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INFLUENCE OF FERTILIZERS ON PHOTOSYNTHETIC AND PRODUCTION CAPABILITY OF WINTER WHEAT UNDER MODERATE HUMIDIFICATION

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Abstract

The regulation of plants mineral nutrition using complex microfertilizers makes it possible to increase the productive capacity of wheat by optimizing physiological processes. Microelements that are part of enzymatic systems improve metabolism, contribute to the normal course of physiological processes that affect photosynthesis. Under the influence of microelements, the resistance of plants to diseases and adverse environmental conditions increases, the assimilation of macroelements from the soil and fertilizers improves. The lack of minor elements leads to a violation of the physiological processes in the plant's body and, as a result, a decrease in yield and a deterioration in its quality. The combination of various minor elements forms various types of microfertilizers. The goal of this research was represented by the microfertilizers Atlantica "Raikat Development", "All Inclusive", Wuxal "Microplant", Polidon "Complex", introduced on a different agricultural background (without fertilizers, recommended –$N_{90}P_{60}$ and calculated –$N_{186}P_{95}K_{45}$). An integrated approach was used, carried out in 2020–2022 in the moderate moisture zone in the Central Ciscaucasia, based on the use of field measurements of the spectral properties of the winter wheat plants physiological state and laboratory studies of micro- and macroelements of fertilizers. A dispersion analysis of the indicators correlation reflecting the physiological state of plants, nitrogen and winter wheat yields was carried out on various agricultural backgrounds.

Key words: *mineral fertilizers, microfertilizers, pigments, winter wheat, vegetation indices*

INTRODUCTION

Optimization of plant nutrition, increasing the efficiency of fertilizer application are largely associated with ensuring the optimal ratio of macro- and microelements in the soil. Moreover, the regulation of plants mineral nutrition, including the use of complex microfertilizers, is necessary to increase the productive capacity of wheat [14, 16].

Microelements are essential nutrients, without which plants cannot fully develop [7]. They are part of the most important physiologically active substances and are involved in the synthesis of proteins, carbohydrates, vitamins, and fats [5, 19].

Under the influence of microelements, plants become more resistant to adverse conditions of atmospheric and soil drought, low and high temperatures, damage by pests and diseases [10, 4].

The most important elements of mineral nutrition are nitrogen, phosphorus, sulfur and magnesium, used as a building material for the photosynthetic apparatus [5]. Iron, potassium, phosphorus, chlorine, copper and other elements that are not part of chloroplasts affect the accumulation of chlorophyll and, consequently, photosynthesis. In addition, nitrogen is an integral part of chlorophyll, which enhances its synthesis. With a lack of copper, chlorophyll is easily destroyed [21].

Potassium, changing the colloidal state of the cytoplasm, affects the photosynthesis intensity and the chlorophyll accumulation.

An excessive concentration of chemicals (for example, sodium and chlorine) leads to inhibition of the photosynthesis process and a decrease in yield [3, 6, 20]. Therefore, it is important that in certain phases of plant growth, the concentration of assimilates and formed substances be optimal for yield formation [6, 11, 17]. To do this, it is necessary to direct all agrotechnical measures (including fertilization) to create the best conditions by creating an appropriate agricultural background that ensures the growth of the photosynthetic apparatus [9, 12, 18].

Today, research is of interest that can integrate field measurements of the spectral properties of the winter wheat plants physiological state and laboratory studies of soil micro- and macroelements. This approach is useful for developing effective strategies for predicting the productivity of wheat based on the planning of agrotechnological measures [15].

The purpose of our study is to analyze the effect of various doses of mineral fertilizers and complex micronutrient fertilizers on the correlation between indicators characterizing the state of the pigment complex, nitrogen content and winter wheat productivity.

The work was carried out on the territory of the educational and experimental farm of the Stavropol State Agrarian University. The soil is leached chernozem with an average supply of organic matter (5.1–5.4%), $N-NO_3$(16–30 mg/kg), P_2O_5 and K_2O (respectively 20–25 mg/kg and 220–270 mg/kg), as well as mobile forms of manganese (16.1–17.0 mg/kg); low availability of zinc (0.5–0.6 mg/kg) and copper (0.12–0.18 mg/kg). The reaction of the soil solution is neutral (6.1–6.5 units).

