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Impact of Nitrogen and Phosphorus on Grain Yield in Winter Triticale Grown on Degraded Vertisol

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Abstract: The objectives of this study were to investigate: (1) the effects of fertilization, environment, and their interactions on the thousand grain weight (TGW), hectolitre weight (HW) and grain yield (GY) of winter triticale, and (2) the correlations between these traits in different environments. The invariable nitrogen (80 kg N ha^{-1}), potassium (60 kg K_2O ha^{-1}) and two phosphorus (60 and 100 kg P_2O_5 ha^{-1}) doses were used in Kragujevac location in central Serbia. Nitrogen was applied individually and in combination with two phosphorus rates and one rate of potassium fertilizer. Eight fertilization treatment controls and N_{80}, P_{60}, P_{100}, $N_{80}P_{60}K_{60}$, $N_{80}P_{100}K_{60}$, $N_{80}P_{60}$ and $N_{80}P_{100}$ were examined during three growing seasons. The yield and quality of triticale significantly varied across years and treatments. The average yield of all treatments in the 2015 growing season was significantly greater than in the previous years (3.597 t ha^{-1}). Combined usage of NPK fertilizer (80 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}) represented the excellent base for optimum supply of major nutrients, resulting in maximum GY (4.0 t ha^{-1}). Negative and significant correlation was found between grain GY and TGW (-0.392^{*}) in 2015, and positive highly significant correlation were in 2013 (0.648^{**}) and 2014 (0.493^{**}). The positive effect over complete application of fertilizer is the result of a lower pH value of the soil, as well as the low content of available phosphorus and potassium in Vertisol soil type. Optimizing fertilization for maximum profitability is of great importance in the future triticale production in Pannonian Environments.

Keywords: Vertisol soil; fertilization; grain yield; correlation; triticale

1. Introduction

The projections are that the human population will increase to 9.2 billion in 2050 [1], which will require an increase of food by 70% and, therefore, increase in yield, with the introduction of new high-yielding cultivars, fertilization, and other cultivation techniques [2–4].

Effective nitrogen fertilization has crucial importance for the economical production of winter cereals and in the protection of underground and surface waters from nitrate leaching as a consequence of excessive and inadequate nitrogen usage [5]. Nitrogen is showing the greatest effect through the combined usage with phosphorus and potassium, while the application of these two elements without nitrogen does not lead to significant yield increases, and often even reduces it [6–10].

Vertisol soil type is distinguished by very unfavourable physical, agrochemical, and microbiological properties. The greatest problem of this soil type is its low pH value and further increase of its acidity, mostly because of the irregular application of fertilizers during the years. The low production ability of Vertisol is the result of poor physical-mechanical, thermal and water-air properties. The application time of mineral fertilizers necessary for the formation of high-triticale grain yield of good quality as well as the amounts and types of mineral fertilizers differ depending on soil fertility [11–15]. Of all macro-elements, nitrogen, phosphorus, and potassium affect normal growth and the development of triticale at most. However, nitrogen influence on the grain yield significantly decreases in the absence of other nutritive elements, especially phosphorus [16]. Therefore, there is a present tendency of applying larger amounts of phosphorus fertilizers, i.e., NPK-fertilizers with a higher share of phosphorus, because the impact of nutrition with this element is especially pronounced on acidic and other devastated types of soils [5].

The amount of nutrition elements which triticale absorbs during vegetation depends on yield level and underground mass. The most frequently applied quantities of nitrogen in Serbia range from 80 to 120 kg ha^{-1} depending on the agrochemical properties of the soil [5,17,18]. Furthermore, Terzic et al. [9] and Rajičić et al. [19] drew attention the point that determining the dose of nitrogen which is administered in combination with phosphorous and potassium fertilizer treatments and years could increase the reliability of fertilizing programs. Nitrogen, of all the elements of mineral nutrition, has the most important role in increasing the yield. Effective fertilization with nitrogen is crucially important for economical production as well as protecting the surface and underground water from pollution caused by nitrate leaching as a consequence of excessive and inappropriate nitrogen application [17,20]. The efficacy of the nitrogen utilization from mineral fertilizers is decreasing with the increase of the nitrogen fertilizing level [9,11,13,21]. A decrease of triticale yield can also be caused by large quantities of fertilizers, harmful both economically and ecologically, which is a common cause of agro-ecosystem pollution. Nutrient utilization from fertilizers and yield forming are under the important influence of weather conditions and specific characteristics of the location [22].

