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CROP PRODUCTION

Use of Microbial Strains to Increase Yields of Spring Soft Wheat (*Triticum aestivum* L.)

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Abstract—This paper presents the study results on the effect that presowing seed treatment and spraying nitrogen-fixing, phosphate-, and potassium-solubilizing bacteria on the seedlings of the Primorskaya 39 spring soft wheat (*Triticum aestivum* L.) cultivar have on the structural elements of productivity, yield, and the number of soil microorganisms. It was found that the total number of bacteria increases in the waxy ripeness stage when using both presowing treatment of seeds and spraying the microorganism strains on the seedlings. The maximum number of bacteria in the soil was detected in the variants when using strains of nitrogen-fixing and potassium-solubilizing microorganisms in presowing treatment (1.9×10^7 CFU/g of soil) and phosphate- and potassium-solubilizing microorganisms when spraying the seedlings (2.0×10^7 CFU/g of soil). The variant N1 + K2 + P6 after presowing treatment with nitrogen-fixing, potassium-, and phosphate-solubilizing microorganisms in the waxy ripeness stage showed the highest content of mobile phosphorus (92 mg/kg). High yield (4.3 t/ha) was shown by the variant N1 + P19 after presowing seed treatment with nitrogen-fixing and phosphate-solubilizing strains.

Keywords: spring wheat, mobile and gross phosphorus, nitrogen-fixing, potassium- and phosphate-solubilizing bacteria strains, yield

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The use of fertilizers in agriculture is highly important for increasing the yield and nutritional value of agricultural crops [1, 2]. Reducing the use of mineral and organic fertilizers creates the need to search for additional sources of plant nutrition. The methods that are able to enrich the soil with nutrients include the use of bacterial fertilizers consisting of microbial strains [3–5]. Active strains of nitrogen-fixing bacteria, which fix atmospheric nitrogen, can enrich the soil with nitrogenous substances. Phosphate-solubilizing microorganisms are able to decompose compounds (organic and mineral) containing phosphorus inaccessible for plants to an easily usable form, and potassium-solubilizing bacteria can release potassium into the soil solution from aluminosilicates [6]. Bacterial preparations are used on various types of soils for many agricultural crops; as a result, yields increase by an average of 10–12% [7, 8]. In this regard, it is relevant to investigate the interaction of plants and microorganisms.

The aim of this work is to study the effect of bacterial strains on the yield and amount of microorganisms at different stages of development of spring bread wheat in Primorsky krai (Russia).

METHODS

The research was carried out in 2018–2019 on experimental crops of the Chaika Federal Scientific Center for Agrobiotechnology of the Far East (Timiryazevsky Village, Ussuriysk) with the Sector of Soil Science and Soil Ecology of the Federal Scientific Center of the East Asia Terrestrial Biodiversity of the Russian Academy of Sciences (Vladivostok). We used bacterial strains that do the following: fix nitrogen in the soil (nitrogen fixers), N1; dissolve silicate minerals and release potassium compounds (potassium-solubilizing microorganisms), K2; participate in the mineralization of organic phosphorus compounds and convert them into a form accessible to plants (phosphate-solubilizing microorganisms), P6 and P19. All of them were obtained from the collection of microorganisms of the Federal Scientific Center of the East Asia Terrestrial Biodiversity (Far East Branch, Russian Academy of Sciences). These microbial strains were used to prepare a consortium of bacteria; as a reference, we used the commercial preparation Extrasol. Complex preparations were used for presowing treatment of seeds (working fluid solution of 10 L/t) and treatment of vegetative plants (working fluid solution of 300 L/ha).

