EFFECTS OF DIFFERENT FERTILIZATION TREATMENTS ON THE YIELD PERFORMANCE, YIELD PARAMETERS AND GRAIN QUALITY OF WINTER WHEAT GROWN ON VERTISOL SOIL TYPE

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Abstract. Fertilization effects were performed in a stationary type of field trial, on a vertisol soil type, on the premises of the Small Grains Research Center in Kragujevac, central Serbia, over a three-year period (2010–2013). In addition to untreated control, the trial included six mineral nutrition treatments: (1) $N_0P_0K_0$; (2) $N_{80}P_0K_0$; (3) $N_{80}P_{60}K_{60}$; (4) $N_{80}P_{100}K_{60}$; (5) $N_{80}P_{60}K_0$; (6) $N_{80}P_{100}K_0$; (7) $N_{80}P_0K_{60}$. Individual fertilizers used in the trial were as follows: KAN (nitrogen fertilizer), super phosphate (phosphate fertilizer), and 60% of potassium salt (potassium fertilizer). Mineral nutrition treatments mentioned above were applied in the two winter wheat cultivars: Ana Morava and KG 100. Favorable physical properties of the soil are of major importance for efficient growth of wheat. In this regard, the aim of this study was to determine to what extent the different fertilizing treatments influence yield performance, yield parameters and grain quality of winter wheat cultivars grown on vertisol soil type. The highest yield of winter wheat over the three-year trial was obtained from the Ana Morava cultivar (6,276 kg ha^{-1}) in the treatment that involved the application of $N_{80}P_{60}K_{60}$. Variance analysis implied very highly significant individual effects of study year and fertilization on grain yield in the studied winter wheat cultivars, as well as very highly significant effect of interaction between year × fertilization.
Keywords: *wheat, vertisol, mineral nutrition, cultivars, grain yield*

Introduction

Wheat is the major product of crop and agricultural production and the most significant food source of the entire human population (Dixon et al., 2009; Todorovska et al., 2009; Nouri et al., 2011; Rizvan et al., 2016). As winter wheat uses large amounts of mineral elements during the growing period, it has high soil fertility requirements (Maleševic et al., 2008). The productivity of winter wheat grown on acidic soils such as vertisol is generally significantly reduced. Yield performance, yield parameters and grain quality are critical indicators of productivity of winter wheat plants. Yield, yield parameters (grain number and grain weight) and quality of winter wheat grain (1000-grain weight and hectoliter weight) are crucial to determining the correlation between plant, soil and mineral nutrition.

A universal method of fertilizing wheat grown on low pH soils is difficult to devise due to numerous nutrition and nutrition application specificities. The nutritional needs of plants grown on acid soils are somewhat difficult to specify due to the highly non-uniform physical and chemical properties of soil (Nemeth, 2006). As wheat cultivated on an acidic soil requires specific mineral nutrition, i.e. appropriately balanced nitrogen

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and phosphorus nutrition, the increased nutritive input of phosphorus is a must (Jevtić et al., 1988; Riley et al., 2001; Dolijanović, et al., 2019).

Low production capacity of vertisols is the result of poor physical and mechanical, and water and air properties (Malešević et al., 2008; Jaćimović et al., 2012). The use of fertilizers is based on soil fertility control, which infers preserving the existing favorable soil fertility or maintaining soil fertility improved with fertilizers. Fertilizers establish a balance between the total amount of nutrients ensuring high yields, on the one hand, and the amount of nutrients contained in the soil, on the other. In order to determine the optimal amount of mineral nutrients from a fertilizer, it is necessary to be acquainted with the specificities of nutrients uptake by plants, as well as with the fertilizer dynamics in the soil (Korchens (2006); Jelić et al., 2012; Djekić, et al., 2013).

Yield performance of winter wheat depends on a number of factors, primarily cultivar genotype, agro-environmental conditions (soil fertility, precipitation and air temperature) and the applied production technology (Fagam et al., 2006; Trethowan et al., 2007; Rashid et al., 2013). Also, studies performed so far suggest that yield performance of wheat depends on a number of yield components, i.e. number of plants, number of grains per spike, grain weight per spike, 1000-grain weight. Correlation among these parameters is highly complex, as the increase in the value of one parameter often results in a decrease in the value of another (Hristov et al., 2008).

Grain number and grain weight are considered as cultivar specificities however, they are generally affected by agro-environmental conditions and mineral nutrition (Savić et al., 2006).

Studies performed so far imply the necessity of continuously determining quantity and nutrients ratios of fertilizers as imposed by specific agro-environmental conditions. Under the agro-environmental conditions of Serbia most commonly applied amounts of N ensuring overall high yields range from 80–120 kg ha^{-1}, depending on the agrochemical properties of the soil.

Stationary field trials, such as ours, are of utmost importance (Cooke (1976); Ragasits et al., 2000; Malešević et al., 2008; Đekić et al., 2014b).

Newly developed wheat cultivars have substantially higher yield potential (Rajaram, 2001; Ogbonnaya et al., 2008; Denčić et al., 2010) however their mineral nutrition requirements are highly demanding consequently (Đekić et al., 2014a; Jelić et al., 2012).

The objective of this research was to examine the effects of different fertilization treatments on yield performance, yield parameters (number of grains per spike and grain weight per spike) and grain quality (1000-grain weight and hectoliter weight) in different winter wheat cultivars grown on a vertisol.

Materials and methods

The experiment was performed in a stationary type field trial (the experimental field of the Small Grains Research Center, Kragujevac (44°02’N, 20°56’E, altitude: 185 m a.s.l.), Republic of Serbia (central Serbia) (*Fig. 1*) involving fertilization over a long-term period (over 30). The study location of Kragujevac is approximately 113 km away from Belgrade. The study was performed over the three-year period, from 2010 to 2013.