In the Republic of Serbia, especially in its central part, the production of cereals is mainly carried out on soils with acidic and extremely acidic reactions, very low-quality structures that are poor in organic matter [6,9,16]. On acid reaction soils, a universal fertilization system does not exist due to the very uneven physical and chemical properties of these soils. Therefore, the application of fertilizers on acid soils must be approached in a much more rational and multi-faceted manner [5,19]. Mineral fertilizers play a vital role in the improvement of crop yields, but one of the main limitations in achieving proven crop potential is imbalanced use of nutrients, particularly low use of P compared to N. The optimum rate of P application is important for the improvement of the yield of most crops [5,9]. Farmers frequently use only nitrogen fertilizers for fodder crops in Serbia, while the use of P fertilizer is negligible. These crops are often grown on marginal lands. Hence, their production is low and quality is poor. Inadequate application of fertilizers, which is not adapted to plant requirements and soil fertility, leads to an accumulation of unused nutrients in the soil, with risks for the ecosystem overall and, consequently, for the production of healthy and safe food [5,17,19].

Bearing in mind the necessity of applying pedomeliorative measures and the use of larger quantities of fertilizers on acid soils, there is a need to review and modify the existing fertilization systems. For these reasons, the hypothesis of the present study was that the fertilizer factors (nitrogen, phosphorus and potassium) would significantly modify the yield and its components in winter triticale grown on a degraded Vertisol. The study was also aimed at optimizing fertilization for maximum profitability in the future triticale production in Pannonian environments.

2. Materials and Methods

2.1. Experimental Design

The present study, located near Kragujevac, Serbia, was established in a stationary 1970 on a Vertisol soil (IUSS Working Group WRB) [23]. The soil was a Vertisol and was degraded and acid (pH < 5.0). In this study, an experiment was carried out on the field of the Small Grains Research Centre in Kragujevac from 2012/2013 to 2014/2015. The winter triticale cultivar used in the experiment was "KG 20".

The study was based on establishing soil acidity and fertility of Vertisol after regular application of mineral fertilizers and followed a long-terms cheme in a randomized block design with five replications. The rate of nitrogen application was 80 kg $ha^{-1}N$ (N_{80}). The following phosphorus doses were continuously used: the lower dose of 60 kg P_2O_5 ha^{-1} (P_{60}) and the higher one of 100 kg P_2O_5 ha^{-1} (P_{100}). The two phosphorus doses were combined with the constant N dose (80 kg N ha^{-1}) in the variants $N_{80}P_{60}$ and $N_{80}P_{100}$ and potassium (60 kg K_2O ha^{-1}) doses in the variants $N_{80}P_{60}K_{60}$ and $N_{80}P_{100}K_{60}$. Fertilization treatments were compared with the control treatment in which no fertilizers were used. The nitrogen, two phosphorus and one potassium, doses were used in Kragujevac location (central Serbia) for over 40 years. 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 control. Total amounts of phosphorus and potassium fertilizers and half of the nitrogen rate were regularly applied during pre-sowing cultivation of the soil. The fertilizers applied were complex NPK fertilizers (15:15:15) and superphosphate (17% P_2O_5). Fertilization was carried out in 2–3 leaf stage and nitrogen was applied in the form of calcium ammonium nitrate (CAN, 27% N). The remaining nitrogen amount was used during vegetation, depending on the climatic circumstances, so that for triticale, it was used in the period from the end of March to the beginning of April.

The area of the elementary plot was 500 m^2 (25 × 20 m). The triticale cultivar, "KG 20", was sown at the experimental field. Triticale sowing was done on two separated stationary fields (A and B) with corn rotation system. Sowing in all analysed years was carried out in the second half of October, at spacing between rows of 12 cm, with a sowing density of 500 germinating grains per m^2. The trial was designed in randomized blocks with five replications. Conventional production technology was applied. The crops were harvested at full maturity stage (dates of harvesting 10 July 2013, 23 July 2014 and 6 July 2015) and the grain yield (GY, t ha^{-1}), the 1000 grain weight (TGW, g) and the hectolitre weight (HW, kg hl^{-1}) were quantified. Grain yield was measured for each plot and converted to yield in t ha^{-1} based on 14% grain moisture, after which a sample was taken for analysis of TGW and HW. Thousand grain weight was determined using an automatic seed counter. Hectolitre weight was determined by a Schoper´s scale, 0.25 l capacity. Standard grain sampling techniques were used in the research [24].

2.2. Soil Analysis

The trial was set up on a Vertisol-degraded soil with heavy texture and very coarse and unstable structure. According agrochemical analysis results, the soil was acid (pH in H_2O 5.19 and pH in KCl 4.15), poor in humus (2.2%), as well in available phosphorus (2 mg P_2O_5 100^{-1} g of soil), and medium provided with readily available potassium (20 mg K_2O 100^{-1} g of soil). The total nitrogen level in the arable soil layer was 0.14%. The soil was analysed using chemical methods: soil pH was determined in a 1:2.5 soil 1 M KCl suspension after a half-hour equilibration period; hydrolytic acidity by Ca acetate extraction using Kappen's method; the sum of exchangeable basic cations by Kappen's method; humus content by Kotzmann's method; total nitrogen by Kjeldahl, and available P_2O_5 and K_2O levels by the Egner-Riehm Al method [25]. In addition to the natural acidification, the long-term and continuous use of mineral fertilizers also favored additional acidification of the Vertisol.

