UDC 633.11:631.84
Acta AgriculturaeSerbica, 30 (59), 33–42, 2025
doi: 10.5937/AASer2559033T
Publisher: Faculty of Agronomy Čačak
www.afc.kg.ac.rs

Evaluation of grain yield properties of wheat depending on long-term fertilization on vertisol soil

Dragan Terzić[1], Vera Rajičić[1], Violeta Babić[1], Kristina Luković[2], Ivan Tupajić[2], Biljana Šević[2], Jelena Stojiljković[2]*

[1] *University of Niš, Faculty of Agriculture, Kosančićeva 4, 37000 Kruševac, Serbia*
[2] *Institute for Vegetable Crops Smederevska Palanka, Karađorđeva 71, 11420 Smederevska Palanka, Serbia*

**Corresponding author: jstojiljkovic@institut-palanka.rs*

Received 11 March 2025; Accepted 19 March 2025

A B S T R A C T

To determine the effect of vegetation season and fertilization on the yield and yield components of winter wheat, a field experiment was conducted at the Small Grains Research Center in Kragujevac (Serbia) to examine eight fertilization treatments during three growing seasons. The experimental study was performed on a degraded acidic vertisol. Annually, nitrogen fertilization rate was 80 kg ha^{-1} N, which was applied in combination with phosphorus (60 kg ha^{-1} and 100 kg ha^{-1}) and potassium (60 kg ha^{-1}). Grain yield, 1000 grain weight, and hectoliter weight were analyzed. Grain yield in all treatments in the 2014/15 growing season was significantly higher than in the other years of the study. The yield, thousand grain weight, and test weight of winter wheat significantly varied across years and treatments. The highest yield was achieved in the treatment NPK, with phosphorous applied at 100 kg ha^{-1} (4.024 t ha^{-1}). Thousand grain weight was the highest in $N_{80}P_{60}K_{60}$ (39.06 g). During the test, significantly higher values of test weight were found in P_{60} (76.36 kg hL^{-1}). The statistical analysis showed a highly significant effect of year on grain yield, thousand grain weight, and test weight. Fertilization had the most significant impact on grain yield. Positive and highly significant correlations between yield and thousand grain weight were found in all investigated treatments, except for the control and the variant fertilized with 60 kg ha^{-1} of phosphorus, where significant correlations were found.

Keywords: fertilization, nitrogen, yield, wheat

И З В О Д

Да би се утврдио утицај вегетационе сезоне и ђубрења на принос и компоненте приноса озиме пшенице, постављен је експеримент у Центру за стрна жита у Крагујевцу (Србија), где је испитано осам третмана ђубрења током три вегетационе сезоне. Студија је изведена као експеримент заснован на деградираном киселом вертисолном земљишту. Годишња стопа ђубрења азотом износила је 80 кг ха$^{-1}$, која је примењивана у комбинацији са фосфором (60 kg ha^{-1} и 100 kg ha^{-1}) и калијумом (60 kg ha^{-1}). Анализиран је принос зрна, маса 1000 зрна и хектолитарска маса. Принос зрна код свих третмана у вегетационој 2014/15. био је значајно већи у односу на остале испитиване године. Принос, маса хиљаду зрна и хектолитарска маса озиме пшенице значајно су варирали током испитиваних година и третмана. Највећи принос је остварен код третмана NPK, где је фосфор примењен у максималној количини од 100 кг ха$^{-1}$ (4,024 t ha^{-1}). Маса хиљаду зрна била је највећа код третмана $N_{80}P_{60}K_{60}$ (39,06 g). Током испитивања утврђене су највеће вредности хектолитарске масе код третмана P_{60} (76,36 kg hL^{-1}). Статистичка анализа је показала веома значајан утицај године на принос зрна, масу хиљаду зрна и хектолитарску масу. Ђубрење је имало најзначајнији утицај на принос. Позитивне и високо значајне корелације између приноса и масе хиљаду зрна утврђене су код свих испитиваних третмана, осим код контроле и варијанте ђубрене са 60 kg ha^{-1} фосфора, где су утврђене значајне корелације.

Кључне речи: ђубрење, азот, принос, пшеница

1. Introduction

Effective nitrogen (N) fertilization is of crucial importance for the economical production of winter wheat and the protection of underground and surface waters from nitrate leaching occurring due to excessive and inadequate nitrogen use (Đekić et al., 2014; Jelić et al., 2015; Khan and Mohammad, 2016; Jamil et al., 2017; Rajičić et al., 2019; Lalević et al., 2019). Nitrogen shows the greatest effect through its joint use with phosphorus and potassium, while applying these two elements without nitrogen not only hampers significant yield increases, but also often reduces grain yields (Jelić et al., 2015; Khan et al., 2017).

A degraded Vertisol is characterized by very unfavorable physical, agrochemical, and microbiological properties. The greatest problems of this soil type are a low pH value and a further increase in its acidity, mostly because of irregular fertilizer application during the years. The low production ability of a pseudogley is the result of poor physico-mechanical, thermal, and moisture-aeration properties. Of all macro-elements, nitrogen, phosphorus, and potassium affect the normal growth and development of wheat the most. However, the influence of nitrogen on grain yield significantly decreases in the absence of other nutrients, especially phosphorus (Jelić et al., 2014).