Table 1. Yields of spring wheat depending on the use of bacterial strains

Variant	Plant height, cm	Grains per ear, pcs.	Weight of 1000 seeds, g	Yield, t/ha
Control	105.4	23.7	34.7	3.8
Presowing seed treatment				
N1+ K2 + P6	112.2	23.5	35.8	3.9
P19 + K2	105.9	26.3	34.9	4.1
N1 + K2	106.4	25.5	36.0	4.0
N1 + P19	106.5	26.8	36.5	4.3
Extrasol	110.8	26.1	34.6	3.9
Seedling treatment				
N1+ K2 + P6	111.5	26.1	35.0	4.0
P19 + K2	107.6	25.8	34.8	4.1
N1 + K2	112.3	26.3	35.3	4.2
N1 + P19	104.6	25.5	34.8	4.0
Extrasol	106.6	23.9	34.2	3.9
LSD_{05}	8.7	2.1	2.0	0.2

The experimental scheme included 11 variants: 1, control (without treatment); 2, N1K2P6; 3, P19K2; 4, N1K2; 5, N1P19; 6, Extrasol, reference (presowing seed treatment); 7, N1K2P6; 8, P19K2; 9, N1K2; 10, N1P19; 11, Extrasol, reference (seedling treatment).

The plot area was 15 m^2, the location was randomized, the replication was threefold. The predecessor was soy. During the growing season, phenological observations and counts, soil sampling for agrochemical analysis, and microflora studies were carried out [9]. The soil of the experimental plots was meadow-brown podzolized with heavy loamy texture. Organic matter content (according to Tyurin) was 2.51%; gross phosphorus, 1530 mg/kg; easily hydrolysable nitrogen (according to Tyurin and Kononova), 69 mg/kg; P_2O_5 and K_2O (according to Kirsanov), 71 and 154 mg/kg, respectively; pH_{KCl} 6.5; S, 25.2 (according to Kappen-Gilkovits); Hr (according to Kappen), 1.12 mmol/100 g of soil. The amount of microorganisms in the soil: nitrogen fixers, 4.6×10^5 CFU/g of soil; potassium and phosphate-solubilizing microorganisms, 8×10^4 and 7×10^2 CFU/g of soil, respectively, were identified by sowing the soil suspension on solid nutrient media [10]. The gross phosphorus content in the test soil samples was determined by energy dispersive X-ray fluorescence spectroscopy (EDX). Harvesting was carried out in the phase of full grain ripeness using the Hege 125 combine. Statistical data processing was carried out according to the methods of B.A. Dospekhov [11].

RESULTS AND DISCUSSION

Bacterial preparations significantly affect the formation of the structural elements of the spring wheat yield; as a result, the yield increases and the quality of products improves [3, 12]. In our experiments, high yield was observed in the variant with presowing treatment of seeds with strains N1 + P19, 4.3 t/ha, and when spraying the seedlings with strains N1 + K2, 4.2 t/ha (in the control, 3.8 t/ha). The same variants had high counts of grains per ear, 26.8 and 26.3 pcs, respectively. The N1 + P19 variant with the use of nitrogen-fixing and phosphate-solubilizing bacteria during presowing seed treatment had the highest weight of 1000 grains, 36.5 g.

The numerical composition of microscopic soil creatures is highly dynamic and can change even over relatively short periods of time [13, 14]. The total amount of microorganisms in the rhizosphere varied according to the phases of plant development (Fig. 1).

According to researchers [7, 15], the reason for the change in the amount of bacterial communities in the rhizosphere during the growing season is a change in the composition and amount of root exudates in plants, which serve as a source of nutrition for microorganisms. During presowing treatment of seeds and spraying of seedlings, the maximum number of microorganisms was observed in the phase of waxy ripeness of grain (2.0 × 10 CFU/g of soil). In our opinion, this is due to the decomposition of dying root residues, which occurs with active participation of microorganisms.