2.3. Statistical Analysis

Experimental data were analysed by descriptive and analytical statistics using the GenStat [26] for PC/Windows 7. The resulting data were analysed using mathematical and statistical analysis of variance and evaluation of the obtained difference of the height by LSD test. The Pearson's correlation coefficient was obtained and tested at the 5% and 1% levels of significance.

3. Results

3.1. Environmental Variables

This study was conducted on Kragujevac location in the Šumadija region, Serbia, on a Vertisol soil. Kragujevac has temperate semi-arid climate, average annual temperature of 11.76 °C, typical of the Šumadija district in Central Serbia and an annual sum of precipitation of about 550 mm. The meteorological station in Kragujevac is at 44° 02′ latitude, 20° 56′ longitude and the altitude is 185 m.

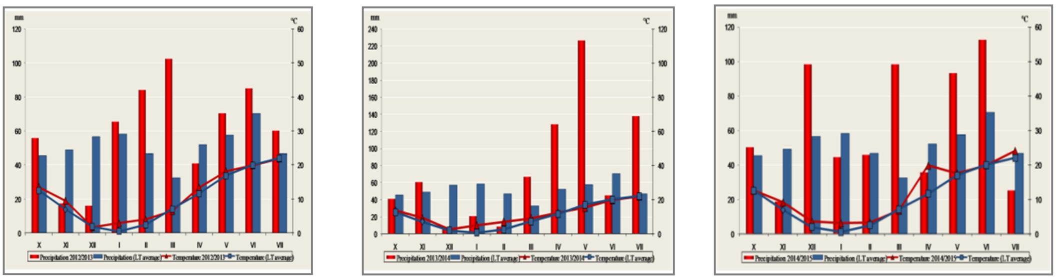
In the vegetation period 2012/2013, the amount of precipitation in Kragujevac was higher compared to the multiannual data (1981–2011). The period from January to March was characterized by above average rainfall. Such climatic parameters indicate that the conditions for germination, shooting/emergence and tillering were extreme. During tillering and stem elongation in March, the weather was characterized by low temperatures and high rainfall if compared to the multiannual average for the period. In April, the precipitation was below the multiannual average. In May, June and July, the precipitation was above the multiannual average. Despite slightly higher precipitation, this period in which the stage of fertilization and grain filling was taking place can be characterized as favourable. During the ripening phase in June, the average temperatures were at the level of multiannual averages. The average air temperature was lower by 1.32 °C and the amount of precipitation was higher by 86.8 mm in 2013 than the average of many years (Table 1).

Table 1. Temperature and precipitation, Kragujevac, Serbia

Months	X	XI	XII	I	II	III	IV	V	VI	VII	Average
Mean monthly air temperature (°C)											
2012/2013	13.5	9.5	1.7	2.9	4.0	6.5	13.4	18.2	19.9	21.9	11.15
2013/2014	13.5	9.2	2.4	5.0	6.9	9.0	12.2	15.3	19.7	21.8	11.50
2014/2015	12.6	9.1	3.5	3.0	3.2	6.7	19.8	17.4	19.9	24.4	11.96
Long term 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)											
2012/2013	56.2	17.7	16.4	65.8	84.4	102.9	41.2	70.8	85.4	60.6	601.4
2013/2014	41.7	61.2	6.4	21.2	9.0	67.1	129	227	45.8	138.6	747.0
2014/2015	50.4	18.9	98.7	44.9	46.2	98.8	35.8	93.6	113	25.4	625.7
Long term average	45.4	48.9	56.6	58.2	46.6	32.4	51.9	57.6	70.4	46.6	514.6

During the vegetative 2013/2014 (October–July) year, a total of 747.0 mm of precipitation was higher by 232.4 mm than the multiannual average of long term and with a very uneven distribution of precipitation per months.

During April and May in2014, precipitation was higher by 77.1 and 169.4 mm, respectively, compared to the multiannual average. Namely, the total amount of precipitation was reflected on the multiannual average, but the distribution, especially at critical stages of development, was significantly disturbed in the 2014 year, Figure 1b.