Nutrient amounts absorbed by wheat during vegetation depend on yield level and underground mass. The most commonly applied quantities of nitrogen in Serbia range from 80 to 120 kg ha^{-1}, depending on the agrochemical properties of the soil (Jelić et al., 2015; Đekić et al., 2017; Rajičić et al., 2020; Terzić et al., 2022). Furthermore, Đekić et al. (2014) and Terzic et al. (2018) drew attention to the point that determining the dose of nitrogen administered in combination with phosphorous and potassium fertilizer could increase the reliability of fertilizing programs. Of all nutrients, nitrogen has the most important role in increasing yield. Nitrogen use efficiency decreases with an increase in nitrogen fertilization level (Terzic et al., 2018; Tmušić et al., 2021). However, the effect of nitrogen on grain yield significantly decreases without other nutrients, especially phosphorus. Hence, there is a growing emphasis on applying larger amounts of phosphorus fertilizers, i.e., NPK fertilizers with a higher proportion of phosphorus, because the influence of phosphorus nutrition is particularly pronounced on acidic, as well as on most other degraded soils (Đekić et al., 2014; Jelić et al., 2015; Terzić et al., 2018; Rajičić et al., 2019). Decreases in wheat yield can also result from the use of large quantities of fertilizers, harmful both economically and ecologically, which is a common cause of pollution of the agroecosystem. Nutrient use efficiency and yield formation are largely affected by weather conditions and the specific characteristics of the location (Biberdžić et al., 2019; Lalević et al., 2022; Zang et al., 2022).

The primary aim of the research was to determine the influence of the long-term use of the same amounts and rates of nitrogen, phosphorus and potassium on the yield and grain quality of the winter wheat variety 'Kruna', during three growing seasons (2012/13, 2013/14 and 2014/15) at a location in Kragujevac in the Republic of Serbia.

2. Materials and methods

2.1. Experimental design and soil analysis

This study, located near Kragujevac in Serbia, was conducted in a stationary experiment established in 1970 on a Vertisol. An experimental field trial was carried out at the Small Grains Research Center in Kragujevac from 2012 to 2015. The winter wheat cultivar used in the experiment was 'Kruna'. The trial was set up in a randomized block design with five replications. Plot size was 50 m^2. Fertilization was regular and followed a long-term scheme. The rate of nitrogen application was 80 kg ha^{-1} N, which was applied either individually or in combination with two P_2O_5 rates and one rate of K_2O fertilizer. Eight treatments of mineral fertilization were applied: N_{80} (80 kg ha^{-1} N), P_{60} (60 kg ha^{-1} P_2O_5), P_{100} (100 kg ha^{-1} P_2O_5), $N_{80}P_{60}K_{60}$ (80 kg ha^{-1} N, 60 kg ha^{-1} P_2O_5, and 60 kg ha^{-1} K_2O), $N_{80}P_{100}K_{60}$ (80 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5, and 60 kg ha^{-1} K_2O), $N_{80}P_{60}$ (80 kg ha^{-1} N and 60 kg ha^{-1} P_2O_5), $N_{80}P_{100}$ (80 kg ha^{-1} N and 100 kg ha^{-1} P_2O_5), and untreated control. Total amounts of phosphorus and potassium fertilizers and half of the nitrogen rate were regularly applied during seedbed preparation. Planting in all years of the study was performed in the second half of October, with a sowing density of 500 germinating grains per m^2. The crops were harvested at full maturity (dates of harvesting: July 10, 2013; July 23, 2014; and July 6, 2015). The study analyzed grain yield (t ha^{-1}), 1000 grain weight (g) and test weight (kg hl^{-1}).

The trial was set up on a degraded Vertisol with a heavy texture and very coarse and unstable structure (humus 2.2%, nitrogen 0.13%, phosphorus 2.0 mg 100 g^{-1} soil, potassium 20.0 mg K_2O 100 g^{-1} soil, and pH in H_2O 5.19).

2.2. Climatic characteristics

This study was conducted at the Kragujevac location in the Šumadija region, Serbia, on a Vertisol. Kragujevac has a temperate continental climate, with an average annual temperature of 11.76°C, and an annual sum of precipitation of about 550 mm. The meteorological station in Kragujevac is located at 44º 02' latitude, 20º 56' longitude, and 185 m altitude.

In the vegetation period 2012/13, the sum of precipitation in Kragujevac was higher than the long-term data (1961–2011). The weather data for January to March 2013 were characterized by above-average rainfall. Such climatic parameters indicated that the conditions for germination, shooting/emergence, and tillering were extreme. During tillering and stem elongation in March 2013, the weather was characterized by low temperatures and high rainfall compared to the long-term average. In April 2013, the precipitation was below the long-term average. In May, June, and July 2013, the values were above the long-term average. Despite the slightly higher precipitation, this period marked by the stages of fertilization and grain filling can be characterized as favorable. During the ripening phase in June, the average temperatures were at the long-term average level. The average air temperature was lower by 0.03°C, and the sum of rainfall precipitation was higher by 86.8 mm in 2013 than the long-term average (Table 1).

The amount of precipitation in the vegetation season 2013/14 was significantly higher than the values in the first and third year of the study, and the long-term average (Table 1). The period of germination, shooting, and tillering (from November 2013 to February 2014) was characterized by mean temperatures above the long-term average. The amount of rainfall was significantly below the average, which provided poor conditions for the growth and development of plants in these phenophases. The period of intensive growth of the vegetative mass (April) was characterized by poor weather conditions with temperatures above the long-term period. This caused lodging on individual plots as well as the sporadic occurrence of diseases. Precipitation in July exceeded long-term values, which to some extent caused slight lodging. The main problem was the enormous amount of precipitation that caused additional lodging and the incidence of rot. All this postponed the wheat harvest, and thus made it more difficult. During 2013/14 (October 2013 to July 2014), the recorded total of 747.0 mm of precipitation was higher by 232.4 mm than the long-term average, and very unevenly distributed across months. April to May 2014 received 129.0 mm and 227.0 mm of rainfall, respectively, which was 77.1 mm and 169.4 mm more than the long-term average. In other words, the total amount of precipitation was reflected in the long-term average, but the distribution, especially at critical stages of development, was significantly disturbed in 2014.

