.74 t ha^{-1}. Based on the quadratic regression, the contribution of N-topdressing and different sowing densities for maximum grain yield were specific to each cultivar. The maximum GY could be achieved by topdressing with 102 kg N ha^{-1} and with sowing density of 862 viable seeds m^{-2}. However, no significant differences were found between densities of 500-900 viable seeds m^{-2}. Consequently, from an economic point of view the optimal sowing density can be considered 500 viable seeds m^{-2}. The existence of significant interaction between N-fertilization and cultivars as well as cultivars and sowing densities indicate that the adjustment of analyzed agro-management practices to each cultivar is essential for achieving high GY in winter wheat.

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