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Assimilation of phosphorus by plants of corn at presence of phosphate mobilizing bacteria

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The purpose. To study action of phosphate mobilizing bacteria on the level of assimilation of phosphorus by plants of corn at cultivation on leached chernozem. **Methods.** Field, microbiological, biochemical, agrochemical, statistical. **Results.** They determined in dynamics amount of phosphate mobilizing bacteria capable to dissolve minerals-phosphates of insoluble complexes with cations of Ca^{++}, Fe^{+++}, Al^{+++} and bacteria which hydrolyze organic forms of phosphate, phosphatase activity of rhizosphere soil, level of assimilation of phosphorus by plants of corn at action of bacterization of seeds. It is fixed the following: amount of bacteria which dissolve Ca_3 (PO_4) 2 increased from 12,7 (in control) up to 27,5 millions/g of soil (in alternative with Agrobacterium radiobacter 5006), $AlPO_4$ — from 9,2 (in control) up to 17,9 millions/g of soil (in alternative with A. radiobacter 5006), $FePO_4$ — from 8,9 (in control) up to 17,3 millions/g of soil (at action of Enterobacter aerogenes 3271), and bacteria which hydrolyze organic forms of phosphate — from 12,7 (in control) up to 29,5 millions/g of soil (in alternative with Basillus sp. 2473). The highest phosphatase activity was observed at action of Basillus sp. 2473 — 4,34 accordingly at indexes of control of 2,84 mg P_2O_5/100 g of soil/hour. **Conclusions.** Bacterization of seeds of corn by active strains of phosphate mobilizing bacteria A. radiobacter 5006, Paenibacillus polymyxa KV, Bacillus sp. 2473, E. aerogenes 3271, E. nimipressuralis 5213 promotes increase of: amount of bacteria converting joints of phosphorus, phosphatase activity and level of mobility of phosphates in root zone, that positively influences phosphorous nutrition of plants. Biological factor of intensification of root nutrition of plants ensures increase of content of phosphorus in grain on 0,08-0,14%, as well as its removal with yield of crop on 24,8-35,9% concerning control.

Key words: *phosphorus, corn, level of mobility of phosphates, phosphate mobilizing bacteria, leached chernozem.*

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In modern agricultural production, the problem of phosphorus is complicated by its acute shortage [1]. Soil fertility is limited by insufficient phosphorus, which can be assimilated by plants, because its availability is reduced due to the rapid formation of insoluble complexes with cations of Ca^{2+}, Fe^{3+}, Al^{3+}, etc. [2] and its incorporation into organic compounds by microorganisms [3, 4]. The problem is exacerbated by the irreversible loss of phosphorus due to the removal of this element from the soil by plants. Therefore, the search for new reserves for improving the regime of phosphorus nutrition of cultivated plants is an important task of agrarian science.

Objective – to investigate the degree of phosphorus assimilation by corn plants and binding of an element to the soil under exposure to phosphate-mobilizing bacteria.

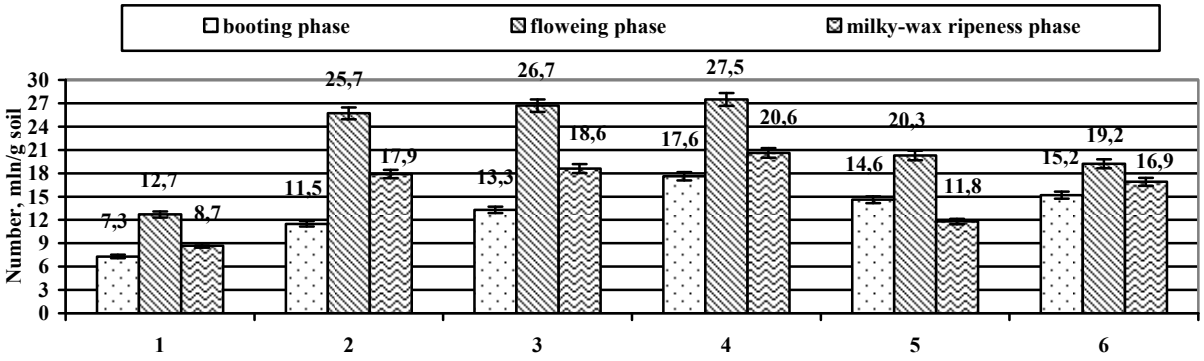
Materials and methods. The study was conducted in a field experiment on the basis of the experimental field of the Institute of Agricultural Microbiology and Agroindustrial Manufacture of the NAAS during 2016-2018. Soil is a leached chernozem which contains 2.12 % of humus, 95.2 mg/kg of easily hydrolysable nitrogen, 226 mg/kg of phosphorus, 108 mg/kg of exchangeable potassium, $pH_{sal.}$ = 5.30 Scheme of experiment included 6 variants:

1. Control – without bacterization; 2 - 6. Bacterization by suspensions of active strains of phosphate-mobilizing bacteria: *Paenibacillus polymyxa KB* (bioagent of microbial preparation Polimiksobakteryn),

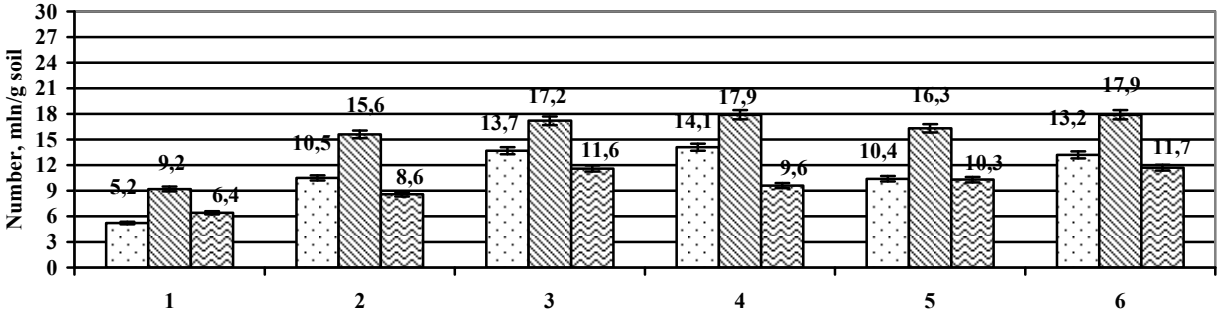
Bacillus sp. 2473, *Agrobacterium radiobacter* 5006, *Enterobacter aerogenes* 3271, *E. nimipressuralis* 5213. Strains pre-selected from the rhizosphere of crops are characterized by high phosphate-mobilizing activity in the laboratory settings. The area of the experimental site is 50.4 m^2, experiment is performed in triplicate.

Bacterization of corn seeds of hybrid Dniprovskyi 181 CB was carried out using aqueous bacterial suspensions at a rate of 0.5 million cells/seed. Soil samples (from the rhizosphere of plants) were selected in the main phases of the organogenesis of corn: booting, flowering, milky-wax ripeness of the grain. Records were made over time in terms of the number of bacteria capable of dissolving phosphate minerals of insoluble complexes with cations of Ca^{++}, Fe^{+++}, Al^{+++} and bacteria that hydrolyze organic forms of phosphates, phosphatase activity – by the method of I. T. Heller and K. Ye. Hinzburh, the content of phosphorus in plants and grain – by the method of Deniges in the modification of Bouvattier [5], the degree of mobility of phosphates – by the method Karpinskii and Zamiatina [6], removal of phosphorus with the yield of grain and leaf-stem mass of corn – by the method of Chyrikov [7].

Results. Implementation of the potential of crop yields is possible only with optimal plant nutrition, which depends on the availability of nutrients in the soil and the degree of their availability. Formation of specific microbial groups in the root zone of plants is important in this case. It is the microorganisms of the soil that transforms inaccessible inorganic compounds to the form, optimal for their metabolism [8], therefore their research is necessary to assess the possibility of intensifying the root nutrition of crops. In the field experiment, it was found that the bacterization of corn seeds contribute to the increase in the number of phosphate-mobilizing bacteria in rhizospheric soils in all phases of plant development compared to the parameters of the control variant and especially in the phase of milk-waxy ripening (Figure 1). For example, the number of bacteria that dissolve $Ca_3(PO_4)_2$ increased from



a



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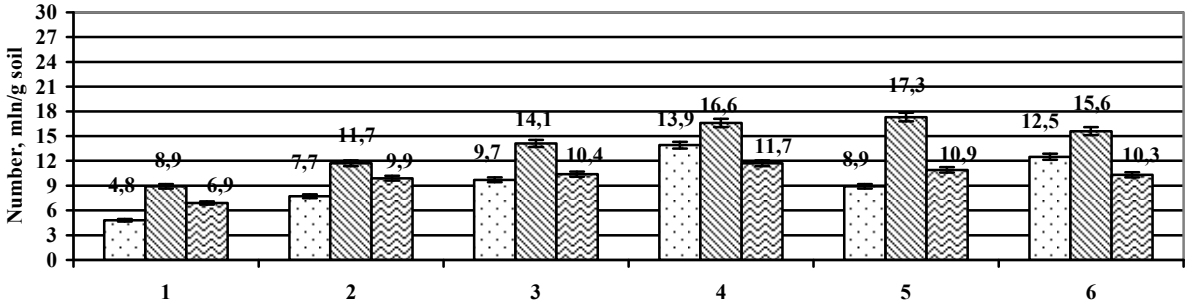