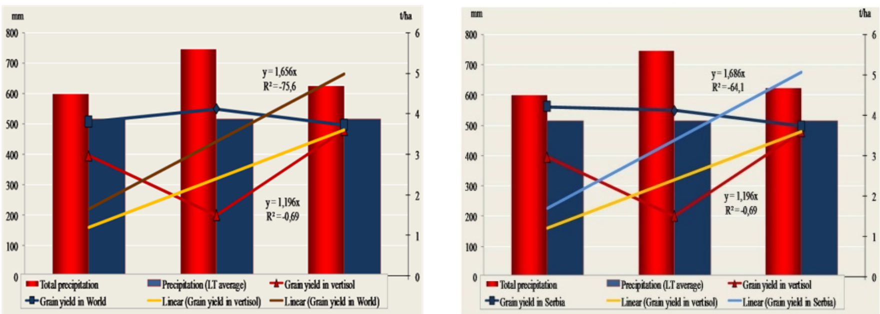
(**a**) (**b**) (**c**)

Figure 1. Mean air temperature and amount of precipitation during the study and long-term periods: (**a**) in 2012/2013; (**b**) in 2013/2014; and (**c**) in 2014/2015.

In the vegetation period 2014/2015, the sum of precipitation in Kragujevac was higher compared to the multiannual data. The mean temperature values were higher in relation to multiannual data (Table 1, Figure 1c). During the ripening phase in June, the mean temperatures were at the level of multiannual averages. The average air temperature was higher by1.78 °C and the amount of rainfall was higher by 111.1mm in 2014/2015 than the multiannual average and with a very even distribution of precipitation per months.

3.2. Grain Yield, 1000 Grain Weight and Hectolitre Weight

The world's average triticale production in tested period was 16,137,927 tons and in Republic of Serbia 80,554 tons [27]. The average area under triticale in the World in tested period was 4.164 mill. ha and in the Republic of Serbia was 19.482 ha. The average triticale yield in the World was 3.88 t ha^{-1} and in Republic of Serbia was 4.14 t ha^{-1}, Figure 2a,b.



(**a**) (**b**)

Figure 2. Average grain yield in triticale in tested years, production in Vertisol soil in Serbia 2012/2013–2014/2015: (**a**) With compared with average grain yield in Word. (**b**) With compared the average grain yield in Republic of Serbia (**b**).

The average yields of triticale obtained in our research, during the study period, are compared with the average global yields, Figure 2a, and with average yields in the Republic of Serbia, Figure 2b. The Average yields obtained in our research, on soil of below 5 pH value, were lower than the world average yields by 1.19 t ha^{-1} and by 1.45 t ha^{-1} relative to the yields in Serbia.

In the present research, the highest values of yield were established in the vegetation season 2015, Table 2.

Table 2. Mean values (x) and standard deviation (S) for grain yield (GY), 1000 grain weight (TGW) and hectoliter weight (HW).

Years	GY (t ha^{-1})		TGW (g)		HW (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						
Control	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		0.690	
P-value	< 0.001		0.932		0.680	

[1] GY-Grain yield (t ha^{-1}), TGW-1000 grain weight (g), HW-Hectolitre weight (kg hl^{-1});.[2] Within years and treatments, the values in each column followed by a different letter are significantly different; * significant at 0.05; ** significant at 0.01.

The highest average yield, of all studied years, was recorded in 2015 (3.597 t ha^{-1}) and it was significantly higher than the yield in 2013 (2.962 t ha^{-1}) and in 2014 (1.500 t ha^{-1}). A significantly higher GY compared to the non-fertilizer treatment was achieved on all fertilizer treatments. On average, for all fertilizer treatments, the highest yield was obtained on the fertilizer treatment NPK with 80 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} (4.024 t ha^{-1}; Table 2).

The thousand grain weight—the average for all fertilizer treatments—was the highest in 2013 (41.95 g), slightly lower in 2015 (41.55 g) and the lowest in 2014 (30.31 g), Table 2. On average for all years, the highest TGW had the fertilizer treatment NPK with 80 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} (39.06 g).

The average value of hectolitre weight of grain for all fertilizer variants tested was significantly higher in 2015 (83.81 kg hl^{-1}) compared to 2014 (69.03 kg hl^{-1}), Table 2. Control and treatment P_{60} with 60 kg ha^{-1} P_2O_5 had the highest HW.

The influence of year and fertilization on the yield of winter triticale is shown in Table 2. The investigated period clearly indicate that highly significant effect of year was found on GY (F = 30.501**), TGW (F = 457.198**) and HW (F = 416.131**). Furthermore, grain yield (F = 12.302**) was highly significant regarding the fertilization. Different fertilizer variants did not significantly affect the weight values of TGW and HW in Table 2.

In the first year, GY varied across treatments, from 1.284 t ha^{-1}in control to 4.358 t ha^{-1} in treatment $N_{80}P_{100}K_{60}$. In the second year, GY varied across treatments, from 0.863 t ha^{-1} in control to 1.955 t ha^{-1} in treatment $N_{80}P_{100}K_{60}$. In 2015, yield significantly varied across treatments, from 1.303 t ha^{-1} in control to 5.758 t ha^{-1} in treatment $N_{80}P_{100}K_{60}$ (Table 3). A significantly higher GY compared to the non-fertilizer variant was achieved on all fertilizer variants. The combined application of NPK fertilizers with 80 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O resulted in a significant increase in the GY of triticale compared to other fertilizer variants tested.

