Studies to optimization of wheat nutrition

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Abstract
The aim of the study was to evaluate the effect of interaction between different rates of fertilizers: nitrogen, phosphorus, potassium, and silicon on the vegetation of Wheat (Triticum aestivum L), medium-early Bulgarian sort – “Sadovo 1”. Experimental design, which is 1/2 replication of a 2^4 factor scheme with added control variant was used in the planning of multifactorial experiments that allow the assessment of actions and interactions of more than three factors, varying on three levels with 3 replications. The plant height on the 195th, 222th, and 248th-day from the sowing date and yield at harvest were studied.

According to the results, the agronomic characteristics were affected significantly by fertilization. The established trends on plant height during the vegetation period of Wheat correlate with the data for the yield of the crop. To sum up, the leading role of nitrogen stands out in treatments with the high rate of nitrogen, low rate of phosphorus and silica.

Keywords: fertilization; nitrogen; phosphorus; potassium; silicon; wheat yield

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops of the world on account of its wide adaptability to different agroclimatic conditions and different soils. Among major cereals, wheat ranks first in area and production at the global level and it contributes more calories and proteins to the world’s human diet than any other cereals. It is the main food of nearly 35 percent of the world population. The total cultivated area of wheat in the world is 240.00 million hectares with an annual production of 765 million tonnes (FAOSTAT, 2020). In Bulgaria, wheat is the first most important food crop; with a cultivated area of 1 198 682 hectares in 2019 which produced 6.2 million tones, with average productivity of 5140 kg.ha^{-1} (Agricultural Report, 2019).

Bulgaria has many competitive advantages in the development of the agricultural sector (favorable climatic conditions, inexpensive labor, and raw materials, convenient location to global sales markets). Intensive agricultural activity is accompanied by a decrease in soil fertility, environmental pollution, and a decrease in production quality (Nenov et al., 2020). Therefore, it is necessary to implement new, environmentally safe, and, highly effective methods of managing agricultural production (Ur & Vasileva, 2014).

The reduction of soil fertility and the agricultural production quality is associated to a significant extent, with the unbalanced nutrition of grown crops (Aristarkhov, 2000; Kurganova, 2002; Bezuglov & Gogmachadze, 2008; Qiu et al., 2014; Davies et al., 2020). The management of modern agriculture requires the fertilization of the soil to take into account the need to preserve the ecological equilibrium created during the soil formation process. This will be achieved by improving key elements in agrotechnology, such as fertilization and crop rotations. The effectiveness of nutrients imported by fertilization depends not only on the number of individual elements but also on complex interactions between them. Every year, 20 to 700 kg of Si/ha are irreversibly removed from the soil (Bazilevich et al., 1975; Bocharnikova & Matichenkov, 2012). The use of the previously neglected element of silicon can contribute to increasing the quantity and quality of yields, as well as to the sustainability of crops in adverse weather conditions and from diseases and enemies.

This study aims to acquire new knowledge through experimental and theoretical activity to develop the scientific basis of appropriate recommendations for optimal fertilization of wheat and to clarify the role and importance of the main macroelements for plant nutrition.

MATERIALS AND METHODS

In the experimental field of ISSAPP "N. Poushkarov" in "Bozhurishte", Sofia has conducted two years 2020-2021 field experiment with the application of mineral fertilizers - N (ammonium nitrate), P (superphosphate), K (potassium sulfate), and Si (diatomic earth, which represents 89-95% silica in amorphous form). The experiment includes 9 variants of fertilization with the size of the experimental parcels - 25 m^2. The design of treatments is presented in Table 1.

Experimental design, which is 1/2 replication of a 2^4 factor scheme with added control variant was used in the planning of multifactorial experiments that allow the assessment of actions and interactions of more than three factors, varying on three levels. The work program of the project envisages the use of schemes of this kind (Petkova et al., 2020).

The corresponding quantities of fertilizers are as follow:

A0 = N 0, A1 = N 100, A2 = N 200 kg/ha; B0 = P 0, B1 = P 80, B2 = P 160 kg/ha;

C0 = K 0, C1 = K 60, C2 = K 120 kg/ha; D0 = Si 0, D1 = Si 14, D2 = Si 28 kg/ha.