The experiment was conducted on two winter wheat cultivars, 1) Ana Morava and 2) KG 100. In addition to an untreated control, the trial included six mineral nutrition

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treatments: 1) $N_0P_0K_0$; 2) $N_{80}P_0K_0$; 3) $N_{80}P_{60}K_{60}$; 4) $N_{80}P_{100}K_{60}$; 5) $N_{80}P_{60}K_0$; 6) $N_{80}P_{100}K_0$; 7) $N_{80}P_0K_{60}$.

The following fertilizers were used in the trial: KAN (nitrogen fertilizer), super phosphate (phosphate fertilizer), and 60% of potassium salt (potassium fertilizer).

The following parameters were examined: grain yield, hectoliter weight, 1000 grain weight, number of grains per spike and grain weight per spike.

The experiment was set up at an area of 50 m^2 following the random block design with five replications Conventional cultural practices were applied in the trial. The seeding rate in the cultivars studied was 600 germinated seeds per m^2. Statistical data processing was performed in the Analyst module of the SAS/STAT program (SAS Institute, 2000). The Descriptive Statistics and Analysis Variance was applied.

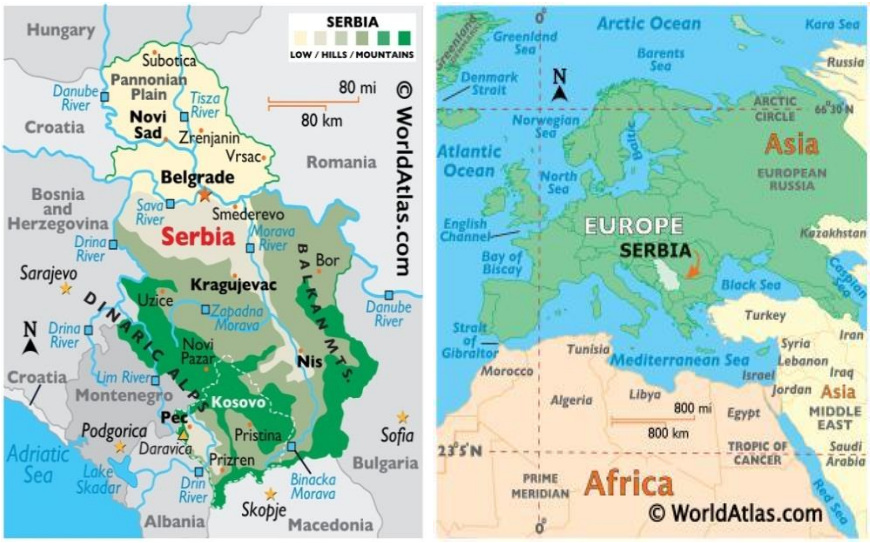

Figure 1. *Study area of (Central Serbia-Kragujevac) and Europe – Serbia*

Climatic conditions

Agricultural production greatly depends on climatic conditions of a production area. As an essential element of the climate, air temperature is crucial to successful wheat growth. In this regard, precipitation is a highly relevant factor, both in terms of its annual amounts and the distribution (Savić et al., 2006). Favorable soil humidity conditions have a stimulating effect on seed germination and sprouting, as well as on plant development.

The area of Kragujevac is located at an altitude of 186 m, in temperate climate zone.

Meteorological conditions, i.e. air temperature and precipitation rates over the 2011/2012 and 2012/2013 growing periods were relatively favorable, whereas the 2010/2011 growing period exhibited lower precipitation rates, as well as lower air temperatures over some periods in the season (Tahmasebi et al., 2014).

Mean monthly air temperatures (°C) and monthly precipitation sum (lm^{-1}) over the examination examined are given in *Table 1*.

In the first year of our study in the area of Kragujevac (2010/2011), the recorded precipitation during spring was 444.2 l m^{-1}, which is some 127.4 l m^{-1} lower than multi-year average, while mean air temperature over the same period was 10.41, or within the multi-year average. Precipitation recorded in March and April, 20.4 l m^{-1} and 20.8 l m^{-1}

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respectively, was lower by 20–30 l m^{-1} compared to the multi-year average. This lack of precipitation in the first year of study (2010/2011) affected growth and development of plants, especially clustering, rooting, leaf mass ratio, which consequently had an adverse effect on yield performance, yield parameters (grain number and grain weight) and grain quality (1000-grain weight and hectoliter weight).

Table 1. *Temperature and water in the course of the vegetation in 2010/2011, 2011/2012 and 2012/2013*

Month	**Temperature (t °C)**				**Water (l m^{-1})**			
	Year			**Average**	**Year**			**Average**
	2010/2011	**2011/2012**	**2012/2013**	**1961/99**	**2010/2011**	**2011/2012**	**2012/2013**	**1961/99**
October	10.2	10.4	13.5	11.3	86.9	33.3	56.2	42.8
November	11.4	3.1	9.5	6.5	27.9	1.3	17.7	46.4
December	2.4	4.6	1.7	1.1	50.1	43.3	16.4	46.8
January	0.9	0.7	2.9	-1.8	29.1	117.2	65.8	38.3
February	0.5	-3.7	4.0	3.0	48.5	60.1	84.4	35.7
March	7.2	8.1	6.5	6.5	20.4	5.7	102.9	40.4
April	12.0	12.9	13.4	11.3	20.8	74.5	41.2	53.1
May	15.8	16.1	18.2	16.3	65.8	83.3	70.8	66.7
Jun	20.9	23.0	19.9	19.0	32.3	57.8	85.4	80.3
July	22.8	25.8	21.9	21.1	62.4	35.4	60.6	70.6
(X – VII)	10.41	10.10	11.50	10.40	444.2	515.9	601.4	571.6

In the second year of the study (growing season 2011/2012), the recorded precipitation was 515.9 lm^{-1}, which is only 56 l m^{-1} lower compared to the multi-year average. The precipitation rate over the growing period was rather high and well distributed, accompanied with favorable air temperature average, all of which ensured proper development of plants. Favorable climatic conditions in June fostered the development of winter wheat plants, which resulted in high winter wheat grain yield.

