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The role of nutrients in the formation of yield and grain quality of winter wheat

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Abstract

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In order to optimize the winter wheat fertilization system, field studies were conducted on Luvic Greyzemic Phaeozem (Loamic) in the western forest-steppe of Ukraine. The influence of nitrogen, phosphorus, potassium, sulfur, magnesium fertilizers and microfertilizers were studied. Under the influence of fertilizers, the structure of the crop changed, in particular, the number of ears increased from 480 pcs/m^2 in control to 642 pcs/m^2 at the highest rate of fertilizers, grain weight per ear, respectively, from 0.78 g to 1.48 g. The grain yield of winter wheat of the variety Kubus increased from 3.64 t/ha on the option without fertilizers to 9.14 t/ha with the application of $N_{180}P_{60}K_{90}S_{30}Mg_{20}$ + Intermag microfertilizer, ie by 5.50 t/ha, or 151.1%. The largest increase of grain was provided by nitrogen fertilizers – 2.94 t/ha (80.8%), from the application of potassium, phosphorus, sulfur, magnesium and microfertilizers the yield increased by 2.56 t/ha (70.3%). Nitrogen fertilizers also had the greatest impact on grain quality indicators: the gluten content increased from 18.8% in the variant without fertilizers to 28.0% for N_{180} application, the protein content, respectively, from 11.5% to 14.0%. From the application of potassium, phosphorus, sulfur, magnesium and microfertilizers, the gluten content increased by 1.4%, the protein content – only by 0.4%.

Keywords: winter wheat; fertilizers; structure; yield; quality

Introduction

In modern technologies, fertilizers have the greatest impact on yields. However, the cost of fertilizer is not always offset by a corresponding increase in yield. The main reason for this is non-compliance with the ratio between nutrients, nitrogen fertilizers have a significant advantage (Avramenko, 2018; Petrichenko & Lykhochvor, 2020; Lykhochvor & Petrichenko, 2020).

In Ukraine in the last three years the application of fertilizers is increasing, 100-110 kg/ha are applied of acting matter of nitrogen, phosphorus and potassium per 1 ha of sown area of all crops. However, this is not enough, even in 1986-1990 more was applied. In the European Union, this figure is much higher and is in the range of 200-300 kg/ha.

In scientific researches are studied mainly nitrogen, phosphorus and potassium fertilizers (Gamayunova et al., 2019; Lisovyi et al., 2019; Ivanina, 2020; Kulyk et al., 2020; Markovskaya & Grechishkina, 2020). Experimental materials on the effect of soil application of magnesium and sulfur on the yield of winter wheat are almost absent. The foliar application of these microelements is investigated mainly.

Optimization of the nutrition background helped to increase the grain yield of winter wheat by 1.45–2.41 t/ha, straw – by 1.16–1.93 t/ha (Sydyakina & Dvoretskyi, 2020). Fertilizer application provided a grain yield of 6.6 t/ha, it increased by 2.64 t/ha relative to control, and the weight of grain from the ear was the largest and amounted to 1.24 g (Voitova, 2020). The highest yield (6.8 t/ha) was observed for the mineral fertilizer system (Centilo, 2019). Yields at the level of 8.22 – 8.64 t/ha were obtained in conditions of sufficient moisture in the western forest-steppe of Ukraine (Voloshchuk, 2018).

In our previous studies (2016-2018) for the application of $N_{160}P_{80}K_{120}$, the yield of winter wheat variety Kubus was 8.01 t/ha with a content of gluten in the grain of 29.1% and protein 13.6% (Lykhochvor, 2019). In other studies, it was found that in areas where fertilizers were not applied in crop rotation, the grain corresponded to the 6-th class, the application of only nitrogen fertilizers at a rate of N_{150} and their application on a phosphorus-potassium background ($P_{60}K_{40}$) provided grain of the 2-nd class quality (Gospodarenko et al., 2018). It is also important to study the influence of structural elements on the grain yield of winter wheat (Oliynyk et al., 2018; Olkhovsky et al., 2019).

The model of development of grain production in Ukraine for the purpose of achievement of an indicator of 100 million tons is considered. Such increase of gross grain harvest can be reached only by the application of 3 million tons of acting matter of mineral fertilizers, application of 20 thousand tons of plant protection products, and expansion of sown areas of this group of crops to 17.4 million hectares (Cherchil & Shevchenko, 2020).

