

The planting density effect on wheat yield structure

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Abstract: The importance of an efficient planting in wheat production technology is associated with the seed quality, date and method of planting, planting depth and density. Optima have been determined for almost all the factors mentioned, but there are always certain dilemmas regarding wheat planting density. The creation of new varieties requires determination of their reaction to crop density which should be performed in a number of sites due to the microclimate specificity in different wheat growing regions and in combination with other cultivation practice elements. Optimal seed rates per unit of area have a direct effect on plant spacing with the sown area being most rationally utilized and the plants being provided with adequate growth and development conditions.

Two Novi Sad wheat varieties, Yugoslavia and Rana Niska, sown at five different densities of 300, 450, 600, 750 and 900 germinating kernels per m². For the purpose of certain theoretical explanations, apart from the planting densities most commonly employed ranging from 450 to 750 germ. kern./m², the investigation included those of 300 and 900 germ. kern./m².

In all the three research years, with the planting density increase the number of spikes also increased. However, the spikes obtained at higher planting densities had a smaller kernel number and lower 1000-kernel weight values. In the first research year, compared to the years to follow, the highest yield was obtained, coupled with the largest kernel number per spike and greatest 1000-kernel weight.

The planting density of the examined winter wheat varieties, at an optimal planting date, should amount to 600 germinating kernels per m², thus producing a sufficient number of good-quality spikes with adequate yield structure. By solving the regression equations, the results were confirmed by the regression analysis of planting density for a maximum grain yield.

Key words: wheat, yield structure, spike number, 1000-kernel weight, kernel number

Introduction

Wheat (*Triticum aestivum* ssp. *vulgare*) is one of the oldest and most important cultivated crops, being grown on every continent and in every season. About 70% of the Earth's inhabitants today consume wheat bread (Jevtic, 1986). Compared to other agricultural crops, it ranks first in the world in terms of the growing area and its production share (Malesevic and Starcevic, 1993). A stable wheat production is a necessity when human nutrition is concerned and it is therefore of extremely high economic significance.

New wheat varieties are more productive and some of them are of higher quality than the old ones. Therefore, their total technological requirements, planting density being one of them, are diverse, due to which they need to be continuously examined for the purpose of determining their requirements in specific conditions. One should know, however, that there is not a perfect genotype and that we should grow a number of mutually differing and complementing varieties being, namely, different biotypes in terms of the duration of the growing season and requirements with respect to basic vegetational factors as well as in terms of different reactions to extreme climatic conditions (Spasojevic and Malesevic, 1987).

In case of a high plant number per unit of area, there is an increased competition among them for all the vegetational conditions. Conversely, when the plant number is lower than an ideal one, there is an intensive water loss, excessive soil heating, irrational nutrient utilization, a more intensive weed coverage ... Under optimal planting density conditions, a plant population can use water, mineral nutrients and sunlight most efficiently. Therefore, when investigating the growing technology of any crop, the most favourable planting density should always be determined.

Planting density in plant production is considered to be a beginning of the technological process of crop growing affecting a number of other cultivar practices but also the product yield and quality. For this reason, in production practice and in scientific investigations an issue of optimization of the plant number per unit of area is constantly being raised. A trend towards yield increase with the density increase exists up to the moment when yield decrease per plant is of higher intensity than the plant number increase. At the time of the expansion of first high-yielding Italian wheat varieties the density recommended ranged from 700-800 germinating kernels/m² (Borojevic et al., 1961). Later investigations included a large number of wheat varieties, and an important conclusion was drawn regarding the existence of a varietal specificity, according to a specific growing density (Spasojevic and Malesevic, 1987; Knoch, 1987; Protic et al., 1988; Dencic, 1990). Malesevic et al. (1994) suggest that there are not any data in our literature to prove the need for planting any variety at densities greater than 650 germinating kernels/m². As with a number of other cultural operations, determination of an optimal planting density is also considerably affected by growth conditions that cannot be controlled, due to which the results often differ with respect to research years (Nedic, 1990; Turner et al., 1994).