The subject of our research was complex microfertilizers:

- Atlantica «Raikat Development» (manufactured in Spain) – liquid organomineral fertilizer (N – 6%, P_2O – 4.0%, K_2O– 3.0%, B – 0.03%, Fe – 0.1%, Zn – 0.01%, Cu – 0.01%, Mn – 0.02%);
- «All Inclusive» (manufactured in Russia) – a complex liquid fertilizer, which includes low molecular weight humic acid with active molecules in the chelate form (N – 6–9%, P_2O_5– 0.5%, K_2O– 2.0%, S – 2.0-2.5%, MgO – 1.6-2.0%, Na – 0.5-0.7%, B – 0.2%, CaO – 0.5–1.0%, Fe – 0.6–0.9%, Zn – 1.6–2.0%, Cu – 0.5–0.7%, Mn – 0.4–0.6%, Co – 0.01–0.025%, Ni – 0.08%, Li –0.01%, Ag – 0.003%);
- Wuxal «Microplant» (manufactured in Germany) – a highly concentrated suspension of microelements (N – 7.8%, K_2O– 15.7%, MgO – 4.7%, SO3 – 20.3%, B – 0.5%, in chelate form: Cu – 0.8%, Fe – 1.6%, Mn – 2.4%, Zn – 1.6%, Mo – 0.01%);
- Polidon «Complex» (manufactured in Russia) – liquid microelement fertilizer (N, P_2O_5, Fe – 4.5%, Mn – 2.5%, Cu – 1.5%, Zn – 1.5%, B – 0.5%, Mo – 0.5%, Co – 0.05%).

MATERIALS AND METHODS

The meteorological conditions of the experimental zone are characterized by moderate moisture, but uneven precipitation throughout the year. According to long-term data, the average annual precipitation is 551 mm, the sum of active temperatures is 3,000–3,200 °C.

Microfertilizers were applied in the tillering phases and the beginning of stem elongation at a dose of 1 l/ha on various agricultural backgrounds:

- control (without fertilizers);
- recommended dose of mineral fertilizers (proposed by scientists of the Stavropol State Agrarian University) –$N_{90}P_{60}$;
- estimated dose for the planned yield of 7.5 t/ha –$N_{186}P_{95}K_{45}$.

The object of research is winter wheat. The predecessor is peas.

Application of the recommended dose: when sowing ammophos 115 kg/ha ($N_{14}P_{60}$), feeding with ammonium nitrate at 109 kg/ha in the tillering phase N_{38} and stem elongationN_{38}.

The calculated dose of mineral fertilizers was applied 281 kg/ha of nitroammophoska ($N_{45}P_{45}K_{45}$) and 96 kg/ha of ammophos ($N_{11}P_{50}$) for the main tillage, fertilizing with ammonium nitrate at 186 kg/ha in the tillering phase (N_{65}), going to stem elongation (N_{65}).

To determine the pigment complex - chlorophyll a, chlorophyll b, carotenoids, and nitrogen in plants, a spectral analysis of the leaf surface was performed with a PolyPen RP 410 NIR spectroradiometer, calculating data on: chlorophyll a [1]; chlorophyll b [8]; nitrogen [13]; carotenoids [2].

The analysis of variance method was used to calculate the correlation coefficients. Statistical processing of the results was carried out using the program Statistics.

RESULTS AND DISCUSSIONS

The photosynthetic productivity of crops is of great importance in the crop formation. It depends on the state of the photosynthetic apparatus functioning throughout the entire period of plant development. The results of the research analysis indicate a very high correlation between chlorophyll a and chlorophyll b in all phases of plant development and mineral nutrition backgrounds (statistical significance 0.95%).

In the stem elongation stage, the correlation was in the range of 0.958–0.983, as shown in Table 1. The closest correlation between chlorophylls a and b was noted at the beginning of flowering (0.978–0.987). Therefore, this fact indicates the readiness of the plant for flowering. Carotenoids are present in chloroplasts, which allows us to consider them as participants in the photosynthesis process. There is an opinion that the content of carotenoids in leaves decreases during the plants flowering period [20].

Analysis of the correlation between the ratio of chlorophyll a / chlorophyll b and the content of carotenoids showed a weak correlation between the values of these indicators for all phases of crop development and agricultural backgrounds (Table 1).

Table 1. Correlation of chlorophyll a and chlorophyll b according to the experiment variants (average)

Soil preparation	**Phase correlation, r**	
	Stem elongation	Flowering
Control	0.964	0.978
Recommended	0.958	0.987
Calculated	0.983	0.986

Source: Developed by the authors.

