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The Rate of Productive Tillers per Plant of Winter Wheat (*Triticum aestivum* L.) Cultivars under Different Sowing Densities

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Abstract

The aim of this two–year research was to determine the rate of productive tillers per plant of different winter wheat cultivars under different sowing densities in the agroecological conditions of Banja Luka. NS 40S, Prima and Nova Bosanka wheat cultivars were sown at eight different sowing densities: 384, 424, 451, 504, 544, 584, 588 and 604 seeds m^{-2}. The experiment was set up in the open field, and each wheat cultivar was sown at different sowing density in four replications. Statistical analysis was performed using factorial analysis of variance 2×8×3 while significant differences between treatments were tested by LSD test. The highest average rate of productive tillers per plant was achieved for the winter wheat cultivar NS 40S (2.29). The highest average rate of productive tillers per plant was achieved at sowing density of 384 seeds m^{-2} and the lowest at sowing density of 588 seeds m^{-2}.

Key words: wheat, tillering, sowing density, productivity

Introduction

As one of the primary food crops, wheat feeds more than a half of the world population (Long and Ort, 2010). Numerous researches have been conducted with the ultimate aim of increasing wheat productivity. At present, improved wheat yield mainly relies on the increase in yield per unit area. The wheat yield per unit area depends on various factors, but primarily on the parameter such as the number of spikes per square meter, which is directly dependent on the genotype ability for tillering under certain conditions, and the ability for forming specific number of productive tillers per plant.

Tillering may affect wheat yield positively or negatively depending on the availability of natural resources such as water, light and nutrients (Elhani et al., 2007). Tillering refers to the growth of lateral shoots from axillary meristems at the plant base in *Poaceae* species such as wheat (Assuero and Tognetti, 2010). Grasses have different tendency to develop tillers. The *Pooid* and *Erhartoid* cereals such as wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) have multiple basal tillers, while *Panicoid* cereals such as maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L.) Moench) and millets have few tillers or even only a single main stem (Doust, 2007). A grass plant can be considered as a collection of tillers that arise from a single primary tiller or crown (Skinner and Nelson, 1992).

Wheat population is directly affected by the growth and development of an individual plant. The quality or structure of wheat population is significantly affected by the compositions of tillers (Xu et al, 2015). Therefore, the development of productive tillers in wheat is very important. According to Thiry et al. (2002) and Fisher (2008) up to 70% of the grain yield comes from tillers. On the other side, up to 60% tillers can abort and die under normal field conditions (Sharma, 1995; Moeller et al., 2014). Tillering is regulated genotypically, but is also influenced by the environment. The number of productive tillers depends on genotype and environment and is strongly influenced by sowing density (Acevedo et al., 2002). Plant density is especially important in wheat because it influences final yield and yield components (Ozturk et al., 2006). Genotypic variation in the degree of tillering expressed as a phenotype has been documented in wheat (Duggan et al., 2005). Nutrient deficiency can have a direct impact on tiller initiation (Rodriguez et al., 1998). Also, tiller emergence and development are influenced by the hormonal balance of auxins and cytokinins. The influence of these hormones is related to apical dominance and dormancy breaking of lateral buds (Valerio et al., 2009; Veit, 2006).

The aim of this study was to determine the rate of productive tillers per plant of different winter wheat cultivars under different sowing densities in the agroecological conditions of Banja Luka region.

Material and Methods

The experiment aimed at studying the rate of productive tillers per plant of three winter wheat cultivars under different sowing densities was set in the agroecological conditions of Banja Luka (44°46' N; 17°11' E) during two experimental years of 2013/14 and 2014/15. NS 40S, Prima and Nova Bosanka wheat cultivars were sown at eight different sowing densities: 384 seeds m^{-2} (arrangement of seeds in the honeycomb), 424 seeds m^{-2} (classical arrangement of seeds in rows), 451 seeds m^{-2} (classical arrangement of seeds in rows), 504 seeds m^{-2} (classical arrangement of grains in rows), 544 seeds m^{-2} (classical arrangement of seeds in rows), 584 seeds m^{-2} (classical arrangement of seeds in rows), 588 seeds m^{-2} (arrangement of seeds in the honeycomb) and 604 seeds m^{-2} (classical arrangement of seeds in rows).