Climatic conditions were the most favorable in the third study year (2012/2013), precipitation being 601.4 l m^{-1} and mean air temperature 11.50 °C.

Air temperatures were higher than average from January to March, which promoted plant growth. Precipitation rate in March, which amounted to 102.9 l m^{-1}, ensured good clustering of winter wheat plants. Mean monthly temperature in April was 13.4 °C, which was by 2.1 °C higher than the multi-year average. Favorable air temperatures in May (18.2 °C) and proper water balance (70.8 l m^{-1}) ensured good plant development and stimulated grain filling.

The values of mean monthly air temperatures (°C) and monthly precipitation sums (l m^{-1}) over the 2012/2013 examination period gave the highest grain yield and quality of winter wheat grain.

The data presented in *Table 1* (mean monthly temperatures and precipitation rates during the study) suggest that climatic conditions varied among the years of study. Weather conditions greatly affected the duration of specific phases of wheat plant

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development as well as the overall dynamics of plant growth and development over the growing periods (Savić et al., 2007; Paunović et al., 2010).

Favorable weather conditions confirmed over season 2012/2013 i.e. highest precipitations rate proper precipitations distribution by months and agreeable monthly air temperatures suggested optimal conditions for growing winter wheat on a vertisol especially during critical phases of plants development.

The 2011/2012 growing season was also favorable for growing winter wheat, while the most unfavorable climatic conditions for growing winter wheat were in the first study year (2010/2011).

Results and discussion

For the successful development, wheat requires fertile soils of favorable physical properties. The soil in the trial is a degrading smonica (vertisol), of an A-Bt-C profile. The upper part of the A horizon is gray, showing signs of substantial deficiencies in bases and humus due to leaching. The upper part of the A horizon is strongly acidic to acidic, the degree of base saturation being lower than 70%. In the deeper layers of this soil, there is a Bt horizon, which is strongly enriched with clay and poorly permeable. During wet periods, surface water is retained above this horizon, which leads to the formation of reddish brown Fe-hydroxide mottles as well as small grains of spodic materials (orstein). In addition to the heavy mechanical composition and rough, unstable structure, this soil is of poor porosity, which significantly deteriorates physical properties of this soil (Li et al., 2010; Meng et al., 2009).

Before the trial, in order to determine soil fertility, samples were taken and analyses were performed involving fertility parameters based on the fertilization treatments (*Table 2*).

Table 2. *Facts of soil fertility at experimental field*

Fertilizing variants	**Profound (cm)**	**HUMUS (%)**	**pH**		**N overall (%)**	**P_2O_5**	**K_2O**
			H_2O	**KCl**		**mg/100 g soil**	
$N_0P_0K_0$	0 - 20	2.13	5.85	4.37	0.12	2.60	18.67
$N_{80}P_0K_0$		2.10	5.83	4.26	0.14	2.20	17.60
$N_{80}P_{60}K_{60}$		2.39	5.58	4.27	0.15	8.17	27.47
$N_{80}P_{100}K_{60}$		2.25	5.72	4.28	0.14	9.83	24.00
$N_{80}P_{60}K_0$		2.34	5.63	4.15	0.15	9.00	17.40
$N_{80}P_0K_{60}$		2.24	5.73	4.22	0.16	2.83	23.53

The soil used in the experiment is strongly acidic (pH in Kcl < 4.5) with a moderate humus content. The highest replaceable acidity was observed in $N_{80}P_{60}K_0$ and $N_{80}P_0K_{60}$ fertilization treatments. Treatments which involved mineral nutrition had higher humus contents (on average) compared to the control. The highest humus content was observed in $N_{80}P_{60}K_{60}$ and $N_{80}P_{60}K_0$ fertilization treatments.

The total nitrogen content was moderate (according to the Wohltmann classification) with fertilizer treatments exhibiting higher total nitrogen content compared to the untreated control. The content of readily available phosphorus was low (2.20–9.83 mg/100 g of soil), while readily available potassium content was moderately high to high (17.40–27.47 mg/100 g of soil).

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Grain yield

Average grain yield in the studied winter wheat cultivars (‘Ana Morava’ and ‘KG 100’) grown in five replications over the three growing periods (2010/2011, 2011/2012 and 2012/2013) are presented in *Table 3*.

Grain yield is the most significant indicator of plant productivity. It is also the most reliable indicator of differences in productivity among cultivars and their mineral nutrition specificities, as yield is the final result of mutual actions, both external factors influencing plant growth and development, and bio-rhythmic dynamics of physiological and biochemical processes.

Average values of yield varied between the studied winter wheat cultivars over the three-year period on a vertisol as influenced by fertilization treatments and climatic conditions.