During plant growth and development, changes were revealed in the ratio of the amounts of nitrogen-fixing, potassium-, and phosphate-solubilizing microorganisms in the rhizosphere of plants. The proportion of potassium-solubilizing bacteria in the rhizosphere increased in the seedling phase after presowing treatment with strains N1 + P19 and amounted to 25% (1.6×10^5 CFU/g of soil) compared to 8.5×10^4 CFU/g of soil in the control. The amount of nitrogen-fixing

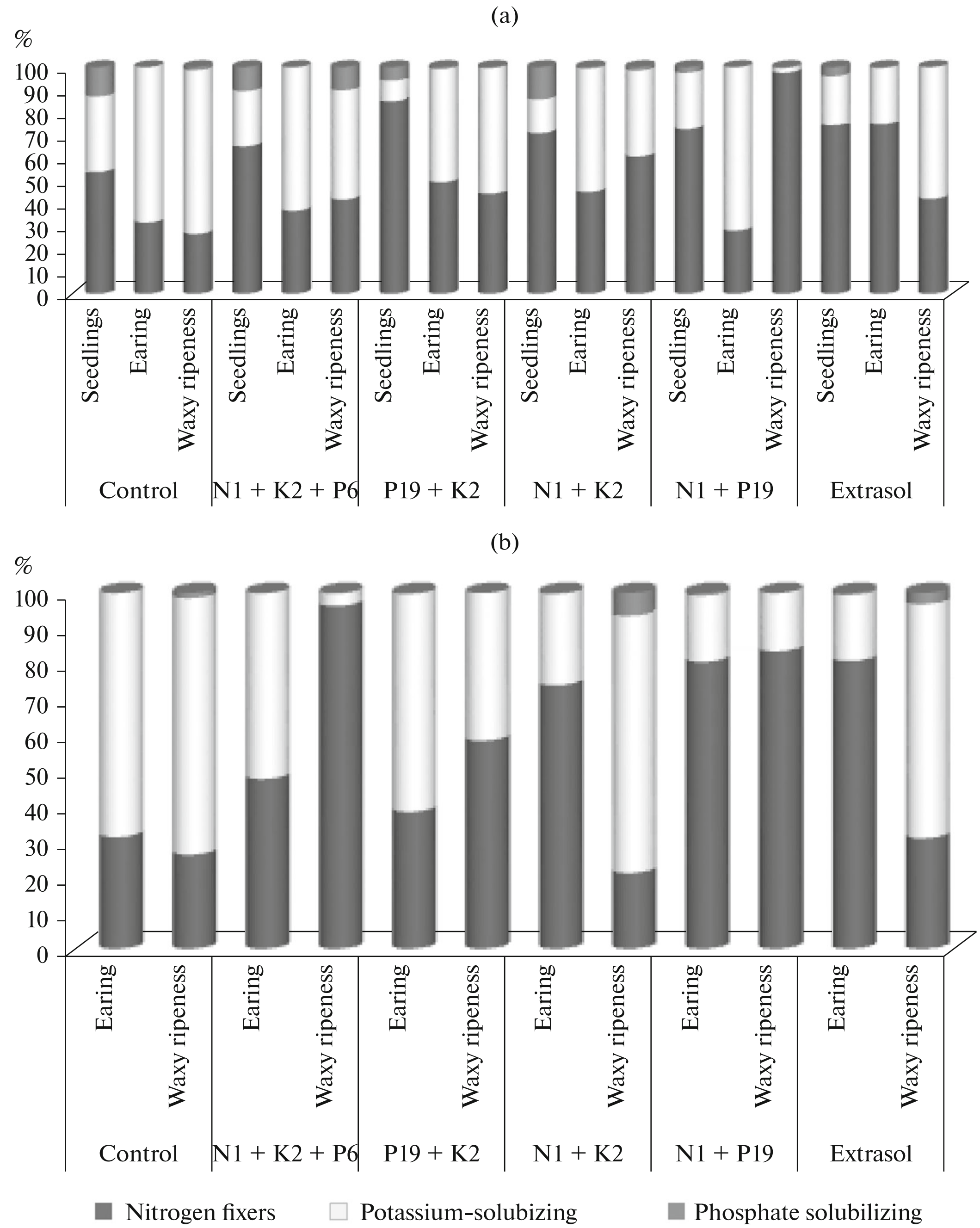

Fig. 1. Ratio (%) of the amount of microorganisms in different phases of plant development: (a) during presowing seed treatment and (b) during seedling treatment.