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

Year	GY ($t\ ha^{-1}$)		TGW (g)		HW($kg\ hl^{-1}$)	
2013	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
Control	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			
Control	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			
Control	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	

[1] GY−Grain yield ($t\ ha^{-1}$), TGW−1000 grain weight (g), HW−Hectolitre weight ($kg\ hl^{-1}$); [2] Within years and treatments, the values in each column followed by a different letter are significantly different; * significant at 0.05; ** significant at 0.01.

The thousand grain weight of winter triticale significantly varied across all years and treatments as presented in Table 3. In 2013, TGW significantly varied across treatments from 39.90 g in treatment P_{100} to 44.86 g in treatment $N_{80}P_{60}K_{60}$ with 80 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}. The highest TGW in the second year of testing had treatment NPK with 80 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O (31.08 g) and the lowest control (29.14 g). The highest TGW in the third year had the fertilization treatment control and P_{60} (44.68 g and 44.20 g, respectively), and the lowest the variant N_{80} with 80 kg ha^{-1} N (36.76 g).

During the study, HW of triticale significantly varied across years and treatments. In 2013, HW significantly varied across treatments from 68.03 kg hl^{-1} in treatment $N_{80}P_{100}K_{60}$ with 80 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} to 71.89 kg hl^{-1} and 71.97 kg hl^{-1} in treatments $N_{80}P_{60}K_{60}$ with 80 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} and P_{60} with 60 kg P_2O_5 ha^{-1}. The highest HW in the second year had the fertilization variant control and P_{60} (73.25 kg hl^{-1} and 72.93 kg hl^{-1}, respectively), and the lowest treatment $N_{80}P_{100}$ (65.57 kg hl^{-1}). In 2015, HW significantly varied across treatments from 82.78 kg hl^{-1} in the treatment $N_{80}P_{100}K_{60}$ where phosphorous was applied in the maximum amount of 100 kg $ha^{-1}P_2O_5$ to 84.46 kg hl^{-1} in control (Table 3).

3.3. Correlations between the Analyzed Traits

The correlation coefficients in different fertilizer variants based on all the traits tested had positive and negative values, Table 4. The correlative dependence of GY in the control was positive and significant with the TGW (r = 0.586*). Significant and positive dependencies were found between TGW and HW (r = 0.574*), Table 4.

Table 4. Correlation coefficients for the traits analyzed across treatments.

Parameters	GY	TGW	HW
		Control	
GY(t ha^{-1})	1.00	0.586*	0.213^{ns}
TGW (g)		1.00	0.537*
TW (kg hl^{-1})			1.00
		N_{80}	
GY(t ha^{-1})	1.00	0.729**	0.604*
TGW (g)		1.00	0.155^{ns}
TW (kg hl^{-1})			1.00
		P_{60}	
GY (t ha^{-1})	1.00	0.524*	0.276^{ns}
TGW (g)		1.00	0.613**
TW (kg hl^{-1})			1.00
		P_{100}	
GY (t ha^{-1})	1.00	0.764**	0.592*
TGW (g)		1.00	0.699**
TW (kg hl^{-1})			1.00
		$N_{80}P_{60}K_{60}$	
GY (t ha^{-1})	1.00	0.801**	0.826**
TGW (g)		1.00	0.575*
TW (kg hl^{-1})			1.00
		$N_{80}P_{100}K_{60}$	
GY (t ha^{-1})	1.00	0.721**	0.748**
TGW (g)		1.00	0.188^{ns}
TW (kg hl^{-1})			1.00
		$N_{80}P_{60}$	
GY (t ha^{-1})	1.00	0.879**	0.765**
TGW (g)		1.00	0.475^{ns}
TW (kg hl^{-1})			1.00
		$N_{80}P_{100}$	
GY (t ha^{-1})	1.00	0.923**	0.853**
TGW (g)		1.00	0.646**
TW (kg hl^{-1})			1.00

[1] GY−Grain yield (t ha^{-1}), TGW−1000 grain weight (g), HW−Hectolitre weight (kg hl^{-1}); [2] Within years and treatments, the values in each column followed by a different letter are significantly different; * significant at 0.05; ** significant at 0.01.

In the nitrogen only fertilization variant (N_{80}), highly significant positive correlation coefficients were found between GY and TGW (r = 0.729**) and significant positive correlation with GY and HW (r = 0.604*) in Table 4. Positive and significant correlation between GY and TGW (r = 0.524*) was established in the treatment P_{60} with 60 kg ha^{-1} P_2O_5. In the phosphorus variant (P_{60}), highly significant and positive correlation coefficients were found between TGW and HW (r = 0.613**), as seen in Table 4. In the phosphorus variant (P_{100}), highly significant and positive correlation coefficients were found between GY and TGW (r = 0.764**) and TGW and HW (r = 0.699**). Significant and positive dependencies were found between GY and HW (r = 0.592*; Table 4).