Investigations on the effect of different factors on wheat grain yield focus specifically on determination of the intensity of the effect of values of certain yield components as well as on their interaction. Numerous yield structure elements determine the yield, but the spike number, kernel number per spike and 1000-kernel weight generally impose as the most important ones. Based upon these parameters, by way of calculation, the so-called calculated yield being always higher than the actual yield can also be determined (Bokan, 1998), with the difference depending on the experience of an analyst creating an average sample by taking a certain number of spikes for the analysis. The bigger the sample, created actually as an average one without favouring longer spikes, the more realistic the picture of a real condition of and effect of all the yield structure elements examined.

The spike number is greater than the planting density, being the result of productive wheat tillering. The spike number in winter wheat per unit of area is affected by planting density, the number of emerged plants, the number of plants that managed to overwinter and the number of productive stems. With the planting density increase the spike number also increases (Protic et al., 1988; Dencic, 1990). The same trend was observed by Nedic (1990), but the increase is not proportional to the density increase, since at the highest difference in the number of planted kernels per m^2 , being 114%, the highest average difference in the number of spikes is 45.4% on chernozem and 77.1% on pseudogley.

The kernel number per spike is a basic yield component, the variation of which accounts for the 90% of variations in the wheat grain yield (Fischer, 1975). The kernel number per spike should be increased in order to achieve high yields (Wicke et al., 1987). The grain yield is dependent on the kernel number per spike much more than on the spike length and spikelet number per spike (Lazovic et al., 1994). Similar observations were made by Kelly et al. (1994), showing that compared to the 1000-kernel weight, spike number and kernel number/ m^2 , the kernel number per spike is a more reliable trait for assessing the size of the wheat grain yield.

Yet, 1000-kernel weight as a varietal trait is susceptible to cultural and agroecological conditions. So, with the planting density increase there is a rise in the spike number yielding kernels of smaller size and smaller weight (Dotlacil and Toman, 1987; Protic et al., 1988; Nedic, 1989; Stojanovic, 1993). Furthermore, under the effect of the growing conditions throughout the research years different 1000-kernel weight values were recorded.

The aim of this investigation was to determine the effect of planting density on wheat yield structure by cultivation of two morphologically divergent varieties under production conditions of the Cacak valley. Optimal seed rate per unit of area directly affected the crop stand with the most rational utilization of the sown area and provision of adequate plant growth and development conditions. The study results on the varieties selected and the planting density should make a practical and theoretical contribution to the wheat growing technology.

Material and Methods

The three-year investigations were conducted in Preljinska Baluga (the Municipality of Cacak), on the alluvial smonitza soil type. Three-factorial field microtrials were set up in a randomized block design with four replications. The plot size was 5 m² (1 x 5 m). The research included two Novi Sad wheat varieties, Yugoslavia and Rana Niska, planted at five different densities being as follows: 300, 450, 600, 750 and 900 germinating kernels per m². For the purpose of some theoretical explanation, apart from the most commonly applied densities of 450 to 750 kernels/m², the investigations also included planting densities of 300 and 900 germinating kernels/m² (germ. kern./m²).

Maize was used as a preceding crop. Primary tillage was carried out in October, by plowing at the depth of 25 cm, and pre-sowing cultivation was performed using a disc harrow and a seedbed conditioner. Wheat was sown in the third decade of October.

Basal dressing provided 30 kg/ha N, 90 kg/ha P₂O₅ and 60 kg/ha K₂O through the use of a compound fertilizer of the 10 : 30 : 20 composition (300 kg/ha). Split-shot application of the second nitrogen rate of 45 kg/ha N was performed in spring by adequate KAN rate used. The first crop dressing was done in the tillering stage with 2/3 of nitrogen and the second one in the stem-elongation stage with 1/3 of nitrogen reserved for top-dressing. Both the spike number and kernel number per spike were determined on a sample collected from 0.4 m², providing a sample with a great number of spikes per variant, being 850 to 1240 (depending on the planting density).

Results and Discussion

The spike number produced per unit of area depends on planting density, the number of emerged plants, the number of plants that managed to overwinter and the number of productive stems. The spike number is greatly affected by growing conditions. Peric (1977) observed a difference of 237 spikes per m² between two years, although the same number of germinating kernels per m² was planted both times. Stojanovic (1993) recorded significant differences in the spike number between three research years and between genotypes.