Table 3. *Grain yield (t ha^{-1}) - cultivars 1) Ana Morava and 2) KG 100*

Cult.	Fertilization	Years									Average		
		2010/2011			2011/2012			2012/2013					
		$\bar{x}$	S	Sx	$\bar{x}$	S	Sx	$\bar{x}$	S	Sx	$\bar{x}$	S	Sx
1	N0P0K0	0.819	0.122	0.071	1.605	0.345	0.199	1.335	0.422	0.255	1.253	0.449	0.150
	N80P0K0	2.448	0.442	0.255	3.931	0.739	0.427	4.491	1.900	1.091	3.623	1.387	0.463
	N80P60K60	3.403	1.147	0.662	4.928	0.711	0.410	6.276	0.130	0.075	4.896	1.417	0.472
	N80P100K60	3.994	0.440	0.254	4.156	1.146	0.662	5.723	0.654	0.377	4.625	1.080	0.360
	N80P60K0	2.898	0.616	0.355	4.050	1.023	0.591	4.195	0.780	0.450	3.714	0.942	0.314
	N80P100K0	3.190	0.421	0.243	3.969	0.685	0.395	4.116	1.018	0.587	3.758	0.778	0.259
	N80P0K60	2.491	0.455	0.263	3.563	1.018	0.588	4.210	0.960	0.544	3.421	1.052	0.351
2	N0P0K0	0.896	0.283	0.164	1.548	0.324	0.187	1.381	0.123	7.131	1.275	0.369	0.123
	N80P0K0	1.690	0.693	0.340	3.186	0.215	0.124	3.563	1.220	0.704	2.813	1.113	0.371
	N80P60K60	3.837	0.889	0.513	4.378	0.530	0.307	4.896	1.608	0.929	4.370	2.155	0.718
	N80P100K60	3.503	0.260	0.150	4.210	0.689	0.398	4.876	1.606	0.927	4.196	1.065	0.355
	N80P600K0	3.368	0.739	0.427	3.962	1.200	0.693	4.017	2.120	1.270	3.782	1.343	0.448
	N80P100K0	2.765	0.308	0.178	3.984	0.260	0.150	4.053	1.286	0.743	3.601	0.921	0.307
	N80P0K60	2.862	0.392	0.226	3.553	0.597	0.345	4.080	1.690	0.976	3.498	1.059	0.353

The lowest grain yield was obtained in untreated control in all study year, in both cultivars (‘Ana Morava’ and ‘KG 100’). Fertilization significantly increased grain yield of winter wheat (Kovačević (2005); Savić et al., 2005). In regard to grain yield, some differences were perceived between the examined winter wheat cultivars.

In the first experimental year, ‘Ana Morava’ fertilized with $N_{80}P_{100}K_{60}$ had the highest grain yield (3,994 kg ha^{-1}), while $N_{80}P_{60}K_{60}$ fertilization treatment gave the highest grain yield in ‘KG 100’ (3,837 kg ha^{-1}) in the same season.

In the second and third years of examination, both cultivars exhibited the best grain yield performance when fertilized with $N_{80}P_{60}K_{60}$. The application of NK fertilizers considerably reduced the grain yield of winter wheat compared to fertilization treatments involving phosphorus (both low and high rates of phosphorus) (Kostić et al., 1987; Tyrone et al., 2002; Bálint et al., 2008) over the entire study period. This confirms that the examined winter wheat cultivars grown on acidic soils (vertisol) had considerably higher productivity when fertilized with NPK compared to the yields obtained on non-acidic soils (Rehman et al., 2006; El-Lethy et al., 2013; Jelić et al., 2015).

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During the three-year period, average grain yield was slightly higher in ‘Ana Morava’ fertilized with $N_{80}P_{60}K_{60}$ (4,836 kg ha^{-1}) than ‘KG 100’ (4,370 kg ha^{-1}) under the same treatment.

N fertilization treatment gave the lowest grain yield in ‘KG 100’ (1,690 kg ha^{-1}) in the first study year.

The highest grain yield of winter wheat grown on a vertisol over the three-year period was obtained in ‘Ana Morava’ (6,276 kg ha^{-1}) fertilized with $N_{80}P_{60}K_{60}$.

‘Ana Morava’ and ‘KG 100’ had a considerably higher grain yield in the second and third years of examination, which confirms that favorable climatic conditions (average values of mean monthly air temperatures (°C) and monthly precipitation sums (lm^{-1}) are crucial to grain yield performance (Paunović et al., 2010). In conclusion, besides genotype, grain yield of winter wheat is governed to a great extent by the fertilization system, which, along with climatic, soil conditions and cultivar specificities, is a key factor in crop yield and quality (Jelic and et al., 2015).

Number of grains per spike

The number of grains per spike is a parameter of wheat yield closely correlated with number of spikelets per spike, number of flowers per spikelet as well as with successful fertilization and germination of grains (Borojević, 1978). As these parameters are greatly governed by agro-environmental conditions and the applied cultural practices, number of grains per spike is considered a highly variable trait (Milošev, 1996).

Average number of grains per spike in the studied winter wheat cultivars (‘Ana Morava’ and ‘KG 100’) grown in five replications over the three growing seasons (2010/2011, 2011/2012 and 2012/2013) are given in *Table 4*.

Table 4. *Number of grains per spike – cultivars 1) Ana Morava and 2) KG 100*

Cult.	Fertilization	Years									Average		
		2010/2011			2011/2012			2012/2013					
		$\bar{x}$	S	Sx	$\bar{x}$	S	Sx	$\bar{x}$	S	Sx	$\bar{x}$	S	Sx
1	N0P0K0	20.67	6.658	3.844	15.67	2.887	1.667	28.33	1.527	0.882	21.56	6.654	2.218
	N80P0K0	35.00	1.000	0.577	35.00	2.646	1.527	36.33	1.528	0.882	35.44	1.740	0.580
	N80P60K60	43.67	5.132	2.963	48.00	8.660	5.000	45.00	1.000	0.577	45.56	5.411	1.804
	N80P100K60	40.67	5.508	3.180	41.67	6.110	3.528	46.00	1.000	0.577	42.78	4.816	1.605
	N80P60K0	39.67	6.110	3.528	41.00	9.849	5.686	45.00	4000	2.309	41.89	6.585	2.195
	N80P100K0	38.33	2.082	1.202	39.67	5.508	3.180	40.33	0.577	0.333	39.44	3.087	1.029
	N80P0K60	37.67	2.082	1.202	36.67	8.327	4.807	39.67	1.528	0.882	38.00	4.555	1.518
2	N0P0K0	13.67	2.517	1.453	19.00	6.000	3.464	25.67	2.517	1.453	19.44	6.267	2.089
	N80P0K0	33.00	7.211	4.163	36.67	4.726	0.728	42.00	5.000	2.887	37.22	6.340	2.113
	N80P60K60	35.33	7.095	4.096	37.00	4.359	2.517	42.00	1.000	0.577	38.11	5.159	3.302
	N80P100K60	34.33	5.774	3.333	36.33	3.215	1.856	40.00	2.000	1.155	36.89	4.256	1.419
	N80P60K0	41.68	9.238	5.333	34.67	5.508	3.180	31.33	4.509	2.603	35.89	7.704	2.469
	N80P100K0	29.33	3.786	2.186	35.33	5.686	3.283	39.67	5.508	3.180	34.78	6.280	2.093
	N80P0K60	22.33	5.508	3.180	32.00	9.539	5.508	41.33	0.577	3.333	31.89	9.905	3.302