Experimental unit size was 1 m^2, with four replications, and sowing was carried out manually on 4 ± 1 cm depth. The soil on which the experiments were conducted was eutric brown degraded soil. Standard agronomic practices for winter wheat were performed. The sowing of winter wheat cultivars was carried out from 6 to 8 November in 2013 and from 3 to 5 November in 2014. Counting of wheat plants during both years was carried out in the second decade of February. Samples of wheat plants within the area of 1 square meter per plot were taken on 14 July in the first experimental year, and on 10 July in the second experimental year.

According to Table 1, the annual average temperature in the 2013 was 12.3 °C and a total amount of precipitation was 892.4 mm, while in the annual period of 2014, it was 13.0 °C and a total amount of precipitation was 1686.2 mm. The average annual temperature in 2015 was 12.7 °C and a total amount of precipitation was 868.3.

Accordingly, all three observed years were relatively consistent when it comes to the average annual temperature, while the same cannot be said for the total amount of precipitation. Thus, we can conclude that the total annual amount of precipitation in 2013 and 2015 were relatively similar, while the amount of precipitation in 2014 was almost twice as high as in the two observed years.

Tab. 1. The average monthly air temperatures and total monthly precipitation for the region of Banja Luka in period 2013-2015
Просјечне мјесечне температуре и укупне мјесечне количине падавина на подручју Бање Луке за период 2013-2015

		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2013	°C	2.8	2.3	6.1	13.4	16.6	20.4	23.0	23.5	16.7	13.1	7.4	2.5
	mm	93.7	115.8	88.5	62.9	119.6	54.3	27.4	36.3	69.7	67.6	156.0	0.6
2014	°C	5.6	6.5	9.6	13.1	15.8	20.3	21.7	20.6	16.4	13.5	8.9	4.0
	mm	52.0	73.5	90.6	214.0	217.8	97.0	139.3	276.3	284.0	117.3	41.8	82.6
2015	°C	3.4	2.4	7.3	11.8	17.4	20.9	25.2	24.0	18.3	11.5	7.1	3.5
	mm	111.2	91.1	79.0	54.1	117.6	60.5	20.5	22.8	75.0	142.7	85.7	8.1

The rate of productive tillers per plant (RPTP) was calculated by the following formula:

RPTP = number of productive tillers m^{-2} / number of overwintered plants m^{-2}

Statistical analysis was performed using factorial analysis of variance 2×8×3 [factorial design: year (2)×sowing density(8)×cultivar (3)] while significant differences between treatments were tested by Fisher's least significant difference test (LSD). The effect of sowing density levels on the RPTP was determined by the second degree polynomial regression (quadratic model), with function equation and coefficient of determination presented.

Results and Discussion

The rate of productive tillers per plant of NS 40S, Prima and Nova Bosanka wheat cultivars at eight sowing densities in the experimental years of 2014 and 2015 is shown in Table 2.

According to Table 2, the average RPTP ranged from 1.32 to 2.83. Factorial analysis of variance 2×8×3 showed that all main effects were statistically very significant ($P \leq 0.01$). There were no statistically significant interaction effects ($P > 0.05$).

The effect of different wheat cultivars on the average RPTP was very significant. Regardless of the different sowing densities and years, the average RPTP was 2.29 for NS 40S cultivar, 1.97 for Nova Bosanka cultivar and 1.92 for Prima cultivar.