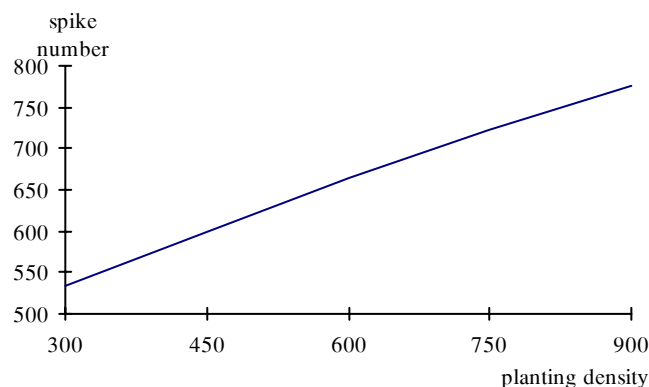
The highest average spike number (tab.1) was determined in 1992 (773) and the lowest number was registered in the third research year (538). In the three-year average, the Rana Niska variety (675 spikes) had yielded 31 spikes more than the Yugoslavia variety (644 spikes).

Tab. 1. The spike number per m²

Variety	Density (germ.kern./m ²)	Years			Average
		1991	1992	1993	
Yugo- slavia	300	523	609	414	515
	450	595	694	470	586
	600	635	762	548	648
	750	681	826	603	703
	900	751	893	659	768
	$\bar{x}$	637	757	539	644
Rana niska	300	589	654	419	554
	450	643	724	471	613
	600	715	802	529	682
	750	752	861	607	740
	900	799	902	658	786
	$\bar{x}$	700	789	537	675
The average for the densities and varieties	300	556	631	417	535
	450	619	709	471	600
	600	675	782	539	665
	750	717	844	605	722
	900	775	898	659	777
Average		669	773	538	660

In all the three research years, with the planting density increase there was an increase in the spike number (graph 1). The greatest differences were recorded between the lowest and highest density, being 219, 267 and 242 spikes, respectively, for the research years. The differences between the increasing densities were relatively uniform and grew higher with each 150 germ. kern./m², the number of spikes increased on average by 55 (1991), 67 (1992) and 61 spikes (1993). Similar results were obtained by Dencic, (1986); Malesevic and Jevtic, (1988); Protic et al., (1988). According to Nedic (1990), with the planting density increase the number of spikes per m² increased too, however the increase was not proportional to the planting density increase. A great number of productive stems cannot guarantee high yields, and so the upper limit for winter wheat, as recommended by Wicke et al., (1987), is 700 spikes per m².

Graph 1. The planting density effect on the spike number



The spike had 24.7 kernels on average (Tab. 2), the highest number being registered in the third research year (27.2) and the lowest one in the second year (23.0). With the Rana Niska variety, the number of kernels amounted to 22.8, being by 3.8 kernels on average lower than with the Yugoslavia variety (26.6). With the planting density increase the kernel number per spike decreased from 28.3 (300 germ. kern./m²) to 20.6 (900 germ. kern./m²). The smallest difference in the kernel number per spike was that between the density of 450 germ. kern./m² and 600 germ. kern./m² (0.9 kernels).

Tab. 2. The kernel number per spike

Variety	Density (germ.kern./m ²)	Years			Average
		1991	1992	1993	
Yugo- slavia	300	29.2	27.7	34.1	30.3
	450	27.8	26.2	31.5	28.5
	600	27.0	25.1	29.2	27.1
	750	24.5	23.2	27.3	25.0
	900	22.2	20.8	23.8	22.3
	$\bar{x}$	26.1	24.6	29.2	26.6
Rana niska	300	24.3	24.1	30.2	26.2
	450	23.2	22.9	27.5	24.5
	600	22.2	22.2	26.4	23.6
	750	20.6	19.4	22.0	20.7
	900	18.9	18.4	19.8	19.0
	$\bar{x}$	21.8	21.4	25.2	22.8
The average for the densities and varieties	300	26.8	25.9	32.2	28.3
	450	25.5	24.6	29.5	26.5
	600	24.6	23.7	27.8	25.4
	750	22.6	21.3	24.6	22.8
	900	20.5	19.6	21.8	20.6
Average		24.0	23.0	27.2	24.7

The results presented are in accordance with the results by numerous authors who determined a decrease in the kernel number per spike at increased planting density, underlining the varietal specificity (Spasojevic and Malesevic, 1984; Kirby, 1985; Dotalcil and Toman, 1987; Toseva Evgenija, 1987; Malesevic and Jevtic, 1988; Dencic, 1990; Nedic, 1990; Stojanovic, 1993). Mihaljev (1986) stresses that there is a wide genetic variability in the kernel number and weight per spike in different wheat genotypes. According to Jovanka Stojanovic (1988), variations in the kernel number between the study years is higher than between the variants examined, being confirmed by a great effect of the environmental factor.