Positive and highly significant correlations between GY and TGW (r = 0.801**) and HW (r = 0.826**) were found in the NPK fertilizer variant with 80 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}. The correlative dependence of the TGW in the treatment $N_{80}P_{60}K_{60}$ was positive and significant with the HW (r = 0.575*) in Table 4. Highly significant and positive correlations between yield and TGW (r = 0.721**) and HW (r = 0.748**) were found in the treatment $N_{80}P_{100}K_{60}$ where phosphorous was applied in the maximum amount of 100 kg ha^{-1} P_2O_5 (Table 4). In the NP fertilizer variant with 80 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} ($N_{80}P_{60}$), highly significant and positive correlation coefficients were found between yield and TGW (r = 0.879**) and HW (r = 0.765**), Table 4. Highly significant and positive correlation coefficients, in the variant with 80 kg ha^{-1} N and 100 kg ha^{-1} P_2O_5 ($N_{100}P_{60}$), were found between GY and TGW (r = 0.923**) and HW (r = 0.853**). Highly significant and positive correlation coefficients were found between TGW and HW (r = 0.646**), as seen in Table 4.

Correlation coefficients based on all traits tested during 2013, 2014 and 2015 had positive and negative values, presented in Table 5.

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

Traits	GY	TGW	HW
		2013	
GY (t ha^{-1})	1.00	0.648**	−0.389*
TGW (g)		1.00	−0.186^{ns}
TW (kg hl^{-1})			1.00
		2014	
GY (t ha^{-1})	1.00	0.493**	−0.082^{ns}
TGW (g)		1.00	−0.231^{ns}
TW (kg hl^{-1})			1.00
		2015	
GY (t ha^{-1})	1.00	−0.392*	−0.641**
TGW (g)		1.00	0.242^{ns}
TW (kg hl^{-1})			1.00

[1] GY−Grain yield (t ha^{-1}), TGW−1000 grain weight (g), HW−Hectolitre weight (kg hl^{-1}); [2] With in years and treatments, the values in each column followed by a different letter are significantly different; * significant at 0.05; ** significant at 0.01.

Positive and highly significant correlation coefficients, in 2013, were found between GY and TGW (r = 0.648**). Significant negative dependencies were found between GY and HW (r = −0.389*). In 2013, negative dependencies were found between TGW and HW (r = −0.186; Table 5).

Highly significant and positive correlation coefficients, in 2014, as presented in Table 5, were found between GY and TGW (r = 0.493**). Insignificant negative dependencies were found between GY and HW (r = −0.082). Thousand grain weight in 2014 was negatively correlated with HW (r = −0.231).

Highly significant and negative correlation coefficients, in 2015, were found between GY and HW (r = −0.641**). Significant and negative dependencies were found between GY and TGW (r = −0.392*). In significant positive dependencies were found between TGW and HW (r = 0.242), Table 5.

4. Discussion

4.1. Meteorological Conditions

The amount of precipitation in the vegetation season 2013/2014 was significantly higher compared to the first and third year of the study as well as in relation to the multiannual average. The period of germination, shooting and tillering (from November 2013 to February 2014) was characterized by mean temperatures above the multiannual average. The amount of rainfall was significantly below the average, which represented poor conditions for the growth and development of plants in these pheno-phases. The period of intensive growth of the vegetative mass in April in 2014 year, was characterized by poor weather conditions with temperatures above the multiannual average. This caused lodging on individual plots as well as the sporadic occurrence of the disease. Precipitation in July in 2014 year exceeded multiannual values, which to some extent caused a slight lodging. The main problem was the enormous amount of precipitation that caused additional lodging and the incidence of rot. All this postponed the triticale harvest, and thus made it more difficult (Table 1, Figure 1a). In the second investigation year (in extreme year 2014, with floods), yields were statistically significantly lower compared to the first and third tested years. Larger precipitation amounts during the spring months (April 129 mm and May 227 mm) in 2014 year caused rising groundwater levels and flooding of agricultural land. The excessive amount of moisture influenced the poorer heading and filling of grain, lodging of crops, the abundance of the weeds and the intense occurrence of the disease in the triticale and other winter grains. Large amounts of rainfall caused lodging of crops and the development of disease that caused a decrease in yield.