Tab. 2. The rate of productive tillers per plant of winter wheat cultivars under diferent sowing densities for 2013/14 and 2014/15
Број продуктивних изданака по биљци за озиме сорте пшенице у условима различите густине сјетве за 2013/14 и 2014/15

Number of seeds m^{-2} *Број сјеменки / m²*	Cultivar *Сорта* / Year *Година*	NS 40S	Prima	Nova Bosanka	$\bar{X} \pm s_x$ for sowing densities *(за густине сјетве)*
384	*2014*	2.52 ± 0.24	2.37 ± 0.14	2.14 ± 0.25	2.41 ± 0.09
	2015	2.81 ± 0.52	2.32 ± 0.26	2.31 ± 0.39	
424	*2014*	2.21 ± 0.22	1.88 ± 0.18	1.97 ± 0.23	2.19 ± 0.10
	2015	2.56 ± 0.34	2.27 ± 0.34	2.24 ± 0.37	
451	*2014*	2.01 ± 0.11	1.67 ± 0.03	1.68 ± 0.24	2.19 ± 0.22
	2015	2.83 ± 0.37	2.12 ± 0.16	2.83 ± 0.60	
504	*2014*	1.82 ± 0.14	1.45 ± 0.10	1.68 ± 0.09	1.97 ± 0.18
	2015	2.55 ± 0.06	2.41 ± 0.27	1.91 ± 0.26	
544	*2014*	1.76 ± 0.12	1.38 ± 0.03	1.72 ± 0.09	2.03 ± 0.19
	2015	2.55 ± 0.40	2.44 ± 0.06	2.31 ± 0.18	
584	*2014*	1.73 ± 0.15	1.50 ± 0.11	1.61 ± 0.13	2.05 ± 0.21
	2015	2.76 ± 0.29	2.29 ± 0.19	2.43 ± 0.31	
588	*2014*	1.57 ± 0.18	1.46 ± 0.04	1.32 ± 0.11	1.78 ± 0.18
	2015	2.51 ± 0.44	1.89 ± 0.08	1.95 ± 0.07	
604	*2014*	1.80 ± 0.32	1.51 ± 0.14	1.40 ± 0.13	1.85 ± 0.18
	2015	2.64 ± 0.37	1.75 ± 0.13	2.00 ± 0.33	
$\bar{X} \pm s_x$ for cultivars *(за сорте)*		2.29 ± 0.11	1.92 ± 0.10	1.97 ± 0.10	

$F_{blocking} = 2.533^{ns}$; $F_{cultivar} = 10.485^{**}$; $F_{sowing\ density} = 4.027^{**}$; $F_{year} = 71.496^{**}$;
$F_{cultivar \times sowing\ density} = 0.323^{ns}$; $F_{cultivar \times year} = 0.685^{ns}$; $F_{sowing\ density \times year} = 1.591^{ns}$
$F_{cultivar \times sowing\ density \times year} = 0.510^{ns}$. ns ($P > 0.05$), * ($P \leq 0.05$), ** ($P \leq 0.01$)

Statistical differences between the average RPTP for the three analyzed wheat cultivars are presented in Table 3. The highest average RPTP was achieved for the winter wheat cultivar NS 40S (2.29). However, LSD test showed that this was significantly higher in comparison with Nova Bosanka (1.97) and Prima (1.92) cultivars. The difference between Nova Bosanka and Prima cultivars was not significant.

Tab. 3. Multiple comparison LSD test for a significant main effect of cultivar
LSD тест вишеструких упоређења за значајност главног фактора сорте

Cultivar *Сорта*	Rate of productive tillers per plant *Број продуктивних изданака по биљци*	
NS 40S	2.29	
Nova Bosanka	1.97	
Prima	1.92	
LSD test ($F_{cultivar}$)	0.05	0.17
	0.01	0.23

However, the effect of different sowing densities on the rate of productive tillers per plant was very significant. Observed regardless of different cultivars and years, the average RPTP was the highest at the sowing density of 384 seeds m^{-2} and the lowest at the sowing density of 588 seeds m^{-2}. Statistical differences between the average RPTP at eight analyzed sowing densities are presented in Table 4.