Table 1.
Mean air temperature and amount of precipitation during the study and long-term periods (data from Kragujevac Experimental Station's meteorological site)

Months	X	XI	XII	I	II	III	IV	V	VI	VII	Aver.
Mean monthly air temperature (°C)											
2012/13	13.5	9.5	1.7	2.9	4.0	6.5	13.4	18.2	19.9	21.9	11.15
2013/14	13.5	9.2	2.4	5.0	6.9	9.0	12.2	15.3	19.7	21.8	11.50
2014/15	12.6	9.1	3.5	3.0	3.2	6.7	19.8	17.4	19.9	24.4	11.96
Average	12.5	6.9	1.9	0.5	2.4	7.1	11.6	16.9	20.0	22.0	10.18
The amount of precipitation (mm)											
2012/13	56.2	17.7	16.4	65.8	84.4	102.9	41.2	70.8	85.4	60.6	601.4
2013/14	41.7	61.2	6.4	21.2	9.0	67.1	129	227	45.8	138.6	747.0
2014/15	50.4	18.9	98.7	44.9	46.2	98.8	35.8	93.6	113	25.4	625.7
Average	45.4	48.9	56.6	58.2	46.6	32.4	51.9	57.6	70.4	46.6	514.6

In the vegetation period 2014/15, the sum of precipitation in Kragujevac was higher than the long-term data. The mean temperatures were higher than the long-term data (Table 1). The period of germination, shooting and tillering (from November 2014 to February 2015) was characterized by mean temperatures above the long-term period. The amount of precipitation was significantly above the long-term average (December 2014), and the average level (January to February 2015), which provided good conditions for the growth and development of plants in these phenophases. In March 2015, the temperatures were comparable to the long-term average, while precipitation was significantly above it. The period of intensive vegetative growth (April) was characterized by favorable weather conditions with above-average temperatures. Precipitation was significantly lower. In May and June 2015, the precipitation was above the long-term average value. During the ripening phase in June 2015, the mean temperatures were at the long-term average level. The average air temperature was higher by 0.78°C, and the sum of rainfall was higher by 111.1 mm in 2014/15 than the long-term average, and with a very even distribution across months.

With respect to total precipitation and its distribution during vegetation, and temperature conditions, the 2014/15 vegetative period was the most suitable for the wheat. Temperature, precipitation, and the amount of water in the soil are the three most important factors that affect yield stability in Serbia. In the ecological conditions of Serbia, high temperatures and water deficit in June lead to reduced yields and deterioration of quality properties of grains, which is why the extension of the total vegetation period cannot result in the prolongation of the grain filling period to increase the yield (Đekić et al., 2017; Kandić et al., 2018; Biberdžić et al., 2019; Grčak et al., 2020; Rajičić et al., 2021; Matković Stojšin et al., 2022).

2.3. Statistical analysis

Experimental data were analyzed by descriptive and analytical statistics using the GenStat (GenStat, 2013) for PC/Windows 7. To evaluate significant differences between environments and treatments (year-fertilization combination), a two-way analysis of variance (ANOVA) was performed. When ANOVA revealed significant differences, t-test was used to estimate the significant differences between the means of the environments and treatments. The differences between the genotype means for grain filling parameters were tested by Tuckey's test. Letter groupings were generated by using a 5% level of significance. Pearson's correlation coefficient was tested at the 5% and 1% levels of significance.

3. Results and discussion

3.1. Grain yield, 1000 grain weight and test weight

In our research, the highest values of grain yield were obtained in 2015. The highest average grain yield of 3.597 t ha^{-1} was recorded in 2015, and it was significantly higher than the yield in 2013 (2.962 t ha^{-1}) and the yield in 2014 (1.500 t ha^{-1}). Across treatments, grain yield significantly varied, and it was highest in $N_{80}P_{100}K_{60}$ (4.024 t ha^{-1}) (Table 2).

The thousand grain weight of winter wheat significantly varied across years, from 30.31 g in 2014 to 41.95 g in 2013. The thousand grain weight varied across treatments, from 36.18 g in N_{80} to 39.06 g in $N_{80}P_{60}K_{60}$.

The test weight significantly varied across years (from 69.03 kg hl^{-1} in 2014 to 83.81 kg hl^{-1} in 2015), and across treatments (from 72.69 kg hl^{-1} in $N_{80}P_{60}$ to 76.36 kg hl^{-1} in P_{60}) (Table 2).

The results clearly indicated that year had a highly significant effect on grain yield ($F=30.501^{**}$), thousand grain weight ($F=457.198^{**}$), and test weight ($F=416.131^{**}$). Furthermore, grain yield ($F=12.302^{**}$) was significant among the fertilization treatments (Table 2).

Table 2.
Mean values for grain yield, 1000 grain weight and test weight

Years	Grain yield (t ha^{-1})		1000 grain weight (g)		Test weight (kg hl^{-1})	
	$\bar{X}$	S	$\bar{X}$	S	$\bar{X}$	S
2013	2.962^{B*}	1.176	41.95^{A}	1.907	70.29^{B}	2.132
2014	1.500^{C}	0.486	30.31^{B}	0.716	69.03^{C}	3.798
2015	3.597^{A}	1.712	41.55^{A}	2.703	83.81^{A}	0.626
F	30.501**		457.198**		416.131**	
P - value	< 0.001		< 0.001		< 0.001	
Treatments						
C	1.150^{C}	0.373	38.25^{A}	6.951	76.16^{A}	6.233
N_{80}	2.286^{B}	0.615	36.18^{A}	5.128	73.86^{A}	7.929
P_{60}	1.722^{BC}	0.488	38.58^{A}	6.074	76.36^{A}	5.821
P_{100}	1.937^{BC}	0.464	37.80^{A}	5.821	75.95^{A}	6.008
$N_{80}P_{60}K_{60}$	3.851^{A}	1.806	39.06^{A}	6.554	74.11^{A}	7.341
$N_{80}P_{100}K_{60}$	4.024^{A}	1.730	37.96^{A}	5.390	72.88^{A}	7.445
$N_{80}P_{60}$	3.193^{A}	1.322	37.28^{A}	5.305	72.69^{A}	8.261
$N_{80}P_{100}$	3.329^{A}	1.390	38.39^{A}	5.461	73.00^{A}	8.385
F	12.302**		0.344^{ns}		0.690^{ns}	
P - value	< 0.001		0.932		0.680	