Many contemporary high-yielding wheat cultivars produce seeds with a relatively small 1000-kernel weight, which could be associated with a great spike and kernel number per unit of productive area (Kreft, 1990). Milovanovic et al., (1994) recorded that the single kernel weight in the varieties investigated ranged from 25 to 61 mg, observing a positive correlation between the kernel weight and yield, coupled with considerable deviations; and so the varieties with the highest kernel weight ranged 24th and 27th in the grain yield of the 42 varieties investigated. 1000-kernel weight is a significant factor when yield increase is concerned (Jovanovic et al., 1992), but its value is rather dependent on the growing conditions, primarily on temperature (Warrington et al., 1977) and soil water relations (Dragovic and Panic, 1986).

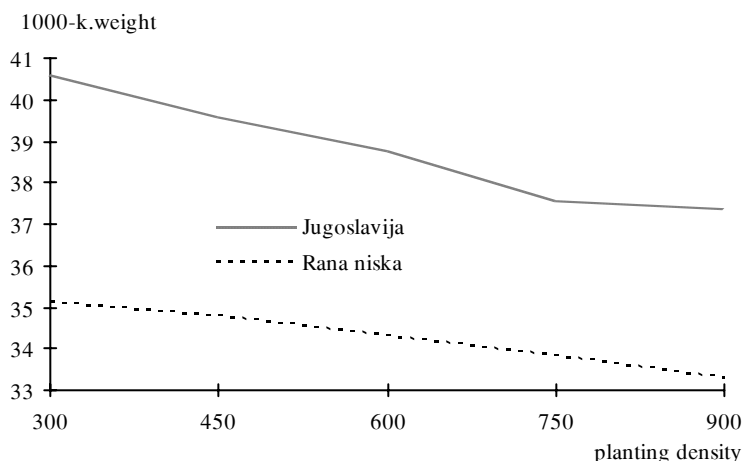
Average value in the trial for 1000-kernel weight in wheat, was 42.9 g with a decreasing trend taken by the research years (49.1 g; 43.2 g and 36.5 g). Higher 1000-kernel weight was constantly registered with the Yugoslavia variety compared to the Rana Niska, by 4.5 g on average (tab. 3).

Tab. 3. 1000-kernel weight (g)

Variety	Density (germ.kern./m ²)	Years			Average
		1991	1992	1993	
Yugo- slavia	300	52.7	46.8	40.6	46.7
	450	51.7	46.6	39.6	46.0
	600	51.6	46.0	38.8	45.5
	750	50.5	44.6	37.6	44.2
	900	49.2	44.1	37.4	43.6
	$\bar{x}$	51.1	45.6	38.8	45.2
Rana niska	300	47.8	42.1	35.1	41.7
	450	47.4	41.4	34.8	41.2
	600	46.7	40.5	34.3	40.5
	750	46.5	39.9	33.8	40.1
	900	46.5	40.0	33.3	39.9
	$\bar{x}$	46.9	40.8	34.3	40.7
The average for the densities and varieties	300	50.3	44.4	37.9	44.2
	450	49.5	44.0	37.2	43.6
	600	49.1	43.3	36.5	43.0
	750	48.5	42.3	35.7	42.2
	900	47.8	42.1	35.3	41.7
Average		49.1	43.2	36.5	42.9

1000-kernel weight of the wheat varieties investigated decreased with the decrease of the vegetational area size, and throughout the three years a similar interactive effect of the variety and planting density was observed (Graph 2)

Graph 2. The interactive effect of variety and planting density on 1000-kernel weight, 1993



Denser planting results in a higher number of spikes yielding kernels of smaller weight (Jevtic, 1967; Dotlacil and Toman, 1987; Protic et al., 1988; Nedic, 1989). 1000-kernel weight decreases with the planting density increase, but very specifically for each variety or genotype (Stojanovic, 1993).