Tab. 4. Multiple comparison LSD test for significant main effect of sowing density
LSD тест вишеструких упоређења за значајност главног фактора густине сјетве

Sowing density *Густина сјетве*	Rate of productive tillers per plant *Број продуктивних изданака по биљци*	
384 seeds m^{-2}	2.41	
424 seeds m^{-2}	2.19	
451 seeds m^{-2}	2.19	
584 seeds m^{-2}	2.05	
544 seeds m^{-2}	2.03	
504 seeds m^{-2}	1.97	
604 seeds m^{-2}	1.85	
588 seeds m^{-2}	1.78	
LSD test ($F_{sowing\ density}$)	0.05	0.28
	0.01	0.37

According to LSD test, the difference between average RPTP at the sowing density of 384 seeds m^{-2} and the sowing densities of 424 and 451 seeds m^{-2} was not significant. However, the average RPTP at the sowing density of 384 seeds m^{-2} was significantly higher in comparison to the sowing density of 584 seeds m^{-2} and very significantly higher in comparison to the sowing densities of 504, 544, 588 and 604 seeds m^{-2} (Table 4).

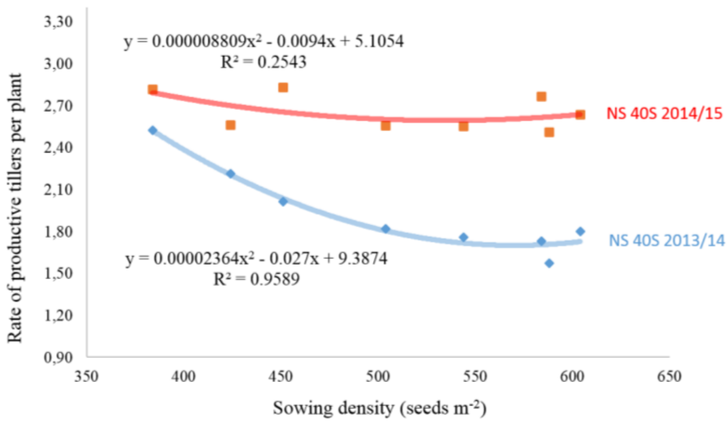
These results are in accordance with numerous researchers (Evers et al., 2006; Assuero and Tognetti, 2010) who investigated relations between tillering and sowing densities. This study also reveals a general tendency of decreasing the average RPTP by increasing the sowing density. This can be due to the fact that at lower sowing densities, plants can use different resources (sun radiation, water, soil nutrients etc.) more efficiently, and also competition among tillers is reduced (Thiry et al., 2002; Lloveras, 2004; Panković and Malešević, 2006; Evers et al., 2006).

The effect of experimental years on the average RPTP was statistically very significant. Observed regardless of different varieties and sowing densities, the average RPTP was 1.76 for 2013/14 and 2.36 for 2014/15. The difference between the average RPTP throughout experimental years is presented in Table 5.

Tab. 5. Multiple comparison LSD test for significant main effect of year
LSD тест вишеструких упоређења за значајност главног фактора године

Year *Година*	Rate of productive tillers per plant *Број продуктивних изданака по биљци*	
2014/15	2.36	
2013/14	1.76	
LSD - test (F_{year})	0.05	0.14
	0.01	0.19