The period of germination, shooting and tillering (from November 2014 to February 2015) was characterized by mean temperatures above the multiannual average. The amount of precipitation was significantly above average December in 2014 year and at the level of perennial average January−February in 2015, which represented good conditions for growth and development of plants in these pheno-phases (Table 1). In March 2015, the temperatures were at the level of multiannual average values and precipitation was significantly above said values. The period of intensive growth of the vegetative mass in April in 2015, was characterized by favourable weather conditions with temperatures above the multiannual averages. Precipitation was significantly below the multiannual average values. In May and June 2015, the precipitation was above the multiannual average.

Variations in the temperature, in the amount of precipitation during vegetation as well as in the soil moisture content are the most important factors of the yield instability e [7,28]. In the Republic of Serbia, high temperatures and the water deficiency during June resulted in yield decrease and deterioration of technological properties of grain, so prolonged vegetation and grain filling period did not contribute to yield increase [9,17,18,20,29]. In addition to the necessary reserve for the spring part of the vegetation, winter precipitation greatly influenced the distribution of easily accessible nitrogen in the soil [11,30,31]. Many authors state that the yields are strongly modified by the environment of different temperatures and weather conditions [13,16,29,32–36]. It is rarely the individual influence of one stress factor, and often development of plants occurs under the combination of a few different stresses which makes for a more complex evaluation of adaptability. The drought has become a main limiting factor of the world plant production, affecting the yield decrease in countries with developed agriculture, too. Commonly, drought-affected stress is followed by high temperatures, which increase its impact additionally [11,37–40].

Achieving high triticale grain yield of desirable quality demands a proper choice of the cultivar and assurance of the optimal growing conditions, i.e., production technology. Cultivars of the new generation exhibit a high degree of tolerance against temperature shocks during the phase of the forming and filling of grain as well as against drought [14,41–43]. It is known that individual or mutual influence of abiotic stress factors (high and low temperatures, drought, acidic and saline soil) in different triticale growth stages limit the expression of the maximum grain yield potential [18,19,21,30].

4.2. Grain Yield, 1000 Grain Weight and Hectolitre Mass

All fertilizer treatmentstested achieved the highest average yield in 2015 and the lowest in 2014 (Table 2). A significant increase in yield in the third year of testing compared to the first and second years was due to the favourable effect of environmental factors, i.e., temperature and precipitation, on the yield components. Compared to the multiannual average, rainfall in the second year of testing was significantly higher in May, which, with favourable temperatures, led to the formation of more grains and thus to higher yields. The significant deviations of precipitation and temperature from the multiannual average in the Republic of Serbia are becoming more pronounced [5,17,19,30]. Namely, the total rainfall is reflected on the multiannual average, but the distribution, especially in the critical stages of development, was significantly disrupted [6,9,19].

The highest average triticale GY of 3.597 t ha^{-1} 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. The highest average yield of 4.024 t ha^{-1} was recorded in treatment $N_{80}P_{100}K_{60}$ and it was significantly higher than the yield in untreated treatment−control (1.150 t ha^{-1}). To achieve high and stable grain yields, new cultivars demand more precise and complex NPK nutrition [18,32,33]. Nitrogen application has a crucial role. Precision in the N application (timing, amount, and quality) represents a specific problem in stress years. Possible losses in conditions of excessive moisture in the soil as well as insufficient efficiency in drought conditions impose the need for improvement of N application method, especially for in-season application. Furthermore, in the application of NPK fertilizers with more precision is needed. A more careful choice of cultivars and respecting of their specificities could contribute to a higher and stable triticale yield in Serbia [9,17–19,22,33].

The average values of productive GY of the investigated winter triticale grown in the experiment was 5.758 t ha^{-1} in $N_{80}P_{100}K_{60}$ treatment, with a variation 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 GY 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. [6], also find that the GY increases with NPK fertilizers application.

The thousand grain weight in 2013 year (41.95 g) and 2015 (41.55 g) were significantly higher compared to 2014 (30.31 g). The highest value of TGW was established for the $N_{80}P_{60}K_{60}$ treatment (39.06 g). Terzić et al. [9] find that the application of mineral fertilizers has a significant impact on TGW, i.e., the grain weight is significantly higher in more intensively fertilized variants, especially winter triticale fertilized with nitrogen. The application of nitrogen in the amount of 120 kg ha^{-1} led to a significant decrease of TGW compared to the application of nitrogen in the amount of 30 kg ha^{-1}, but the application of nitrogen in the amount of 150 kg ha^{-1} led to slight increase of TGW [13]. Kondić-Špika et al. [44] find that the GY significantly varies among the genotypes and the environments (13.7% to 21.2%). Application of mineral fertilizers has a significant impact on TGW which is significantly higher in more intensively fertilized variants as observed by Terzić et al. [9], Lalevic et al. [15], Rajičić et al. [19] and Bielski et al. [39]. The present results confirm the opinion of many authors that the GY and TGW are genetically determined but are strongly modified by the weather conditions and soil nutrient availability [14,27,40,42]. The contribution of fertilization to the TGW was 15% more in the treatment without fertilizer compared to nitrogen treatment in GY variation [45]. Bielski et al. [40,46] have found that 40 kg N ha^{-1} caused a significant rise of TGW (10.2%), but the second highest dose of nitrogen (120 kg N ha^{-1}) caused a decrease and a significant decline in this trait occurred. According to Lalevic et al. [15], the conditions of the external environment, as well as the certain nutritional elements, significantly influence TGW. Additionally, it was noted that the application of the highest nitrogen dose in combination with phosphorus and potassium ($N_{120}P_{80}K_{80}$), in all three years of the research, resulted in the highest average TGW in all triticale cultivars. Many researchers have noted a positive effect of nitrogen on GY and TGW in winter triticale [6,9,11,19,40].