It should be taken into account that yield increases and quality indicators will increase while meeting the needs of the plant in all nutrients. Therefore, the aim of our research was to obtain real experimental data as to the influence of individual nutrients and their interaction in conditions of sufficient moisture and to establish the expediency of including them in the fertilizer system of winter wheat.

Materials and Methods

In order to optimize the fertilizer system in 2018–2020 on the research field of the Department of Plant Technology of Lviv National Agrarian University conducted field researches. The soil of the experimental plot is Luvic Greyzemic Phaeozem (Loamic) (WRB, 2015) with a humus content of 2.5–2.6%. The content of light hydrolysis nitrogen (according to the method Kornfild, DSTU 7863:2015) – 68–72 mg (Soil Quality, 2016), mobile forms of phosphorus and potassium (according to the method of Chiricov, DSTU 4115-2002) – respectively 85–88 mg and 89–95 mg per 1 kg of soil (DSTU 4115-2002, 2003). The reaction of the soil solution (DSTU ISO 10390:2007) is close to neutral, the pH of the salt extract is 5.9–6.0.

Weather conditions in the years of researches were quite contrasting and differed from the average long-term data both for the amount of precipitation and for terms of temperature. During the year in 2018 fell 760 mm, in 2019 – 818 mm, in 2020 – 710 mm with a long-term average of 615 mm. Precipitation in June 2018 and in May 2019 created conditions of excessive moisture, which led to reduced yields. Air temperature in the years of researches was not a limiting factor of yield growth. In 2018, the average monthly temperature was 8.8° C, in 2019 – 9.1° C, in 2020 – 9.4° C, with a long-term average of 7.8° C.

The calculated area is 50 m^2, the experiment is repeated three times. Placement of plots – systematized.

The predecessor of winter wheat is winter rape. After harvesting the predecessor, disking was carried out, two weeks before sowing plowing and on the day of sowing pre-sowing tillage by the Compactor. The Kubus variety was sown on September 30 with a sowing rate of 3.0 million/ha at a seed wrapping depth of 3 cm. The row width was 15 cm. The seeds were treated by Kinto Duo, 2.5 l/t (prochloraz, 60 g/l + triticonazole, 20 g/l) and Cruiser, 0.5 l/t (thiamethoxam, 350 g/l). In autumn, in the phase of 3 wheat leaves, the herbicide Marathon, 4.0 l/ha (pendimethalin, 250 g/l + isoproturon, 125 g/l) was applied to control weeds.

Experiment options: 1 – without fertilizers (control); 2 – N_{180}; 3 – N_{180} + P_{60}; 4 – $N_{180}P_{60}$ + K_{90}; 5 – $N_{180}P_{60}K_{90}$ + S_{30}; 6 – $N_{180}P_{60}K_{90}S_{30}$ + Mg_{20}; 7 – $N_{180}P_{60}K_{90}S_{30}Mg_{20}$ + Microfertilizer Intermag grain. The following types of mineral fertilizers were applied to perform the research scheme. Nitrogen fertilizers in all variants were applied in the form of ammonium nitrate: N_{60} during the restoration of spring vegetation (BBCH 25) + N_{80} at the end of the tillering phase (BBCH 29) + N_{40} in the earing phase (BBCH 59). The entire rate of phosphorus, potassium and sulfur fertilizers was applied in the form of triple superphosphate (P_{46}), potassium chloride (K_{60}) and Vigor (S_{90}) under plowing. Magnesium and sulfur fertilizers on variant $N_{180}P_{60}K_{90}S_{30}Mg_{20}$ were applied in the form of magnesium sulfate ($S_{30}Mg_{20}$). Microfertilizer Intermag grain ($N_{15}Mg_{2}S_{4,5}Cu_{0,9}Fe_{0,8}Mn_{1,1}Zn_{1}Mo_{0,005}Ti_{0,02}$) with a rate of 2 l/ha was applied at the beginning of the exit phase into the tube. Fertilizer application rates were typical for the yields at the level of 8.0–9.0 t/ha.