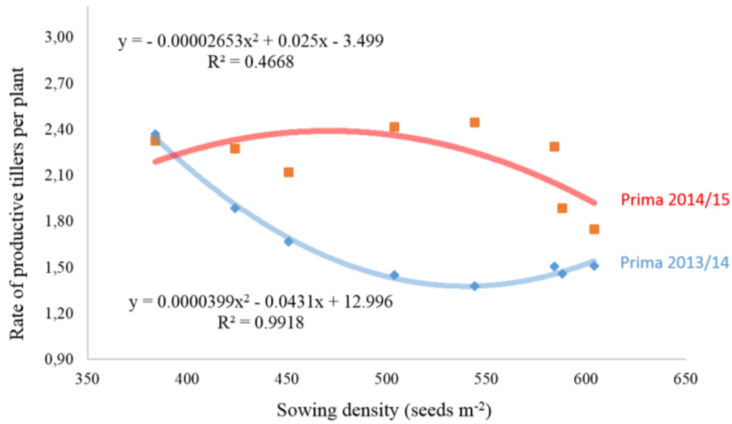
The average RPTP was very significantly higher in the experimental year of 2014/15 (2.36) compared to the first experimental year. Although the analyzed wheat cultivars were sown at approximately the same time, tillering can be influenced by the environmental conditions, which can affect the number of productive tillers per plant. Precipitation during November (sowing period) in 2013 was 156.0 mm which was extremely high, while the same cannot be said for the same period in 2014 when the precipitation was 41.8 mm, which could have an impact on the plant emergence and preparation for the winter. Also, precipitation in the period of January–March in 2014 was 216.1 mm, while in the same period in 2015 year it was 281.3 mm, or 65.2 mm higher than in the same period of the previous year, which could have had an impact on tillering in that year. The sum of the average temperatures in the period January–March in 2014 was 21.7 °C, while in the same period in 2015 it was 13.1 °C, which is 8.6 °C less than the previous year.



Graph 1. Regression analysis of the rate of productive tillers per plant for the winter wheat cultivar NS 40S under different sowing densities in 2013/14 and 2014/15
Регресиона анализа броја продуктивних изданака по биљци за озиму сорту пшенице НС 40С у различитим густинама сјетве за 2013/14 и 2014/15

The conducted regression analysis showed that a variation of average RPTP for the NS 40S cultivar was 95.89% determined by the different sowing densities (R^2 = 0.9589) in 2013/14 (Graph 1.) According to regression equation, if the sowing density for NS 40S cultivar increases for 10 seeds m^{-2}, the average RPTP, in conditions like those in 2013/14, will decrease for 0.2676 on average to the point of 571.07 seeds m^{-2}, while the further increase of the sowing density (until 604 seeds m^{-2}) will increase RPTP for the same amount. In 2014/15 a variation of the average RPTP for NS 40S wheat cultivar was 25.43% determined by the different sowing densities (R^2 = 0.2543) and if the sowing density increases for 10 seeds m^{-2}, the average RPTP will decrease for 0.0931 to the point of 533.55 seeds m^{-2}, while the further increase of the sowing density will increase RPTP for the same amount.

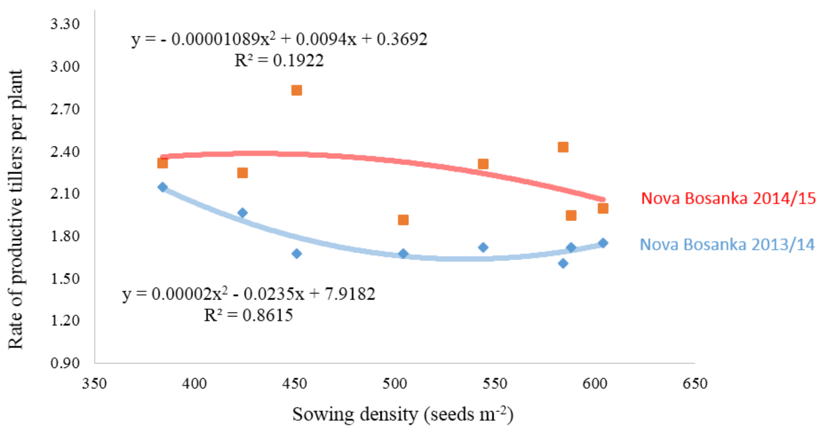
The variation of the average RPTP for the Prima cultivar (Graph 2) was 99.18% determined by different sowing densities (R^2 = 0.9918) in 2013/14. According to regression equation, if the sowing density for the Prima cultivar increases for 10 seeds m^{-2}, RPTP will decrease for 0.4270 to the point of 540.10 seeds m^{-2}, while the further increase of the sowing density (until 604 seeds m^{-2}) will increase RPTP for the same amount. In 2014/15 a variation of the average RPTP for the Prima cultivar was 46.68% determined by the different sowing densities (R^2 = 0.4668) and if the sowing density increases for 10 seeds m^{-2}, RPTP will increase for 0.2473 to the point of 471.16 seeds m^{-2}, while the further increase of the sowing density will decrease RPTP for the same amount.