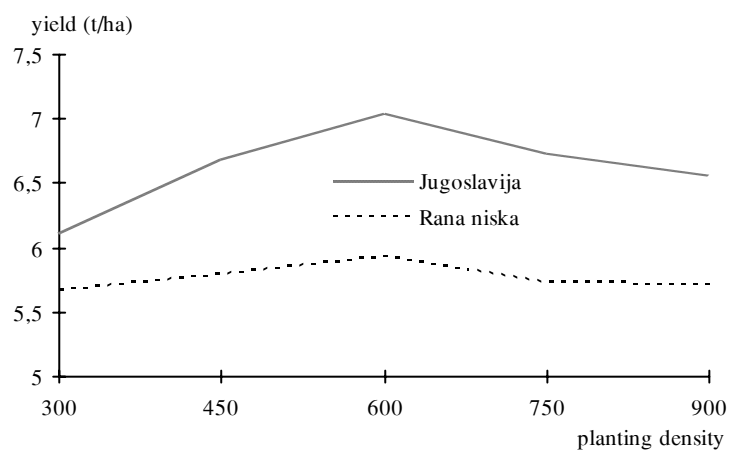
The average wheat kernel yield was 5.727 t/ha (Tab. 4); the highest yield was recorded in the first research year (6.200 t/ha), followed by 6.031 t/ha and 4.951 t/ha in the second and last research years.

The highest yields in all the three research years were obtained with the Yugoslavia variety (yields higher by 864, 1078 and 1482 kg/ha, taken chronologically). Justification of the results was confirmed by the investigations by Scepanovic et al. (1990) who also gave a varietal specificity in terms of nitrogen requirements, and classified the Rana Niska variety into the group of varieties requiring more nitrogen from mineral fertilizers and the Yugoslavia variety into the less-demanding group using quite successfully residual nitrogen from the soil. The reasons for the lower yield of the Rana Niska variety (by 1.141 t/ha on average), compared to Yugoslavia, lie in the fact that the former one has a very good performance only in certain regions (Dencic, 1991), as opposed to the latter variety as a representative of a group of varieties producing satisfactory yields in all the four agroecological wheat growing regions. In all the research years yield differences were determined dependent on different densities with the presence of the interactive effect of variety and density (graphs 3, 4 and 5).

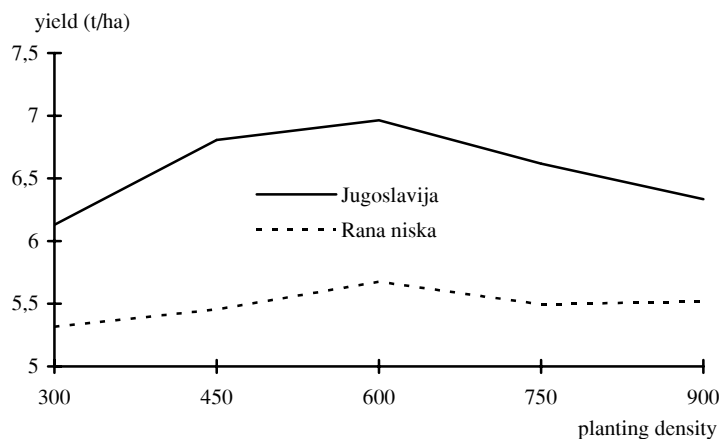
Tab. 4. Grain yield (t/ha)

Variety	Density (germ.kern./m ²)	Years			Average
		1991	1992	1993	
Yugo- slavia	300	6.121	6.129	5.468	5.906
	450	6.689	6.805	5.573	6.356
	600	7.057	6.964	5.948	6.656
	750	6.732	6.617	5.908	6.419
	900	6.563	6.335	5.564	6.154
	$\bar{x}$	6.632	6.570	5.692	6.298
Rana niska	300	5.661	5.316	4.123	5.033
	450	5.794	5.454	4.179	5.142
	600	5.939	5.677	4.409	5.342
	750	5.735	5.495	4.239	5.156
	900	5.710	5.518	4.100	5.109
	$\bar{x}$	5.768	5.492	4.210	5.157
The average for the densities and varieties	300	5.891	5.722	4.795	5.469
	450	6.241	6.130	4.876	5.749
	600	6.498	6.321	5.178	5.999
	750	6.234	6.056	5.073	5.788
	900	6.137	5.927	4.832	5.632
Average		6.200	6.031	4.951	5.727

