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SOIL SCIENCE

Influence of Nitrogen Fertilizers and Biopreparations on Productivity and Quality of Spring Wheat Grain

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Abstract—The results of research on the influence of biologics based on rhizosphere microorganisms on the yield of spring wheat grain on different backgrounds of mineral nutrition on sod-podzolic light-loamy soil are presented. It was found that inoculation of spring wheat seeds with biologics provides an increase in grain yield by 1.2–1.3 times, while nitrogen fertilizer at doses of N_{45} and N_{90} provide increases by two and 3.5 times, respectively. The collection of raw protein due to the improvement of nitrogen nutrition increases with the introduction of N_{45} by two times and with N_{90} by 3.6 times; that with the use of biological products is by 25–45%. The vast majority of the nitrogen consumed accumulated in the grain, while less in the straw. The grain of spring wheat, while improving the supply of nitrogen to plants during the growing season, contained 76–81% of this-element from the accumulated harvest. It is concluded that the use of biologics on sod-podzolic light-loamy soil has a positive effect on the growth of spring wheat grain mass, improves the quality of products, and increases the payback of mineral fertilizers by increasing the yield.

Keywords: spring wheat, microbial preparations, biopreparations, nitrogen fertilizers, raw protein, grain weight

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INTRODUCTION

The contemporary development of agriculture in Russia that implies the wide use of adaptive-landscape farming systems and decrease in the use of mineral fertilizers in comparison with 1990 (from 83 to 57 kg/ha) results in increased importance of additional nutritious elements for plants, especially nitrogen [1–3]. Lack of mineral nitrogen and the necessity to increase agricultural productivity at decreased energy expenses for the plant-breeding industry requires the complex use of both mineral and biological nitrogen [4].

Therefore, it is important to study utilization of biological nitrogen by plants since up to 70–90% of arable soil nitrogen is fixed from air by symbiotic, associated, and free-living microorganisms [5]. Moreover, the introduced microorganisms, which are used to inoculate the agricultural grains, stimulate plant growth and development and increase their resistance to biotic and antibiotic factors, including phytopathogens [5–9].

At the same time, rhizosphere microorganism-based biological preparations are not widely used in agriculture. Practical importance of the associated nitrogen fixation and its role in regulation of soil fertility are obviously underestimated [10, 11]. One of the factors that prevents the wide use of bacterial preparations in agriculture is the irregular repeatability of the inoculation results, which complicates the reliable prognosis of plant reaction [12, 13].

The goals of this study were to scientifically explain the effects of rhizosphere microbial-based biopreparations on spring grain cultures and to reveal the principles of their influence on nitrogen utilization by plants.

MATERIALS AND METHODS

The effect of the rhizosphere bacteria-based biopreparations and the role of different nutrition sources in the formation of spring wheat productivity has been studied in a microfield experiment in accordance with the scheme given in Table 1. Spring wheat (*Triticum aestivum L.*) cultivar *Zlata* grains inoculated with rhizosphere bacteria were sown. The microfield experiment was carried out in 2018–2019 in bottomless flasks with the area of 0.018 m^2 on the sod-podzol light-loamy soil from Smolensk oblast with the following agrochemical parameters: humus content (by Turin)—1.91–1.96%; mobile forms of P_2O_5 and K_2O (by Kirsanov)—125.1–140.8 and 129.0–166.0 μg of soil, respectively; pH_{KCl} 5.6–5.7. The experiment was repeated four times. To improve the appreciation of the results obtained, the corresponding parameters are represented as g/m^2. Buckwheat was the ancestor of spring wheat.