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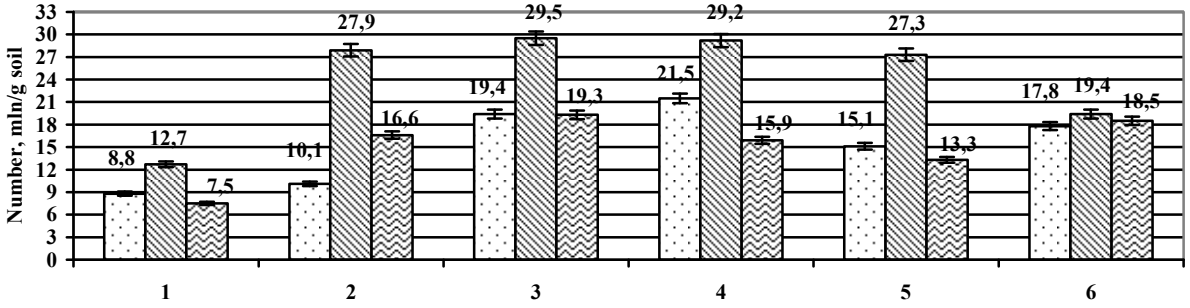

d

Fig. 1. **Influence of bacterization on the number of bacteria that dissolve the following components in rhizospheric soil of corn plants: a – $Ca_3(PO_4)_2$; b – $AlPO_4$**; c – $FePO_4$; d – organophosphates**.

Note: 1. – Control (without bacterization); 2. *Paenibacillus polymyxa* KB;
3. *Bacillus sp.* 2473*;* 4. *A. radiobacter* 5006; 5. *Enterobacter aerogenes* 3271;
6. *Enterobacter nimipressuralis* 5213.

12.7 mln/g soil (in control) to 27.5 mln/g soil (in the variant with *A. radiobacter* 5006), $AlPO_4$ – from 9.2 mln/g soil (in control) to 17.9 mln/g soil (in the variant with *A. radiobacter* 5006), $FePO_4$ – from 8.9 mln/g soil (in control) to 17.3 mln/g soil (under exposure to *E. aerogenes* 3271) and bacteria that hydrolyze organic forms of phosphates – from 12.7 mln/g soil (in control) to 29.5 mln/g soil (in variant with *Basillus sp*. 2473).

A unique reflection of the number of microorganisms of certain ecological trophic groups in the soil and their functional activity is biological activity, and in particular, enzymatic activity, as a sensitive parameter of the most important biochemical processes [9]. Isolation of enzymes in the soil by microorganisms and the roots of plants usually have an adaptive nature in the form of a reaction-response to the presence or absence of a substrate for the action of the enzyme or product of the reaction, which is particularly clearly manifested with phosphatases. Due to lack of mobile compounds of phosphorus in the environment, microorganisms and plants sharply enhance release of enzymes. This relationship is the basis for the application of the index of phosphatase activity of the soil for diagnostics of the provision of plants with phosphorus [10].

The results of studies have shown that the phosphatase activity of the rhizospheric soil during the growing season gradually increases and reaches the highest values in the phase of milk-wax ripeness of the grain (Figure 2). For example, the highest phosphatase activity was observed in *A. radiobacter* 5006 and *Basillus sp.* 2473, and it was 4.04 mg P_2O_5/100 g soil/hour and 4.34 mg P_2O_5/100 g soil/hour, respectively, with control values of 2.84 mg P_2O_5/100 g soil/hour. Literary data indicate that *A. radiobacter* predominantly carry out the enzymatic process of dissolution of organic phosphates [11], which occurs due to the production of phosphatases. This explains the increase of phosphatase activity in the rhizospheric soil of corn plants in the corresponding variants of the experiment.