*Means within columns followed by different lowercase letters are significantly different. P<0.01 very significant (**); P<0.05 significant (*); P>0.05 non-significant (^{ns})

Climate change on the global level creates hotter summers and mild winters, which will lead to alterations in sowing and heading dates in the future, in the production regions of wheat. In Serbia, drought occurs almost every year. In years with normal spring precipitations, winter wheat finishes vegetation mostly before the first severe moisture deficiency; otherwise, it uses moisture accumulated during the winter (Jelic et al., 2015; Đekić et al., 2017; Kandić et al., 2018; Rajičić et al., 2019; Sekulić et al., 2022; Terzić et al., 2022). The highest average grain yield of 3.597 t ha^{-1} of the studied wheat was recorded in 2015, and it was significantly higher than the yield in 2014 (1.500 t ha^{-1}), which can mostly be associated with higher precipitation during the second vegetation period. Variations in temperature, the amount of precipitation during vegetation, and soil moisture content are the most important factors causing grain yield instability in wheat. In the ecological conditions of Serbia, high temperatures and water deficiency during June decrease both grain yield and grain quality properties; therefore, prolonged vegetation and grain filling periods do not improve crop yield (Đekić et al., 2017; Kandić et al., 2018; Grčak et al., 2020; Rajičić et al., 2021; Matković Stojšin et al., 2022). In addition to being the necessary reserve for the spring part of the growing season, winter precipitation greatly influences the distribution of readily available nitrogen in the soil (Jelic et al., 2015; Rajičić et al., 2020). Grain yield is strongly modified by an environment with different temperatures and weather conditions (Zafaranaderi et al. 2013; Al-Ashkar et al., 2020). It is rarely an acting of a single stress factor; often, plant development is affected by a combination of a few different stresses, which makes an evaluation of plant adaptability more complex (Zeeshan et al., 2020; El Sabagh et al., 2021). Drought has become a main limiting factor for the world plant production, and it decreases yields in countries with developed agriculture, too. Commonly, drought induced stress is followed by high temperatures, which increase its impact additionally (Wahid et al., 2017).

During the first year (2013), grain yield significantly varied across treatments, from 1.284 t ha^{-1} in control to 4.358 t ha^{-1} in $N_{80}P_{100}K_{60}$. In the second year (2014), grain yield varied across treatments, from 0.863 t ha^{-1} in the control to 1.955 t ha^{-1} in $N_{80}P_{100}K_{60}$. In 2015, significant variations across treatments ranged from 1.303 t ha^{-1} in control to 5.758 t ha^{-1} in $N_{80}P_{100}K_{60}$ (Table 3).

To achieve high and stable grain yields, new cultivars demand more precise and more complex NPK nutrition. Furthermore, a good soil supply with P_2O_5 and K_2O is very important (Jelić et al., 2014). Nitrogen application has a crucial role. Precision in N application (timing, amount, and quality) is a specific problem in stress years. Possible losses under excessive soil moisture conditions as well as insufficient efficiency under drought conditions necessitate improvement of N application methods, especially in-season application. Furthermore, the application of NPK fertilizers requires greater precision. A more careful choice of cultivars and respect for their specificities could contribute to a higher and stable wheat yield in Serbia (Đekić et al., 2017; Terzić et al., 2018; Đurić et al., 2020).

The thousand grain weight of winter wheat significantly varied across years and treatments – in 2013, from 39.90 g in P_{100} to 44.86 g in $N_{80}P_{60}K_{60}$; in 2014, from 29.14 g in control to 31.08 g in $N_{80}P_{100}K_{60}$; and in 2015, from 36.76 g in N_{80} to 44.68 g in the control (Table 3).

Mineral fertilization had a significant impact on 1000 grain weight, i.e., grain weight was significantly higher in more intensively fertilized variants, especially those treated with nitrogen (Terzić et al., 2018). The contribution of fertilization to thousand grain weight was 15% higher in the treatment without fertilizer compared to nitrogen treatment in grain yield variation (Khalilzadeh et al., 2013).

The test weight of winter wheat significantly varied across years and treatments - in 2013, from 68.03 kg hl⁻¹ in $N_{80}P_{100}K_{60}$ to 71.89 kg hl^{-1} and 71.97 kg hl^{-1} in $N_{80}P_{60}K_{60}$ and P_{60}, respectively; in 2014, from 65.57 kg hl^{-1} in $N_{80}P_{100}$ to 73.25 kg hl^{-1} in control; and in 2015, from 82.78 kg hl^{-1} in the triple treatment NPK where phosphorous was applied in the maximum amount of 80 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O to 84.46 kg hl^{-1} in control (Table 3).

Table 3.
Mean values of yield and quality across fertilization treatments and vegetation seasons