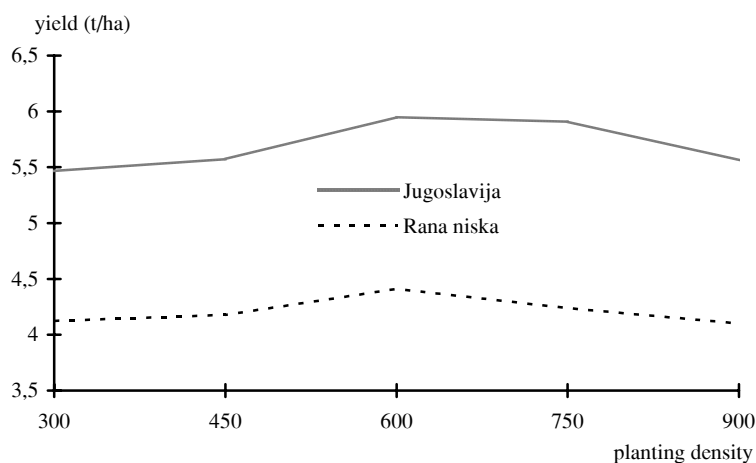
Graph 3. The interactive effect of variety (A) and density (C) on yield, 1991



Graph 4. Interactive effect of variety (A) and density (C) on yield, 1992



Graph 5. The interactive effect of variety (A) and density (C) on yield, 1993



In all the three research years the highest yields in both varieties were obtained by planting 600 germ. kern./m² (graph 6). The yield of 5.999 t/ha was achieved with 665 spikes on average with 25.4 kernels and 1000-kernel weight being 43 g. Of the five densities investigated, the medium one (600 germ. kern./m²) was the bound above which the yield decrease per plant could not be compensated for by the spike number increase at higher densities. All the kernel-yield component traits had considerably lower values at densities of 750 and 900 germ. kern./m², so

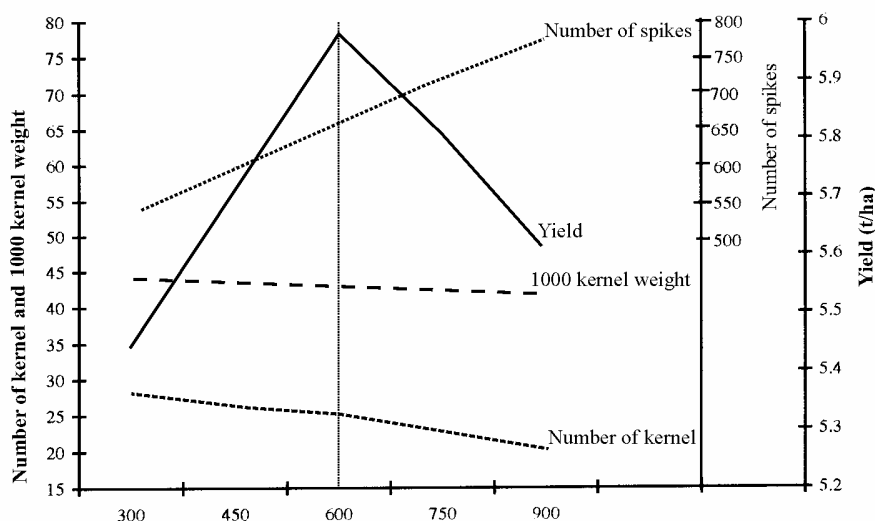
that a higher number of short and shrivelled spikes from these densities (Djurovic&Bokan 2004) did not bring about an increase in grain yield.

These results have been also confirmed by the regression analysis of the planting density for maximum grain yield (tab. 5). By solving the equations (on average for all the three years) it was determined that the highest yield in similar agroecological and cultural conditions could be produced by planting of 629 germ. kern./m² for the Yugoslavia variety and 607 germ. kern./m² for the Rana Niska variety.