strains was the highest at the waxy ripeness of grain: 97% (1.9×10^7 CFU/g of soil) of the total count of bacteria (2.0×10^7 CFU/g of soil) compared to 4.1×10^5 CFU/g of soil in the control. Representatives of phosphate-solubilizing microorganisms accounted for 10% (8.7×10^4 CFU/g of soil) of the total amount, 8.5×10^5 CFU/g of soil, after presowing treatment with N1 + K2 + P6 in the waxy ripeness phase of grain. Thus, the proportion of nitrogen-fixing and phosphate-solubilizing bacteria in the total amount of microorganisms in the rhizosphere of wheat increases during the growth and development of plants and is the highest in the waxy ripeness phase of grain.

The vital activity of soil microorganisms results in the mobilization of nutrients in the soil from a form inaccessible to plants. Microbiological processes most intensively occur in the rhizosphere of the root system,

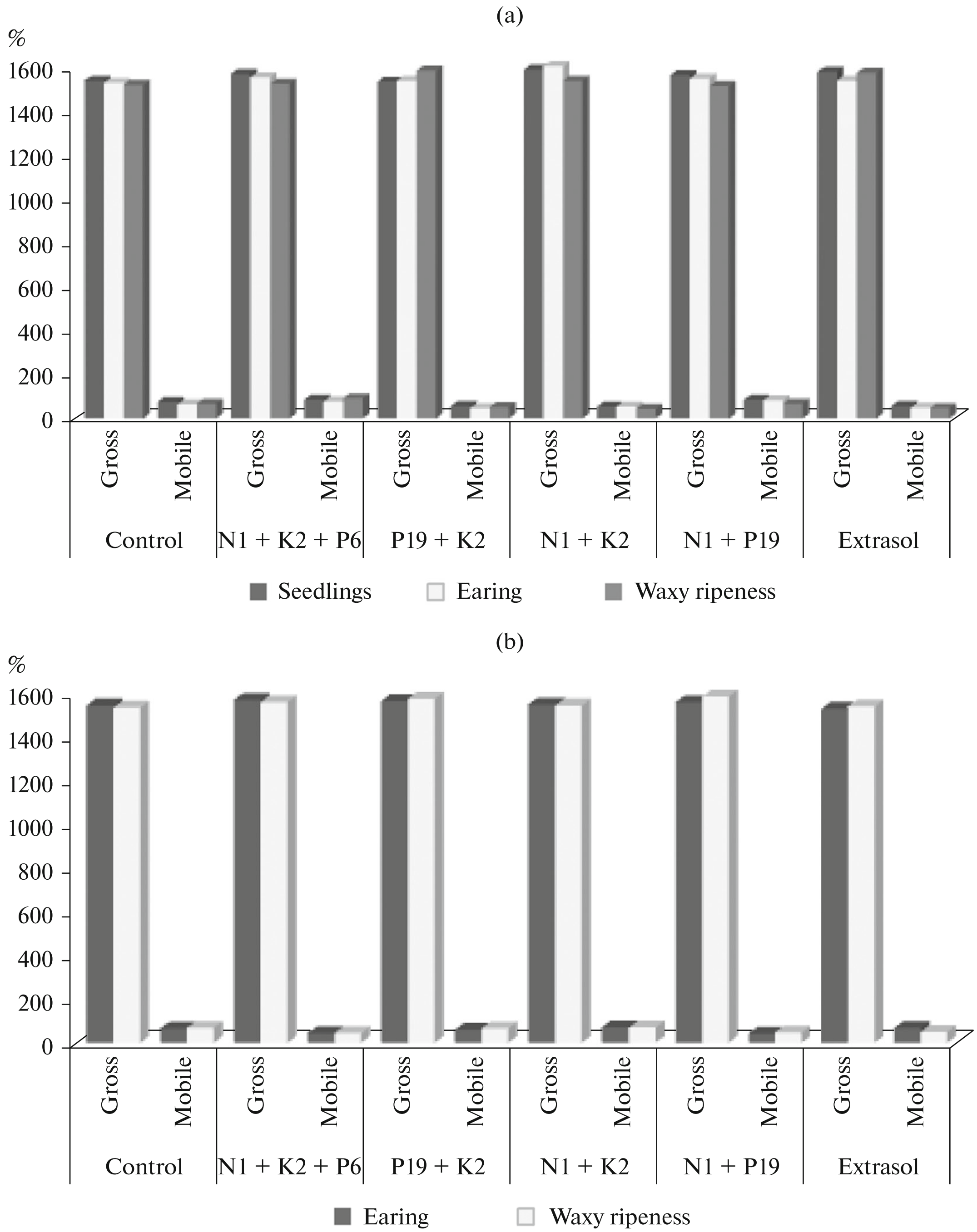

Fig. 2. Dynamics of content (mg/kg) of gross and mobile phosphorus in the soil at different stages of plant development: (a) during presowing seed treatment and (b) during seedling treatment.

which leads to the accumulation of a large amount of mineral nutrients available to plants [15].

In terms of its importance in plant nutrition, phosphorus ranks second after nitrogen [16, 17]. Plant growth and development depend on the presence of water-soluble forms of phosphorus in the soil. Compared to other soil nutrients, the content of phosphorus available to plants in the soil is very low, 25–37 mg/kg [18]. Recently, it has become more common to use biological products containing bacteria whose activity contributes to the transition of this element from a difficult-to-dissolve to an easily usable form.

In our experiments, the use of microorganisms affected the content of mobile forms of phosphorus in the soil at different stages of plant development (Fig. 2).