Mineral fertilizers were introduced while filling the flasks with soil. We used ammonium nitrate ($^{15}NH_4{}^{15}NO_3$) with 54.04 at % enrichment in the doses of 81 mg per flask and 162 mg per flask, which corresponded to 45 and 90 kg N/ha. Double superphosphate and potassium chloride in the doses of $P_{45}K_{45}$ were used both in the background and control. On the day of sowing, spring wheat grains were treated with microbiological preparations: *Rhizoagrin* (*RA*), which is based upon the 204 strain of *Agrobacterium radiobacter*, able to fix atmospheric nitrogen and transform it into the easily assimilable forms; KL-10, which is based on the associated rhizobacterium strain that belongs to the *Pseudomonas sp.* and was isolated from barley rhizosphere and characterized by high growth-stimulating activity; 17-1, which is based on the associated rhizobacterium strain that belongs to the *Pseudomonas sp*. It was isolated from barley rhizosphere and is characterized by high antifungal activity with respect to a large spectrum of phytopathogenic fungi as well as by high growth stimulating activity. Preparations, which contained 5–10 milliards bacterial cells per 1 g, were represented by powdery peat substrates with 45–50% humidity. These strains are well accustomed in the rhizosphere of cereal plants [14]. The study was carried out using the conventional methods of soil and plant analysis. Selyaninov's hydrothermal coefficient (HTC) was estimated as the ratio of total precipitation (O) expressed in mm for the period of average daily air temperature higher than 10°C to the sum of temperatures ($\sum t$) for the same period decreased ten times, i.e., $HTC = O/0.1\sum t$. The statistical data processing was performed by dispersion analysis with the model of a three-factor field experiment using the Excel and Statistica programs. Confidence of differences was assessed by the F-method of Fisher.

Meteorological conditions during the vegetation period significantly affected the efficacy of nitrogen fertilizers and grain inoculation with biopreparations [14, 15]. Weather conditions in the years of the experiment were different. The vegetation period in 2018 was characterized by mainly increased air temperature and extremely uneven distribution of atmospheric precipitation. In May–June, the amount of precipitations reached 65% of the average for several years, while it reached 268% in July. The HTC for the spring wheat vegetation period was 1.78. In May–June of 2019, the air temperature was 2.5–4.6°C higher than the climatic norm and was associated with significant level of precipitations (+14% to the average for several years). This allowed plants to accumulate significant biomass. Weather conditions in July–August of 2019 were similar to those of the climatic norm. The HTC for the spring wheat vegetation period was 1.31.

RESULTS AND DISCUSSION

Weight of the spring wheat grain depended on the fertilizers and biopreparations used (Table 1), and it also varied in different years because of changing hydrothermal conditions during the vegetation periods. Lack of moisture in the phenological stages of 2018 (shoots–booting) led to the significant decrease in the grain yield by 24–40% from the average for the years of the study. Use of the phosphorus-potassium fertilizers (PP) resulted in an average grain weight of 105.7 g/m^2. Improvement of nitrogen nutrition of plants provided by introduction of the N_{45} dose of fertilizer of the same name led to a more than twofold increase in the average grain weight, while use of the N_{50} dose increased it 3.5-times. Inoculation of spring wheat grains with *Rhizoagrin* at the background use of phosphorus-potassium fertilizers provided a 25% increase in the grain weight on average for 2 years; treatment with the KL-10 provided a 33% increase and the 17-1 strain provided 22%. Therefore, inoculation of grains with rhizosphere bacteria provided lower increase in the grain weight as compared with the N_{45} nitrogen fertilizer due to low level of nitrogen available for plants in soil [14, 16, 17].

The agricultural efficacy of the yield is significantly affected by weather conditions during the vegetation period. The highest value of this parameter (0.42–0.48) was observed in 2019 when sufficient humidity and favorable temperature conditions took place (HTC 1.31). Droughty vegetation conditions in 2018 resulted in significant decrease in the spring wheat grain weight and agricultural coefficient, which reached 0.32–0.42 in most cases. This effect was due to the decrease in the caryopsis weight and the number of seeds in the ear (the weight of 1000 seeds was decreased by 7–12% and the number of seeds in the ear by 1.3–2.2 times).

The agricultural coefficient (C_{agr}) was more affected by the increase in the level of nitrogen fertilizer dose up to N_{90} at the background of $P_{45}K_{45}$. The C_{agr} value was 0.46, which is 18% higher than at the background use of phosphorus-potassium fertilizers due to the increase in the portion of grains in the general biological yield. This is, apparently, due to the changes in the donor-acceptor relationships between the ear and vegetative mass [16]. When phosphorus-potassium fertilizers and the N_{45}PP were used, no significant differences in the C_{agr} values were observed. We also observed a positive tendency in the growth of this parameter when the spring wheat grains were inoculated with biopreparations, especially with the 17-1 strain (+8%).