Tab. 5. Quadratic regression equations

Variety	Year	Equation
Yugoslavia	1991	$Y = 4.0946 + 0.008873x - 0.000007x^2$
	1992	$Y = 4.0584 + 0.009376x - 0.000008x^2$
	1993	$Y = 4.1684 + 0.005353x - 0.000004x^2$
Rana niska	1991	$Y = 5.0872 + 0.002559x - 0.000002x^2$
	1992	$Y = 4.6790 + 0.002716x - 0.000002x^2$
	1993	$Y = 3.4144 + 0.003019x - 0.000003x^2$

Graph 6. The planting density effect on the yield and some yield structure components



The density of 300 germ. kern./m² proved to be inadequate and, therefore, in terms of the density recommendations for these varieties, considering the statistical parameters, planting density of over 600 germ. kern./m² cannot be justified, which is in accordance with the results of numerous researchers (Spasojevic and Malesevic, 1984; Pucaric et al., 1987; Malesevic and Jevtic, 1988; Protic et al., 1988; Stojanovic, 1993; Malesevic et al., 1994). The

yields produced with the Rana Niska variety are in partial disagreement with the recommendation by Spasojevic and Malesevic (1987) to plant it at a density of over 600 to 700 germ. kern./m². This is supposedly the result of its marked regionality (Dencic, 1991) as well as of insufficient crop nutrition, because different results would be probably achieved with a higher nitrogen rate since wheat varieties have pronouncedly diverse nitrogen nutrition requirements (Malesevic, 2001).

Conclusions

In all the three research years, with the planting density increase the spike number increased, too. However, the spikes obtained at higher planting densities had a smaller kernel number as well as lower 1000-kernel weight values.

The average wheat grain yield in the trial was 5.727 t/ha. The Yugoslavia variety produced by 1.141 t/ha on average higher grain yield than Rana Niska variety. With the planting density increase the yield increased up to the medium of the five investigated densities (600 germ. kern./m²). In the first research year, compared with the other years, the highest yield was obtained, coupled with the largest kernel number per spike and greatest 1000-kernel weight.

The three-year research results indicate that the planting density of the winter wheat varieties examined, within optimal planting date, should be 600 germinating kernels per m², because this is how a sufficient good-quality spike number with adequate yield structure could be produced. These results, by solving the regression equations, were confirmed by the regression analysis of the planting density for maximal grain yield.

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UTICAJ GUSTINE SETVE NA STRUKTURU PRINOSA PŠENICE

-originalni naučni rad -

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Rezime

Značaj kvalitetno obavljene setve u tehnologiji proizvodnje pšenice, vezuje se za kvalitet semena, vreme i način setve, dubinu i gustinu setve. Za skoro sve navedene faktore su utvrđeni optimumi, međutim, kod gustine setve pšenice uvek postoje određene dileme. Pojavom novih sorti neophodno je utvrditi njihovu reakciju na gustinu useva, i to na više lokaliteta, zbog specifičnosti mikroklima u različitim reonima gajenja pšenice i u kombinaciji sa drugim elementima agrotehnike. Optimalnom količinom semena po jedinici površine direktno se utiče na sklop biljaka pri kojem se najracionalnije koristi zasejana površina, a biljkama pružaju odgovarajući uslovi za rast i razvoj.

U ogledu su ispitivane dve novosadske sorte pšenice, Jugoslavija i Rana niska, sejane u pet različitih gustina: 300, 450, 600, 750 i 900 klijavih zrna po m². U istraživanja su, pored u praksi primenjivanih gustina od 450 do 750 zrna/m², radi nekih teoretskih objašnjenja, uključene i gustine od 300 i 900 kl.zr./m².

U sve tri godine, povećanjem gustine setve povećava se i broj klasova. Međutim, klasovi dobijeni u većim gustinama gajenja imaju manji broj zrna, kao i manje vrednosti za masu 1000 zrna. U prvoj godini proučavanja u poređenju sa narednim godinama, dobijen je je najveći prinos, praćen najvećim brojem zrna u klasu i najvećom masom 1000 zrna.

Gustina setve ispitivanih sorti ozime pšenice, u optimalnom roku setve, trebala bi da bude 600 klijavih zrna po m², jer se tako ostvaruje dovoljan broj kvalitetnih klasova sa odgovarajućom strukturom prinosa. Ove rezultate, rešenjem regresionih jednačina, potvrdila je i regresiona analiza gustine setve za maksimalni prinos zrna.