When the seeds were treated by the consortium of nitrogen-fixing and potassium-solubilizing bacteria (N1 + K2), the concentration of phosphorus available to plants was the highest in the earing phase, 83 mg/kg. A high content of mobile phosphorus was also observed in the variant with nitrogen-fixing, potassium-, and phosphate-solubilizing microorganisms (N1 + K2 + P6) in the seedling phase, 86 mg/kg, and the waxy ripeness phase of grain, 92 mg/kg. When spraying the seedlings with nitrogen-fixing and potassium-solubilizing bacteria in the phases of earing and waxy ripeness of grain, the amount of available phosphorus in the soil increased to 69 mg/kg, while its gross forms slightly exceeded the control. High values of gross forms of phosphorus were observed during presowing treatment of seeds in variants with nitrogen-fixing and potassium-solubilizing microorganisms (N1 + K2) in the seedling and earing phases, 1585 and 1600 mg/kg, respectively, as well as in variants with phosphate- and potassium-solubilizing strains (P19 + K2), 1580 mg/kg, in the phase of waxy ripeness of grain.

Thus, agronomically useful soil microorganisms in different phases of plant development contribute to an increase in the total amount of microorganisms in the rhizosphere depending on the phases of development of spring wheat plants. Spraying the seedlings with phosphate- and potassium-solubilizing bacteria in the variant (P19+K2) in the waxy ripeness phase of grain increases the total amount of microorganisms from 4.1×10^5 to 2.0×10^7 CFU/g of soil. The variant with presowing treatment (N1 + K2 + P6) using nitrogen-fixing, potassium-, and phosphate-solubilizing microorganisms in the waxy ripeness phase of grain showed a high content of mobile phosphorus, 92 mg/kg. The largest count of grains per ear, 26.8 pcs, and the weight of 1000 grains, 36.5 g, were obtained by inoculation of seeds before sowing with strains N1+P19, which positively affected the formation of the spring wheat yield, which was 4.3 t/ha.

COMPLIANCE WITH ETHICAL STANDARDS

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

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