	Grain yield (t ha^{-1})		1000 grain weight (g)		Test weight (kg hl^{-1})	
2013	$\overline{X}$	S	$\overline{X}$	S	$\overline{X}$	S
C	1.284^{E}	0.328	40.92^{CD}	1.665	70.77^{AB}	1.480
N_{80}	2.593^{C}	0.293	41.86^{BC}	1.320	69.33^{BC}	1.842
P_{60}	1.874^{DE}	0.408	40.88^{CD}	1.927	71.97^{A}	0.867
P_{100}	2.116^{CD}	0.195	39.90^{D}	0.689	71.45^{A}	1.918
$N_{80}P_{60}K_{60}$	4.233^{AB}	0.802	44.86^{A}	0.737	71.89^{A}	1.345
$N_{80}P_{100}K_{60}$	4.358^{A}	0.836	43.58^{AB}	0.864	68.03^{C}	0.524
$N_{80}P_{60}$	3.585^{B}	0.308	41.60^{CD}	1.518	68.43^{C}	1.806
$N_{80}P_{100}$	3.656^{B}	0.228	42.02^{BC}	1.033	69.41^{BC}	1.889
F	28.122^{**}		7.555^{**}		6.134^{**}	
P - value	< 0.001		< 0.001		< 0.001	
2014						
C	0.863^{B}	0.175	29.14^{D}	0.336	73.25^{A}	0.848
N_{80}	1.554^{A}	0.328	29.92^{C}	0.492	67.94^{B}	3.269
P_{60}	1.376^{AB}	0.548	30.66^{AB}	0.646	72.93^{A}	1.480
P_{100}	1.452^{A}	0.498	30.18^{BC}	0.295	71.73^{A}	3.254
$N_{80}P_{60}K_{60}$	1.688^{A}	0.211	30.30^{BC}	0.255	66.98^{B}	2.789
$N_{80}P_{100}K_{60}$	1.955^{A}	0.526	31.08^{A}	0.327	67.79^{B}	3.146
$N_{80}P_{60}$	1.518^{A}	0.370	30.18^{BC}	0.228	66.02^{B}	2.809
$N_{80}P_{100}$	1.595^{A}	0.554	31.04^{A}	0.643	65.57^{B}	2.360
F	2.669^{*}		10.700^{**}		7.051^{**}	
P - value	0.027		< 0.001		< 0.001	
2015						
C	1.303^{E}	0.440	44.68^{A}	1.359	84.46^{A}	0.261
N_{80}	2.713^{C}	0.337	36.76^{E}	0.568	84.30^{A}	0.510
P_{60}	1.918^{D}	0.373	44.20^{AB}	0.693	84.18^{AB}	0.642
P_{100}	2.243^{CD}	0.133	43.34^{B}	1.280	83.66^{BCD}	0.456
$N_{80}P_{60}K_{60}$	5.633^{A}	0.852	42.03^{C}	0.851	83.46^{D}	0.167
$N_{80}P_{100}K_{60}$	5.758^{A}	0.506	39.21^{D}	0.461	82.78^{E}	0.363
$N_{80}P_{60}$	4.476^{B}	0.353	40.05^{D}	0.472	83.62^{CD}	0.228
$N_{80}P_{100}$	4.736^{B}	0.191	42.10^{C}	1.300	84.02^{ABC}	0.228
F	76.761^{**}		41.053^{**}		9.833^{**}	
P - value	< 0.001		< 0.001		< 0.001	

*Means within columns followed by different lowercase letters are significantly different. P<0.01 very significant (**); P<0.05 significant (*); P>0.05 non-significant (^{ns})

The average value of the productive grain yield of the investigated winter wheat grown at the Center for Small Grains, in Kragujevac (Serbia) in the experiment was 5.758 t ha^{-1} in $N_{80}P_{100}K_{60}$ treatment, with a range of 1.955 t ha^{-1} in the second year to 4.358 t ha^{-1} in the first year of the study. The results of the present study clearly suggest that maximum grain yield on Vertisol can be obtained with the NPK fertilizer (80 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O). Đekić et al. (2014) also found that grain yield increased with NPK fertilizer application.

Achieving high wheat grain yields with desirable quality requires a proper cultivar choice and optimal growing conditions, i.e., production technology. New-generation cultivars exhibit a high degree of tolerance to temperature shocks during the grain forming and filling phase as well as to drought (Matković Stojšin et al., 2022). Early ripening cultivars finish the synthesis of most of the dry matter before the start of the drought period but they have lower yield potential because of the positive correlation between vegetation length and grain yield (Djuric et al., 2018). It is known that the effect of individual or combined abiotic stress factors (high and low temperatures, drought, acidic and saline soil) in different wheat growth stages limits the expression of maximum grain yield potential (Biberdžić et al., 2019; Grčak et al., 2020; Zeeshan et al., 2020; El Sabagh et al., 2021; Rajičić et al., 2021).

3.2. Analysis of variance of the analyzed traits

The two-way ANOVA (Table 4) showed that the effect of the year was highly significant (P<0.01) for all the traits. The highly significant influence of the year x fertilization interaction on grain yield, 1000 grain weight, and test weight indicated that there was a difference among the investigated treatments in their response to the vegetation period. Furthermore, the effect of fertilization was not significant (P>0.05) for all the traits except grain yield, which was very significant (P<0.01).

A considerable variation in yield depending on the study year was determined by Jelic et al. (2015) and Terzić et al. (2018). Similarly, in the study by Đekić et al. (2014), the highly significant effect of the year on grain yield (P<0.01) was associated with changes in vegetation seasons as a result of changing environmental conditions. The present results confirm the findings of many authors that grain yield, thousand grain weight, and test weight are genetically determined, but are strongly modified by nutrient status, weather conditions, and soil salinity (Khan and Mohammad 2016; Khan et al., 2017; Wahid et al. 2017). Đekić et al. (2014) and Terzić et al. (2018) found that the application of mineral fertilizers had a significant impact on grain yield, and that thousand grain weight was significantly higher in more intensively fertilized variants.

Table 4.
The analysis of variance for the tested parameters in Kragujevac, Serbia

Effect	df	Mean sqr Effect	Mean sqr Error	F	p-level
The analysis of variance for grain yield					
Year, (Y)	2, 117	46.275	1.517	30.500**	0.000
Fertilization, (F)	7, 112	16.770	1.363	12.302**	0.000
Year x Fertilization, (YxF)	14, 96	2.881	0.206	13.983**	0.000
The analysis of variance for 1000 grain weight					
Year, (Y)	2, 117	1745.57	3.818	457.198**	0.000
Fertilization, (F)	7, 112	11.845	34.419	0.344ns	0.932
Year x Fertilization, (YxF)	14, 96	19.700	0.917	21.493**	0.000
The analysis of variance for test weight					
Year, (Y)	2, 117	2686.11	6.455	416.131**	0.000
Fertilization, (F)	7, 112	36.194	52.447	0.690ns	0.680
Year x Fertilization, (YxF)	14, 96	14.286	3.144	4.543**	0.000

ns-non-significant, *-P<0.05, **-P<0.01, ***-P<0.001

3.3. Correlation between the analyzed traits

As shown in Table 5, grain yield in 2012/13 was positively and highly significantly correlated with thousand grain weight (0.648**), and negatively but significantly correlated with test weight (-0.389*). Thousand grain weight was negatively correlated with test weight (-0.186) (Table 5).