In the stem elongation stage, the coefficient was 0.103–0.404; in the flowering phase, 0.280–0.351.

There was a tendency to decrease the strength of the correlation between the values of the indicators to the flowering phase for all options, with the exception of the recommended dose, where the strength of the correlation varies from weak to moderate.

Moreover, in the stem elongation stage, the lowest bond strength was observed according to $N_{90}P_{60}$ (0.103), and in the flowering phase, according to the calculated one (0.280) (Table 2).

Table 2. Correlation of chlorophyll a/chlorophyll b indices and carotenoids by experiment variants (average)

Soil preparation	**Phase correlation, r**	
	Stem elongation	Flowering
Control	0.404	0.351
Recommended	0.103	0.327
Calculated	0.357	0.280

Source: Developed by the authors.

Perhaps the weak dependence is due to the carotenoids instability as a result of their isoprenoid structure, which implies a variable number of conjugated double bonds. Carotenoids are metabolites of isoprenoids synthesized de novo (synthesis of complex molecules from simple ones).

Against the background of the external environment, their concentration was determined by the agricultural background and the use of microfertilizers and had little effect on the change in plants processes (including photosynthesis).

Therefore, carotenoid derivatives act only as signaling molecules, they are regulators of plant growth and crop productivity. Such conclusions are confirmed in foreign studies [4, 20].

The application of nitrogen fertilizers causes an increase in the photosynthetic activity of plants, since numerous enzyme proteins are involved in this process [20].

Correlation analysis, reflected in Table 3, shows the ratio of chlorophyll a/chlorophyll b and nitrogen content (with a statistical significance of 0.95%) in the stem elongation phase and reflected a significant correlation at $N_{186}P_{95}K_{45}$, almost no correlation in the control and $N_{90}P_{90}$, and strong (0.733–0.799) in the flowering phase for all variants.

Table 3. Correlation between chlorophyll a/chlorophyll b and nitrogen indices by experiment variants (average)

Soil preparation	**Phase correlation, r**	
	Stem elongation	Flowering
Control	0.057	0.737
Recommended	0.164	0.733
Calculated	0.581	0.799

Source: Developed by the authors.

The use of all variants of microfertilizers with full control (without macrofertilizers) and the introduction of the recommended and calculated doses of macrofertilizers increased the tightness of the correlation between the pigment complex and nitrogen. The closest correlations between them in the control were noted after the introduction of the «All Inclusive» microfertilizer and, as shown in Table 4, between the accumulation of chlorophyll a and b in the stem elongation phase – 0.981, in the flowering phase – 0.994; the ratio of chlorophylls and carotenoids, 0.667 and 0.707, respectively; the ratio of chlorophylls and nitrogen is 0.512 and 0.832.

The strength of the correlation between the ratio of chlorophyll a/chlorophyll b and nitrogen, according to our research, proved the correlation of the "chlorophyll-yield" system, since the maximum yield of winter wheat in terms of agricultural backgrounds was achieved precisely in the variants of using micronutrient fertilizers, where the tightest correlation between the pigment complex and nitrogen was noted.

Table 4. Correlation of the pigment complex indices and nitrogen according to the experiment variants (average)

Stem preparation	Microfertilizers	Phase					
		Stem elongation			Flowering		
		PSSRa and PSSRb	PSSRa/ PSSRband CRI_{500}	PSSRa PSSRb and N_{550}	PSSRa and PSSRb	PSSRa/ PSSRb And CRI_{500}	PSSRa/ PSSRb and N_{550}
Control	Control	0.960	0.359	0.268	0.970	0.447	0.548
	Atlantica «Raikat Development»	0.963	0.496	0.356	0.978	0.568	0.781
	«All Inclusive»	0.981	0.667	0.512	0.994	0.707	0.832
	Wuxal «Microplant»	0.965	0,535	0.363	0.989	0.652	0.720
	Polidon «Complex»	0.961	0.495	0.349	0.977	0.454	0.640
Recommended	Control	0.929	0.127	0.526	0.982	0.106	0.595
	Atlantica «Raikat Development»	0.933	0.225	0.574	0.990	0.392	0.664
	«All Inclusive»	0.961	0.407	0.582	0.990	0.654	0.818
	Wuxal «Microplant»	0.979	0.413	0.851	0.990	0.692	0.866
	Polidon «Complex»	0.975	0.325	0.566	0.982	0.413	0.702
Calculated	Control	0.964	0.085	0.535	0.969	0.250	0.568
	Atlantica «Raikat Development»	0.985	0.187	0.565	0.991	0.430	0.766
	«All Inclusive»	0.990	0.379	0.787	0.995	0.874	0.863
	Wuxal «Microplant»	0.986	0.205	0.777	0.993	0.550	0.828
	Polidon «Complex»	0.974	0.151	0.565	0.988	0.322	0.696

Indices: PSSRa, chlorophyll a; PSSRb index, chlorophyll b; index CRI_{500} - carotenoids; index N_{550} - nitrogen.
Source: Developed by the authors.