The use of mineral nitrogen fertilizer affected the nitrogen distribution among the individual organs of spring wheat. The major fraction of the nitrogen consumed was accumulated in grains, while it was to a smaller degree in the straw. When plants were better

Table 1. Efficacy of fertilizers and rhizosphere bacterium biopreparations with respect to spring wheat on an average for 2 years

Variation	Grain weight, g/m^2	C_{agr}	Increase in the grain weight with respect to the control		Content N, %		Nitrogen index, %
			g/m^2	%	grain	straw	
Background—$P_{45}K_{45}$ (BG)—control	105.7	0.39	–	–	1.78	0.42	74
BG + Rhizoagrin (RA)	132.4	0.41	26.7	25	1.94	0.45	75
BG + KL-10 strain	140.1	0.40	34.4	33	1.94	0.45	74
BG + 17-1	128.5	0.42	22.8	22	1.83	0.37	78
BG + N_{45}	219.7	0.42	114.0	108	1.70	0.36	77
BG + N_{45} + RA	225.8	0.40	120.1	114	1.71	0.34	77
BG + N_{45} + KL-10 strain	243.3	0.41	137.6	130	1.82	0.35	78
BG + N_{45} + 17-1 strain	242.6	0.42	136.9	130	1.76	0.40	76
BG + N_{90}	369.3	0.46	263.6	249	1.83	0.37	81
P, %	4.43	3.11	4.43		2.74	3.41	
Lowest confident difference, LSD_{05} A—fertilizer	8.9	0.02	8.9		0.03	0.02	
LSD_{05} B—biopreparation	20.6	0.02	20.6		0.06	0.03	
LSD_{05} of individual differences	30.5	0.03	30.5		0.09	0.05	

supplied with nitrogen during the vegetation period, the grains accumulated up to 76–81% of yield nitrogen. This proves the efficacy of nitrogen utilization by plants in order to form the agriculturally valuable portion of the spring wheat yield. In case of lack of nitrogen (the variation of the PP), plants were forced to reutilize the nitrogen consumed from the vegetative organs into the generative ones (grains), especially under the conditions of either insufficient excessive humidity. This was demonstrated by the portion of grain nitrogen (74%) from the total nitrogen accumulated in the overground biomass.

The efficacy of nitrogen utilization is assessed by its accumulation in plants, first of all in grains, which directly affects the protein level. It was shown that the content of nitrogen in protein in grains is highly variable and depends on growing conditions (modification variability) and hereditary (genotypic) features [18]. In our experiment, the nitrogen content in grains of plants grown in the presence of fertilizers and microbial biopreparations was 1.7–1.94%. In the presence of phosphorus and potassium fertilizers, the level of nitrogen in the spring wheat grains reached 1.78%. Introduction of the nitrogen fertilizer in the N_{45} dose led to the decrease in the nitrogen content to 1.70% due to the growth-related dilution. Sufficient humidification at the tillering stage sustains the further formation of a higher number of grains in the ear and increases growth-related nitrogen dilution in the plant owing to the increase in productivity at the same nitrogen storage in soil [19]. Introduction of the nitrogen fertilizer in the N_{90} dose resulted in a positive tendency towards the increase in the nitrogen content in grains by 0.05%. Inoculation of the spring wheat grains with biopreparations confidently increased the nitrogen level in grains by 0.05–0.16% due to the improvement of plant nutrition.

Nitrogen concentration in the spring wheat straw was decreased in the presence of fertilizers because of the growth-related dilution. In the case of inoculation with biopreparations, no significant changes were observed.

The grain protein content was significantly affected by hydrothermal conditions during the vegetation period (Table 2). Insufficient precipitation level in May–June 2018 led to a 12.0–14.3% protein level in grains. In 2019, which was characterized by normal humidity, the level of protein in grains was decreased by 2.5–5.1%. Introduction of the nitrogen fertilizer in the N_{45} dose led to the decrease in the protein level due to the growth-related dilution, while positive tendency towards the increase in this parameter was observed in the dose of N_{90}. At the same time, introduction of the N_{45} dose of nitrogen fertilizer led to a two times increase in the protein collection because of the increase in the grain weight. Introduction of the N_{90} dose of nitrogen fertilizer increased the protein collection 3.6 times. Confident effect of biopreparations was only observed in 2018. Introduction of phosphorus-potassium fertilizers, as well as inoculation of grains with biopreparations, led to the increase in the grain weight and protein collection in comparison with the use of mineral fertilizers. This confirms the improvement of nitrogen nutrition in plants because of associated nitrogen fixation (RA) and growth-stimulating activity of the microbial preparations studied.