Wheat yield in 2013/14 was positively and highly significantly correlated with thousand grain weight (0.493**), and negatively correlated with test weight (−0.082). Thousand grain weight in 2014 was negatively correlated with test weight (−0.231) (Table 5).

The correlative dependence of grain yield in the 2014/15 vegetation season was negatively and significantly correlated with thousand grain weight (−0.392*), and negatively but highly significantly correlated with test weight (−0.641**). Thousand grain weight in 2015 was positively but non-significantly correlated with test weight (0.242) (Table 5).

Grain yield in all vegetation seasons (2012–2015) in Table 5, was positively and highly significantly correlated with thousand grain weight (0.514**) and test weight (0.375**). Thousand grain weight in all vegetation seasons was positively and highly significantly correlated with test weight (0.468).

The study results indicated that grain yield in all vegetation seasons was positively and highly significantly correlated with 1000 grain weight, except in the 2015 season. The positive and significant correlation with grain yield and thousand grain weight was established by Terzić et al. (2018). Đekić et al. (2014) determined a negative and significant correlation between thousand grain weight and test weight.

Table 5.
Correlations between the traits analyzed in three vegetation seasons

Traits	Grain yield	1000 grain weight	Test weight
Correlations between the traits analyzed in 2012/13			
Grain yield ($t\ ha^{-1}$)	1.00	0.648^{**}	-0.389^{*}
1000 grain weight (g)		1.00	-0.186^{ns}
Test weight ($kg\ hl^{-1}$)			1.00
Correlations between the traits analyzed in 2013/14			
Grain yield ($t\ ha^{-1}$)	1.00	0.493^{**}	-0.082^{ns}
1000 grain weight (g)		1.00	-0.231^{ns}
Test weight ($kg\ hl^{-1}$)			1.00
Correlations between the traits analyzed in 2014/15			
Grain yield ($t\ ha^{-1}$)	1.00	-0.392^{*}	-0.641^{**}
1000 grain weight (g)		1.00	0.242^{ns}
Test weight ($kg\ hl^{-1}$)			1.00
Correlations between the traits analyzed in 2012–2015			
Grain yield ($t\ ha^{-1}$)	1.00	0.514^{**}	0.375^{**}
1000 grain weight (g)		1.00	0.468^{**}
Test weight ($kg\ hl^{-1}$)			1.00

Grain yield in the control was positively and highly significantly correlated with thousand grain weight (0.586^{*}), and positively and significantly correlated with test weight (0.537^{*}). A positive and highly significant correlation with grain yield and thousand grain weight (0.729^{**}) and a significant correlation with yield and test weight (0.604^{*}) were determined in treatment N_{80}. The correlative dependence of grain yield in treatment P_{60} was positive, with a medium significant correlation also found with test weight (0.524^{*}), and positive and highly significant correlations with thousand grain weight and test weight (0.613^{**}). In treatment N_{100}, there was a positive and highly significant correlation with grain yield and thousand grain weight (0.764^{**}), and a significant correlation with test weight (0.592^{*}). Moreover, positive and highly significant correlations were found with thousand grain weight and test weight (0.699^{**}). Treatment $N_{80}P_{60}K_{60}$ led to positive and highly significant correlations with yield and thousand grain weight (0.801^{**}) and test weight (0.826^{**}). The correlative dependence of thousand grain weight had a positive and significant correlation with test weight (0.575^{*}). In treatment $N_{80}P_{100}K_{60}$, there were highly significant and positive correlations with yield and thousand grain weight (0.721^{**}) and test weight (0.748^{**}). The correlative dependence of yield in $N_{80}P_{60}$ and $N_{80}P_{100}$ was positive, and highly significant correlations were also found between thousand grain weight (0.879^{**} and 0.923^{**}) and test weight (0.765^{**} and 0.853^{**}) (Table 6).

The correlative dependence of yield in all treatments was positive, and significant correlations were also found for thousand grain weight. Many authors have reported positive correlations of grain yield and 1000 grain weight in treatments with nitrogen and phosphorus (Đekić et al., 2014; Terzić et al., 2018).

Table 6.
Correlation coefficients for the traits analyzed across treatments

	Grain yield	1000 grain weight	Test weight
Correlations between the traits analyzed in the unfertilized control			
Grain yield ($t\ ha^{-1}$)	1.00	0.586*	0.213ns
1000 grain weight (g)		1.00	0.537*
Test weight ($kg\ hl^{-1}$)			1.00
Correlations between the traits analyzed in treatment N_{80}			
Grain yield ($t\ ha^{-1}$)	1.00	0.729**	0.604*
1000 grain weight (g)		1.00	0.155ns
Test weight ($kg\ hl^{-1}$)			1.00
Correlations between the traits analyzed in treatment P_{60}			
Grain yield ($t\ ha^{-1}$)	1.00	0.524*	0.276ns
1000 grain weight (g)		1.00	0.613**
Test weight ($kg\ hl^{-1}$)			1.00
Correlations between the traits analyzed in treatment P_{100}			
Grain yield ($t\ ha^{-1}$)	1.00	0.764**	0.592*
1000 grain weight (g)		1.00	0.699**
Test weight ($kg\ hl^{-1}$)			1.00
Correlations between the traits analyzed in treatment $N_{80}P_{60}K_{60}$			
Grain yield ($t\ ha^{-1}$)	1.00	0.801**	0.826**
1000 grain weight (g)		1.00	0.575*
Test weight ($kg\ hl^{-1}$)			1.00
Correlations between the traits analyzed in treatment $N_{80}P_{100}K_{60}$			
Grain yield ($t\ ha^{-1}$)	1.00	0.721**	0.748**
1000 grain weight (g)		1.00	0.188ns
Test weight ($kg\ hl^{-1}$)			1.00
Correlations between the traits analyzed in treatment $N_{80}P_{60}$			
Grain yield ($t\ ha^{-1}$)	1.00	0.879**	0.765**
1000 grain weight (g)		1.00	0.475ns
Test weight ($kg\ hl^{-1}$)			1.00
Correlations between the traits analyzed in treatment $N_{80}P_{100}$			
Grain yield ($t\ ha^{-1}$)	1.00	0.923**	0.853**
1000 grain weight (g)		1.00	0.646**
Test weight ($kg\ hl^{-1}$)			1.00