The results achieved over the entire study period showed that the smallest number of grains per spike was observed in the control, while the treatments involving mineral

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nutrition gave a significantly larger number of grains per spike. Compared to the untreated control, this increase in number of grains per spike was only due to the application of nitrogen over the entire study period (all the three study years) (Blandino et al., 2016; Litke et al., 2018; Terzić et al., 2018).

Under NP_1K treatment, average number of grains per spike over the three-year period was significantly higher in 'Ana Morava' (45.56) than in 'KG 100 (38.71).

The third year of study (2012/2013) resulted in the highest number of grains per spike in both cultivars ('Ana Morava' and 'KG 100') as this season provided the most favorable conditions for the wheat crop.

The smallest number of grains per spike was observed in cv. 'KG 100' (22.33) in the first study year (2010/2011) in the treatment under $N_{80}P_0K_{60}$ mineral nutrition.

The greatest number of grains per spike in all years was obtained by cv. 'Ana Morava' under $N_{80}P_{60}K_{60}$ treatment in the third study year (2012/2013).

Grain weight per spike

Average grain weight per spike in the studied winter wheat cultivars ('Ana Morava' and 'KG 100') grown in five replications over the three growing periods (2010/2011, 2011/2012 and 2012/2013) are shown in *Table 5*.

Grain weight per spike in wheat is considered a relevant indicator of yield quality in general. It depends on agro-environmental conditions and applied cultural practices, as well as on fertilization percentage and grain formation in flowers (Milošev, 2000).

Table 5. *Grain weight per spike (g) - cultivars 1) Ana Morava and 2) KG 100*

Cult.	Fertilization	Years									Average		
		2010/2011			2011/2012			2012/2013					
		$\bar{x}$	S	Sx	$\bar{x}$	S	Sx	$\bar{x}$	S	Sx	$\bar{x}$	S	Sx
1	N0P0K0	0.603	0.015	0.009	0.560	0.075	0.044	1.347	0.031	0.018	0.837	0.385	0.128
	N80P0K0	1.157	0.211	0.122	1.240	0.010	0.006	1.720	0.060	0.035	1.372	0.285	0.095
	N80P60K60	1.343	0.211	0.122	2.233	0.484	0.279	2.073	0.095	0.055	1.883	0.491	0.164
	N80P100K60	1.237	0.055	0.032	1.653	0.352	0.203	2.220	0.110	0.063	1.703	0.466	0.155
	N80P60K0	1.073	0.102	0.059	1.560	0.387	0.233	2.203	0.145	0.084	1.612	0.535	0.178
	N80P100K0	1.280	0.020	0.011	1.637	0.275	0.159	1.810	0.010	0.006	1.576	0.272	0.091
	N80P0K60	1.143	0.107	0.062	1.547	0.226	0.130	1.970	0.040	0.023	1.553	0.380	0.127
2	N0P0K0	0.597	0.075	0.043	0.513	0.100	0.058	1.260	0.060	0.035	0.790	0.361	0.120
	N80P0K0	1.213	0.115	0.066	1.417	0.239	0.138	1.817	0.165	0.095	1.482	0.308	0.103
	N80P60K60	1.203	0.050	0.029	1.517	0.293	0.169	1.983	0.097	0.056	1.568	0.374	0.125
	N80P100K60	1.283	0.247	0.142	1.463	0.294	0.169	1.757	0.275	0.159	1.501	0.314	0.105
	N80P60K0	1.323	0.071	0.041	1.273	0.273	0.158	1.777	0.285	0.165	1.458	0.313	0.104
	N80P100K0	1.200	0.050	0.029	1.673	0.281	0.162	1.483	0.215	0.124	1.452	0.273	0.091
	N80P0K60	1.167	0.153	0.088	1.495	0.220	0.129	1.495	0.220	0.129	1.386	0.518	0.173

The application of different fertilizers had a strong impact on grain weight per spike. In both cultivars studied ('Ana Morava' and 'KG 100') grain weight per spike was markedly higher over the second and third growing seasons compared to the season 2010/2011.

Compared to the untreated control and the other fertilization treatments, both cultivars exhibited the highest grain weight per spike under the fertilization treatment

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involving NPK, at both rates of phosphorus, which is in agreement with the results (Jelić et al., 2012; Djekić, et al., 2014b). Grain weight per spike varied between the winter wheat cultivars examined.

The highest grain weight per spike was obtained in ‘Ana Morava’ (2.233 g) under $N_{80}P_{60}K_{60}$ fertilization treatment in the third year of study, while ‘KG 100’ gave the lowest grain weight per spike (1.167 g) when fertilized with $N_{80}P_0K_{60}$, also in season 2012/2013. Weather conditions (precipitation and air temperature) during the seasons 2011/2012 and 2012/2013 were more favorable, as shown by the results of the study. Grain weight per spike was lower in the first study year, when precipitation and air temperatures were less favorable for wheat plant growth and development.