Table 2. Content and collection of the grain protein

Variation	Raw grain protein content, %			Raw protein collection, g/m^2		
	2018	2019	mean	2018	2019	mean
Background–$P_{45}K_{45}$ (BG)	12.0	9.0	10.1	9.6	11.8	10.7
BG + Rhizoagrin (RA)	13.1	9.9	11.1	12.5	16.8	14.7
BG + KL-10 strain	14.3	9.2	11.1	14.9	16.1	15.5
BG + 17-1	13.3	8.8	10.4	12.3	14.5	13.4
BG + N_{45}	12.3	8.5	9.7	16.9	25.6	21.3
BG + N_{45} + RA	12.1	8.6	9.7	18.2	25.7	22.0
BG + N_{45} + KL-10 strain	12.9	9.1	10.3	20.5	29.9	25.2
BG + N_{45} + 17-1 strain	11.7	9.3	10.0	17.0	31.6	24.3
BG + N_{90}	13.1	9.2	10.5	30.6	46.7	38.6
LSD_{05} of individual differences	0.4	0.5	0.5	0.5	1.3	1.0

Table 3. Nutritious element carry out (g/m^2) by spring wheat with the grain yield and straw

Variation		Grain		Straw		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Background–$P_{45}K_{45}$ (BG)	1.88	1.68	2.08	0.67	0.73	0.62
BG + Rhizoagrin (RA)	2.57	2.20	2.95	0.85	0.99	0.71
BG + KL-10 strain	2.72	2.61	2.83	0.94	1.12	0.76
BG + 17-1	2.35	2.16	2.55	0.67	0.74	0.61
BG + N_{45}	3.73	2.96	4.49	1.09	1.13	1.04
BG + N_{45} + RA	3.86	3.19	4.52	1.18	1.12	1.23
BG + N_{45} + KL-10 strain	4.43	3.59	5.24	1.24	1.14	1.34
BG + N_{45} + 17-1 strain	4.27	2.98	5.54	1.31	1.33	1.30
BG + N_{90}	6.76	5.37	8.19	1.61	1.43	1.79
LSD_{05} of individual differences	0.31	0.23	0.29	0.16	0.21	0.24

Nitrogen carry-over depended on biological specificity of the culture and soil conditions (Table 3). Introduction of the N_{45} dose sustained the increase by two times of the nitrogen carry-out, whereas the N_{90} dose increased this parameter 3.6-fold at the background presence of phosphorus-potassium fertilizers. Inoculation of grains with biopreparations facilitated a 1.2–1.4-times increase in nitrogen accumulation at the background presence of nitrogen-phosphorus-potassium fertilizers, though this increase was lower in comparison with that in the presence of the nitrogen fertilizer. Use of the nitrogen fertilizer and biopreparations increased the nitrogen carry-out from the spring wheat biomass by 2.1–2.4-times.

Phosphorus and potassium carry-out was determined by their concentration in grain as well as by the level of grain productivity. Introduction of the nitrogen fertilizer in the N_{45} dose resulted in a 1.8-times increase in the phosphorus carry-out and 2.2-times increase in the potassium carry-out. Use of the N_{90} dose led to the 3.2- and 3.9-times increase in the phosphorus and potassium consumption, respectively. Inoculation of the spring wheat grains with biopreparations facilitated the increase in the grain productivity as well as 1.3–1.6- and 1.2–1.4-times increase in the phosphorus and potassium carry-out respectively.

Therefore, introduction of biopreparations into the sod-podzolic light-loamy soil increases the spring wheat grain weight, improves the quality of the production obtained, and increases the recoupment of mineral fertilizers by the increase in productivity.

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COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