In spring, wheat sowings were treated by Medax Top (mepiquat chloride, 300 g/l + prohexadione calcium, 50 g/l) at the rate of 1 l/ha at the beginning of plant emergence in the tube (BBCH 30) and Terpal (mepiquat-chloride, 305 g/l + ethephon, 155 g/l) in the phase of appearance of the tongue at the top leaf (BBCH 39) from lodging. To protect against diseases, the sowings were sprayed with fungicides Flexiti (metrafenone, 300 g/l) with the rate of

0.25 l/ha in the early phase of plant emergence in the tube (BBCH 30), by Amistar Extra (azoxystrobin, 200 g/l + cyproconazole, 80 g/l) with the rate of 0.75 l/ha in the top leaf phase (BBCH 39), by Osiris Star fungicide (epoxiconazole, 56.25 g/l + metconazole, 41.25 g/l) with the rate of 1.5 l/ha in the flowering phase (BBCH 65). To control pests, the sowings were sprayed twice by insecticides: Karate Zeon (lambda-cyhalothrin, 50 g/l) with the rate of 0.30 l/ha in the phase of BBCH 30 and Engio (lambda-cyhalothrin, 106 g/l + thiamethoxam, 141 g/l) with the rate of 0.18 l/ha in the phase of BBCH 39.

Indicators of grain quality of winter wheat were determined in accordance with current State standards: weight of 1000 grains – DSTU ISO 520: 2015, crude gluten – DSTU ISO 21415-1: 2009, protein – DSTU ISO 20483: 2016, glassiness – GOST 10987-76.

Statistical processing of the obtained research results was performed using OriginPro 2019b software (Origin Lab Corporation, USA, 2019). Data were compared using the Tukey test. Differences between samples were considered statistically significant at $p < 0{,}05$. The data in the tables are presented as the arithmetic mean with standard deviation (x ± SD).

Results and Discussion

Fertilizers affected the structure of the crop. Under the influence of nitrogen fertilizers, the number of ears per 1m2 increased by 130 pieces (Table 1). Other types of fertilizers had a much smaller effect on the density of ears, in total this figure increased by only 32 pieces.

Nitrogen fertilizers also had the greatest effect on the coefficient of productive tillering, they increased it from 1.8 to 3.0. Other types of fertilizers had almost no effect on the process of tillering winter wheat plants.

Fertilizers increased the number of spikelets in the ear from 14 pieces on the variant without fertilizers to 18 pieces at the highest level of fertilizer. The number of grains in the ear changed even more significantly. If there were only 27 grains on the control in the ear, then with the maximum amount of fertilizer on the 7th variant, this figure increased to 49 grains. It should be noted that the number of grains in the ear increased the most also under the influence of nitrogen from 27 to 40 pieces, as well as from the application of other fertilizers from 40 to 49 pieces.

The most yield of winter wheat depended on the weight of grain from the ear. If on the control it was only 0.78 g, then with the application of N_{180} increased to 1.10 g. All other types of fertilizers increased the weight of grain from the ear, as a result, it increased to 1.48 g, i.e. it increased almost twice.

The yield of winter wheat of the Kubus variety also changed under the influence of fertilizers in a significant range. On the control it was only 3.64 t / ha. The application of nitrogen, phosphorus, potassium, as expected, had the greatest impact on the level of winter wheat grain yield.

The research was carried out on dark grey podzolic soils which were characterized by a very low nitrogen content before the experiment. It is known that the content of mineral nitrogen in the soil is one of the most important factors on which depends both the high grain yield of winter wheat and its quality (Partika et al., 2020). As a result, the largest increase of the yield in our studies was provided by nitrogen fertilizers – 2.94 t/ha or 80.8% (Table 2).

Winter wheat reacts so strongly to nitrogen that fertilization at certain stages of growth can affect the value of almost all elements of productivity. The greatest impact on yield was due to a significant increase of two main elements of yield – ear density and grain weight from one ear.