1000-grain weight

The average 1000-grain weight in the studied winter wheat cultivars (‘Ana Morava’ and ‘KG 100’) grown in five replications over the three growing periods (2010/2011, 2011/2012 and 2012/2013) are given in *Table 6*.

1000-grain weight is an important parameter of wheat grain quality which is governed by genotype, however it is largely influenced by agro-environmental conditions and cultural practices.

1000-grain weight varied considerably between the cultivars under the different mineral nutrition treatments. The data given in *Table 6* infer that 1000-grain weight was lowest in untreated control, as show in the results (Savić et al., 2005).

Table 6. *1000-grain weight (g) - cultivars 1) Ana Morava and 2) KG 100*

Cult.	Fertilization	Years									Average		
		2010/2011			2011/2012			2012/2013					
		$\bar{x}$	S	Sx	$\bar{x}$	S	Sx	$\bar{x}$	S	Sx	$\bar{x}$	S	Sx
1	N0P0K0	33.67	1.258	0.726	32.83	2.082	1.202	39.83	0.725	0.419	35.44	3.546	1.182
	N80P0K0	39.33	1.527	0.882	35.50	1.803	1.041	43.33	0.757	0.437	39.39	3.612	1.204
	N80P60K60	44.50	0.866	0.500	46.33	2.021	1.167	45.67	1.332	0.769	45.50	1.516	0.505
	N80P100K60	41.17	0.764	0.441	43.33	3.055	1.764	46.23	1.002	0.578	43.58	2.753	0.917
	N80P60K0	39.67	3.819	2.205	43.33	2.517	1.453	42.73	1.563	0.902	41.91	2.956	0.985
	N80P100K0	38.17	0.764	0.441	41.67	2.082	1.202	45.73	0.643	0.371	41.86	3.477	1.159
	N80P0K60	37.50	2.784	1.607	40.67	2.021	1.167	45.63	0.666	0.384	41.27	3.959	1.320
2	N0P0K0	32.50	2.179	1.258	32.17	0.577	0.333	40.38	0.520	0.300	35.02	4.190	1.397
	N80P0K0	38.50	1.803	1.041	42.17	1.041	0.601	41.33	0.379	0.219	40.70	1.986	0.662
	N80P60K60	40.67	2.566	0.481	42.00	3.464	2.000	43.47	3.449	1.991	42.04	3.015	1.005
	N80P100K60	40.33	1.528	0.882	43.00	2.000	1.150	42.73	0.462	0.267	42.02	1.804	0.601
	N80P60K0	39.83	1.258	0.726	42.83	0.577	0.333	42.73	1.501	0.867	41.80	1.794	0.598
	N80P100K0	41.83	1.756	1.014	41.17	5.008	2.892	41.73	1.724	0.996	41.58	2.807	0.936
	N80P0K60	38.33	1.527	0.882	38.33	1.893	1.093	43.00	0.346	0.200	39.96	2.726	0.909

Treatments that involved full NPK fertilization, at both rates of phosphorus, gave the highest 1000-grain weight, while mineral nutrition treatments that contained nitrogen fertilizer (Protić et al., 2007) only or $N_{80}P_0K_{60}$ treatments resulted in lower 1000-grain weights.

The lowest 1000-grain weight over the three years of examination was observed in ‘KG 100’ (38.33) treated with NK (the result of the first year of the study). This cultivar

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had the highest 1000-grain weight (43.47) when treated with $N_{80}P_{60}K_{60}$ (the result of the third study year).

The highest 1000-grain weight over the entire study period was obtained in ‘Ana Morava’ (46.33) under the fertilization treatment that involved $N_{80}P_{60}K_{60}$.

Higher 1000-grain weights in both cultivars were recorded in the 2011/2012 and 2012/2013 seasons, characterized by favorable weather conditions.

Hectoliter weight

Average values of hectoliter weight in the studied winter wheat cultivars (‘Ana Morava’ and ‘KG 100’) grown in five replications over the three growing periods (2010/2011, 2011/2012 and 2012/2013) are presented in *Table 7*.

Hectoliter weight is a parameter most commonly considered when assessing wheat grain quality.

Average hectoliter grain weight in the untreated control was lower than in the fertilized plants over the entire three-year examination period, which is in agreement with a results (Savić et al., 2005).

‘Ana Morava’ exhibited the best performance in terms of average hectoliter weight of grain across experimental years. As for ‘KG 100’, it recorded lower average hectoliter grain weight in all the three growing periods examined.

Based on the fertilization treatments, ‘Ana Morava’ treated with $N_{80}P_{60}K_{60}$ gave the highest hectoliter grain weight on average in all three study years (74.01hl $^{-1}$), while ‘KG 100’ had the highest hectoliter grain weight when treated with $N_{80}P_{100}K_{60}$ (71.83 hl^{-1}) over the entire study period.

Table 7. *Hectoliter weight (kg hl^{-1}) - cultivars 1) Ana Morava and 2) KG 100*