Graph 2. Regression analysis of the rate of productive tillers per plant for the winter wheat cultivar Prima under different sowing densities in 2013/14 and 2014/15

Регресиона анализа броја продуктивних изданака по биљци за озиму сорту пшенице прима у различитим густинама сјетве за 2013/14 и 2014/15

The variation of the average RPTP for the cultivar Nova Bosanka (Graph 3) was 86.15% determined by different sowing densities (R^2 = 0.8615) in 2013/14.



Graph 3. Regression analysis of the rate of productive tillers per plant for the winter wheat cultivar Nova Bosanka under different sowing densities in 2013/14 and 2014/15

Регресиона анализа броја продуктивних изданака по биљци за озиму сорту пшенице нова босанка у различитим густинама сјетве за 2013/14 и 2014/15

According to the regression equation, if the sowing density increases for 10 seeds m^{-2}, RPTP will decrease for 0.2330 to the point of 587.50 seeds m^{-2}, while the further increase of the sowing density (until 604 seeds m^{-2}) will increase RPTP for the same amount. In 2014/15 a variation of average RPTP for the cultivar Nova Bosanka was 19.22%, determined by the different sowing densities (R^2 = 0.1922) and if sowing density increases for 10 seeds m^{-2}, RPTP will increase for 0.0929 to the point of 431.59 seeds m^{-2}, while the further increase of sowing density will decrease RPTP for the same amount.

These results indicate that sowing density had more influence on the average RPTP in 2013/14, for all the cultivars. On the other side, 2013/14 had lower average RPTP values for all the cultivars.

Conclusion

Based on the two-year research on the effect of different sowing densities on the rate of productive tillers per plant for NS 40S, Prima and Nova Bosanka wheat cultivars we can conclude the following:

- the highest average rate of productive tillers per plant was achieved for the winter wheat cultivar NS 40S (2.29), and this was significantly higher in comparison with Nova Bosanka (1.97) and Prima (1.92) cultivars;
- regardless of the different varieties and years, the average RPTP was the highest at the sowing density of 384 seeds m^{-2} and the lowest at the sowing density of 588 seeds m^{-2};
- in general, with the increase of examined sowing densities the rate of productive tillers per plant decreased;
- the average rate of productive tillers per plant was significantly higher in 2014/15 (2.36) in comparison to 2013/14 (1.76);
- the experimental year of 2014/15 had greater values of rate of productive tillers per plant even though it was less determined by sowing densities (R^2 ranged from 19.2 to 46.6) in comparison to 2013/14.

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Број продуктивних изданака по биљци сорти озиме пшенице (*Triticum aestivum* L.) у условима различите густине сјетве

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Сажетак

Циљ двогодишњег истраживања био је да се утврди број продуктивних изданака по биљци различитих сорти озиме пшенице у условима различите густине сјетве у агроеколошким условима Бање Луке. Сорте пшенице NS 40S, прима и нова босанка су биле засијане у осам различитих густина сјетве: 384, 424, 451, 504, 544, 584, 588 и 604 зрна по m^2. Експеримент је постављен на отвореном пољу, гдје је свака сорта пшенице засијана у различитој густини сјетве у четири понављања. Статистичка обрада података је извршена коришћењем факторијалне анализе варијансе 2×8×3, док је значајност разлика између третмана тестирана LSD тестом. Највећи просјечни број продуктивних изданака по биљци имала је сорта пшенице NS 40S (2,29). Највећи просјечни број продуктивних изданака по биљци остварен је при густини сјетве од 384 зрна по m^2, а најмањи код густине сјетве од 588 зрна по m^2.

Кључне ријечи: пшеница, бокорење, густина сјетве, продуктивност

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