Table 1. Indicators of the structure of the yield of winter wheat variety Kubus depending on fertilizers (average for 2018–2020) (x ± SD, n = 9)

№	Fertilizers	Number of ears, pcs / m^2	Coefficient of productive tillering	Number spikelets in the ear, pcs.	The number of grains in the ear, pcs.	Weight of grain from one ear, g
1	Without fertilizers (control)	480±7.0^{d}	1.8±0.06^{b}	14±1.0^{b}	27±2.00^{d}	0.78±0.03^{e}
2	N_{180}	610±4.7^{c}	3.0±0.06^{a}	16±0.58^{ab}	40±1.53^{c}	1.10±0.10^{d}
3	$N_{180}+P_{60}$	620±5.0^{bc}	3.0±0.06^{a}	17±0.58^{a}	44±1.15^{bc}	1.25±0.04^{c}
4	$N_{180}P_{60}+K_{90}$	630±7.2^{ab}	3.1±0.06^{a}	17±1.15^{a}	46±2.00^{ab}	1.33±0.03^{bc}
5	$N_{180}P_{60}K_{90}+S_{30}$	634±3.8^{ab}	3.1±0.06^{a}	17±1.00^{a}	48±0.58^{ab}	1.39±0.02^{ab}
6	$N_{180}P_{60}K_{90}S_{30}+Mg_{20}$	640±4.5^{a}	3.1±0.06^{a}	18±0.58^{a}	49±1.53^{a}	1.44±0.02^{ab}
7	$N_{180}P_{60}K_{90}S_{30}Mg_{20}$ + Microfertilizer Intermag grain	642±3.5^{a}	3.1±0.03^{a}	18±0.58^{a}	49±0.58^{a}	1.48±0.01^{a}

Note: Values that have at least one identical letter within a table column do not differ when using the Tukey test ($p < 0.05$)

Table 2. Yield of winter wheat variety Kubus depending on fertilizers, t/ha (x ± SD, n = 9)

№	Fertilizers	2018	2019	2020	Average for three years	Yield increase	
						t/ha	%
1	Without fertilizers (control)	$3.60{\pm}0.05^{f}$	$3.50{\pm}0.08^{f}$	$3.82{\pm}0.07^{g}$	$3.64{\pm}0.16^{e}$	–	–
2	N_{180}	$6.44{\pm}0.04^{e}$	$6.42{\pm}0.13^{e}$	$6.88{\pm}0.05^{f}$	$6.58{\pm}0.26^{d}$	2.94	80.8
3	$N_{180} + P_{60}$	$7.23{\pm}0.09^{d}$	$7.20{\pm}0.19^{d}$	$7.80{\pm}0.13^{e}$	$7.41{\pm}0.34^{cd}$	3.77	103.6
4	$N_{180}P_{60} + K_{90}$	$7.85{\pm}0.08^{c}$	$7.85{\pm}0.05^{c}$	$8.45{\pm}0.04^{d}$	$8.05{\pm}0.35^{bc}$	4.41	121.2
5	$N_{180}P_{60}K_{90} + S_{30}$	$8.30{\pm}0.08^{b}$	$8.26{\pm}0.24^{bc}$	$8.88{\pm}0.06^{c}$	$8.48{\pm}0.35^{ab}$	4.84	133.0
6	$N_{180}P_{60}K_{90}S_{30} + Mg_{20}$	$8.67{\pm}0.08^{a}$	$8.58{\pm}0.06^{ab}$	$9.24{\pm}0.11^{b}$	$8.83{\pm}0.36^{ab}$	5.19	142.6
7	$N_{180}P_{60}K_{90}S_{30}Mg_{20}$ + Micro-fertilizer Intermag grain	$9.00{\pm}0.29^{a}$	$8.92{\pm}0.35^{a}$	$9.50{\pm}0.07^{a}$	$9.14{\pm}0.31^{a}$	5.50	151.1

Note: Values that have at least one identical letter within a table column do not differ when using the Tukey test ($p < 0.05$)

Phosphorus has a positive effect on all processes of plant life. Phosphorus fertilizers, first of all, provided better development of the root system and increased the number of grains in the ear, as a result, the yield increased to 7.41 t/ha, or by 0.83 t/ha (Table 2).

The increase of the yield by 0.64 t/ha under the influence of potash fertilizers also occurred due to higher quantity of grains in the ear. Potassium activates a number of enzymes, increases resistance to diseases, activates the movement of carbohydrates from the vegetative organs to the ear, promotes better grain filling, increases protein content.

It was important to establish the impact on the yield of nutrients that are not always applied in the cultivation of winter wheat. The analysis of the results of our research shows that sulfur fertilizers increased the yield by 0.43 t/ha. This was due to the optimization of physiological processes, in particular the intensification of nitrogen assimilation. Highly effective effect of nitrogen on the growth of wheat yield is impossible without sufficient supply of sulfur to plants.