REFERENCES

1. Sychev, V.G., Sokolov, O.A., Zavalin, A.A., and Shmyreva, N.Ya., *Rol' azota v intensifikatsii produktsionnogo protsessa sel'skokhozyaistvennykh kul'tur* (The Role of Nitrogen in the Intensification of Growing Crops), Vol. 2: *Ekologicheskie aspekty roli azota v produktsionnom protsesse* (Environmental Aspects of the Role of Nitrogen in the Production Process), Moscow: Vseross. Nauchno-Issled. Inst. Agrokhim., 2012.
2. Kudeyarov, V.N., Assessment of nutrient degradation of arable soils in Russia, *Vestn. Ros. Akad. Nauk,* 2015, vol. 85, no. 9, pp. 771–775.
3. Kudeyarov, V.N., Sokolov, M.S., and Glinushkin, A.P., The current state of soils of agrocenoses of Russia and measures for their improvement and rational use, *Agrokhimiya,* 2017, no. 6, pp. 3–11.
4. Tikhonovich, I.A. and Provorov, N.A., Agricultural microbiology as the basis of environmentally sustainable agricultural production: Fundamental and applied aspects, *S-kh. Biol.,* 2011, no. 3, pp. 3–9.
5. Tikhonovich, I.A. and Zavalin, A.A., Prospects for the use of nitrogen-fixing and phytostimulating microorganisms to increase the efficiency of the agro-industrial complex and improve the agro-ecological situation of the Russian Federation, *Plodorodie,* 2016, no. 5, pp. 28–32.
6. Pishchik, V.N., Vorob'ev, N.I., Moiseev, K.G., Sviridova, O.V., and Surin, V.G., Influence of *Bacillus subtilis* on the physiological state of wheat and the microbial community of the soil under different rates of nitrogen fertilizers, *Eurasian Soil Sci.,* 2015, vol. 48, pp. 77–84.
7. Rothballer, M., Schmid, M., and Hartmann, A., Diazotrophic bacterial endophytes in gramineae and other plants, *Microbiol. Monogr.,* 2009, vol. 8, pp. 273–302.
8. Ruby, E.J. and Raghunath, T.M., A review: Bacterial endophytes and their bioprospecting, *J. Pharm. Res.,* 2011, vol. 4, no. 3, pp. 795–799.
9. Ohkama-Ohtsu, N. and Wasaki, J., Recent progress in plant nutrition research: Cross-talk between nutrients, plant physiology and soil microorganisms, *Plant Cell Physiol.,* 2010, vol. 51, pp. 1255–1264.
10. Shabaev, V.P., The role of biological nitrogen in the soil–plant system when introducing rhizospheric microorganisms, *Doctoral (Biol.) Dissertation,* Pushchino, 2004.
11. Ilyas, N. and Bano, A., *Azospirillum* strains isolated from roots and rhizosphere soil of wheat (*Triticum aestivum* L.) grown under different soil moisture conditions, *Biol. Fertil. Soils,* 2010, vol. 46, pp. 393–406.
12. Umarov, M.M., Nitrogen fixation in associations of organisms, *Probl. Agrokhim. Ekol.,* 2009, no. 2, pp. 22–26.
13. Skonieski, F.R., Viégas, J., Martin, T.N., Nörnberg, J.L., Meinerz, G.R., Tonin, T.J., Bernhard, P., and Frata, M.T., Effect of seed inoculation with *Azospirillum brasilense* and nitrogen fertilization rates on maize plant yield and silage quality, *Rev. Bras. Zootec.,* 2017, vol. 46. https://doi.org/10.1590/s1806- 92902017000900003
14. Zavalin, A.A., *Biopreparaty, udobreniya i urozhai* (Biological Products, Fertilizers, and Crops), Moscow: Vseross. Nauchno-Issled. Inst. Agrokhim., 2005.
15. Shaposhnikov, A.I., Belimov, A.A., Kravchenko, L.V., and Vivanko, D.M., Interaction of rhizospheric bacteria with plants: Formation mechanisms and efficiency factors of associative symbioses, *S-kh. Biol.,* 2011, no. 3, pp. 16–22.
16. Zavalin, A.A. and Sokolov, O.A., *Potoki azota v agroekosisteme: Ot idei D.N. Pryanishnikova do nashikh dnei* (Nitrogen Flows in the Agroecosystem: From the Ideas of D.N. Pryanishnikov to the Present), Moscow: Vseross. Nauchno-Issled. Inst. Agrokhim., 2016.
17. Kozhemyakov, A.P., Belobrova, S.N., and Orlova, A.G., Creation and analysis of a database on the efficiency of microbial biological products of complex action, *S-kh. Biol.,* 2011, no. 3, pp. 112–115.
18. Zavalin, A.A., *Azotnoe pitanie i produktivnost' sortov yarovoi pshenitsy* (Nitrogen Nutrition and Productivity of Spring Wheat Cultivars), Moscow: Agrokonsalt, 2003.
19. Pasynkova, E.N., Agrochemical methods of regulating the yield and quality of wheat grain, *Doctoral (Biol.) Dissertation,* Kirov, 2013.

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