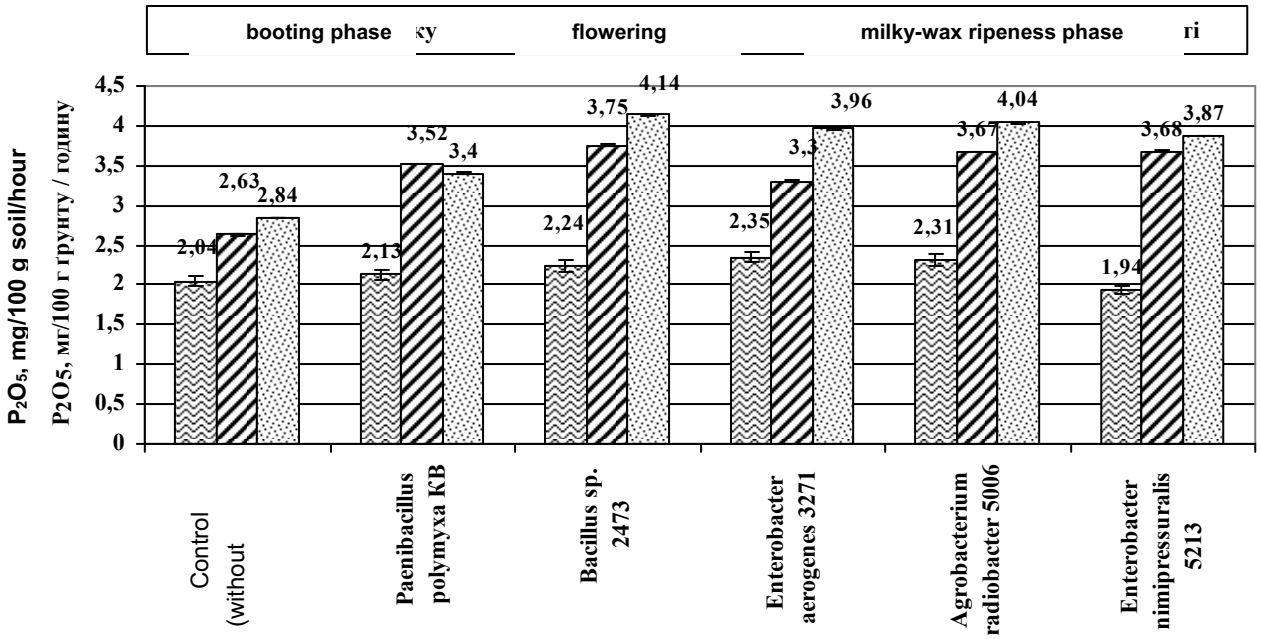

Fig. 2. **Total phosphatase activity in the root zone of corn plants under the action of active strains of phosphate-mobilizing bacteria**

The main source of phosphorus nutrition of plants is the most mobile phosphate of soil solution. In this case, the degree of mobility of phosphates in the soil directly depends on the content of total phosphorus and its mobile forms [12]. It is known that an increase in the degree of mobility of phosphates in the root zone of corn plants is expressed in the decrease of the content of mobile phosphate forms in the rhizosphere soil due to increased assimilation by plants. Our studies found that the lowest levels of P_2O_5 in the soil are observed under exposure to *Bacillus sp.* 2473 (Figure 3). For example, the content of phosphorus in the root zone of plants decreased in the flowering phase from 0.23 mg P_2O_5/dm^3 in the control to 0.13 mg P_2O_5/dm^3 of soil solution, in milky-wax ripeness phase – from 0.17 mg P_2O_5/dm^3 in the control to 0.05 mg P_2O_5/dm^3 of soil solution under exposure to *Bacillus sp.* 2473. The use of other strains of phosphate-mobilizing bacteria also positively affected the degree of mobility of phosphates, which indicates an increase in the availability of soil phosphates for corn plants.