The test crop was Wheat (*Triticum aestivum* L) - medium-early Bulgarian sort "Sadovo 1", which is used to be a national standard. The soil used is Leached smolnitsa according to Bulgarian classification (Koynov et al., 1964) and it is defined as Pelic Vertisol - according to FAO (2015). Some agrochemical characteristics of soil, getting before starting the experiment are presented in Table 1.

It is apparent from the presented data (Table 2) that the total nitrogen content of the arable horizon of the Leached Smolnitsa is 0,139 %, which characterizes it as relatively well-stocked. However, the mineral nitrogen content is not high- 12,67-14,98 mg N per 1000 g of soil. In terms of mobile phos-

Table 1. Design of 1/2 × 2^4 type

Variant	Factors			
No	A	B	C	D
1	1	1	1	1
2	2	1	1	2
3	1	2	1	2
4	2	2	1	1
5	1	1	2	1
6	2	1	2	2
7	1	2	2	2
8	2	2	2	1
9	0	0	0	0

Table 2. Agrochemical characteristic of Pelic Vertisol, Bozhurishte

Leached Smolnitsa/ Pellic Vertisol	pH		$\sum$ N-NH_4+NO_3	Total N	P_2O_5	K_2O	Humus
	H_2O	KCl	mg.kg^{-1}	%	mg.$100g^{-1}$		%
0-30 cm	6,2	5,4	12,67	0,139	0,20	30,11	3,02
30-60cm	6,5	5,6	8,64	0,113	0,34	21,8	3,09

phorus, the reserves are also low - from 0,20 to 0,34 P_2O_5 mg.100g^{-1}, but is better stocked with digestible potassium - up to 30,11 K_2O mg.100g^{-1}.

The soil is characterized by a slightly acidic to neutral reaction (pH_{H2O}) in the surface soil layer.

The following methods of analysis are used: determination of Hummus - by oxidation during heating along with the Turin (Kononova, 1963); pH- potentiometrically in H_2O and KCl (Arinushkina, 1962); total N – by Kjeldahl (PanReacAppliChem), mineral N - Bremner and Kiney method (Bremner,1965a, Bremner,1965b); mobile forms of phosphorus and potassium (P_2O_5 and K_2O) - by the acetate method of Ivanov (Ivanov, 1984).

The plant height on the 195th, 222th, and 248th day from the beginning of the experiment and yield of fresh and dried biomass from the aboveground part of the crop at harvest were studied.

For the statistical processing of the data, the One-way ANOVA method was used from the package Statgraphics 18 program. To identify the differences between the variants studied, the least significant differences (LSD) were used at $p \leq 0.05$ (95%).

RESULTS AND DISCUSSION

During vegetation of Wheat, phenological observations were carried out. Wheat sprouted 20-22 days after sowing at 13.11.2020. Two-thirds of the N norm were imported in the early spring to nourish wheat. At the end of May - 26.05.2021 there were noticeable differences between treatments.

The experimental data on plant growth and the yield of wheat at harvesting are presented in Table 4. Observations during vegetation are confirmed by the measured heights of plants on the 195th, 222th, and 248th-day from the sowing date. One-way ANOVA analysis on plant height on the 195th day was made and a significant difference between the variants was found ($p \leq 0.05$). The nine treatments are distributed in 6 homogeneous classes – A, B, C, D, E, and F (Table 4). The variants in separate homogenous groups have significant differences between them (LSD = 6.808 cm at 95.0% confidence level). The lowest are the values for plant height in variants 9 - 45.33 cm (control variant). It forms a homogeneous class A and it is significantly different from those in the other variants. The highest is the plants in V8 ($N_{200}P_{160}K_{120}Si_{14}$)- 87.5 cm with the highest rate of N, P, and K applied. V8 is a homogenous group F in which is V2 ($N_{200}P_{80}K_{60}Si_{28}$) - 85.0 cm also with the highest rate of N, but small norms of P, K and high norm of Si. As we can see variant 2 keeps his homogenous group F at the next 2 dates of observations. Close to the data of variant 2 are the values for the height of plants in variants 4 ($N_{200}P_{160}K_{60}Si_{14}$) which forms group EF and V7 ($N_{100}P_{160}K_{120}Si_{28}$)- group DE. V5 is in group B with an average height of 63.33 cm. V1 and V3 are in intermediate homogeneous group CD, V6 in BC, and V7 – in DE. The differences between the variants