Magnesium fertilizers increased the yield by 0.35 t/ha. Magnesium affects all processes in plant cells, where the transfer of chemical energy is occured, or its accumulation (photosynthesis, respiration, glycolysis, etc.). Magnesium is especially important for the absorption of nitrogen, phosphorus and potassium in large quantities. This element is part of chlorophyll and increases the intensity of photosynthetic activity. Activates an enzyme that catalyzes the participation of CO_2 in photosynthesis. In the amount of magnesium and sulfur application led to the increase of grain yield by 0.78 t/ha. Under the influence of phosphorus, potassium, sulfur and magnesium, the yield increased by 2.25 t/ha (Table 3).

Table 3. The increase of the grain yield of winter wheat from nutrients (average for 2018-2020)

№	Yield increase from application	Indicators of yield	Increase of yield	
			t/ha	%
1	Nitrogen N_{180}	6.58 – 3.64	2.94	80.8
2	Phosphorus P_{60}	7.41 – 6.58	0.83	22.8
3	Potassium K_{90}	8.05 – 7.41	0.64	17.6
4	Phosphorus P_{60}, Potassium K_{90}	8.05 – 6.58	1.47	40.4
5	Sulfur S_{30}	8.48 – 8.05	0.43	11.8
6	Phosphorus P_{60},Potassium K_{90}, Sulfur S_{30}	8.48 – 6.58	1.90	52.2
7	Magnesium Mg_{20}	8.83 – 8.48	0.35	9.6
8	Phosphorus P_{60}, Potassium K_{90}, Sulfur S_{30} Magnesium Mg_{20}	8.83 – 6.58	2.25	61.8
9	Magnesium Mg_{20}, Sulfur S_{30}	8.83 – 8.05	0.78	21.4
10	Microfertilizer Intermag grain	9.14 – 8.83	0.31	8.5
11	Phosphorus P_{60}, Potassium K_{90}, Magnesium Mg_{20}, Sulfur S_{30}, Micro	9.14 – 6.58	2.56	70.3
12	Nitrogen N_{180}, Phosphorus P_{60}, Potassium K_{90}, Magnesium Mg_{20}, Sulfur S_{30}, Micro	9.14 – 3.64	5.50	151.1

Table 4. Grain quality depending on fertilizers, average for 2018–2020 (x ± SD, n = 9)

№	Fertilizers	Mass of 1000 grains, g	Glassiness,%	Gluten content, %	Protein content,%
1	Without fertilizers (control)	42.3±2.12[b]	62±2.1[b]	18.8±0.21[e]	11.5±0.12[c]
2	N_{180}	49.4±0.36[a]	78±2.0[a]	28.0±0.76[d]	14.0±0.20[b]
3	$N_{180} + P_{60}$	50.0±0.47[a]	79±2.0[a]	28.1±0.40[cd]	14.1±0.06[ab]
4	$N_{180}P_{60} + K_{90}$	50.1±2.67[a]	80±4.0[a]	28.3±0.30[bcd]	14.1±0.06[ab]
5	$N_{180}P_{60}K_{90} + S_{30}$	50.4±0.35[a]	82±2.6[a]	28.7±0.21[abcd]	14.3±0.06[ab]
6	$N_{180}P_{60}K_{90}S_{30} + Mg_{20}$	50.8±1.12[a]	83±1.5[a]	29.1±0.10[abc]	14.3±0.15[ab]
7	$N_{180}P_{60}K_{90}\ S_{30}Mg_{20}$ + Microfertilizer	51.0±0.40[a]	84±2.6[a]	29.4±0.06[a]	14.4±0.12[a]

Note: Values that have at least one identical letter within a table column do not differ when using the Tukey test ($p < 0.05$)

Table 5. The relationship between the yield of winter wheat Kubus with the main indicators of structure

Indicator	Equation	Multiple correlation coefficient, R	Determination coefficient, D
The number of grains in the ear, pcs	$Y = 16.3045 - 0.6564X + 0.0103X^2$	0.992	98.4
Weight of grain from one ear, g	$Y = 4.8661 - 2.3786X_1 + 3.5693X_1^2$	0.998	99.6

Note: Y – yield, t/ha; X – the number of grains in the ear, pcs.; X_1 – weight of grain from one ear, g