Cult.	Fertilization	Years									Average		
		2010/2011			2011/2012			2012/2013					
		$\bar{x}$	S	Sx	$\bar{x}$	S	Sx	$\bar{x}$	S	Sx	$\bar{x}$	S	Sx
1	N0P0K0	70.98	1.514	0.874	69.45	0.200	0.115	74.93	3.826	2.209	71.79	3.201	1.067
	N80P0K0	69.78	2.663	1.538	70.52	2.101	1.213	76.73	1.643	0.949	72.34	3.806	1.269
	N80P60K60	71.38	2.572	1.485	73.52	1.007	0.581	77.13	1.685	0.973	74.01	2.992	0.997
	N80P100K60	71.25	1.744	1.007	72.98	0.611	0.353	74.32	3.402	1.964	72.85	2.349	0.783
	N80P60K0	69.63	4.087	2.359	72.05	2.400	1.386	75.40	2.751	1.588	72.36	3.714	1.238
	N80P100K0	72.45	0.400	0.231	72.45	2.000	1.155	73.65	4.613	2.663	72.85	2.592	0.864
	N80P0K60	70.32	2.013	1.162	71.78	1.155	0.667	75.12	4.046	2.336	72.41	3.159	1.053
2	N0P0K0	66.42	2.462	1.421	69.12	2.948	1.702	74.98	1.847	1.067	70.17	4.351	1.450
	N80P0K0	66.83	1.087	0.627	70.45	1.058	0.611	73.78	1.155	0.667	70.36	3.158	1.052
	N80P60K60	67.50	0.953	0.550	68.83	2.646	1.528	77.00	1.314	0.759	71.11	4.717	1.572
	N80P100K60	69.65	0.800	0.462	70.32	1.007	0.581	75.52	2.411	1.392	71.83	3.099	1.033
	N80P60K0	67.37	1.249	0.721	70.18	0.231	0.133	75.12	2.444	1.411	70.89	3.666	1.222
	N80P100K0	67.57	1.184	0.683	68.52	2.026	1.170	75.20	2.433	1.405	70.44	4.002	1.334
	N80P0K60	67.92	0.462	0.267	68.70	3.866	2.232	74.85	1.442	0.833	70.49	3.889	1.296

The lowest hectoliter grain weight was recorded in ‘KG 100’ (66.83 hl^{-1}) under N treatment in the first study year on a vertisol.

The highest hectoliter grain weight was obtained by ‘Ana Morava’ (77.13 hl^{-1}) under $N_{80}P_{60}K_{60}$ fertilization treatment in the third growing period on a vertisol.

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Variance analysis

Variance analysis of individual effect of year, cultivar specificity, and fertilization on grain yield in the studied cultivars of winter wheat grown in five replications over the three growing periods (2010/2011, 2011/2012 and 2012/2013) is presented in *Table 8*.

Variance analysis implied very highly significant individual effects of year of the study and fertilization on grain yield in the studied winter wheat cultivars, as well as very highly significant effect of interaction between year × fertilization. The individual effect of cultivar specificity, along with the effects of interactions between year × cultivar, cultivar × fertilization, and year × cultivar × fertilization on grain yield in the investigated winter wheat cultivars was nonsignificant statistically.

Table 8. *Effect of year, cultivar specificity, and fertilization on grain yield (t ha $^{-1}$)*

Effect	df	Mean sqr effect	Mean sqr error	F	p-level
Year (A)	2, 123	21.050	2.169	9.703***	0.000
Cultivar (B)	2, 124	5.865	2.444	2.400ns	0.234
Fertilization (C)	6, 119	19.983	1.589	12.579***	0.000
Year × Cultivar (AB)	2, 120	3.467	2.117	1.638ns	0.469
Year × Fertilization (AC)	12, 105	3.097	1.045	2.962***	0.001
Cultivar × Fertilization (BC)	6, 112	1.913	1.533	1.248ns	0.222
Year × Cultivar × Fertilization (ABC)	12, 84	0.739	0.912	0.810ns	0.033

Variance analysis of individual effects of year, cultivar specificity, and fertilization on number of grains per spike in the investigated winter wheat cultivars grown in five replications over the three growing periods (2010/2011, 2011/2012, 2012/2013) are shown in *Table 9*.

Table 9. *Effects of year, cultivar specificity, and fertilization on number of grains per spike*

Effect	df	Mean sqr effect	Mean sqr error	F	p-level
Year (A)	2, 123	328.032	77.310	4.243*	0.016
Cultivar (B)	2, 124	595.841	77.172	7.721**	0.006
Fertilization (C)	6, 119	846.590	42.737	19.809***	0.000
Year × Cultivar (AB)	2, 120	51.460	73.420	0.701ns	0.498
Year × Fertilization (AC)	12, 105	49.356	36.546	1.351ns	0.202
Cultivar × Fertilization (BC)	6, 112	95.267	34.984	2.723*	0.017
Year × Cultivar × Fertilization (ABC)	12, 84	31.025	26.127	1.187ns	0.305

The individual effect of fertilization on number of grains per spike in the examined winter wheat cultivars was statistically very highly significant. The individual effect of cultivar as well as the effect of interaction between cultivar × fertilization on number of grains per spike in the studied winter wheat cultivars was statistically highly significant. The effects of interactions between year × cultivar, year × fertilization, and year × cultivar × fertilization on number of grains per spike was statistically nonsignificant.

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Variance analysis of individual effects of year, cultivar, and fertilization on grain weight in the studied winter wheat cultivars grown in five replications over the three growing periods (2010/2011, 2011/2012, 2012/2013) are given in *Table 10*.

Variance analysis indicated very highly significant individual effects of year and fertilization on grain weight in the examined winter wheat cultivars, whereas the effects of interactions between year × fertilization, and year × cultivar × fertilization on grain weight was statistically highly significant in the studied winter wheat cultivars. The individual effect of cultivar specificity as well as the effects of interactions between year × cultivar and cultivar × fertilization on grain weight in the studied winter wheat cultivars was statistically nonsignificant.

Table 10. *Effects of year, cultivar, and fertilization on grain weight (g)*

Effect	df	Mean sqr effect	Mean sqr error	F	p-level
Year (A)	2, 123	5.122	0.137	37.424^{***}	0.000
Cultivar (B)	2, 124	0.517	0.214	2.413^{ns}	0.123
Fertilization (C)	6, 119	1.504	0.151	9.914^{***}	0.000
Year × Cultivar (AB)	2, 120	0.184	0.132	1.387^{ns}	0.254
Year × Fertilization (AC)	12, 105	0.155	0.057	2.728^{**}	0.003
Cultivar × Fertilization (BC)	6, 112	0.125	0.150	0.834^{ns}	0.546
Year × Cultivar × Fertilization (ABC)	12, 84	0.094	0.038	2.474^{**}	0.008

Variance analysis of individual effects of year, cultivar specificity, and fertilization on 1000-grain weight in the examined winter wheat cultivars grown in five replications over the three growing periods (2010/2011, 2011/2012 and 2012/2013) is shown in *Table 11*.