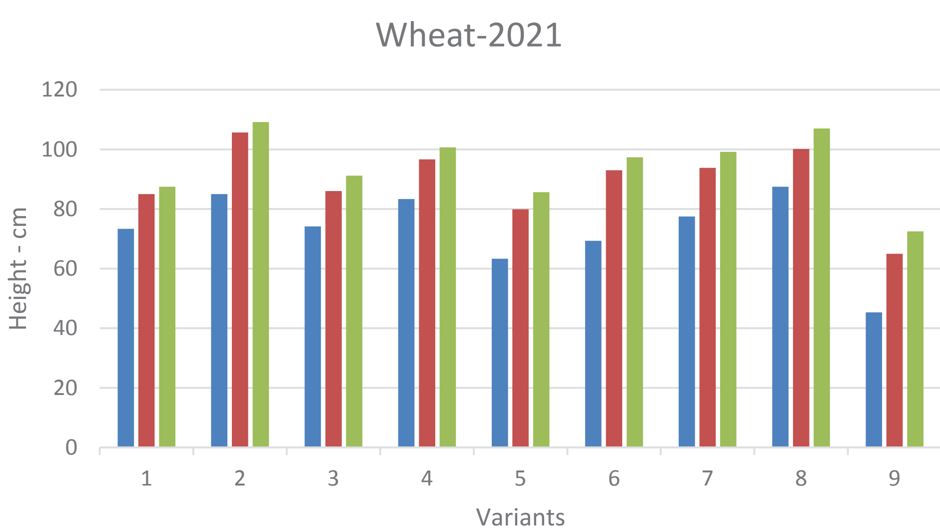

Figure 1. Bar chart of plant's height.

in intermediate homogeneous groups are not statistically significant. A similar tendency is observed with the obtained data for the other 2 periods- 22.06 and 19.07.2021 – 6 groups, 4 of them are in separated groups A-B-D-F. Five variants are in intermediate homogeneous groups. In Figure 1 the data for the heights of Wheat plants (in cm) during the vegetation are presented.

It is evident that in all variants (2, 4, 6, and 8) in which the biggest norm of N_{200} is applied the height of plants is higher than in those with $N_{100.}$ The plant's height is high also in Variant V7 ($N_{100}P_{160}K_{120}Si_{28}$), where the high norms of P, K, and Si are added (see Figure 1).

The tendencies established from the statistical processing of the data on plant height during the period of Wheat vegetation correlate with the data for the yield of grain depending on the fertilization applied.

The results from the One-way ANOVA analysis of yield data are given in the next Table 3.

From this table it is obvious that the most significant is the influence of nitrogen and phosphorus on the yield, while the influence of potassium and silicon is significantly less.

During the statistical processing of the data for wheat yield (kg/ha), 5 homogeneous classes were formed, and the LSD between the different variants is 2522.63 kg/ha and only 3 of them are in separated groups (Table 4). The lowest is the yield in V9- control – 2067.95 kg/ha and it is homogenous group A, next value in ascending order is in Variant 1 ($N_{100}P_{80}K_{60}Si_{14}$) – 4581.53 kg/ha, group B. Close to V1 is V3 – BC group, the next is V2- group BCD. The differences between V2, V3, V5, V6, V7, and V8 are not statistically proved.

The highest yields are in V4- group E and V8-DE followed by V6, V7, and V2. Therefore maxi-

Table 3. Analysis of variance of Wheat yield.

Source	SSQ	DF	MS	F	p
N	120093	1	120093	9.210	0.0114
P	48240	1	48240	3.700	0.0807
K	40633	1	40633	3.120	0.1053
Si	6202	1	6202	0.480	0.5047
Factors	215167	4	53792	4.125	0.0202
Residual	143456	11	13041		
Total	358623	15			

Table 4. Effect of fertilization on the height of Wheat sort "Sadovo 1" during the vegetation and the Yield in Bozhurishte Experimental Station, 2020/2021.