4. Conclusion

The effects of the mineral nutrition efficiency of wheat have been studied in the stationary field trial of the Small Grains Research Center in Kragujevac (Serbia) for three vegetation seasons. Nitrogen had the most significant impact on the yield of wheat. The average grain yield of all treatments in the 2015 growing season was significantly greater than in the following years. The highest average yields were obtained by the treatments $N_{80}P_{100}K_{60}$ (4.024 $t\ ha^{-1}$) and $N_{80}P_{60}K_{60}$ (3.851 $t\ ha^{-1}$) in three years. The average grain yield, thousand grain weight, and test weight were significantly higher in 2015.

The analysis of variance indicated highly significant effects of year on grain yield, thousand grain weight, and test weight. Furthermore, the effects of fertilization on grain yield were significant. The positive and highly significant correlations between yield and thousand grain weight ranged from 0.493** in 2014 to 0.648** in 2013.

Acknowledgments

This study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 451-03-137/2025-03/200383 and 451-03-136/2025-03/200216) and Bilateral Project Serbia and Croatia (2025–2027): Alternative and fodder plants as a source of protein and functional food, and Project Bulgaria and Serbia (2024–2027): Intercropping in maize growing for sustainable agriculture.

Declaration of competing interests

The authors declare that they have no personal or financial relationships with other individuals or organizations that could inappropriately influence or bias their work, ensuring full compliance with the academic code of conduct.

References

Al-Ashkar, I., Alderfasi, A., Romdhane, W.B., Seleiman, M.F., El-Said, R.A., Al-Doss, A. (2020). Morphological and genetic diversity within salt tolerance detection in eighteen wheat genotypes. *Plants*, 9, 287. https://doi.org/10.3390/plants9030287

Biberdžić, M., Barać, S., Lalević, D., Đikić, A., Đekić, V., Stojković, J. (2019). Yields of some varieties of wheat, depending on soil type and compaction. Proceedings, 6th international scientific/professional conference "Agriculture in Nature and Environment Protection", Osijek, Croatia, 27-29 May 2019, pp. 54-59.

Đekić, V., Milovanović, M., Popović, V., Milivojević, J., Staletić, M., Jelić, M., Perišić, V. (2014). Effects of fertilization on yield and grain quality in winter triticale. *Romanian Agricultural Research*, 31, 175-183.

Đekić, V., Jelić, M., Milivojević, J., Popović, V., Branković, S., Staletić, M., Terzić, D. (2017). Winter wheat yield and yield components depending on the level of nitrogen, phosphorus and potassium fertilization. Proceedings, VIII International Scientific Agriculture Symposium "Agrosym 2017", 05-08 October, Jahorina, Bosnia and Herzegovina, p. 650-657.

Đurić, N., Cvijanović, G., Rajičić, V., Branković, G., Poštić, D., Cvijanović, V. (2020). Analysis of grain yield and flour quality of some winter wheat varieties in the 2020 production. *Agronomski Glasnik*, 82 (5-6), 253-262. https://doi.org/10.33128/ag.82.5-6.3

Djuric, N., Prodanovic, S., Brankovic, G., Djekic, V., Cvijanovic, G., Zilic, S., Dragicevic, V., Zecevic, V., Dozet, G. (2018). Correlation-Regression Analysis of Morphological-Production Traits of Wheat Varieties. *Romanian Biotechological Letters*, 23 (2), 13457-13465.

El Sabagh, A., Islam, M.S., Skalicky, M., Ali Raza, M., Singh, K., Anwar Hossain, M., Hossain, A., Mahboob, W., Iqbal, M.A., Ratnasekera, D., et al. (2021). Salinity stress in wheat (*Triticum aestivum* L.) in the changing climate: Adaptation and management strategies. *Frontiers in Agronomy*, 3, 661932. https://doi.org/10.3389/fagro.2021.661932

GenStat Release 16.2 (PC/Windows 7) 2013. GenStat Procedure Library. Release PL24.2. VSN International Ltd. Rothamsted, UK. 2013.

Grčak, M., Grčak, D., Penjišević, A., Simjanović, D., Orbović, B., Đukić, N., Rajičić, V. (2020). The trends in maize and wheat production in the Republic of Serbia. *Acta agriculturae Serbica*, 25 (50), 121-127. https://doi.org/10.5937/AASer2050121G

Iftikhar, R., Khaliq, I., Ijaz, M., Rahman, A.M. (2012). Association analysis of grain yield and its components in spring wheat (*Triticum aestivum* L.). *American-Eurasian Journal of Agricultural & Environmental Sciences*, 12(3): 289-392.

Jamil, M., Hussain, S.S., Amjad Qureshi, M., Mehdi, S.M., Nawaz, M.Q. (2017). Impact of sowing techniques and nitrogen fertilization on castor bean yield in salt affected soils. *Journal of Animal and Plant Sciences*, 27 (2), 451-456.