Table 11. *Effects of year, cultivar specificity, and fertilization on 1000-grain weight (g)*

Effect	df	Mean sqr effect	Mean sqr error	F	p-level
Year (A)	2, 123	192.809	12.404	15.544^{***}	0.000
Cultivar (B)	2, 124	21.833	15.238	1.433^{ns}	0.234
Fertilization (C)	6, 119	136.668	9.171	14.903^{***}	0.000
Year × Cultivar (AB)	2, 120	9.419	12.375	0.761^{ns}	0.469
Year × Fertilization (AC)	12, 105	15.056	5.000	3.011^{***}	0.001
Cultivar × Fertilization (BC)	6, 112	12.408	8.884	1.397^{ns}	0.222
Year × Cultivar × Fertilization (ABC)	12, 84	7.610	3.793	2.006^{*}	0.033

The individual effects of year and fertilization, as well as the effect of interaction between year × fertilization on thousand-grain weight in the examined winter wheat cultivars was very highly statistically significant. The effect of the interaction between cultivar × fertilization on thousand-grain weight in the examined winter wheat cultivars was statistically significant. Variance analysis indicated that the individual effect of cultivar specificity as well as the effects of interactions between year × cultivar and cultivar × fertilization on 1000-grain weight in the examined winter wheat cultivars was nonsignificant.

Variance analysis of individual effects of year, cultivar specificity, and fertilization on hectoliter weight in the studied winter wheat cultivars grown in five replications over the three growing periods (2010/2011, 2011/2012 and 2012/2013) are given in *Table 12*.

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Table 12. *Effects of year, cultivar specificity, and fertilization on hectoliter weight (kg hl $^{-1}$)*

Effect	df	Mean sqr effect	Mean sqr error	F	p-level
Year (A)	2, 123	401.788	6.135	65.489***	0.000
Cultivar (B)	2, 124	114.095	11.646	9.797**	0.002
Fertilization (C)	6, 119	3.013	12.942	0.233ns	0.965
Year × Cultivar (AB)	2, 120	46.306	4.566	10.141***	0.000
Year × Fertilization (AC)	12, 105	3.283	6.640	0.494ns	0.914
Cultivar × Fertilization (BC)	6, 112	4.296	12.502	0.344ns	0.912
Year × Cultivar × Fertilization (ABC)	12, 84	3.886	4.977	0.780ns	0.668

Variance analysis inferred very highly significant individual effect of the year as well as the effect of interaction between year × cultivar on hectoliter weight in the studied winter wheat cultivars. The individual effect of cultivar specificity on hectoliter weight in the examined winter wheat cultivars was statistically highly significant. The individual effect of fertilization and the effects of interactions between year × fertilization, cultivar × fertilization, and year × cultivar × fertilization on hectoliter weight in the studied winter wheat cultivars was statistically nonsignificant.

Conclusion

Productivity and grain quality of winter wheat depend on genotype, agro-environmental conditions and applied cultural practices. Acidic soils, such as vertisol, on which the trial was conducted, substantially reduce the productivity of winter wheat.

The results obtained in our study suggest that grain yield of winter wheat grown on a vertisol varied across fertilization treatments and cultivars. Given that the trial was set up on an unfavorable vertisol, grain yield of winter wheat was significantly higher in fertilization treatments involving NPK, both at low and high rates of phosphorus included.

The highest grain yield of winter wheat over the trial period was obtained in ‘Ana Morava’ (6,276 kg ha^{-1}) in $N_{80}P_{60}K_{60}$ fertilization treatment. Number of grains per spike and grain weight per spike produced by ‘Ana Morava’ correlated with the yield of ‘Ana Morava’ in our three-year trial, which is in agreement with the data of similar trials performed by other authors.

As regards quality of winter wheat, the highest thousand-grain weight in the first, second and third years of testing was recorded in ‘Ana Morava’, which also produced the highest hectoliter grain weight in all the three years of study.

Over the entire trial period, weather conditions influenced significantly all the parameters of winter wheat grown on a vertisol. Given that weather conditions were more favorable in the second and particularly the third year of study, the performance of both winter wheat cultivars (‘Ana Morava’ and ‘KG 100’) was higher in these years than in the first study year.

Based on the results obtained in our three-year examination, given all the parameters studied, ‘Ana Morava’ is highly recommended for cultivation both in our country and abroad.

Variance analysis indicated the existence of very highly significant individual effects of year and fertilization, as well as the effect of the interaction between year ×

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fertilization on grain weight and 1000-grain weight parameters in the studied winter wheat cultivars. The individual effect of year and the effect of interaction between year × cultivar on hectoliter weight in the examined winter wheat cultivars was also statistically very highly significant. The effect of cultivar specificity on hectoliter weight in the examined winter wheat cultivars was highly significant statistically.

Variance analysis suggested very highly significant individual effect of fertilization on both number of grains per spike and grain weight in the studied winter wheat cultivar. The analysis also points to a statistically highly significant individual effect of cultivar specificity and the effect of interaction between cultivar × fertilization in the investigated winter wheat cultivars. The effects of interactions between year × fertilization, and year × cultivar × fertilization on grain weight in the studied winter wheat cultivars was highly significant statistically.

Future studies will be focused on cultivars newly developed in Kragujevac as well as the application of different fertilization treatments involving higher nitrogen rates (N 120 kg ha^{-1}). The studies will be performed under identical environmental conditions (in the same region), and will include monitoring identical parameters. The above aims at yield increase of newly developed winter wheat cultivars and the selection based on significance of fertilization for growing this culture.

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