Table 6. The relationship between the yield of winter wheat Kubus with the amount of gluten and protein in the grain

Indicator	Equation	Multiple correlation coefficient, R	Determination coefficient, D
The amount of gluten,%	$Y = 54.3980 - 4.7711X + 0.1102X^2$	0.984	96.8
The amount of protein,%	$Y = 234.4379 - 37.6469X_1 + 1.5285X_1^2$	0.987	97.4

Note: Y – yield, t/ha; X – the amount of gluten, %; X_1 – the amount of protein, %

The application of Intermag grain microfertilizer in the feed system of winter wheat provided the yield increase by 0.31 t/ha, on the seventh variant it was the highest in the researches and amounted 9.14 t/ha. In the presence of the required number of trace elements, plants synthesize a full range of enzymes that allow more intensive use of energy, water, nutrients to form higher yields. In the conditions of the growing zone, manganese and copper are the most effective for winter wheat. Manganese improves the application of nitrogen by plants, promotes the synthesis and increase of sugar content in the leaves. Copper has a great influence on the formation of generative organs. The increase of the yield is due to the improvement of photosynthesis, metabolic reactions, the influence of certain trace elements to increase resistance to diseases: brown rust – zinc, copper; stem rust – iron, manganese; powdery mildew – boron, manganese; helminthosporiosis – manganese.

It should be noted that the largest increase of winter wheat grain yield (2.94 t/ha) is expected to be obtained from nitrogen fertilizers. Under the influence of other nutrients, the yield increased much less, but the total increase from phosphorus, potassium, sulfur, magnesium and microfertilizers is 2.56 t/ha (70.3%), which is almost equal to the increase from nitrogen. In general, under the influence of fertilizers, the yield increased from 3.64 t/ha to 9.14 t/ha, or by 5.50 t/ha (by 151.1%).

Fertilizers also had a positive effect on wheat grain quality indicators. As can be seen from table. 4, nitrogen fertilizers also had the greatest impact on grain quality. Thus, the mass of 1000 grains under the influence of nitrogen fertilizers increased by 7.1 g, while from all other nutrients only by 1.6 g. The glassiness of the grain increased from nitrogen by 16%, from other elements by 6%. The most important quality indicators are the content of gluten and protein in the grain. The gluten content increased by 9.2% from nitrogen application, while it increased by only 1.4% from the total action of other elements. The protein content under the influence of nitrogen fertilizers increased from 11.5% to 14.0%, and from other nutrients from 14.0% to 14.4%.

In addition, according to the results of correlation-regression analysis, on the background of applied fertilizers, a close relationship was established between winter wheat yield and grain structure and quality indicators, which is reflected in the equations presented in Tables 5 and 6.

The calculated mathematical models are 95% reliable according to the Fisher criterion and the Student's criterion and make it possible to predict the yield of winter wheat from the structure and quality of grain included in the equations.

It should be noted that the relationship between winter wheat yield and structure indicators was slightly closer (R = 0.992; 0.998) compared to grain quality indicators (R = 0.984; 0.987).

Conclusions

Mineral fertilizers contributed to the growth of crop structure, in particular, the number of ears increased from 480 pcs/m^2 on the control to 642 pcs/m^2 at the highest rate of fertilizers, the weight of grain per ear, respectively, from 0.78 g to 1.48 g.

The grain yield of Cubus winter wheat increased from 3.64 t/ha on the variant without fertilizers to 9.14 t/ha with the application of $N_{180}P_{60}K_{90}S_{30}Mg_{20}$ + Microfertilizer Intermag grain , i.e. by 5.50 t/ha, or by 151.1%. The largest increase of grain was provided by nitrogen fertilizers – 2.94 t/ha (80.8%), the total increase of the yield from the application of potassium, phosphorus, sulfur, magnesium and microfertilizers is 2.56 t/ha (70.3%). The expediency of including sulfur and magnesium in the fertilizer system has been established.

Nitrogen fertilizers also had the greatest impact on grain quality indicators: the gluten content increases from 18.8% on the variant without fertilizers to 28.0%, for N_{180} application, the protein content, respectively, from 11.5% to 14.0%. From the application of potassium, phosphorus, sulfur, magnesium and microfertilizers, the gluten content increased by 1.4%, the protein content – only by 0.4%.

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