Jelić, M., Milivojević, J., Đekić, V., Paunović, A., Tmušić, N. (2014). Impact of liming and fertilization on grain yield and utilization of nitrogen and phosphorus in wheat plant grown on soil type pseudogley. Proceedings of research papers PKB Agroekonomik, 20 (1-4), 49-56.

Jelic, M., Milivojevic, J., Nikolic, O., Djekic, V., Stamenkovic, S. (2015). Effect of long-term fertilization and soil amendments on yield, grain quality and nutrition optimization in winter wheat on an acidic pseudogley. *Romanian Agricultural Research*, 32, 165-174.

Kandić, V., Dodig, D., Zorić, M., Nikolić, A., Šurlan Momirović, G., Kaitović, Ž., Aleksić, G., Đurić, N. (2018). Grain filling parameters of two- and six-rowed barley genotypes in terminal drought conditions. *Italian Journal of Agrometeorology*, 2, 5-14.

Khalilzadeh, G., Azizov, E., Eivazi, A. (2013). Genetic differences for nitrogen uptake and nitrogen use efficiency in some Azerbijani bread wheat landraces (*Triticum aestivum* L.). *Global Advanced Research Journal of Agricultural Science*, 1 (3), 48-55.

Khan, F.U., Mohammad, F. (2016). Application of stress selection indices for assessment of nitrogen tolerance in wheat (*Triticum aestivum* L.). *Journal of Animal and Plant Sciences*, 26 (1), 201-210.

Khan, F.U., Mohammad, F., Raziuddin, Z., Shah, M., Ahmad, M., Shah, Z. (2017). Genotypic differences and genotype × nitrogen interactions for yield traits in bread wheat. *Journal of Animal and Plant Sciences*, 27 (4), 1264-1268.

Lalević, D., Biberdžić, M., Ilić, Z., Milenković, L., Tmušić, N., Stojiljković, J. (2019). Effect of cultivar and increased nitrogen quantities on some productive traits of triticale. *Agriculture and Forestry*, 65 (4), 127-136.

Lalević, D., Miladinović, B., Biberdžić, M., Vuković, A., Milenković, L. (2022).Differences in grain yield and grain quality traits of winter triticale depending on the variety, fertilizer and weather conditions. *Applied Ecology & Environmental Research*, 20 (5), 3779-3792.

Matković Stojšin, M., Petrović, S., Banjac, B., Zečević, V., Roljević Nikolić, S., Majstorović, H., Đorđević, R. and Knežević, D. (2022). Assessment of genotype stress tolerance as an effective way to sustain wheat production under salinity stress conditions. *Sustainability*, 14 (12), 6973. https://doi.org/10.3390/su14126973

Rajičić, V., Milivojević, J., Popović, V., Branković, S., Đurić, N., Perišić, V., Terzić, D. (2019). Winter wheat yield and quality depending on the level of nitrogen, phosphorus and potassium fertilization. *Agriculture and Forestry*, 65 (2), 79-88. https://doi.org/10.17707/AgricultForest.65.2.06

Rajičić, V., Terzić, D., Perišić, V., Dugalić, M., Dugalic, G., Madić, M., Ljubičić, N. (2020). Impact of long-term fertilization on yield in wheat grown on soil type vertisol. Agriculture & Forestry, 66 (3), 127-138. https://doi.org/10.17707/AgricultForest.66.3.11

Rajičić, V., Terzić, D., Babić, V., Perišić, V., Dugalić, M., Đokić, D., Branković, S. (2021). Yield components and genetic potential of winter wheat on pseudogley soil of Western Serbia. *Biologica Nyssana*, 12 (2), 141-150. https://doi.org/10.5281/zenodo.5759859

Sekulić, J., Cvijanović, G., Cvijanović, V., Bajagić , M., Đurić, N., Rajičić, V. (2022). Possibility of wheat production in an integral system. *Journal of Agricultural, Food and Environmental Sciences*, 76 (5), 77-85.

Terzić, D., Đekić, V., Milivojević, J., Branković, S., Perišić, V., Đokić, D. (2018). Yield components and yield of winter wheat in different years of research. *Biologica Nyssana*, 9 (2), 119-131. https://doi.org/10.5281/zenodo.2538604

Terzić, D., Rajičić, V., Biberdžić, M., Perišić, V., Dugalić, M., Đokić, D., Branković, S. (2022). Genetic potential of Novi Sad winter wheat varieties on smonica-type soil. *Biologica Nyssana*, 13 (2), 129-139. https://doi.org/10.5281/zenodo.7437258

Tmušić, N., Ćirić, S., Nikolić, K., Knežević, J., Rajičić, V. (2021). Effects of different fertilization treatments on the yield performance, yield parameters and grain quality of winter wheat grown on vertisol soil type. *Applied Ecology and Environmental Research*, 19 (6), 4611-4627. https://doi.org/10.15666/aeer/1906_46114627

Wahid, F., Alam, M., Ahmad, I., Gurmani, A.R., Sajid, M., Noor Ul A., Ali A. (2017). Effect of pre-soaking agents on salinity stressed cucumber seedlings. *Pakistan Journal of Agricultural Sciences*, 54, 781-790.

Zafaranaderi, N., Aharizad, S., Moha-Mmadi, S.A. (2013). Relationship between grain yield and related agronomic traits in bread wheat recombinant inbred lines under water deficit condition. *Annals of Biological Research*, 4 (4), 7-11.

Zhang, R., Yang, Y., Dang, T., Zhu, Y., Huang., M. (2022). Responses of wheat yield under different fertilization treatments to climate change based on a 35-year in situ experiment. *Agriculture*, 12 (9), 1498. https://doi.org/10.3390/agriculture12091498

Zeeshan, M., Lu, M., Sehar, S., Holford, P., Wu, F. (2020). Comparison of biochemical, anatomical, morphological, and physiological responses to salinity stress in wheat and barley genotypes deferring in salinity tolerance. *Agronomy*, 10, 127. https://doi.org/10.3390/agronomy10010127