In particular, in the control variant (without fertilizers), the maximum yield in the experiment (3.79 t/ha) was observed with the «All Inclusive» application, which is 0.7 t/ha higher than in the variant without microfertilizers, as reflected in Table 5.

On the background of the recommended dose of macrofertilizers, the greatest increase in the experiment was provided by the application of Wuxal «Microplant» – 1.44 t/ha, in comparison with the control.

On the soil preparation with the calculated dose, the maximum yield, as well as the tightness of the correlation between the pigment complex and nitrogen, was noted with the application of «All Inclusive» – 7.74 t/ha (increase to the control 1.4 t/ha).

Table 5. Yield of winter wheat depending on the use of microfertilizers on different soil preparation, t/ha (average)

Dose of mineral fertilizers	Microfertilizers				
	Control	Atlantica «Raikat Development»	«All Inclusive»	Wuxal «Microplant»	Polidon «Complex»
Control	3.09±0.62	3.22±0.65	3.79±0.67	3.49±0.64	3.13±0.58
Recommended	4.95±0.35	5.49±0.20	6.35±0.14	6.39±0.47	5.84±0.09
Calculated	6.34±0.52	6.96±0.28	7.74±0.42	7.45±0.34	6.84±0.30

Source: Developed by the authors.

The largest average yield deviations were noted in the control (0.59–0.67 centner/ha), the smallest - when using the recommended dose (0.10–0.47 centner/ha) in combination with all types of microfertilizers.

Consequently, their use on the recommended agricultural background led not only to an increase in the productivity of the cultivated crop, but also to the stabilization of its yield.

In general, the analysis of the correlation between chlorophyll a/chlorophyll b, nitrogen and yield showed a medium and high degree of their interaction, as shown in Table 6.

Table 6. Correlation between the indices of the pigment complex, nitrogen and yield by experimental options (average)

Soil preparation	**Phase correlation, r**	
	Stem elongation	Flowering
Control	0.907	0.777
Recommended	0.653	0.972
Calculated	0.926	0.972

Source: Developed by the authors.

In the control, the correlation from very high to the flowering phase decreased to high, and on the recommended soil preparation, it increased from noticeable to very high.

CONCLUSIONS

Through our study, it became clear that on the leached chernozem in the zone of sufficient moisture in the control, the closest correlation between the pigment complex components (chlorophyll a and chlorophyll b), the ratio of chlorophylls and carotenoids, and between the ratio of chlorophyll a / chlorophyll b to nitrogen in the stem elongation and flowering phases achieved with the use of microfertilizer «All Inclusive»: respectively 0.981 and 0.994; 0.667 and 0.707; 0.512 and 0.832.

Against the background of $N_{90}P_{60}$, the strongest correlations were observed in the variant with microfertilizer Wuxal «Microplant»: 0.979 and 0.990, respectively; 0.413 and 0.692; 0.851 and 0.866, against the background of $N_{186}P_{95}K_{45}$ – «All inclusive»: 0.990 and 0.995; 0.379 and 0.874; 0.787 and 0.863.

The maximum yield of winter wheat in terms of soil preparation was achieved in the variants of using microfertilizers, where the tightest correlation between the pigment complex and nitrogen was noted: on a zero background when applying «All Inclusive»– 3.79 t/ha (increase to control 0.7 t/ha); against the background of the recommended dose when applying Wuxal «Microplant» – 6.39 t/ha (an increase of 1.44 t/ha); on the soil preparation with the estimated dose – «All inclusive» – 7.74 t/ha (increase to control 1.4 t/ha).

Our study showed that in experiments with microfertilizers «All Inclusive» and Wuxal «Microplant» yields are higher than in control, on average 1.2 times.

Through our research, it became clear that an integrated approach of field measurements of the spectral properties of the physiological state of winter wheat plants and laboratory studies of soil micro- and macroelements can be used to calculate the planned yield.

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