Treatments	**Height of Plants, cm**			**Yields, kg.ha^{-1}**	**Increase of Yield, %**
	26 May	22 June	19 July	19 July	Rel. to Contr.
1 N100P80K60Si14	73.33 cd	85.00 b	87.50 b	4581.53 b	121.5
2 N200P80K60Si28	85.00 f	105.67 f	109.17 f	6386.44 bcd	208.8
3 N100P160K60Si28	74.17 cd	86.00 bc	91.17 bc	5390.49 bc	160.7
4 N200P160K60Si14	83.33 ef	96.67 d	100.67 de	8997.21 e	335.1
5 N100P80K120Si14	63.33 b	79.89 b	85.67 b	6664.65 bcde	222.3
6 N200P80K120Si28	69.33 bc	93.00 cd	97.33 cd	7604.45 cde	267.7
7 N100P160K120Si28	77.50 de	93.83 cd	99.17 d	7233.14 cde	249.8
8 N200P160K120Si14	87.50 f	100.17 ef	107.00 ef	8265.02 de	299.7
9 N0P0K0Si0	45.33 a	65.00 a	72.50 a	2067.95 a	0.0
Average	73.203	89.463	94.463	6354.54	
Std. dev.	13.508	13.143	12.418	2199.17	
Std. error	2.390	2.757	2.585	788.52	
LSD≥95%	6.808	7.854	7.365	2522.63	

Table 5. Regression coefficients of Wheat yield

Coeff.	Variable	Estimate	Std. err.	|t|	p
β0	Constant	2068	787.136	2.627	0.0253
β1	N	18.455	31.362	0.588	0.5693
β2	P	-17.726	49.073	-0.361	0.7255
β3	K	40.010	40.435	0.989	0.3458
β4	Si	-63.977	201.741	-0.317	0.7577
β5	NP	0.215	0.334	0.644	0.5338
β6	PK	-0.287	0.186	-1.545	0.1534
β7	KSi	1.018	1.325	0.768	0.4603

mum yield is obtained in treatments with the highest norm of N, combined with the highest norm of P (V4- $N_{200}P_{160}K_{60}$ Si_{14}) and low norm of K and Si. Many researchers (Tsenov et al., 2011; Gaj, 2008; Aristarkhov, 2000; Valeva & Stamenov, 2017; Ur & Vasileva, 2014) found that fertilization with N and P is the basic factor in conditions of intensive plant production.

Regression analysis also includes control variant No. 9. So the number of variants for this design is equal to 9. Results are presented on Table 5.

The following regression equation is obtained with $R^2 =$ 0.8493.

Y = 2068 + 18.455*N - 17.726*P + 40.010*K - 63.977*Si + 0.215*NP - 0.287*PK + 1.018*KSi

The local maxima of the nutrients within their experimental intervals are respectively

N = 200.0; P = 150.2; K = 110.9; Si = 19.8.

The global maximum of the yield is 11456 kg/ha at N=200, P=80, K=120 and Si=28 kg/ha.

CONCLUSIONS

As a result of the experiment with fertilization on Pelic Vertisol and Wheat, sort "Sadovo 1" as a test plant, after One-way Anova analysis of plant heights on the 195th, 222th, and 248th day from the beginning of the experiment and yield, the leading role of nitrogen fertilization in the norm of 200 kg/ha was established ($p \leq 0.001$).

The distribution of the variants by heights is in 6 homogeneous groups - A, B, C, D, E, F, and by the yield - in 5 groups. This is an indicator of the increased differences between variants during the vegetative development of Wheat.

The lowest is the yield in V9- control – 2067.95 kg/ha and it is homogenous group A, next value in ascending order is in Variant 1 ($N_{100}P_{80}K_{60}Si_{14}$) – 4581.53 kg/ha, group B. Close to V1 is V3 – BC group, the next is V2- group BCD. The V2, V3, V5, V6, V7, and V8 are in intermediate homogeneous classes, and differences between them are not statistically proved.

The highest yields are in V4- group E and V8-DE followed by V6, V7, and V2. It was found that the combination of high rates of fertilizers maximum yield is obtained in treatments with the highest norm of N, combined with the highest norm of P (V4- $N_{200}P_{160}K_{60}Si_{14}$) and low norm of K and Si. It is confirmed that nitrogen has the strongest effect during the vegetation of Wheat in comparison with the other 3 elements.

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