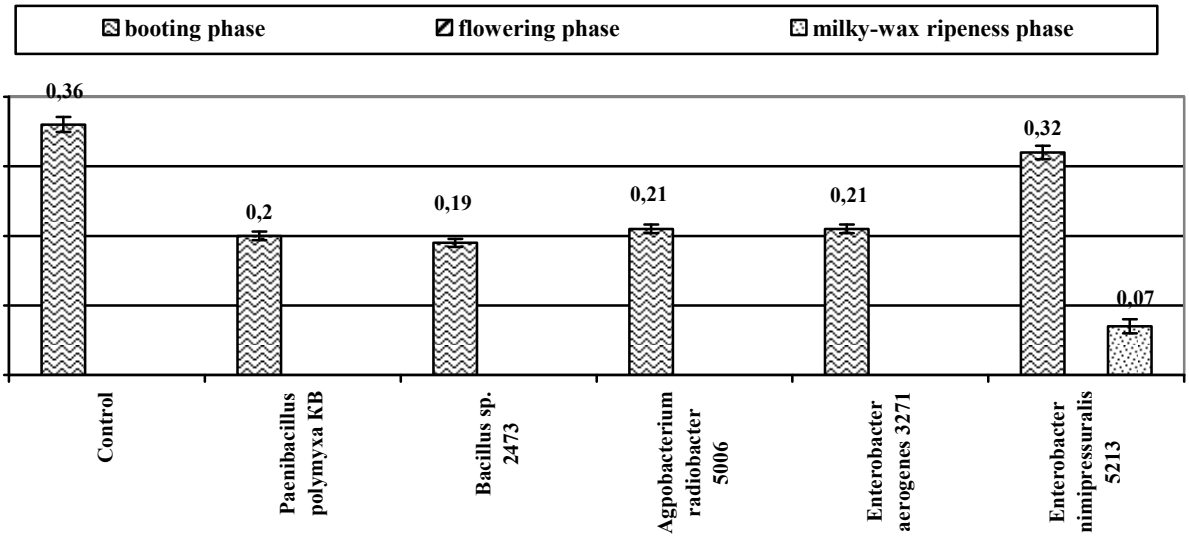

Fig. 3. **Degree of mobility of phosphates in the root zone of corn plants under the action of active strains of phosphate-mobilizing bacteria**

The content of phosphorus in leafy-stem mass and corn grains under the action of phosphate-mobilizing bacteria characterizes the effect of the investigated factors on phosphorus nutrition of plants. Significant difference was noted in the content of phosphorus in the leafy-stem mass of plants and grain compared to control (Table 1).

1. The content of phosphorus in leafy-stem mass and corn grains

Variants of experiment	P_2O_5 in leafy-stem mass, %			Phosphorus in the grain, %
	booting	flowering phase	milky-wax ripeness phase	
Control – without bacterization	0.35±0.01	0.37±0.01	0.45±0.01	0.41±0.01
Paenibacillus polymyxa KB	0.37±0.01	0.41±0.01	0.53±0.01	0.49±0.01
Bacillus sp. 2473	0.39±0.01	0.45±0.01	0.55±0.01	0.55±0.01
Enterobacter aerogenes 3271	0.41±0.01	0.43±0.01	0.48±0.01	0.50±0.01
A. radiobacter 5006	0.40±0.01	0.44±0.01	0.54±0.01	0.53±0.01
Enterobacter nimipressuralis 5213	0.44±0.01	0.45±0.01	0.50±0.02	0.52±0.01

For example, the content of phosphorus in the leafy-stem mass of corn in the milky-wax grain ripeness was the highest and ranged from 0.45 % in control to 0.54 % under exposure to *A. radiobacter* 5006; and in the grain it was ranged from 0.41 % in control to 0.53 % under exposure to *A. radiobacter* 5006. It has been determined that bacterization contributes to a significant increase in the removal of phosphorus by grain and leafy-stem mass of corn, which is not inferior to those obtained under exposure to *P. polymyxa KB* – bioagent of the well-known microbial preparation Polimiksobakteryn (Table 2).

2. Removal of phosphorus with corn yield under exposure to bacterization

Variants of experiment	Removal of phosphorus, kg/ha		Total removal of phosphorus with yield, kg/ha	Phosphorus nutrition efficacy*	
	with grain	with leafy-stem mass		kg/ha	%
Control – without bacterization	32.8	26.4	59.2	–	–
A. radiobacter 5006	47.2	29.4	76.6	17.4	29.4
P. polymyxa KB	46.6	31.4	78.0	18.8	31.7
Bacillus sp. 2473	47.8	32.7	80.5	21.3	35.9
E. aerogenes 3271	44.5	29.4	73.9	14.7	24.8
E. nimipressuralis 5213	47.8	30.4	78.2	19.0	32.1

Note. * – the difference between the total phosphorus removal rates with the yield of the studied and control variants.

For example, the removal of phosphorus by grain increased from 32.8 kg/ha to 47.8 kg/ha, and by leafy-stem mass – from 26.4 kg/ha (in control) to 32.7 kg/ha under exposure to *Bacillus sp.* 2473. The total removal of phosphorus ranged from 59.2 kg/ha (in control) to 80.5 kg/ha, which is 35.9 % higher compared to control.

Therefore, bacterization of corn seeds with active strains of phosphate-mobilizing bacteria *Agrobacterium radiobacter* 5006, *Paenibacillus polymyxa KB*, *Bacillus sp.* 2473, *Enterobacter aerogenes* 3271, *Enterobacter nimipressualis* 5213 contributed to increase in the number of bacteria that transform phosphorus compounds, increase of phosphatase activity and the degree of mobility of phosphates in the root zone of corn plants, which affects the phosphorus nutrition of plants. *Bacillus sp.* 2473 strain can be used as a bioactive agent for a microbial preparation to improve the phosphorus nutrition of crops.

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