The study results indicated that the growing season influenced highly significant differences in all investigated traits. In addition, highly significant differences ($P < 0.01$) were determined between the fertilization variants for GY, except TGW and HW (Table 2). Similarly, Đekić et al. [6] found highly significant effect of year on the yield and they report that this stems from the changing of vegetation seasons as a result of changing environmental conditions. Considerable variation in yield depending on years of research has been established by Đekicć et al. [17], Terzić et al. [9,10], Lalevic et al. [15], Rajičić et al. [19], Biberdzic et al. [30], Bielski et al. [40] and Cathy et al. [47]. Derejko and Studnicki [48] find that the conditions of the external environment, as well as certain locations, significantly influence the yield of cultivars of agricultural crops.

4.3. Correlations between the Analyzed Traits

The study results indicate that GY in all vegetation seasons was positively and highly significantly correlated with TGW, except in 2015. The correlative dependence of the GY in the vegetation seasons was positive and highly significant with TGW as established by Terzić et al. [9] and Rajičić et al. [19]. The negative and significant correlation between GY and HW in the vegetation season has been established by Rajičić et al. [19]. A negative and insignificant correlation between GY and TGW of the winter triticale has been established by Bielski et al. [40]. Early ripening cultivars finish the synthesis of the 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 GY [35,46,49,50].

The study results indicate that GY in all treatments was positive and significantly correlated with TGW. Rajičić et al. [19], have found that GY correlation with TGW in the control, P_{60} and P_{100} treatments was positive. Đekić et al. [6] report a positive correlation of GY and TGW in all treatments, except in variants $N_{80}P_{60}$, $N_{80}P_{80}K_{60}$ and $N_{80}P_{100}K_{60}$. Negative correlation of GY and TGW of the winter triticale has been established by Terzić et al. [9], except in treatments $N_{120}P_{60}$ and $N_{120}P_{100}K_{60}$.

The correlative dependence of GY in all treatments was positive and significant correlations were also found between HW. Janušauskaite [11], found that GY correlation with HW at single N_{60} and N_{180} treatments was significant. Many authors state that positive correlations of GY and HW in the fertilization have been established [6,9,19].

The correlative dependence of TGW in all treatments was positive correlations were also found between HW. Đekić et al. [6] and Terzić et al. [9] have determined strong and negative correlation between HW and TGW in all treatments of the winter triticale.

The results of this study showed that the values of the examined productive traits (yield, components of the yield and the quality of the grain) of the winter triticale, which varied depending on the applied dose of nitrogen, phosphorus and potassium. Grain yields do not depend only on the dose of fertilizers, but also on the climatic conditions, as confirmed by previous researches [6,9,18,19,22,30,40,47,49,50].

5. Conclusions

The method proposed by the present study for the evaluation of the distribution of fertilizers on triticale was practical and efficient.The study presents detailed investigations related to defining the optimal fertilization system and finding possibilities of plant adaption to the low soil pH values. Environmental conditions (weather and soil) and fertilization had a significant effect on grain yield and quality in triticale. Grain yield showed a tendency to increase in the years with higher total amount and better distribution of rainfall during critical plant development stages. The effect of environmental factors on grain quality was clearly evident. The physical quality of the grain declined in the less favourable years for triticale production (decreased total rainfall and unfavourable rainfall distribution).

Based on the study of possibilities for the increase of yield and quality of triticale, planted on a degraded Vertisol soil of low pH in Serbia, a high-phosphorus application resulted in a significant but lower increase in GY and quality, which was not likely to provide a significant economic benefit. NPK fertilization increased GY but showed no effect on TGW and HW. The results of the present study clearly suggest that maximum yield and quality on Vertisol can be obtained with the optimum rate of NPK fertilizer (80 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1}, 60 kg K_2O ha^{-1}). The study results indicate that the GY in all treatments was positive and significantly correlated with TGW and HW.

The positive effect of the complete application of fertilizer is the result of lower pH value of the soil, as well as the low content of available phosphorus and potassium in this soil which, for this reason, must be added in the form of fertilizer.

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